STUDIES ON LIFE FERTILITY TABLE OF DIAMONDBACK MOTH, *Plutella xylostella* (Lepidoptera) ON DIFFERENT HOSTS

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis titled **"Studies on life fertility table of diamondback moth, *Plutella xylostella* (Lepidopetera) on different hosts"** submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE) ENTOMOLOGY** in the discipline of **PLANT PROTECTION** to Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Nauni, Solan (H.P.) – 173 230 is a bonafide research work carried out by **Mr. Devender Singh (H-2017-87-M)** son of Shri Jai Bhagwan, under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Nauni, Solan
Dated: 10-01-2020

Dr. Anil Sood
Chairman
Advisory Commitee

CERTIFICATE - II

This is to certify that the thesis titled, **"Studies on life fertility table of diamondback moth, *Plutella xylostella* (Lepidoptera) on different hosts" submitted by Mr. Devender Singh (H-2017-87-M)** son of Sh. Jai Bhagwan to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) -173 230, India in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE) ENTOMOLOGY** in the discipline of **PLANT PROTECTION** has been approved by the Student's Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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I own entire responsibility for all errors and omissions.

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CONTENTS

LIST OF ABBREVIATIONS

l_x	=	Age specific survival
T_c	=	Approximate generation time
et al.	=	Co-workers
DBM	=	Diamondback Moth
DT	=	Doubling time
m_x	=	Female progeny per female
GRR	=	gross reproductive rate
M_x	=	gross fecundity
HP	=	Himachal Pradesh
r_m	=	intrinsic rate of increase
λ	=	Lambda (finite rate of increase)
R_o	=	Net reproductive rate
viz.	=	namely, that is to say
X	=	Pivotal age in days
T	=	The mean generation time
WM	=	Weekly multiplication rate
L: D	=	Light and dark hours

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Chapter-1

INTRODUCTION

In agriculture, vegetables play an important role by providing food, nutrition and economic security to the people. Vegetables occupy an area of 59 million hectare at global level with an annual production of 1159 million tonnes (FAO, 2018). India is the second largest producer of vegetable after China with estimated production of about 187 million tonnes during 2018-19 from an area of more than 10.4 million hectares (Anonymous, 2018) accounting for 14 per cent of worlds production. More than 70 kinds of vegetables belonging to different groups, namely cucurbits, cole crops, solanaceous vegetables, root and leafy vegetables are grown in India (Salaria and Salaria, 2010). Cole crops represent as one of the highly polymorphic class which include crops like cabbage, cauliflower, broccoli, mustard, turnip, kale, Brussels sprouts, etc. These are important vegetables grown in tropical and temperate regions of the world during winter and also grown enormously in hills and plains of India. Among these, cabbage, cauliflower and broccoli assume the prime importance while knol-khol, radish, mustard etc. occupy secondary position.

Cauliflower (*Brassica oleracea* var. *botrytis* Linn.) is an economically important winter vegetable. In India, It is cultivated in an area of 4.2 lakh hectare with an average annual production of 8199 Metric tonnes and productivity of 19.2 Metric tonnes per hectare (*www.indiastat.com*). It is mostly cultivated in West Bengal, Bihar, Uttar Pradesh, Haryana, Orissa, Assam and Maharashtra.

Broccoli is another important and popular vegetable crop in many countries of the world due to its high nutritive value. In India, it is cultivated in an area of 10,172 million hectare with an annual production of 1,80,684 million tonnes and productivity of 18.27 tonnes per hectare (Anonymous, 2018). It is mostly grown in the hilly areas of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, Nilgiri hills of Western Ghats and Northern plains of India.

Mustard is an important oilseed crop in the world. Indian mustard (*Brassica juncea* L.) occupies a prominent place next to soybean and groundnut, both in area and production. In India, it is cultivated on 5.76 million hectare area with the production of 79.77 lakh tonnes

and 1184 kg/ ha productivity (Anonymous, 2018). It accounts for nearly 20-22 per cent of the total oilseeds produced in the country. Rajasthan, Haryana, Uttar Pradesh, Madhya Pradesh and Gujrat are the major mustard producing States.

One of the major factors which limit the successful cultivation of these crops is the variety of insect pests and diseases which reduce the yield and quality. These crops are attacked by insect pests like, the cabbage butterfly (*Pieris brassicae* L.), cabbage aphid (*Brevicoryne brassicae* L.), painted bug (*Bagrada cruciferarum*), diamondback moth (*Plutella xylostella*), cabbage semilooper (*Thysanoplusia orichalcea* F.), mustard aphid (*Lipaphis erysimi* K.), mustard saw fly (*Athalia lugens proxima* K.) etc. at different growth stages. Among them, the diamondback moth *Plutella xylostella* (Linnaeus) (Lepidoptera: Yponomeutidea) is one of the serious insect-pests of these crops throughout the world (Furlong *et al.,* 2013; Niu *et al.,* 2013; Grzywacz *et al.*, 2010; Harika *et al.*, 2019) because of its enormous appetite, lack of bio control agents and high reproductive rate (Haseeb *et al.*, 2001; Gowri and Manimegalai , 2017). It causes 52-100 per cent crop loss worldwide (Kamala, 2006, Shelton *et al.,* 2008; Shakeel *et al.*, 2017). It was originated from Europe (Hardy, 1938) or possibly South Africa (Kfir, 1998). In India, its first incidence was recorded by Fletcher (1914) and now it has been noticed all over India where Brassicaceae family crops are grown (Devi *et al*., 2004). It has now been recorded from at least 145 countries of the world (Saeed *et al.*, 2010). The growth and reproduction potential of DBM vary with density and diversity of crucifer plant species (Kahuthia *et al.*, 2009).

In India the estimated annual crop losses due to this pest amount to 16 million US Dollars (Mohan and Gujar, 2003) and can cause 30-100 per cent crop losses to cole crops (Ahmad *et al.,* 2009). DBM control costs for about 4-5 billion US$ annually worldwide alone in *Brassica* crops (Zalucki *et al.*, 2012; Furlong *et al.*, 2013). In Himachal Pradesh, this pest was reported to be serious in those areas where cauliflower and cabbage are grown (Ram *et al*., 2016). This insect is active throughout the year with wider host range (Chand and Choudhary, 1977). Cabbage and cauliflower are the most preferred host plants for *P. xylostella* because of their fleshy and succulent leaves as compared to other cruciferous crops. The damage is caused by larvae which feed on leaves, flowers, buds, and seed-buds of cultivated cruciferous plants. Although the larvae are small, yet they can cause complete damage of foliar tissue except for the leaf veins. The first instar larvae mine inside the leaf

and the subsequent instars feed on the leaf and skeletonize it ultimately affecting the plant growth and become unfit for further use.

There are differences in the biological activities of the diamondback moth when feed on different host plants (Zhang *et al*., 2012; Niu *et al*., 2014) and on different climatic conditions and temperatures (Liu *et al*., 2003; Golizadeh *et al*., 2007). Sarfraz *et al.* (2007, 2011) reported that the developmental time of *P. xylostella* larvae was notably affected by feeding on various cultivated and wild food plants. The nutritional quality of various cruciferous plants also affects larval development time. Apart from host plants, weather also affects the field incidence of DBM, with rainfall being a major mortality factor (Ahmad and Ansari 2010; Sow *et al.*, 2013). Variability in temperatures from 7 to 35°C and quality of available host plants are reported to remarkably influence the survival and rate of oviposition of diamondback moth (Syed and Abro, 2003; Golizadeh *et al.*, 2007, 2009). Life table and population studies revealed that rainfall, temperature, natural enemies as well as host plants, influence the survival and reproduction of diamondback moth (Wakisaka *et al*., 1992; Haseeb *et al*., 2001). The host range of diamondback moth is the plants of Brassicaceae that are characterized by the 'mustard oils', or glucosinolates (Warwick *et al.*, 2003).

Diamondback moth being a ubiquitous pest of cruciferous plants throughout the world, the knowledge of its biology and life-fecundity is very much essential with respect to host plants. Development of life tables for diamondback moth on different host plants will help to assess the relative contribution made by the various hosts to the local adult population pool, and to answer other relevant questions associated with this pest. Keeping this in mind, the present studies were conducted with the following objectives;

OBJECTIVES

i) To study the biology of diamondback moth, *P. xylostella* (L.) on different hosts.

ii) To construct life fertility tables of *P. xylostella* on different hosts.

Chapter-2

REVIEW OF LITERATURE

The relevant literature pertaining to the present studies entitled "**Studies on life fertility table of diamondback moth *Plutella xylostella* (Lepidoptera: Yponomeutidae) on different hosts**" is reviewed under the following headings:

2.1 Biology of *Plutella xylostella* (L.)

2.2 Life fertility studies of *Plutella xylostella* (L.)

2.1 BIOLOGY OF *Plutella xylostella* (L.)

Wan (1970) studied the bionomics of *P. xylostella* (L.) on *Brassica* spp. at 26.4 ± 2.7°C and 86 ± 14 per cent relative humidity. The egg stage was 2.1 days, the growth of I, II and III larval instars was completed in 1.1, 1.2 and 1.4 days, respectively, while the fourth larval instar was completed in 1.7 days together with pre-pupal stage of 0.6 days. The mean pupal period was 3.9 days and the total life-cycle from oviposition to adult emergence was completed in 10 days.

Jayarathnam (1977) noticed the total life-cycle of *P. xylostella* as 19-27 days in different seasons. The total developmental period of diamondback moth from egg to adult emergence was 16.50, 17.8, 20.80 and 19.40 days when reared on the leaves of knolkhol and sprouting broccoli, brussel sprouts, cabbage and cauliflower, respectively under laboratory conditions.

Liu and Lee (1984) observed that the egg, larval, pupal, male and female adult stages of *P. xylostella* as 3.49, 8.24, 5.10, 7.33 and 7.19 days, respectively. The oviposition period lasted for 3.33 days. One generation was completed in 24.10 days and the total egg laying capacity was 74.24 eggs/ female.

Chelliah and Srinivasan (1986) reported that *P. xylostella* (L.) moved through four larval instars and total larval period including pre-pupal was 12 to 15 days in the cold season and 10 days in the hot and rainy seasons. The pupal period lasted for 4 to 5 days in the cold season and 4 days in the hot and rainy seasons. Adult longevity ranged from for 6 to 13 days.

Stapathi (1990) studied the biology of *P. xylostella* on Indian mustard at 24º C and 85 per cent relative humidity in the laboratory and reported the average duration of larva of diamondback moth to be 16 days.

Kim and Lee (1991) studied that *P. xylostella* overwintered at any stage in its life cycle. Developmental time from egg to adult was 19 to 23 days in June and September, 11 to 18 days in July and August, 28 to 34 days in April, May and October and approximately 50 to 100 days in other months. Adults lived for 4 to 11 days in summer and 7 to 17 days in spring and autumn. Individual female laid 50-240 eggs, with highest egg laying in spring and autumn. The egg, larval and pupal stage lasted for 4 to 5, 3 to 12 and 6 to 8 days in June and September; 2 to 3, 7 to 8 and 4 to 6 days in July and August; 6 to 18, 13 to 20 and 8 to 14 days in March, April, May and October; and 12 to 40, 50 to 100 and 20 days in winter, respectively. The developmental time of diamondback moth from egg to adult emergence varied between 11.93 and 21.2 days under the laboratory conditions.

Park *et al.* (1993) studied the life cycle of *P. xylostella* and reported that hatching of eggs required 3.1- 4.2 days at 24.9°C to 27.6°C, 5.1- 5.4 days at 21.0°C to 22.2°C and 7.2-7.8 days at 15.2°C to 19.2°C. The larval stage was completed in 5.4-6.7 days at 25.4° to 28.0 °C, 8.2-8.5 days at 22.7° to 23.1°C and 10.7-18.3 days at 16.7° to 19.5°C. The pupal period was completed in 4.4-6.0 days at 22.0° to 28.0°C, 7.2-7.3 days at 20.6° to 21.4°C and 8.7- 9.2 days at 17.6° to 18.6°C. Average adult longevity was 9.5-10.8 days at 25.6° to 27.9°C, 12.1-12.6 days at 20.3° to 22.8°C, and 13.2-14.2 days at 18.1°C to 19.9°C. The mean numbers of eggs laid per female were 118.0-145.2 at 24.4° to 28.1°C, 154.6-174.8 at 18.2° to 22.1°C and 116.0-144.3 at 14.0°C to 15.8°C.

Salas *et al.* (1993) determined the survival and population parameters of *P. xylostella* on cabbage, cauliflower, broccoli, mustard, brussels sprouts and radish in the laboratory at 24°C and 45 per cent relative humidity. Larval survival was greatest on cauliflower and longest on Brussels sprouts. The longest generation time was on Brussels sprouts (28.55 days) while it was 22.41 days on cabbage.

Kandoria *et al.* (1994) studied that the egg, larval, pre-pupal and pupal periods of diamondback moth on cauliflower during different months from September to October varied from 1.8-5.4, 6.5-24.7, 0.7-2.4 and 3.3-11.4 days and the pre-oviposition, oviposition and

post-oviposition periods were 0.7-3.5, 2.4-21.4 and 0.5-7.5 days, respectively. The average fecundity was recorded as 73.7 eggs during June and 256.4 eggs in December and January. Mean longevity of male and female adults without food was 1.3 to 18.2 and 1.2 to 19.6 days and with food it was 5.7 to 32.4 and 4.3 to 33 days, respectively. In the laboratory reared culture male to female ratio was 1:1.1, while it was 1:1.2 in the field collected adults.

Devi and Raj (1995) studied the biology of *P. xylostella* on cauliflower. The incubation, larval and pupal periods were 3 to 4, 5 to 7 and 10 to 12 days, respectively. Adult longevity was 4 to 5 days and the total life cycle ranged from 22 to 28 days during April-May at 28°C.

Salas *et al.* (1993) studied the survival and population parameters of *P. xylostella* on cabbage, cauliflower, broccoli, mustard, brussels sprouts and radish in the laboratory at 24°C and 45 per cent relative humidity. Larval survival was greatest on cauliflower and longest on Brussels sprouts. The longest generation time was on Brussels sprouts (28.55 days) while on cabbage it was 22.41 days.

Idris and Grafius (1996) observed the effect of wild and cultivated *Brassica* on oviposition, egg hatching and larval survival of *P. xylostella*. They concluded that the larval survival was generally higher on cultivated *Brassica* crops than on wild *Brassica* spp. and there was no survival on *B. vulgaris*. Development time of larvae of DBM was generally longer on the wild than on the cultivated *Brassica* spp.

Chauhan *et al.* (1997) at Solan, Himachal Pradesh investigated the infestation of *P. xylostella* on cabbage and cauliflower. They observed that the duration of egg, larval and pupal stages were 3.3, 11.0 and 5.9 days, respectively. Male lived longer (18.6 days) than female (16.2 days) in laboratory conditions.

Idris (1998) observed that the total developmental time of larvae and pupae of *P. xylostella* were significantly affected by the host plants. The larval developmental time was considerably longer (10.9 days) when fed on cultivated mustard than on the other host plants. The wild host plants extended the developmental time of the pupae compared to cultivated host plants.

GuoQuan *et al.* (1998) reported the oviposition preference of *P. xylostella* during 1993. Among the six species of cruciferous plants, the adult females preferred Indian mustard (*Brassica juncea*) and flowering Chinese cabbage (*B. parachinensis*) to lay their eggs in comparison with radish and cauliflower (*B. oleracea* var. *botrytis*).

Devjani and Singh (1999) studied the biology of diamondback moth at 23 ± 1°C and 45 ± 2 per cent RH. They studied that the incubation, larval, pre-pupal and pupal period and adult longevity was 2.18, 10.5, 1.6, 6.86 and 16.7 days, respectively and the mean fecundity was 153 eggs/ female.

Sharma *et al.* (1999) reported that the incubation period of *P. xylostella* was 3- 4 days. The time period of I, II, III and IV larval instars was 2 to 3, 1 to 1.5, 1 to 2 and 1.5 to 2.5 days, respectively. The pupal period varied from 3 to 5 days and the longevity of male and female was observed as 6 to 9 and 14 to 20 days, respectively. Pre-oviposition, oviposition and post-oviposition periods were 2 to 4, 6 to 7 and 5 to 14 days, respectively. Fecundity of the female ranged from 147 to 251 eggs.

Capinera (2000) mentioned that the eggs of *P. xylostella* were oval and flattened, yellow or pale green in colour, 0.44 mm long and 0.26 mm wide and were deposited singly or in small groups of two to eight eggs in depressions on the surface of foliage or occasionally on other plant parts. Adult females may deposit 250-300 eggs but the average total egg production was about 150 eggs.

Justin *et al.* (2001) investigated that the average duration of immature stages of *P. xylostella* was 21, 22 and 25 days on cauliflower, cabbage and Indian mustard, respectively. The survival time from egg to adult emergence was 97.6, 98.4 and 93.6 per cent, while the maximum longevity of the reproductive female was 16, 16 and 15 days on cauliflower, cabbage and Indian mustard, respectively.

Liu *et al.* (2002**)** determined the survival and developmental period from egg to adult emergence of the *P. xylostella* at 4°C to 40°C temperature. The pest developed successfully from egg to adult emergence at constant temperature from 8°C to 32°C. At temperatures from 4°C to 6°C or from 34°C to 40°C, partial or complete development of individual stages or instars was possible, with III and IV instars having the widest temperature limits. They reported that the insect developed successfully from egg to adult emergence under alternating regimes including temperatures as low as 4°C or as high as 38°C.

Arvanitakis *et al.* (2002) studied the oviposition behavior of *P. xylostella*, collected from seven different locations from South Africa. They reported that the population from Cotonou, Parakou, Malanville, Natitingou and Songhai produced on average of 210 eggs/ female while the populations were least productive from Agoue (115 eggs/ female) and Lokossa (170 eggs/ female). Cotonou, Parakou and Malanville population produced 60-70 per cent of eggs within the 1st four days of oviposition while those of Lokossa and Agoue produced less than 30 per cent of eggs. The total oviposition period for the Lokossa population was 26 days and it was 16-19 days for other populations.

Syed and Abro (2003) studied the shortest and longest larval period of diamondback moth on cauliflower and radish as 9.45 and 10.95 days, respectively. The lowest and highest survival to adult stage was found to be 58.3 and 76.7 per cent on mustard and broccoli, respectively. While, shortest and longest pupal period was recorded 5.84 and 6.48 days on mustard and cabbage, respectively.

Varela *et al.* (2003) investigated that the *P. xylostella* has four larval instars. Larvae remain quite small and active throughout their development and if disturbed, they often wriggle violently, move backward and spin down from the plant on a strand of silk. The total length of all the four instars hardly exceeded 1.7, 3.5, 7.0, and 11.2 mm, respectively. Average head capsule widths were about 0.16, 0.25, 0.37, and 0.61 mm, respectively, for these instars. The larval body form tapers at both the ends and a pair of pro-legs protrudes from the posterior end and forming a distinctive "V" shape. The first instar larvae were colourless but thereafter they achieved pale green colour and were widest in the middle part of the body and measure from 8-12 mm when fully grown. The body beared relatively few hair, short in length and most of them were marked by the presence of small white patches. Initially the feeding habit of the first instar larvae was leaf mining, although the mines were very small. The larvae emerged from their mines at the end of the first instar, molted beneath the leaf and thereafter fed on the lower surface of the leaf. Their chewing resulted in irregular patches of damage and the upper leaf epidermis left intact and the total larval period ranged from 14 to 28 days.

Sarfraz *et al.* (2005**)** noticed that each larval instar survived for about four days followed immediately by pupation. When the fourth instar larva completed its feeding, it constructed a cocoon on the leaf surface and remained inactive as pre-pupa for next two days.

The pupa shed the larval skin, which remained attached to its caudal end. The yellowish pupae were wrapped in a loose silk cocoon and about 8 mm long. They are usually found on the lower or outer leaves of the host plant, except for cauliflower and broccoli where pupation may occur in the florets.

Ramegowda *et al.* (2006) investigated the biology of *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae) in the laboratory and reported that incubation period ranged between 3.00 and 5.25 days and larval stage lasted for 3.74, 5.13, 5.60 and 5.61 days, respectively for I, II, III and IV instar. The total larval duration ranged from 27.00 to 32.75 days with a mean of 29.86 days, pupal period lasted for 3.50 to 4.75 days with a mean of 4.27 days, and adult longevity was 4.27 days. The total developmental period from egg to adult ranged from 27.00 to 32.75 days and the fecundity was 55.14 eggs. The number of eggs laid was more on the lower surface of leaves.

Oke (2008) studied that generally *P. xylostella* takes about 32 days to develop from egg to adult but time to complete a generation ranged from 21 to 32 days depending on weather conditions and host plants. He reported several overlapped generations of the pest per growing season and all the life stages were present in the field at the same time interval.

Ahmad *et al.* (2008) investigated the biology of *P. xylostella* under laboratory conditions on mustard plant. The oviposition period of diamondback moth was 6.5 ± 0.41 days. It passed through four instars, the larval duration was 5.0 ± 0.55, 3.5 ± 0.60, 4.0 ± 0.45 and 3.5 ± 0.85 days, respectively. The pupal period was completed in 4.50 ± 1.11 days. The adult longevity of male and female was 8.0 ± 0.70 and 11.0 ± 0.82 days, respectively. The total life period of male and female was 32.5 ± 4.03 and 35.5 ± 4.32 days, respectively.

Ebrahimi *et al.* (2008) studied the developmental and reproduction potential of *P. xylostella* at 25 ± 1°C, 60 ± 5 per cent relative humidity and a photoperiod of 16L: 8D hours on five frequently grown *Brassica napus* cultivars *viz.*, Modena, Licord, Okapi, REGX kobra and RGsoo3. The duration from egg to adult varied from 15.05 ± 0.26 days on Licord to 16.87 ± 0.40 days on Modena. Adult longevity of diamondback moth was recorded to be 5.00 ± 0.31 on Modena and 10.02 ± 0.69 days on RGsoo3 cultivars.

Kahuthia *et al.* (2008) studied the development, survival and reproductive potential of *P. xylostella* at 25 ± 1°C temperature in the laboratory conditions in response to two cultivated *Brassica oleracea* cultivars (cabbage and kale) and four wild crucifer species *viz.*,

Raphams raphanistrum, Erucastrum arabicum, Rorippa nudiuscula and *Rorippa micrantha*. They found that the developmental period was shortest on *R. micrantha* (14.1 days), while it was longest on *R. raphanistram* (15.6 days). Longevity of Adult ranged from 18.2 days on *R. raphanistrum* to 24.7 days on *R. nudiuscula*.

Hasan and Singh (2008) observed that the duration of incubation, larval, pre-pupal and pupal stage of *P. xylostella* was 3.4, 9.4, 1.1 and 7.4 days on cabbage while on mustard the duration ranged 3.6, 10.4, 1.4, and 6.2 days, respectively. However, the longevity of male and female was reported as 8.4 and 10.4 days on cabbage as well as 8.6 and 10 days on mustard, respectively.

Ahmad *et al.* (2009) investigated the biology of diamondback moth on *B. juncea* under laboratory conditions and protected natural conditions. Under laboratory conditions, the oviposition period of diamondback moth was 6.5 ± 0.41 days. Larval duration was 5.0 ± 0.55, 3.5 ± 0.60, 4.0 ± 0.45 and 3.5 ± 0.85 days of 1^{st}, 2^{nd}, 3^{rd} and 4^{th} instar, respectively. The pupal period was completed in 10.0±1.58 days. The adult longevity of male and female was 8.0 ± 0.70 and 11.0 ± 0.82 days, respectively. The total life period of male and female was 8.0±0.70 and 11.0±0.82 days, respectively, while under field condition, larval periods ranged from 9.5±0.36, 16.5±0.41, 7.5±0.79 and 7.5±0.72 days of 1^{st}, 2^{nd}, 3^{rd} and 4^{th} instar, and the pupal period ranged from 4.50±1.11 days. The adult longevity of males and females was 12.5±1.11 and 20.0±1.00 days, respectively.

Raghuwanshi *et al.* (2010) studied the biology of *P. xylostella* on five different host plants, viz., cauliflower, cabbage, mustard, radish and chandrasoor. The incubation period varied from 4.75 days on cauliflower to 5.28 days on mustard. The larvae passed through 4 instars and the time span of first, second, third and fourth instar on cabbage, cauliflower, radish, mustard and chandrasoor was 2.75, 2.56, 3.00 and 3.39; 3.42, 1.32, 1.26 and 1.77; 1.95, 2.15, 1.65 and 2.06; 2.09, 2.45, 2.68 and 2.09; and 2.37, 2.69, 2.64 and 2.93 days, respectively. The mean larval period was found shortest on cauliflower (7.62 days), followed by cabbage (8.44 days), radish (9.55 days), mustard (10.43 days) and chandrasoor (11.18 days) and the survival rate of the larvae on cauliflower, mustard, cabbage, radish and chandrasoor was 89.0, 86.0, 82.0, 78.0 and 74.0 per cent, respectively. The pupal period was reported as 5.53 days on cauliflower followed by cabbage (5.87 days), radish (7.16 days), mustard (7.45 days) and (8.50 days) on chandrasoor.

Ahmad *et al.* (2011) studied the biology of diamondback moth and reported that after mating period of 69.9 ± 2.58 minutes and laid eggs 3.1 ± 0.16 days after mating. Single female laid on an average of 45.11 ± 2.31 eggs and the oviposition period was 4.8 ± 0.24 days. The post oviposition period lasted for 5.5 ± 0.34 days. The pre-pupal and pupal period varied from 1.20 ± 0.13 and 4.6 ± 0.37 days, respectively. Total larval development period from egg to adult emergence ranged from 21.5 ± 1.10 days. Longevity of adult male was 7.0 ± 0.25 days, while it was 11.8 ± 0.44 days for female.

Alizadeh *et al.* (2011) reported the development time of immature stages of diamondback moth viz., egg, I, II, III and IV larval instars, pre-pupa and pupa as 2.39 ± 0.17, 2.18 ± 0.17, 2.06 ± 0.28, 2.14 ± 0.14, 2.54 ± 0.12, 0.40 ± 0.12 and 4.23 ± 0.23 days, respectively. The longevity of male and female was 30.22 ± 0.05 and 28.26 ± 0.05 days, respectively.

Silva and Furlong (2012) reported that the preferred site for oviposition on mustard was the lower first, second and third true leaves. They can lay up to 200 eggs on both the upper and lower leaf surfaces but ideally on the lower surface away from direct sunlight and where there is protection from the rain and the wind and does not found to prefer to ovipositon the stem of *Brassica napus* like other hosts in the Brassicaceae family, for example wild cabbage plants where tests have shown that eggs are just as well laid on the stem as on the leaves also. The incubation time before the larval stage is temperature-dependent and varies between 15 to 3 days with temperatures varying from 10 to 28°C.

Kaur *et al.* (2012) investigated the biology of *P. xylostella* collected from Amritsar at different temperatures and recorded that the average incubation period varied from 3.25 to 4.24 days at 24.73-28.07ºC temperature. The larval and pupal period was recorded as 9.83 to 14.25 and 5.72 to 5.99 days, respectively at 24.74 to 31.55ºC and 39.50 to 58.76 per cent relative humidity. With the rise in temperature, adult emergence decreased from 100-75 per cent relative humidity and the highest numbers of eggs (168.50) were laid at 24.74-27.50ºC and 51.93-58.76 per cent and the time taken to complete the life cycle was 27.43 days.

Niu *et al.* (2013) studied the development, survival, and reproductive potential of diamondback moth on eight wild cruciferous species. The developmental period of immature stage from egg to adult emergence was found to be considerably longest on *Cardamine macrophylla* (20.8 days), while it was recorded shortest on *Raphanus indica* (15.8 days). The

survival from egg to adult emergence varied from 95.7 per cent on *R. indica* to 48.8 per cent on *Thlaspi arvense* and the longevity and the opposition period of *P. xylostella* was recorded as longest when their larval stage fed on *R. indica* than those fed on other wild species. The egg laying capacity of diamondback moth ranged from 305-351 eggs/ female on *Orychophragmus violaceus, C.macrophylla* and *C. bursa- pastoris*, while it was recorded to be lowest on *R. indica* (134 eggs/ female).

Gowri and Manimegalai (2016) found that larvae of diamondback moth fed on the foliage of the cruciferous plants from the seedling stage to harvest and significantly reduce the yield and quality. *P. xylostella* has only become a notable pest of the cruciferous, with serious problems. Wing length of male and females were different from each other and it was larger in females than males and the adult males lived about 12 days and females for about 16 days under laboratory conditions. Mated females started laying eggs singly or in groups and 300 eggs were laid by single female in laboratory condition.

Ram *et al.* (2017) studied the variations in the development, biology and morphometrics of diamondback moth collected from five different geographic regions viz., Hisar (800 feet), Solan (4200 feet), Kangra (2200 feet), Theog (7500 feet) and Kinnaur (9000 feet) on cauliflower (*brassica oleracea* var. *botrytis*). Wing span was maximum (13.25 and 14.95 mm) in Kinnaur population and minimum (12.05 and 13.15 mm) in Solan and the notable differences were observed in developmental duration for the population of different geographical regions. The total developmental duration found to be maximum (17.03) days) for the Kangra population whereas it was minimum (14.65 days) for the Kinnaur population and was considerably different from each other.

Harika *et al.* (2019) studied biology of diamondback moth, *P. xylostella* (L.) (Lepidoptera: Yponomeutidae) on cauliflower and revealed that the egg period (incubation period) varied from 2 to 4 days (Av. 3 ± 0.5 days). The larva passed through four different instars. The first, second, third and fourth instar larva lived for 2 to 3 days (Av. 2.5), 2 days (Av. 1.5), 1 to 3 days (Av. 1.75 ± 0.25) and 2 to 4 days (Av. 2.75 ± 0.25) respectively, with a total larval period of 7 to 12 days (Av. 9). The pre-pupal and pupal stage lasted for 1 to 2 days (Av. 1.5 ± 0.5) and 3 to 5 days (Av. 4.25 ± 0.25), respectively. The adults lived for 3 to 7 days (Av. 4.5 ± 1) and the entire life span under laboratory conditions varied from 13 to 22 days (Av. 17.75 ± 0.25).

Huaripata and Sanchez (2019) observed that the duration of incubation, larval, pupal and biological cycle of *P. xylostella* was 3, 9.76, 5.1 and 19.5 days on broccoli while on cauliflower these were recorded as 3, 9.69, 5.3, and 19.9 days, respectively. However, the egg laying capacity of mated females was reported as 175 eggs on broccoli as well as 187 eggs on cauliflower, respectively.

2.2 LIFE-FECUNDITY TABLES OF *Plutella xylostella* (L.)

Liu *et al.* (1985) noticed differences in the intrinsic rate of increase (r_m) from Taiwan in the population of the *P. xylostella* collected from three different localities and its value was 0.228, 0.188 and 0.151, respectively. The population of diamondback moth caused severe damage in tropical areas but in temperate areas less damage was recorded to the crops (Lim, 1986).

Reddy and Singh (1998) recorded that the net reproductive rate that represents the total female birth was found to be 3.6078. The population of diamondback moth was increased with intrinsic rate of increase (r_m) of 0.0584 and finite rate of increase (λ) of 1.0602 females/ female/ day. The mean generation time (T) was 22.05 days and the population on reaching stable age distribution constitutes about 98 per cent or more immature stages. From the stable-age distribution the instantaneous birth rate (b) was recorded as 0.1639.

Justin *et al.* (2001) reported that gross reproductive rate of *P. xylostella* to the extent of 86.78, 89.16, and 115.40 female eggs/female on Indian mustard, cauliflower, and cabbage, respectively. The innate capacity for natural increase in numbers was found to be 0.16, 0.17 and 0.13 female per day and daily finite rate of increase was 1.18, 1.19 and 1.14 females per day. The multiplication of *P. xylostella* was recorded to be 3.18, 3.38 and 2.50 times per week on these three host plants, respectively.

Hemchandra and Singh (2003) recorded that the net reproductive rate (R_o) of diamondback moth was 27.19 eggs/female with a mean length of generation (T_c) of 26.54 days. The intrinsic rate of increase (r_m) was 0.12 and finite rate of increase (λ) was 1.13 females/female/day. On reaching the stable-age distribution, the population comprised mainly of immature stages mid further life at the time of adult emergence, was reduced from 7.40 to 3.11 days.

Syed and Abro (2003) observed that net reproductive rate (R_o) of *P. xylostella* (L.) was highest (89.71) when fed on *B. oleracea* var. *botrytis* while it was lowest when its larvae fed on *B. napus* with R_o value of 26.77. The intrinsic rate of increase (r_m) and finite rate of increase (λ) was highest on *B. oleracea* var. *botrytis* and lowest on *B. compestris*, respectively.

Hemchandra and Singh (2004) recorded the rate of increase and stable-age distribution for the diamondback moth on *Brassica oleracea*. They found that net reproductive rate (R_o) was 19.23 representing the total birth with a mean length of generation (T_c) as 32.542 days. The population increase with intrinsic rate of increase (r_m) and finite rate of increase (λ) was 0.0921 and 1.0964 females/ female/ day, respectively. On reaching the stable-age distribution, the population comprised mainly of immature stages and further life at the time of adult emergence was reduced from 9.51 to 5.27 days.

Hemehandra and Singh (2005) further worked out the number of diamondback moth survived on cauliflower from egg to adult emergence. According to them, the net reproductive rate (R_o) was 24.916; mean length of generation (T_c) was 29 43 days, intrinsic rate of increase (r_m) was 0.1109 and finite rate of increase of *P. xylostella* on cauliflower was 1.117 females/ female/ day, respectively.

Das and Chaudhuri (2007) recorded the high level of potential fecundity (76.5), net reproductive rate (14.145), innate capacity for increase in number (0.101), of adults of February -March generation than the adults of March - April generation.

Dabhi (2007) from Anand, Gujarat reported that, the maximum anticipation of newly deposited eggs of *P. xylostella* was on cabbage, followed by cauliflower, mustard and cress. The highest survival of immature stages (on the basis of L_x values) was recorded on cabbage followed by cauliflower, cress and mustard. The highest reproductive rate (R_o) was recorded on cabbage while it was lowest on the mustard. The mean length of generation was lowest on cress and maximum on mustard. The innate capacity of increase in number (r_m) was 0.1332-0.1720. The order of host crops for *P. xylostella* considering the values of the 'r_m' was as cress > cabbage > cauliflower > mustard. The finite rate of increase (λ) was 1.1912, 1.1806, 1.1713 and 1.1447 females/ day on cress, cabbage, cauliflower and mustard, respectively. Studies on age-specific distribution of this pest on different hosts revealed that the eggs and

larvae contributed the highest to the population of stable age, while the contribution of pupae and adults was negligible.

Kahuthia *et al.* (2008) studied the survival, development and reproductive potential of *P. xylostella* at 25 ± 1°C in the laboratory in response to two cultivated cultivars of knol-khol and four wild crucifer species. They reported that moths reared on *Rorippa nudiuscula* recorded the highest fecundity (326 eggs), while fecundity was lowest (262 eggs) when the moths were reared on cabbage. *B. oleracea* var. *sabellica* and *Rorippa nudiuscula* recorded the longest generation time of 31.7 days, while *Erucastrum arabicum* had the highest net reproductive rate (126.4 eggs/ day). The highest intrinsic rate of increase (r_m) was observed on *R. micrantha* (0.179), whereas it was lowest on *B. oleracea* var. *sabellica* (0.147).

Dabhi *et al.* (2009) recorded that the net reproductive rate as 95.33, mean length of generation 27.45 days and intrinsic rate of natural increase was 0.1635 females/ female/ day in *P. xylostella* (L.) on cabbage. On reaching the stable-age distribution the eggs, larvae, pupae and adults constituted 37.71, 4.27 and 1.44 per cent, respectively.

Golizadeh *et al.* (2009) reported the development, survival and reproduction of *P. xylostella* on five host plants. The reproduction period and adult longevity was observed to be longest on cauliflower and cabbage and the highest fecundity of *P. xylostella* (L.) was also observed on these two.

Fathi *et al.* (2010) recorded that the fecundity of diamondback moth was lowest on *Matthiola incana* (Opera), (95.4 eggs/ female) and highest on *Agastache foeniculum* (Adder) (145.7 eggs/ female). The survival rate from egg to adult was significantly lower on Opera, Option SOO and Hyola 401 than on other tested cultivars. The intrinsic rate of natural increase (r_m) and the population growth rate were lowest on Opera and highest on Zarfam while the generation time (T) was shortest on Zarfam (17.2 days) and longest on Hyola 401 (19.9 days).

Saeed *et al.* (2010) studied the effect of various host plants on the fitness of diamondback moth and tested the hypothesis by studying development time, growth, fecundity and survival on cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*), radish (*Raphanus sativus*), turnip (*Brassica rapa*), mustard (*Brassica compestris*) and canola (*Brassica napus* var. *canola*). They reported that the developmental

time from eggs to adult was shortest on canola (10 days), longest on turnip (13 days); fecundity was greatest on canola (350 eggs/ female) followed by cauliflower (268 eggs/ female), while it was minimum (184 eggs/ female) on cabbage. The egg hatching was highest (80 per cent) when larvae were fed on cauliflower, survival to the adult stage was highest on mustard (94 per cent) followed by cauliflower and lowest on turnip (64 per cent). There was lowest net reproductive rate (32.3) and intrinsic rate of population increase (0.20) on cabbage.

Niu *et al.* (2013) found the highest and lowest intrinsic rates of increase (r_m) of diamondback moth to be 0.2402 and 0.1577 on hairy bitter-cress and penny-cress, respectively.

Ahmad and Ansari (2014) studied the life-table parameters of *P. xylostella* on four host plants viz., cauliflower, cabbage, broccoli and radish during two consecutive years. They reported that the mortality and survival ratio for immature stages was highest on radish and lowest on cauliflower. The fecundity of diamondback moth was found to be highest in the beginning of age on all host plants, however it slowly declined with advancing age of the crop. The highest net reproductive rate (R_o) was observed on cauliflower during both the years upto the extent of 48.5 and 55.4 females/ female/ generation, while it was lowest on radish (3.5 and 4.2 females/ female /generation). The intrinsic rate of population increase (r_m) was observed to be highest on cauliflower (0.1413 and 0.1368 female/ female/ day). Diamondback moth completed a single generation in 27.5 days on cauliflower and 35.1 days on radish. The population of *P. xylostella* was doubled in 4.9 and 5.1 days on cauliflower while, it took 19.3 and 17.0 days on radish during both the years, respectively.

Pan *et al.* (2014) recorded the variations in life-histories and life-table parameters of *P. xylostella* from five geographical regions of China, Beijing (BJ), Shandong (SD), Shaanxi (SX), Yunnan (YN), and Guangdong (GD). The oviposition period of diamondback moth ranged from 10.47 to 17.18 days, whereas, fecundity varied from 337.18- 411.47 eggs per female. Variations in the intrinsic rate of increase (r_m) were also recorded, which was highest for the Beijing population (0.2888) and lowest for the Shandong population (0.2165).

Hasanshahi *et al.* (2014) recorded the life-table parameters of diamondback moth on five cauliflower cultivars viz., Smilla, White cloud, Buris, Galiblanka and Tokita under laboratory conditions at 25 ± 2°C temperature, 65 ± 5 per cent RH and 16L: 8D photoperiod. They reported that the developmental time of immature stages ranged from 13.44 days on

Smilla cultivar to 15.88 days on Buris cultivar. The highest fecundity of *P. xylostella* was observed on Buris cultivar. Intrinsic rate of increase of *P. xylostella* reared on Smilla cultivar was highest (0.27 ± 0. 02) and finite rate of increase was 1. 32 ± 0.13 and the lowest doubling time (2. 50 days).

Saeed *et al.* (2017) studied the life-table parameters for *P. xylostella* on napa cabbage (*Brassica oleracea* var. *napa*), white cabbage (*B. oleracea* var. *capitata*), and cauliflower (*B. oleracea* var. *botrytis*) under laboratory conditions at 25 ± 2°C, 50 to 60 per cent relative humidity. The time for development from an egg to a male or female adult *P. xylostella* on white cabbage (mean ± SE: 41.15 ± 0.54 and 39.50 ± 0.54 days, respectively) was significantly longer than that on cauliflower and napa cabbage. Furthermore, *P. xylostella* fecundity on cauliflower (261.90 ± 4.53 eggs/ female) was significantly highest than on napa cabbage and white cabbage. Intrinsic rate of increase (r_m) and finite rate of increase (λ) were highest on cauliflower 0.182 females/day and 1.199 females/day, respectively as comparison to napa cabbage and white cabbage. The highest gross reproductive rate (GRR) and net reproductive rates (R_o) of *P. xylostella* was 65.87 and 52.58, respectively.

Jahed *et al.* (2018) studied the life-table parameters of diamondback moth on six host plants viz., broccoli, cauliflower, kohlrabi, canola, red cabbage, and white cabbage. They reported that total development time of immature stages was shortest on cauliflower (17.60 days) and longest on kohlrabi (21.12 days). The net reproductive rate (R_o) of *P. xylostella* ranged from 65.46 offspring per individual when larvae were reared on cauliflower to 12.71 offspring per individual on kohlrabi. The rates were relatively high for cauliflower, canola, and broccoli compared with white cabbage, red cabbage, and kohlrabi. The intrinsic rate of population increase (r_m) had a pattern similar to that of net reproductive rates (R_o) in which cauliflower produced the highest (0.200 female/ female/ day) and kohlrabi the lowest (0.105 female/ female/ day). The finite rate of increase (λ) ranged from 1.222 when cauliflower was the cultivar to 1.111 for kohlrabi. The mean generation time (T) was shortest on cauliflower (20.78 d) and longest on kohlrabi-reared larvae (23.77 days).

Chapter-3

MATERIALS AND METHODS

The present investigations entitled “Studies on life fertility table of diamondback moth, *Plutella xylostella* (Lepidoptera) on different hosts” were conducted in the Department of Entomology, College of Horticulture, University of Horticulture and Forestry, Nauni, Solan (H.P) during 2018-2019. The details of material used and methods employed during the present investigations are presented below in this chapter:

3.1 Raising of host plants

3.2 Maintenance of laboratory culture of diamondback moth

3.3 Biological studies of *P. xylostella*

3.4 Life fertility studies of *P. xylostella*

3.1 RAISING OF HOST PLANTS

The seeds of three different host plants viz., cauliflower, broccoli and mustard were sown in the open field in the experimental farm of the Department of Entomology, Dr. Yashwant Singh Parmar University of Horticulture and Forestry (Nauni, Solan, HP, India) on 28th November 2018. Transplanting was done after 4 weeks, when the plants had 4-5 leaves, individually in open field. These leaves were used for rearing the culture of *P. xylostella* under laboratory conditions (PLATE 1)**.**

3.2 MAINTENANCE OF LABORATORY CULTURE OF DIAMONDBACK MOTH

The larva and pupae were collected from the field and were brought to the laboratory and transferred into the insect rearing cages of 36×34×24 cm size with glass pan on three sides. They were fed in the cage with fresh leaves of cauliflower, broccoli and mustard with their petiole dipped in glass vials (7cm x 1.5cm) and allowed to develop up to adult stage (PLATE 2). Emerged adults were kept separately in glass chimneys with 10 per cent sugar syrup in cotton swab along with fresh leaves of cauliflower, broccoli and mustard for egg laying. The eggs laid by female moths in the oviposition cage were used for the

investigations on biology and life-fecundity of *P. xylostella* on three different host plants under laboratory conditions.

3.3 BIOLOGICAL STUDIES OF *P. xylostella*

The studies on biology of *P. xylostella* (L.) on different host plants were carried out in laboratory conditions at room temperature of 12-26°C with relative humidity (70-75 per cent) during January to March, 2019. About 20-25 pairs of adults of diamondback moth were kept separately inside the glass chimneys. 10 % sugar solution in a cotton swab was also kept inside as food for adults along with leaves of respective host plants for mating and egg laying (PLATE 4).

3.3.1 Study on various stages of *P. xylostella*

3.3.1.1 Egg stage

Eggs thus laid on the respective host plants were separated from the glass chimney and were counted. One hundred eggs were transferred to moist tissue paper kept in the five petri dishes having 20 eggs in each (diameter 9cm) in order to study the biology of *P. xylostella* on three different host plants.

The observations on number of eggs hatched were recorded daily in the morning till unhatched eggs shrank. Incubation period was calculated from the date of egg laying to the date of hatching of eggs and the hatching per cent was calculated from the number of eggs hatched out of the total number of eggs kept for hatching.

3.3.1.2 Larval period

Newly hatched larvae were transferred with the help of camel's hair brush to the petri plates (diameter 9.0 cm) containing leaves of the respective host plants. The leaves were changed periodically as and when exhausted. Exuvium as well as shed head capsule was observed daily. The molting was confirmed by the presence of casted off head capsule and increased size of the head capsule of the larva of subsequent instars. The larva in each instar was studied for their colour and size. Observations on number of instars, duration of instars and total larval period were recorded separately on three different host plants (PLATE 5).

3.3.1.3 Pre-pupal period

In order to determine the pre-pupal period, the larvae were observed from the time when they became fully matured, stopped feeding and became sluggish before turning to pupa.

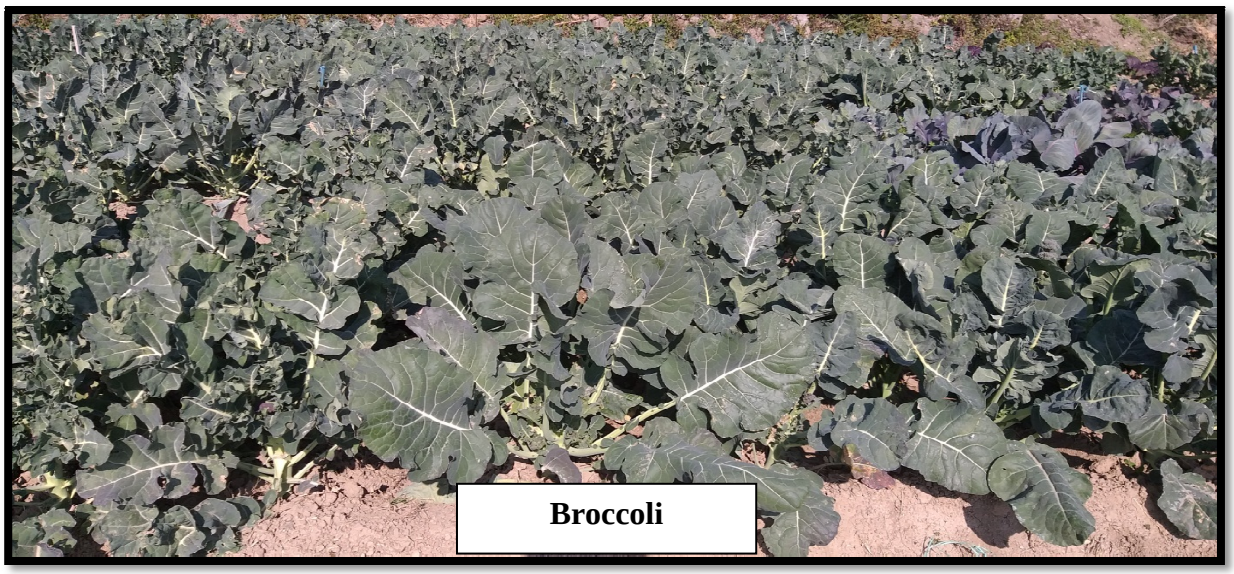

PLATE 1: General view of the Experimental Field

PLATE 2: *Plutella xylostella* rearing cage

PLATE 3: Rearing of *Plutella xylostella*

3.3.1.4 Pupal period

The pre-pupae developed from each larva were kept separately along with infested leaves and allowed to pupate. The number of days for which the insect remained in the pupal stage till emergence of adults was counted as the pupal period (PLATE 4).

3.3.1.5 Adult longevity

The male and female adults emerged out from the pupae were kept separately in glass chimneys (20cm x 15cm), the tops of which were covered with muslin cloth and tied with rubber bands. A pair of adults was kept in each chimney along with the host (cauliflower, broccoli and mustard leaves) and 10 per cent sugar solution in cotton swab to stimulate egg laying (PLATE 3).

Eggs laid by a single female were counted daily in the morning till the death of the female. The longevity of male and female was recorded separately from the date of emergence till the death of the adult. The observations on longevity of the adult were also recorded. Longevity of male and female was calculated separately from the date of emergence till the death of the adult.

3.4 LIFE FERTILITY STUDIES

The life tables were constructed by using the data on all the biological parameters of the test insect. Daily age-specific survival and age specific fecundity data were used to construct life fertility table of *P. xylostella* as per the method of Birch (1948) and elaborated by Howe (1953) and Carey (2001). Based on information from the life fertility of each female on different hosts, the average number of eggs per female (m_x) on each oviposition date (x) was calculated. The accumulated survival index of the female (l_x) during the oviposition period and the number of descendants that reached age x in the following generation ($l_x m_x$). By using survivorship and different fertility schedules, the following parameters were calculated:

i) Gross Reproductive Rate (GRR)

It is the total number of female eggs laid per female, represented by summation of mx (female egg / female)

$GRR = \Sigma m_x$

ii) Net Reproductive Rate (R_o)

It is the rate of multiplication of the population in each generation measured in terms of females produced per generation. It is calculated by multiplying lx and mx and then summation of their values. The number of times a population would multiply per generation was calculated by the following formula:

$R_o = \Sigma l_x m_x$

iii) Approximate Generation Time (T_c)

It is the mean length of a generation (birth to weighted mean reproductive age of the adult). It was calculated as under:

$T_c = \Sigma x l_x m_x / R_o$

iv) Innate capacity for natural increase (r_c)

It is the capacity of a species to increase in number i.e. the reproductive rate. The numbers of individuals survived and mean number of female offspring produced at each age interval were recorded. From the data on life-table, the arbitrary value of innate capacity for natural increase in numbers 'r_c' was calculated by using formula:

$r_c = \log_e R_o / T_c$

v) True intrinsic rate of natural increase (r_m)

It is the actual rate of increase of population under specified constant environmental conditions in which food and space are unlimited, as defined by Andrewartha and Birch (1954). Southwood (1976) gave a graphical method for the calculation of precise value of r_m. The arbitrary values of r_c up to two decimal places were substituted in the formula $\Sigma (e^{7-rmx}.l_x m_x) = 1096.6$ until the two values were found which lie immediately above or below 1. These values were then plotted on the horizontal axis against their respective arbitrary 'r_m' on the vertical axis. The points were joined to give a line which intersected a vertical line drawn from the desired value of $\Sigma (e^{7-rmx}.l_x m_x)$ =1096.6. The point of intersection gave the value of r_m accurate upto three decimal places.

vi) True generation time (T)

It is the mean period elapsing from the birth of parents to the birth of offspring and calculated as:

$T = \log_e R_o / r_m$

Eggs

Larva

Pupa

Adult

PLATE 4: Different Life stages of *Plutella xylostella*

I instar larva

II instar larva

III instar larva

IV instar larva

PLATE 5: Different Larval stages of *Plutella xylostella*

vii) Finite rate of natural increase (λ)

It is the number of times the population increases per unit time and calculated by using formula:

$\lambda = \text{Antilog}_e r_m$

viii) Weekly multiplication rate (WM)

It is the number of times a population multiplied in a week and calculated as:
$WM = {}_e7\ r_m$

ix) Doubling time (DT)

It is the time taken by a species to double its population, calculated by the formula**:**

$DT = \log_e 2 / r_m$

x) Gross fecundity

It is the total number of eggs laid per female and calculated as ΣM_x

Chapter-4

RESULTS AND DISCUSSION

The present investigations entitled, **"Studies on life fertility table of diamondback moth, *Plutella xylostella* (Lepidoptera) on different hosts"** were conducted in the Department of Entomology, College of Horticulture, University of Horticulture and Forestry, Nauni-Solan (H.P) during the year 2018-2019. The results thus obtained are reported under the following heads:

4.1 Biology of *P. xylostella* on different host plants

4.2 Life fertility studies of *P. xylostella* on different host plants

4.1 BIOLOGY OF *P. xylostella* ON DIFFERENT HOST PLANTS

Biology of *P. xylostella* was studied at room temperature of 12-26°C in the Department of Entomology, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (H.P)**.** Studies on different biological parameters were undertaken on cauliflower, broccoli and mustard.

4.1.1 Biology of *P. xylostella* on cauliflower

A perusal of data presented in the Table 1 revealed that the average incubation period of *P. xylostella* was 3.04 days which varied from 2 to 4 days with 82 per cent hatchability. These findings are in agreement with those of earlier workers who reported incubation period from 2-4 days (Chauhan *et al*., 1997; Sharma *et al*., 1999; Gangurde and Wankhede, 2010; Gowri and Manimegalai, 2017 and Harika *et al.*, 2019) on this host. Duration of I, II, III and IV instar larva was 2.50 ± 0.06, 1.62 ± 0.11, 2.10 ± 0.12 and 2.81 ± 0.11 days, respectively. Similar results were obtained by Sharma *et al*. (1999), Kumar *et al.* (1999) and Dhaduk (2007). They have recorded the duration of first and second instar larva as 2 to 3 days, 2 to 3, 2.50 ± 0.50, 2 to 3 days and 1 to 1.5 days, 1 to 1.5 and 1.20 ± 0.25 days, respectively. Similarly Alizadeh *et al*. (2011), Niu *et al*. (2013) and Saeed *et al*. (2017) found duration of third instar larva as 2.14 ± 0.14, 2.1 ± 0.1 and 2.33 ± 0.13 days, respectively. Sharma *et al*. (1999), Dhaduk (2007), Alizadeh *et al.* (2011) and Saeed *et al.* (2017) also recorded the duration of fourth instar as 2.5, 2.04 ± 0.24, 2.54 ± 0.12, 2.08 ± 0.13 days, respectively on cauliflower. The total larval period was 9.05 ± 0.22 days with a range of 7 to 11 days with 41 per cent survival. The present studies are in conformity with those of Syed and Abro (2003),

Gangurde and Wankhede (2010), Kaur *et al*. (2012) and Harika *et al*. (2019), who have reported duration of total larval period as 7-11 days. The pupal period was found to be 5.05 ± 0.12 days with a range value of 4 to 6 days and the survival was 38 per cent (Table 1). Similar results were obtained by Sharma *et al*. (1999), Gowri and Manimegalai (2016), Harika *et al.* (2019), who recorded the pupal period of *P. xylostella* as 3 to 5 days, 3 to 4, and 3 to 5 days, respectively. Total developmental period was 16.97 ± 0.28 days with a range of 14 to 19 days. In congruence with present findings, Niu *et al*. (2013), Saeed *et al*. (2017), Jahed *et al.* (2018) and Harika *et al.* (2019) also recoded the total development period as 17.4 days, 15.69, 17.60 and 17.75 days, respectively on cauliflower.

The pre-oviposition, oviposition and post-oviposition period of *P. xylostella* on cauliflower was 1.29 ± 0.08, 10.74 ± 0.22 and 0.80 ± 0.13 days with range of 1 to 2, 9 to 13 and 0 to 2 days, respectively (Table 1). Similar results were found by Niu *et al*. (2013) and Saeed *et al*. (2017) on cauliflower, who reported oviposition period as 11.90 ± 1.30 and 10.83 ± 0.33 days, respectively. The male lived for 10.92 ± 0.50 days with a range of 8 to 14 days whereas, longevity of female was 14.06 ± 0.40 days with range of 10 to 17 days. The present studies are in line with different authors who reported longevity of the male and female as 12 and 16 days (Gowri and Manimegalai, 2016), 14.9 ± 1.9 days (Niu *et al.,* 2013), 9.70 ± 0.26 days (Jahed *et al.,* 2018).

Table 1. Biological parameters of *Plutella xylostella* on cauliflower

Sr.No.	Biological parameters		Duration (days)		Survival (%)
			Mean±SE	Range	
1	Incubation period		3.04±0.08	2-4	82
2	Larval period	I instar	2.50±0.06	2-3	66
		II instar	1.62±0.11	1-3	52
		III instar	2.10±0.12	1-4	44
		IV instar	2.81±0.11	2-4	41
3	Total larval period		9.05±0.22	7-11	41
4	Pupal period		5.05±0.12	4-6	38
5	Total developmental period		16.97±0.28	14-19	38
6	Pre-oviposition period		1.29±0.08	1-2	34
7	Oviposition period		10.74±0.22	9-13	-
8	Post-oviposition period		0.80±0.13	0-2	-
9	Adult longevity	Male	10.92±0.50	8-14	-
		Female	14.06±0.40	10-17	-

4.1.2 Biology of *P. xylostella* on broccoli

A perusal of data presented in the Table 2 revealed that the incubation period of *P. xylostella* was 3.01 ± 0.08 days with range of 2 to 4 days and the hatchability was 83 per cent.

Larval duration for I, II, III and IV instar was 3.06 ± 0.09, 2.42 ± 0.07, 2.53 ± 0.08 and 3.18 ± 0.11 days, respectively. The duration of the total larval period was 11.11 ± 0.16 days with a range of 9 to 13 days and the survival was 45 per cent. The mean pupal period was 3.80 ± 0.11 days with a range of 3 to 5 days and the survival was 39 per cent. The total developmental period was 18.15 ± 0.29 days with a range of 17 to 23 days. The durations of the pre-oviposition, oviposition and post-oviposition period of *P. xylostella* on broccoli was 1.06 ± 0.13, 11.88 ± 0.28 and 0.74 ± 0.16 days with ranges of 0 to 2, 10 to 14 and 0 to 3 days, respectively. The longevity of female was 12.79 ± 0.30 days with a range of 10 to 16 days whereas, the male lived for 10.25 ± 0.25 days with a range of 9 to 12 days. The present studies are more or less on agreement with those of Jahed *et al.* (2018) and Huaripata and Sanchez (2019), who reported the duration of incubation period, I, II, III, IV larval instar, total larval period, pupal period, total developmental period of *P. xylostella* as 3.07 ± 0.03, 2 to 3, 3, 2 to 3, 3.10 ± 0.10, 10.68 ± 0.11, 4.68 ± 0.06, 18.61 and 3 days, 2 to 3, 3, 2 to 3, 3, 10.85 ± 0.09, 5.01, 17.9 days, respectively. However, Syed and Abro (2003) recorded the total larval duration and pupal period as 10.68 ± 0.11 and 5.89 ± 0.10 days, respectively on broccoli. Slight variations can be attributed to the difference in the temperature and relative humidity under which the studies were undertaken.

Table 2. Biological parameters of *Plutella xylostella* on broccoli

Sr.No.	Biological parameters		Duration (days)		Survival (%)
			Mean±SE	Range	
1	Incubation period		3.01±0.08	2-4	83
2	Larval period	I instar	3.06±0.09	2-4	70
		II instar	2.42±0.07	2-4	62
		III instar	2.53±0.08	2-3	53
		IV instar	3.18±0.11	2-4	45
3	Total larval period		11.11±0.16	9-13	45
4	Pupal period		3.80±0.11	3-5	39
5	Total developmental period		18.15±0.29	17-23	35
6	Pre-oviposition period		1.06±0.13	0-2	35
7	Oviposition period		11.88±0.28	10-14	-
8	Post-oviposition period		0.74±0.16	0-3	-
9	Adult longevity	Male	10.25±0.25	9-12	-
		Female	12.79±0.30	10-16	-

4.1.3 Biology of *P. xylostella* on mustard

Data presented in the Table 3 revealed that the incubation period of *P. xylostella* was 3.56 ± 0.06 days with range of 3 to 4 days and 78 per cent hatchability. Duration of I, II, III

and IV instar larva was 3.17 ± 0.11, 2.62 ± 0.08, 2.86 ± 0.10, and 3.24 ± 0.14 days, respectively. The duration of total larval period was 11.86 ± 0.21 days with a range of 9 to 14 days and the survival of 37 per cent. The pupal period was found to be 4.73 ± 0.15 days with a range value of 4 to 7 days and 34 per cent survival. Total developmental period was 16.59 ± 0.27 days with a range of 14 to 20 days. The duration of the pre-oviposition, oviposition and post-oviposition period of the *P. xylostella* on mustard was 1.54 ± 0.12, 12.07 ± 0.31 and 0.71 ± 0.15 days with a range of 1 to 3, 9 to 14 and 0 to 3 days, respectively. The male lived for 9.44 ± 0.34 days with a range of 7 to 12 days whereas, longevity of female was 12.32 ± 0.32 days with range value of 9 to 14 days.

Table 3. Biological parameters of *Plutella xylostella* on mustard

Sr.No.	Biological parameters		Duration (days)		Survival (%)
			Mean±SE	Range	
1	Incubation period		3.56±0.06	3-4	78
2	Larval period	I instar	3.17±0.11	2-5	60
		II instar	2.62±0.08	2-4	55
		III instar	2.86±0.10	2-4	44
		IV instar	3.24±0.14	3-5	37
3	Total larval period		11.86±0.21	9-14	37
4	Pupal period		4.73±0.15	4-7	34
5	Total developmental period		16.59±0.27	14-20	34
6	Pre-oviposition period		1.54±0.12	1-3	29
7	Oviposition period		12.07±0.31	9-14	-
8	Post-oviposition period		0.71±0.15	0-3	-
9	Adult longevity	Male	9.44±0.34	7-12	-
		Female	12.32±0.32	9-14	-

4.1.4 Comparative analysis of biological parameters of *P. xylostella* on different hosts

The comparative duration of different developmental stages of *P. xylostella* on different hosts is presented in Table 4. It is evident from this table that there were variations among different hosts with respect to their biological parameters. The total larval period among the three host plants was the longest on the mustard (11.86 days) followed by broccoli (11.11 days) and cauliflower (9.08 days). These values were significantly different from one another. Syed and Abro (2003) in conformity to present studies had reported the total larval duration of *P. xylostella* as 9.45 ± 0.08 days, 10.68 ± 0.11 and 10.57 ± 0.19 days on cauliflower, broccoli and mustard, respectively. Raghuwanshi *et al.* (2010) also recorded the longest larval duration of *P. xylostella* when grown on mustard (10.43 days) as compared to its larval duration when grown on cabbage (8.44 days) and cauliflower (7.62 days).

The total developmental period on mustard (16.59 days) and cauliflower (16.97 days) did not differ significantly, whereas significantly higher developmental time was recorded on broccoli (18.15 days). Similarly, Justin *et al.* (2001) recorded maximum duration of immature stages of *P. xylostella* when reared on Indian mustard (25 days) followed by cabbage (22 days) and cauliflower (21 days).

Reproductive biology of the diamondback moth was studied on different hosts. The average duration of the pre-oviposition period on these three hosts varied from 1.06 to 1.54 days. The oviposition period on cauliflower, broccoli and mustard was 10.74, 11.88 and 12.04 days, respectively and was found to be significantly highest in case of mustard, whereas it was lowest on cauliflower. The post-oviposition period on cauliflower, broccoli and mustard was 0.80, 0.74 and 0.71 days, respectively.

Table 4. Comparative analysis of biological parameters of *Plutella xylostella* on different hosts

Sr. No.	Biological parameters		Host plant			$C.D_{0.05}$
			cauliflower	broccoli	mustard	
1	Incubation period		3.04±0.08	3.01±0.08	3.56±0.06	0.21
2	Larval period	I instar	2.50±0.06	3.06±0.09	3.17±0.11	0.26
		II instar	1.62±0.11	2.42±0.07	2.62±0.08	0.26
		III instar	2.10±0.12	2.53±0.08	2.86±0.10	0.30
		IV instar	2.78±0.11	3.18±0.11	3.24±0.14	0.35
3	Total larval period		9.08±0.23	11.11±0.16	11.86±0.21	0.59
4	Pupal period		5.03±0.12	3.80±0.11	4.73±0.15	0.37
5	Total developmental period		16.97±0.29	18.15±0.29	16.59±0.27	1.03
6	Pre-oviposition period		1.29±0.08	1.06±0.13	1.54±0.12	NS
7	Oviposition period		10.74±0.22	11.88±0.28	12.07±0.31	0.81
8	Post-oviposition period		0.80±0.13	0.74±0.16	0.71±0.15	NS
9	Adult longevity	Male	10.92±0.50	10.25±0.25	9.44±0.34	0.95
		Female	14. 06±0.40	12.79±0.30	12.32±0.32	1.05
10	Total no. of eggs/ female		253.36±2.62	182.72±2.63	245.48±4.32	NS

The results also revealed that the highest fecundity of 253.36 eggs/female was recorded in cauliflower followed by mustard (245.48 eggs). The minimum fecundity of 182.72 eggs was recorded on broccoli. In congruence with the present findings, Syed and Abro (2003) recorded highest fecundity on cauliflower (212.30 eggs/ female) followed by

mustard (118.70) and minimum fecundity was recorded on broccoli (97.70 eggs). The variations may be due to different cultivars or different climatic conditions.

The present findings on the duration of different stages on different host plants revealed that the total larval period as well as oviposition period of *P. xylostella* was extended when reared on mustard as compared to cauliflower and broccoli. This could be because of variations in the nutritional status of different host plants used in the present studies as also stated by Zhang *et al*. (2012) and Saeed *et al.* (2017) that development of immature stages can be reflections of differences in nourishment acquired during its immature stages.

In the present studies cauliflower was found to be the most suited host for *P. xylostella* followed by broccoli and mustard as larval period was completed in shorter duration on this host. These findings are in conformity with those of Chand and Choudhary (1977) who reported that diamondback moth although fed on all the cruciferous plants, yet exhibited preference for cauliflower and cabbage. These two plant species possess fleshy succulent leaves that provide both olfactory and gustatory stimuli. Singh and Singh (1982) have also observed that *P. xylostella* completed its larval and pupal development in the shortest time on cauliflower. Ramachandran *et al*. (1998) also reported significant differences in biological parameters of *P. xylostella* feeding on different *Brassica* spp.

4.2 FERTILITY STUDIES OF *P. xylostella* ON DIFFERENT HOSTS

4.2.1 Age –specific survival and age- specific fecundity of *P. xylostella* on cauliflower

Fertility table was constructed by utilizing the data on fertility of *P. xylostella* on cauliflower which revealed that at the time of adult emergence on 15th day, there was 34 per cent adult survival, which continued upto 20th day. However, on the 21st day of the pivotal age, there was 31 per cent survival. On 22nd and 23rd day, the survival was found to be 28 and 26 per cent respectively, which further reduced to 22 per cent on 24th day of the pivotal age. The survival rate reduced to 19 per cent on 25th day while, on 26th and 27th day of the pivotal age, the survival was 13 and 9 per cent, respectively. The adult survival reduced to 4 per cent and 2 per cent on 29th and 30th day of the pivotal age and all adults died on 31st day of the pivotal age (Table 5).

Table 5. Life table (for female) and age-specific fecundity of *Plutella xylostella* on cauliflower

Pivotal age in days (x)	Age specific survival (l_x)	Female progeny per female (m_x)	l_xm_x	xl_xm_x	$e^{7-rmx}l_xm_x$	
					r_m=0.17	r_m=0.18
0-3	0.82	**Egg stage**				
4-14	0.34	**Larval, pupal & pre-oviposition period**				
15	0.34					
16	0.34	4.50	1.53	26.01	110.53	94.19
17	0.34	5.91	2.01	36.17	122.50	103.35
18	0.34	7.95	2.70	51.36	138.83	115.96
19	0.34	11.55	3.93	78.54	170.48	140.98
20	0.34	15.02	5.11	107.24	187.02	153.12
21	0.31	17.38	5.39	118.53	166.43	134.90
22	0.28	15.67	4.39	100.91	114.36	91.77
23	0.26	11.96	3.11	74.63	68.35	54.31
24	0.22	9.81	2.16	53.96	40.05	31.50
25	0.19	7.73	1.47	38.19	22.99	17.91
26	0.13	5.92	0.77	20.78	10.16	7.84
27	0.09	5.33	0.48	13.43	5.34	4.08
28	0.05	3.20	0.16	4.64	1.50	1.14
29	0.04	3.25	0.13	3.90	1.03	0.77
30	0.02	1.50	0.03	0.93	0.20	0.15
31	0	0.00	0.00	0.00	0.00	0.00
		126.68	**33.36**	**729.22**	**1159.78**	**951.96**

A female on an average laid 4.50 female eggs on the second day of oviposition while on 17th, 18th and 19th day, the female progeny produced was 5.91, 7.95 and 11.55 female eggs/ female. The maximum female eggs/ female (17.38) were recorded on 7th day of oviposition at the pivotal age of 21st day. Thereafter, a decreasing trend in the egg laying was recorded till 30th day of the pivotal age and a minimum of 1.50 eggs per female were laid on 30th day of the pivotal age. The egg laying was completely stopped on the 31st day of the pivotal age (Figure 1).

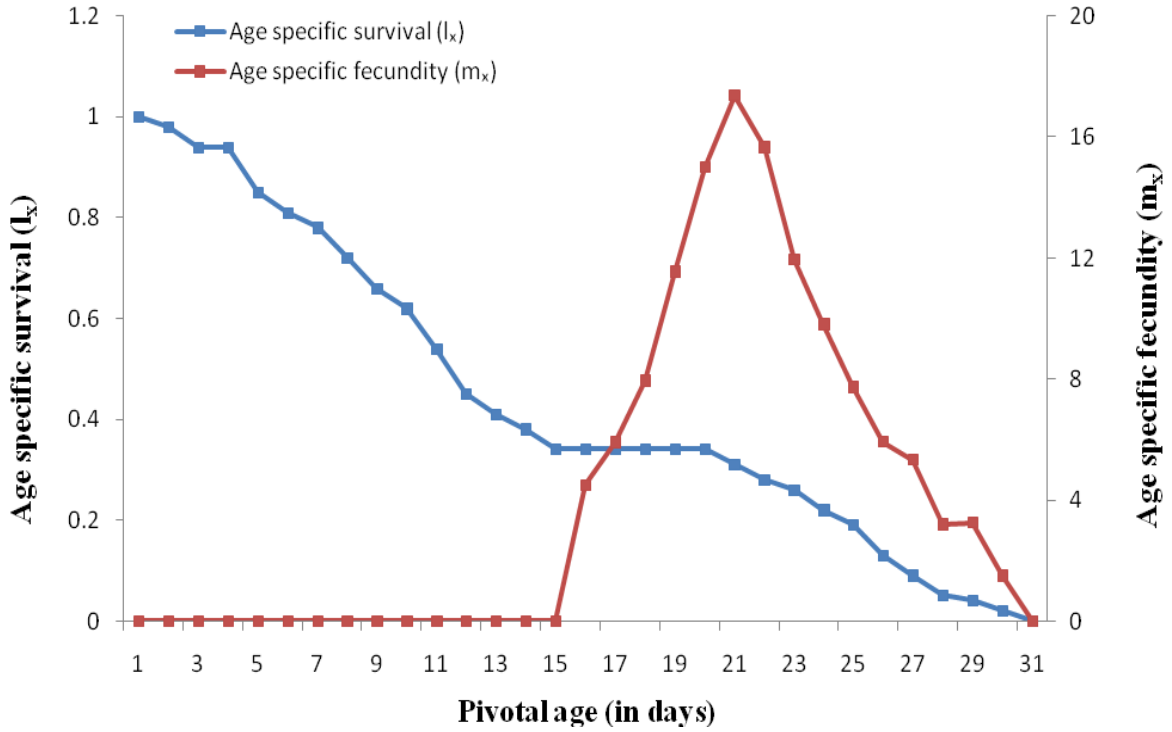

Figure 1. **Age-specific survival and age specific fecundity of *Plutella xylostella* on cauliflower**

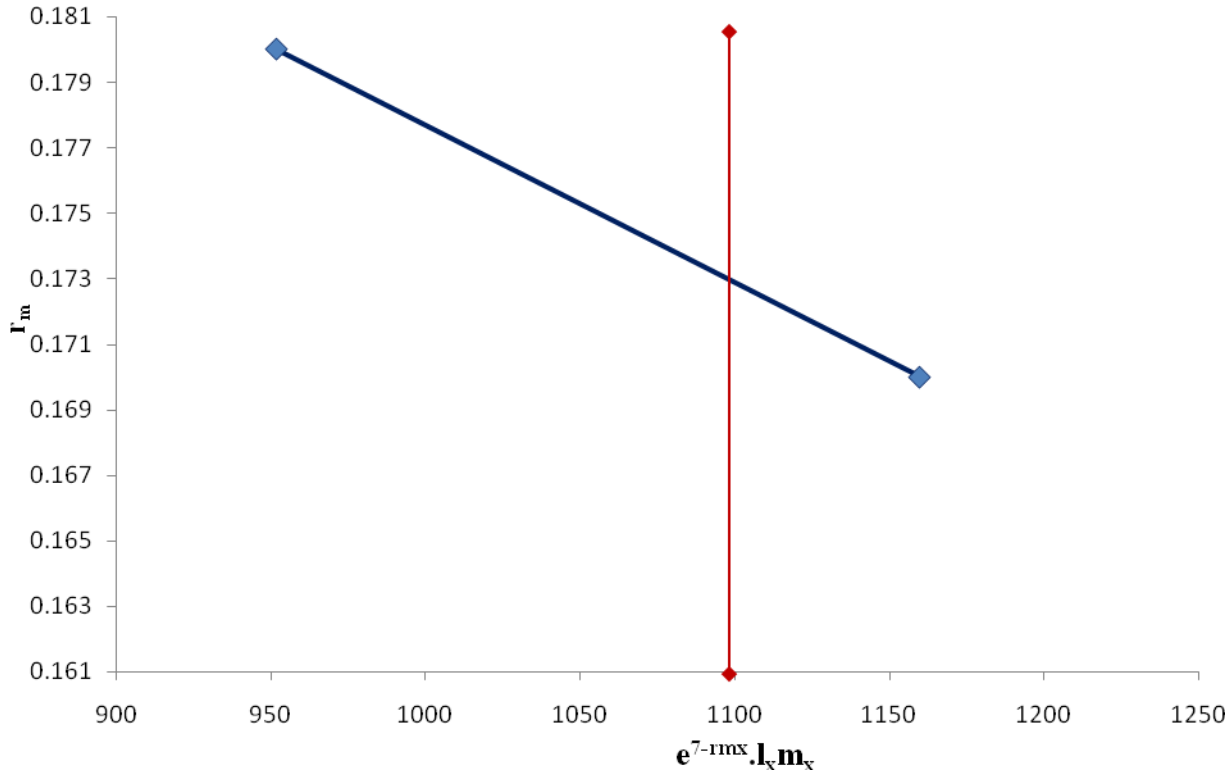

Figure 2. **Determination of true intrinsic rate of increase (r_m) of *Plutella xylostella* on cauliflower**

The data presented in Table 6 was utilized to compute the gross reproductive rate (GRR) and the net reproductive rate (R_0) which was 126.68 and 33.36 female eggs per female, respectively. The species had the approximate generation time (T_c) of 21.85 days. The innate capacity for natural increase (r_c) was 0.17, while the true intrinsic rate of increase (r_m) which was calculated graphically and was found to be 0.1730 (Figure 2). The true generation time was 20.27 days while the finite rate of increase (λ) was 1.18 days, with a doubling time (DT) of 4.2 days. Weekly multiplication rate was 3.19 times and the gross fecundity of this population was 253.36 eggs per female.

Table 6. Fertility parameters of *Plutella xylostella* on cauliflower

Parameters	Unit	Host (cauliflower)
Gross reproductive rate (GRR)	Female eggs/ female	126.68
Gross fecundity (M_x)	Number of eggs	253.36
Net reproductive rate (R_o)	Female eggs/ female	33.36
Approximate generation time (T_c)	Days	21.85
The innate capacity for increase (r_c)	Females/ female/ day	0.17
Intrinsic rate of natural increase (r_m)	Females/ female/ day	0.1730
True generation time (T)	Days	20.27
Finite rate of increase (λ)	Females/ day	1.18
Doubling time (DT)	Days	4.20
Weekly multiplication rate (WM)	Folds	3.19

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4.2.2 Age–specific survival and age- specific fecundity of *P. xylostella* on broccoli

Fertility table of diamondback moth was constructed on cauliflower under laboratory conditions. The data presented in Table 7 revealed that at the time of adult emergence, there was 35 per cent survival, which continued upto 20th day after that the adult morality started. On 21th, 22nd and 23rd days there was 33 per cent, 31 per cent and 28 per cent adult survival, respectively which further decreased to 25 and 21 per cent on 24th and 25th day of pivotal age. Further, the survival reduced to 15 and 8 per cent on 26th and 29th day of pivotal age and only 4 per cent adults survived on 30 day of pivotal age. All individuals died on 32nd day of pivotal age.

The data revealed that the egg laying started on the 18th day of pivotal age on broccoli when 12.53 female progeny were produced (Table 7). On 19th day the female egg laying was 10.04 eggs/ female. Maximum egg laying/ female (13.12) were recorded on 20th day. There were 11.47 and 11.66 eggs on 21st and 22nd day of pivotal age, respectively. Thereafter, a declining trend in the female progeny was recorded upto 29th day of pivotal age. On 23th, 24th,

25^{th} , 26^{th} , 27^{th} , 28^{th} and 29^{th} days of pivotal age the egg laying was 9.56, 7.94, 5.92, 4.81, 2.71 and 1.25 eggs/female, respectively. Minimum egg laying of 0.15 eggs/female was recorded on 30^{th} day and after that the egg laying was completely stopped (Figure 3).

Table 7. Life table (for female) and age-specific fecundity of *Plutella xylostella* on broccoli

Pivotal age in days (x)	Age specific survival (l_x)	Female progeny per female (m_x)	l_xm_x	xl_xm_x	$e^{7-rmx}l_xm_x$	
					r_m=0.15	r_m=0.16
0-3	0.83	**Egg stage**				
4-16	0.35	**Larval, pupal & pre-oviposition period**				
17	0.35					
18	0.35	12.53	4.39	78.94	323.54	270.25
19	0.35	10.04	3.51	66.77	222.65	184.13
20	0.35	13.12	4.59	91.84	250.61	205.18
21	0.33	11.47	3.79	79.49	178.10	144.37
22	0.31	11.66	3.61	79.52	146.01	117.18
23	0.28	9.56	2.68	61.57	93.30	74.13
24	0.25	7.94	1.99	47.64	59.63	46.91
25	0.21	5.92	1.24	31.08	31.98	24.91
26	0.15	4.81	0.72	18.76	15.98	12.32
27	0.12	2.71	0.33	8.78	6.30	4.81
28	0.09	1.25	0.11	3.15	1.18	1.37
29	0.08	0.2	0.02	0.46	0.28	0.21
30	0.04	0.15	0.01	0.18	0.12	0.09
31	0.01	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00	0.00
		91.36	**26.98**	**568.17**	**1330.33**	**1085.85**

Population growth statistics of *P. xylostella* on broccoli are presented in Table 8 which revealed that it had the gross reproductive rate (GRR) of 91.36 female eggs per female and the net reproductive rate (R_o) was 26.98 female eggs per female. The approximate generation time (T_c) was 21.05 days, while the innate capacity of natural increase (r_c) was 0.15. This arbitrary value of r_c was used to determine the true intrinsic rate of increase (r_m) graphically as 0.1595 (Figure 4). The finite rate of increase (λ) was 1.173, while the true generation time (T) and the time taken to double the population (DT) were 20.66 days and 4.34 days, respectively. Weekly multiplication rate was 3.06 times and the gross fecundity was 182.72 eggs per female.

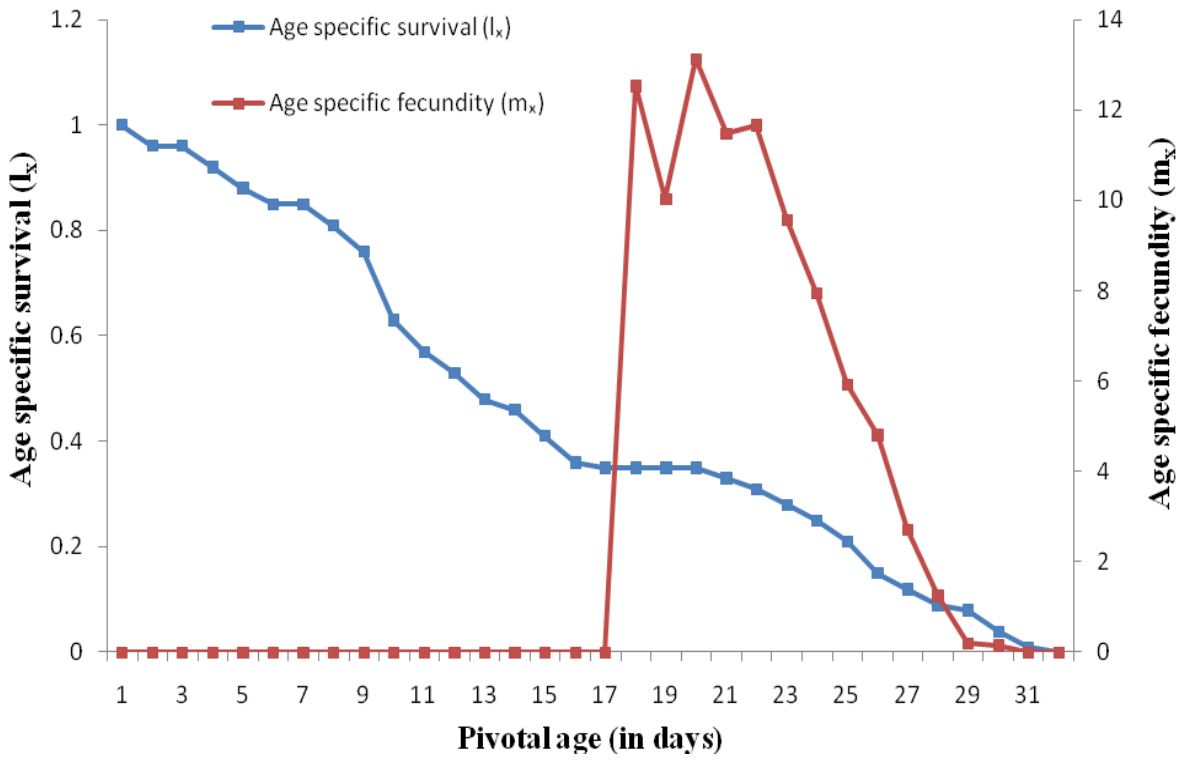

Figure 3. Age-specific survival and age specific fecundity of *Plutella xylostella* on broccoli

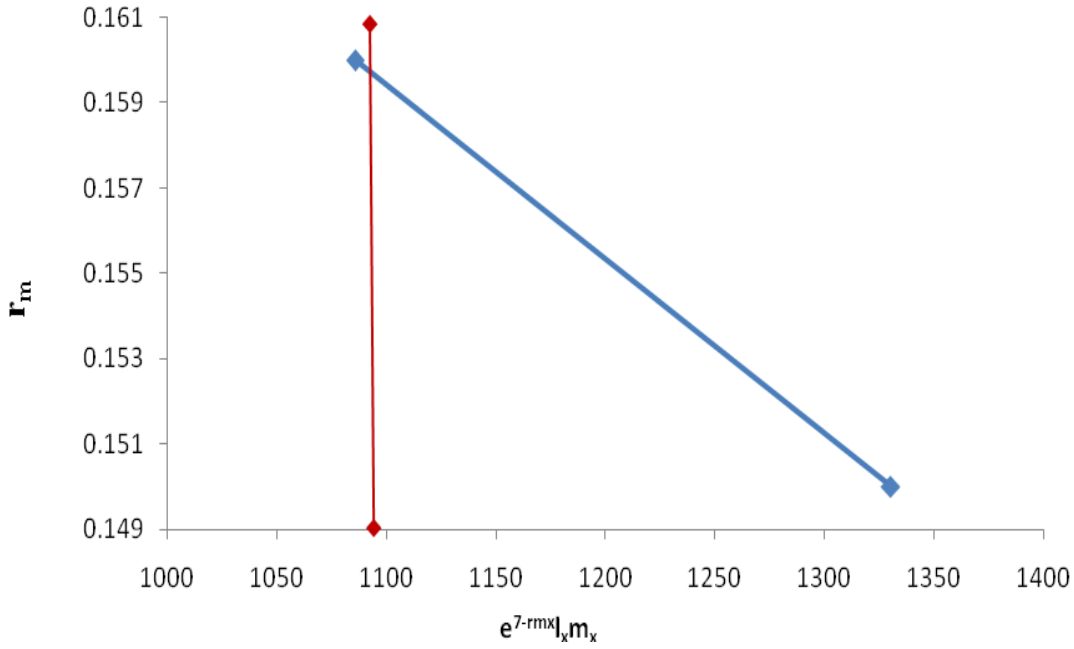

Figure 4. Determination of true intrinsic rate of increase (r_m) of *Plutella xylostella* on broccoli

Table 8. Fertility parameters of *Plutella xylostella* on broccoli

Parameters	Unit	Host (broccoli)
Gross reproductive rate (GRR)	Female eggs/ female	91.36
Gross fecundity (M_x)	Number of eggs	182.72
Net reproductive rate (R_o)	Female eggs/ female	26.98
Approximate generation time (T_c)	Days	21.05
The innate capacity for increase (r_c)	Females/ female/ day	0.15
Intrinsic rate of natural increase (r_m)	Females/ female/ day	0.1595
True generation time (T)	Days	20.66
Finite rate of increase (λ)	Females/day	1.173
Doubling time (DT)	Days	4.34
Weekly multiplication rate (WM)	Folds	3.06

4.2.3 Age -specific survival and age specific fecundity of *P. xylostella* on mustard

The data presented in Table 9 revealed that the adult emergence was observed on 18th day. There was 29 per cent survival at the time of emergence which persisted upto 21th day of the pivotal age. However on 22nd day the survival was 27 per cent, which reduced to 23 per cent on 23nd day of the pivotal age. On 24th day the survival was 19 per cent while, on 25th day the survival was found to be 15 per cent. The adult survival reduced to 9, 8, 6, 5 per cent, respectively on 26th, 27th, 28th and 29th day of the pivotal age. Only 2 per cent adults survived on pivotal age of 30th day and all adults died on 31st day of pivotal age.

The perusal of data presented in Table 9 revealed that the egg laying of *P. xylostella* on mustard started on the 19th day of pivotal age when 11.38 female progeny were produced. On 20th day the female egg laying was 10.06 eggs/ female. Maximum egg laying of 24.23 eggs/ female was recorded on 21st day. There were 21.04 and 16.21 eggs on 22 and 23 day of pivotal age, respectively, while it was 14.42, 11.75, 6.74, 5.47 and 0.64 eggs/ female on 24th, 25th, 26th, 27th and 28th day of pivotal age. The egg laying was completely stopped on the pivotal age of 30th day (Figure 5).

Table 9. Life table (for female) and age-specific fecundity of *Plutella xylostella* on mustard

Pivotal age in days (x)	Age specific survival (l_x)	Female progeny per female (m_x)	l_xm_x	xl_xm_x	$e^{7-rmx}l_xm_x$	
					r_m=0.15	r_m=0.16
0-4	0.78	**Egg stage**				
5-17	0.29	**Larval, pupal & pre-oviposition period**				
18	0.29					
19	0.29	11.38	3.30	62.70	209.34	173.12
20	0.29	10.06	2.92	58.35	159.28	130.41
21	0.29	24.23	7.03	147.56	330.21	267.66
22	0.27	21.04	5.68	124.98	229.77	184.40
23	0.23	16.21	3.73	85.75	129.79	103.13
24	0.19	14.42	2.74	65.76	82.10	64.58
25	0.15	11.75	1.76	44.06	45.46	35.40
26	0.09	6.74	0.61	15.77	13.47	10.38
27	0.08	5.47	0.44	11.82	8.36	6.38
28	0.06	0.64	0.04	1.08	0.63	0.48
29	0.05	0.80	0.04	1.16	0.57	0.42
30	0.02	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00
		122.74	**28.28**	**501.60**	**1208.98**	**976.36**

The data presented in Table 10 revealed that the mean female progeny per female over the entire reproductive period on mustard was 122.74. The net reproductive rate (R_0) which takes into consideration the age specific survival of the diamondback moth was 28.28 female eggs/ female. This moth had an approximate generation time (T_c) of 21.88 days and the true generation time (T) of 21.71 days. The capacity for natural increase (r_c) was 0.15, while the true intrinsic rate of natural increase (r_m) was 0.1548 (Figure 6). The finite rate of increase (λ) was of 1.166 female eggs /female/ day, whereas time taken to double the population (DT) was 4.49 days. The weekly multiplication rate was 2.93 times and gross fecundity of the species was 245.48 eggs.

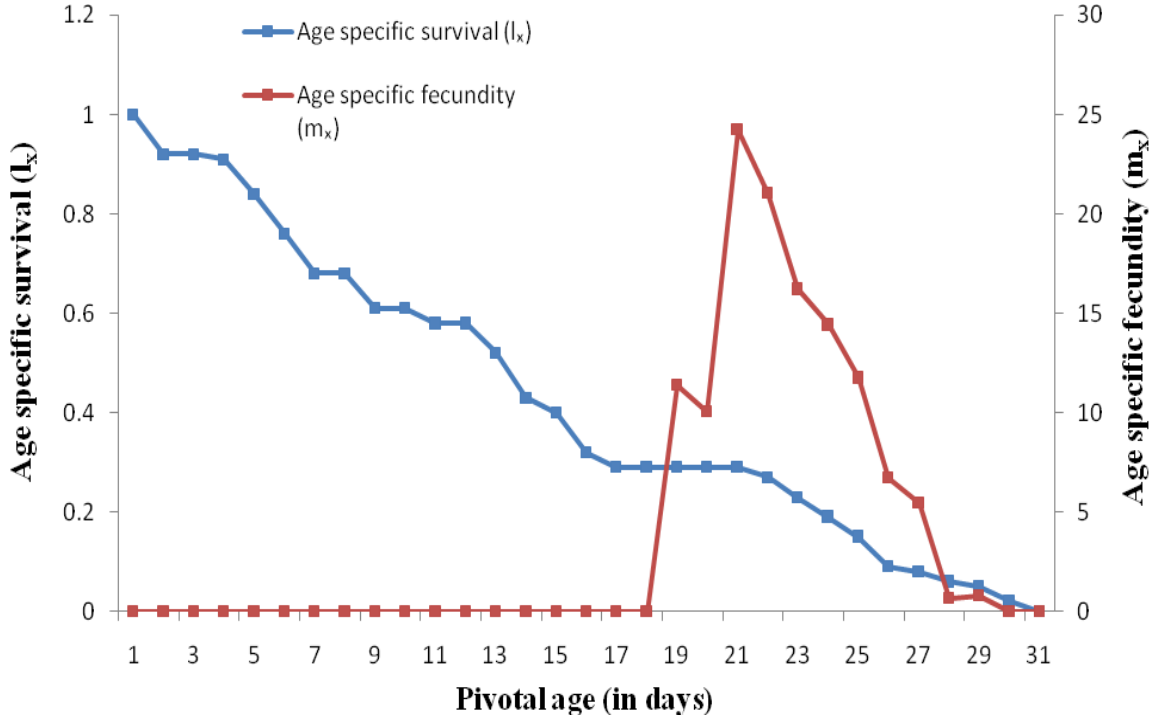

Figure 5. Age-specific survival and age specific fecundity of *Plutella xylostella* on mustard

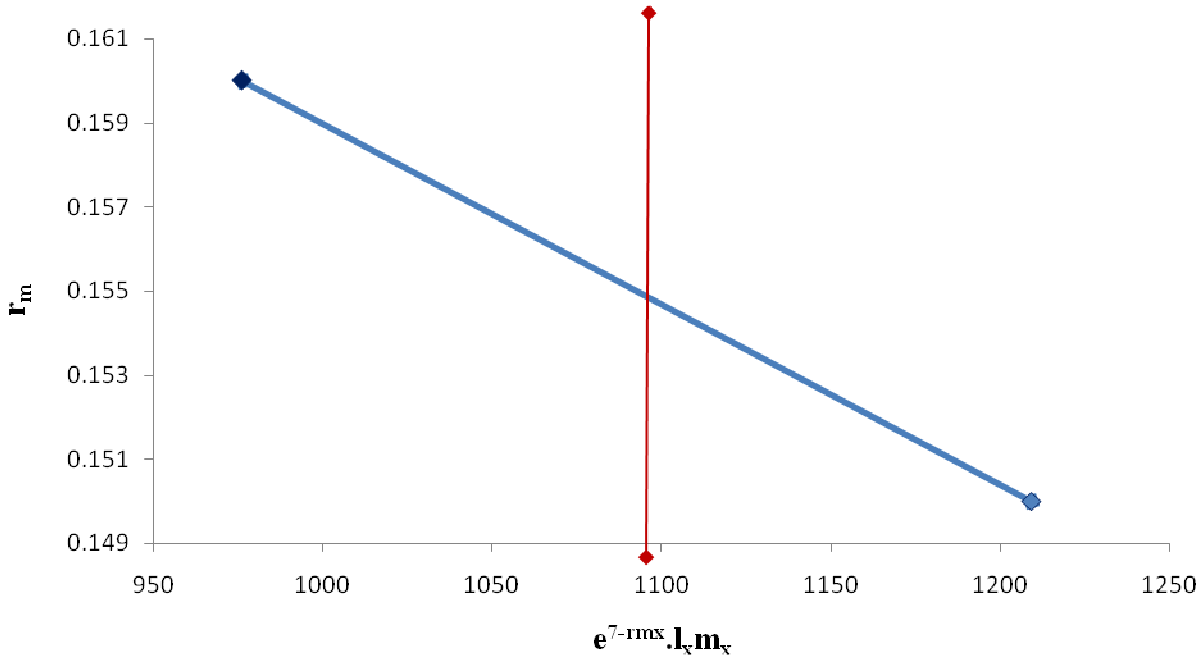

Figure 6. Determination of true intrinsic rate of increase (r_m) of *Plutella xylostella* on Mustard

Table 10. Fertility parameters of *Plutella xylostella* on mustard

Parameters	Unit	Host (mustard)
Gross reproductive rate (GRR)	Female eggs/ female	122.74
Gross fecundity (M_x)	Number of eggs	245.48
Net reproductive rate (R_o)	Female eggs/ female	28.28
Approximate generation time (T_c)	Days	21.88
The innate capacity for increase (r_c)	Females/ female/ day	0.15
Intrinsic rate of natural increase (r_m)	Females/ female/ day	0.1548
True generation time (T)	Days	21.71
Finite rate of increase (λ)	Females/ day	1.166
Doubling time (DT)	Days	4.49
Weekly multiplication rate (WM)	Folds	2.93

4.2.4 Comparative life fertility parameters of *Plutella xylostella* on different hosts

Life fertility parameters of *P. xylostella* on different hosts are presented in Table 11 which revealed that there were observable differences on different hosts with respect to their life fertility parameters. According to Pan *et al.* (2014) life table parameters often vary due to different rearing conditions, host plants, and other factors. The gross reproductive rate (GRR) was highest on cauliflower (126.68 female eggs/ female) followed by mustard (122.74) and was minimum on broccoli (91.36 female eggs/ female). The gross fecundity (M_x) was the highest on cauliflower (253.36 eggs per female) followed by mustard (245.48) and was minimum on broccoli (182.72 eggs per female). Similar trend was observed with respect to the net reproductive rate (R_o). It was highest on cauliflower (33.36) followed by mustard (28.28) and broccoli had the least R_o value (26.98 female eggs / female). The present findings are in corroboration with those of Syed and Abro (2003) who reported that the net reproductive rate (R_o) was highest on cauliflower (89.71) whereas, it was lowest on rapeseed (26.77).

The approximate generation time (T_c) was 21.85, 21.05 and 21.88 days on cauliflower, broccoli and mustard, respectively. The innate capacity for increase (r_c) was the highest on cauliflower (0.17) followed by broccoli and mustard (0.15) (Table 11 and Figure 9). Further, the intrinsic rate of natural increase (r_m) of different populations was estimated from r_c values. The highest value of r_m was observed on cauliflower (0.1730) followed by broccoli (0.1595).

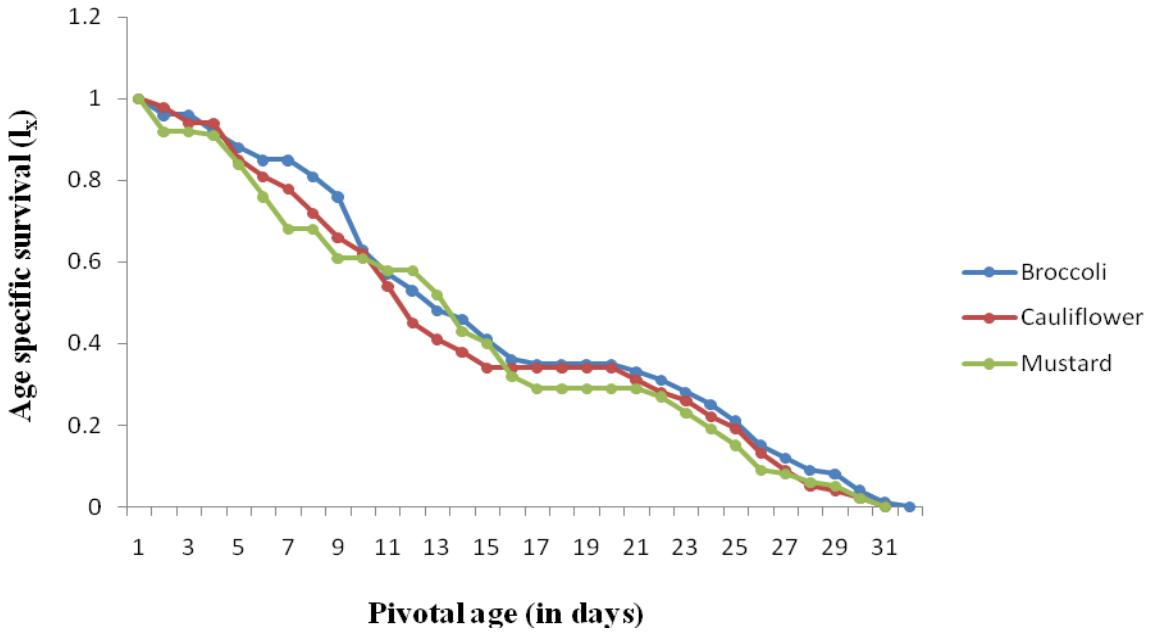

Figure 7. Age specific survival of *Plutella xylostella* on broccoli, cauliflower and mustard

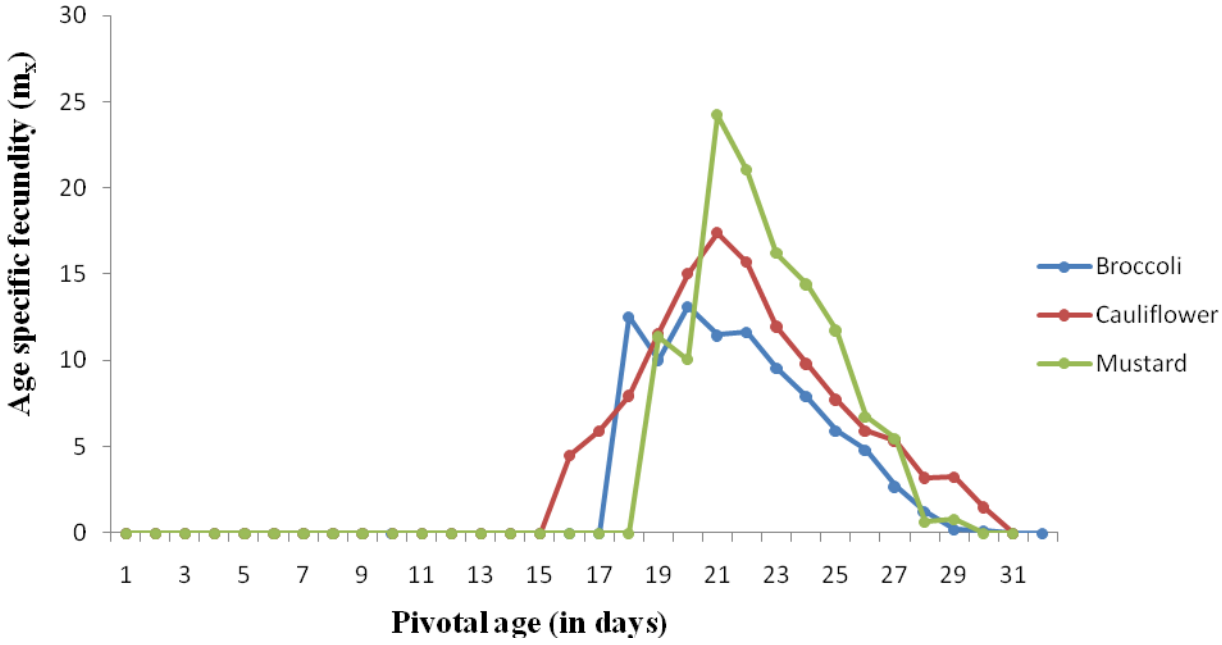

Figure 8. Age specific fecundity of *Plutella xylostella* on broccoli, cauliflower and mustard

The minimum value of r_m was observed on mustard (0.1548). The finite rate of increase (λ) was 1.18, 1.17 and 1.17 females per day while the true generation time (T) and the time taken to double the population (DT) was 20.27, 20.66 and 21.71 days and 4.20, 4.34 and 4.49 days, respectively on cauliflower, broccoli and mustard. Weekly multiplication rate was 3.19, 3.06 and 2.93 times on cauliflower, broccoli and mustard, respectively. These findings are in

close proximity with that of Justin *et al.* (2001) who found that the diamondback moth had a capacity for natural increase of 0.16, 0.17 and 0.13 females per day on cauliflower, cabbage and mustard, respectively. They had also revealed that finite rate of increase of *P. xylostella* were 1.18, 1.19 and 1.14 females per day, respectively on these hosts which is in line with the present findings. They have also reported that diamondback moth population multiplied 3.18, 3.38 and 2.50 times per week.

P. xylostella has been reported to feed on a wide range of cruciferous host plants (Harcourt, 1957; Singh and Singh, 1982; Ramachandran *et al.*, 1998). The effect of host plant on development and reproduction of *P. xylostella* vary (Wakisaka *et al.*, 1992). Syed and Abro (2003) reported that the intrinsic rate of increase (r_m) and finite rate of increase (λ) was highest on cauliflower and lowest on mustard, respectively. These results are in line with the present findings. Lanteren and Noldus (1990) have stated that shorter developmental time and greater total oviposition on a host reflected the suitability of host plant which support the present studies, where, *P. xylostella* showed higher intrinsic rate of increase (r_m) on cauliflower resulting from faster development, higher survivorship and higher fecundity rates. Similar results were also reported by Salas *et al.* (1993), when they studied the life table parameters of *P. xylostella* on different host plants and observed that the highest r_m was on cauliflower.

On comparing fertility parameters of *P. xylostella* on different hosts, it was found that the cauliflower was the most prolific host than broccoli or mustard while the mustard was the least prolific as revealed by the minimum value of the true intrinsic rate of increase. These findings are in line with those of Hamilton *et al*. (2005) and Jahed *et al.* (2018) who reported that the net reproductive rate was higher and mean generation time was shortest when *P. xylostella* was reared on cauliflower followed by broccoli. However, slight differences in the values of life fertility parameters in *P. xylostella* can be attributed to the nutritional status of different host plants. The earlier studies showed that development and reproduction of *P. xylostella* is directly affected by the *Brassica* spp. This is because of different level of glucosinolate present in *Brassica* spp. (Hopkins *et al.* 2009, Sarfraz *et al*. 2007 and Nikooei *et al*. 2015). The overall amount of glucosinolate in leaves of the tested Brassicaceous plants determined oviposition preferences, rates of immature development and survival, adult longevity and the resulting net reproductive rate for *P. xylostella* (Hamilton *et al*., 2005; Jahed *et al.*, 2018).

Table 11. Comparative fertility parameters of *Plutella xylostella* on different hosts

Fertility parameters	Unit	Host		
		Cauliflower	Broccoli	Mustard
Gross reproductive rate (GRR)	Female eggs/ female	126.68	91.36	122.74
Gross fecundity (M_x)	Number of egg	253.36	182.72	245.48
Net reproductive rate (R_o)	Female eggs/ female	33.36	26.98	28.28
Approximate generation time (T_c)	Days	21.85	21.05	21.88
The innate capacity for increase (r_c)	Females/ female/ day	0.17	0.15	0.15
Intrinsic rate of natural increase (r_m)	Females/ female/ day	0.1730	0.1595	0.1548
True generation time (T)	Days	20.27	20.66	21.71
Finite rate of increase (λ)	Females/ day	1.18	1.17	1.17
Doubling time (DT)	Days	4.20	4.34	4.49
Weekly multiplication rate (W)	Folds	3.19	3.06	2.93

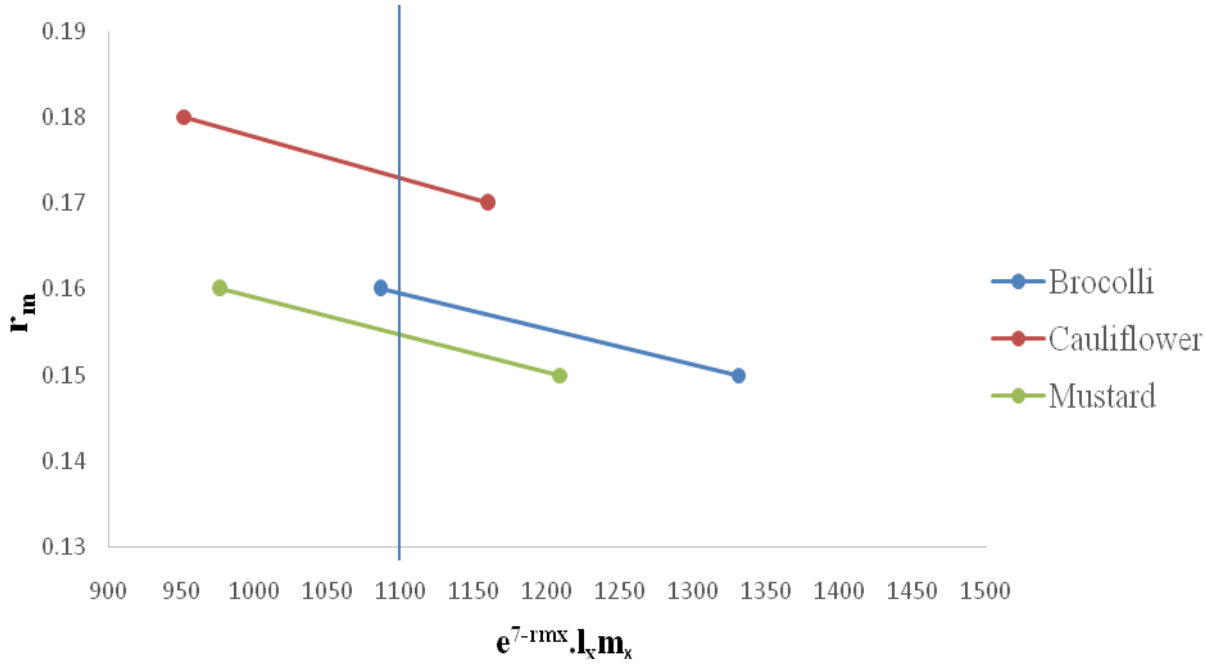

Figure 9. Determination of true intrinsic rate of increase (r_m) of *Plutella xylostella* on broccoli, cauliflower and mustard

Chapter-5

SUMMARY AND CONCLUSION

The present investigations entitled, "Studies on life fertility table of diamondback moth, *Plutella xylostella* (Lepidopetera) on different hosts" were undertaken in the laboratory of Department of Entomology, College of Horticulture, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (H.P). The results thus obtained are summarized as under:

- Studies on biology of *P. xylostella* were undertaken under laboratory conditions on different hosts viz. cauliflower, broccoli and mustard.
- The studies on different developmental stages revealed that maximum total developmental period was 18.15 days on broccoli followed by cauliflower (16.97 days) and minimum developmental period was observed in mustard (16.59 days).
- Longevity of the male and the female moth was significantly affected by the host. The longevity of the male and female was minimum on mustard (9.44 and 12.32 days, respectively) and it was significantly different from that on cauliflower and broccoli, while it was at par on cauliflower (10.92 and 14.06 days) and broccoli (10.25 and 12.79 days).
- The highest net reproductive rate (R_o) of diamondback moth was recorded on cauliflower (33.36 female eggs/ female), whereas it was lowest on broccoli (26.98 female eggs/ female). Thus, on the basis of values of net reproductive rate, the host plants can be arranged in order as: cauliflower > mustard > broccoli.
- The gross fecundity was highest on cauliflower (253.36 eggs) followed by mustard (245.48 eggs) and it was minimum on broccoli (182.72 eggs).
- The approximate generation time (T_c) was lowest on broccoli (21.05 days) and highest on mustard (21.88 days).
- The highest true intrinsic rate of natural increase (r_m) was recorded on cauliflower (0.1730 female progeny/ female/ day) whereas, it was minimum on mustard (0.1548 female progeny/ female/ day) thereby indicating that cauliflower was the most suitable host for the development of *P. xylostella*. The r_m value on broccoli was 0.1595 female progeny/ female/ day.

CONCLUSION

On the basis of these studies it is concluded that there were significant variations with respect to developmental and reproductive biology of *P. xylostella* on different hosts. Besides, the difference in the true intrinsic rate of natural increase (r_m) on different hosts was also found. It was highest on cauliflower (0.1730 female progeny/ female/ day), indicating thereby that the diamondback moth on cauliflower is more prolific followed by broccoli (0.1595 female progeny/ female/ day) and mustard (0.1548 female progeny/ female/ day).

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APPENDIX-I

1. Analysis of variance for egg stage of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	16.179	8.090	17.940	0.00000
Error	231	104.167	0.451		
Total	233	120.346			

2. Analysis of variance for first instar larva of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	13.633	6.817	13.098	0.00000
Error	177	92.117	0.520		
Total	179	105.750			

3. Analysis of variance for second instar larva of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	29.346	14.673	33.671	0.00000
Error	153	66.673	0.436		
Total	155	96.019			

4. Analysis of variance for third instar larva of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	11.652	5.826	11.865	0.00002
Error	129	63.341	0.491		
Total	131	74.992			

5. Analysis of variance for fourth instar larva of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	4.667	2.333	4.148	0.01839
Error	108	60.757	0.563		
Total	110	65.423			

6. Analysis of variance for total larval period of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	151.694	75.847	45.769	0.00000
Error	108	178.973	1.657		
Total	110	330.667			

7. Analysis of variance for pupal period of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	26.741	13.370	21.262	0.00000
Error	105	66.028	0.629		
Total	107	92.769			

8. Analysis of variance for total developmental period of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	3,302.796	1,651.398	341.444	0.00000
Error	105	507.833	4.837		
Total	107	3,810.630			

9. Analysis of variance for pre oviposition period of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	2.167	1.083	2.700	0.07325
Error	81	32.500	0.401		
Total	83	34.667			

10. Analysis of variance for oviposion period of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	31.738	15.869	6.792	0.00188
Error	81	189.250	2.336		
Total	83	220.988			

11. Analysis of variance post oviposition period of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	0.095	0.048	0.063	0.93891
Error	81	61.143	0.755		
Total	83	61.238			

12. Analysis of variance for female longevity of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	42.310	21.155	5.441	0.00606
Error	81	314.929	3.888		
Total	83	357.238			

13. Analysis of variance for male longevity of *P. xylostella*

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Signficance
Treatment	2	15.292	7.646	4.335	0.01899
Error	45	79.375	1.764		
Total	47	94.667			

DEPARTMENT OF ENTOMOLOGY
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Title of Thesis	**:**	**Studies on life fertility table of diamondback moth, *Plutella xylostella*, (L.) (Lepidoptera) on different hosts**
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ABSTRACT

The present investigations entitled "Studies on life fertility table of diamondback moth, *Plutella xylostella*, (L.) (Lepidoptera) on different hosts" were carried out under laboratory conditions in the Department of Entomology, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP). The effect of three hosts viz. cauliflower, broccoli and mustard on biology and life fertility of *P. xylostella* was studied. Biological studies revealed that the maximum incubation period of 3.56 days was recorded on mustard followed by cauliflower (3.04 days) and broccoli (3.01 days). The total larval period was shortest on cauliflower (9.08 days) and longest on mustard (11.86 days). The total Fecundity was highest on cauliflower (253.36 females) followed by mustard (245.48 females) and minimum fecundity was observed on broccoli (182.72 females). Adults fed on cauliflower and broccoli lived longer than mustard. The Intrinsic rate of increase (r_m) and finite rate of increase (λ) were highest on cauliflower (0.1730 females/female/day and 1.18 females/day, respectively) as compared to broccoli and mustard. The highest value of gross reproductive rate (GRR) and net reproductive rates (R_0) (126.68 female eggs/female and 33.36 female eggs/female, respectively) were found when the pest was reared on cauliflower as compared to other hosts. The studies thus revealed that among the three hosts, cauliflower was the most suitable host for this pest.

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