Journal of Entomology and Zoology Studies
Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2018; 6(4): 1394-1399

Received: 22-05-2018
Accepted: 23-06-2018

MP Gautam
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Hem Singh
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Sushil Kumar
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Vinod kumar
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Gajendra Singh
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

SN Singh
Subject Matter Specialist, KVK Sohana, Siddharthnagar, Narendra Deva University of Agriculture and Technology, Faizabad, Uttar Pradesh, India

Correspondence
MP Gautam
Department of Entomology, Sardar Vallabhbhai Patel University of Agriculture and Technology Meerut, Uttar Pradesh, India

Diamondback moth, *Plutella xylostella* (Linnaeus) (Insecta: Lepidoptera: Plutellidae) a major insect of cabbage in India: A review

MP Gautam, Hem Singh, Sushil Kumar, Vinod Kumar, Gajendra Singh and SN Singh

Abstract
The present experiment was conducted on diamondback moth, *Plutella xylostella* (Linnaeus) (Insecta: Lepidoptera: Plutellidae), their ecology and integrated management with the objectives of arriving at the crucial conclusion on the most suitable techniques to decrease pest infestation for higher yield and productivity with least damage to the environment. Therefore, up to date knowledge about the diamondback moth, *Plutella xylostella* (L.) and their natural enemies on cabbage, *Brassica oleracea,* is a prerequisite for implementation of an effective and successful management tactics against them. The judicious use of chemicals with novel mode of action needs to be implemented to manage this insect pest. There are many insecticides which have different mode of action than the conventional ones. These novel insecticides in conjunction with other IPM approaches may play a pivotal role in devising effective management strategy against diamondback moth.

Keywords: Diamondback moth, *Plutella xylostella*, insecticide resistance, abiotic factor, management rotation strategy

Introduction
The diamondback moth (*Plutella xylostella* L.) is a major pest insect in more than 100 countries across the globe; it affects cruciferous plants, especially *Brassica oleracea* crops such as cabbage, cauliflower, broccoli, Brussels sprout and turnip. It is a globally important pest, causing serious yield losses to crucifers. In India the estimated annual crop losses due to this pest amount to 16 million USD [31]. It was first observed in North America in 1854. The most important insect pest of cabbage crop is Diamondback moth (DBM) *P. xylostella* (Plutellidae: Lepidoptera), recorded from more than 128 countries of the world [49]. Cabbage (*Brassica oleracea* L. var. *capitata*) is being grown in an area of 3088 hectares with production of 8.75 million tonnes. Major cabbage growing states in the country are Uttar Pradesh, Orissa, Bihar, West Bengal, Assam, Karnataka, Maharashtra, Madhya Pradesh and Tamil Nadu [13, 30] recorded this pest for the first time in India on cruciferous vegetables and perusal of literature revealed that the pest is distributed all over India. In India, diamondback moth has national importance on cabbage as it causes 50-80% annual loss in the marketable yield [12, 4, 22] also reported that there is 52% loss in yield due to the attack of diamondback moth. The most devastating pest that causes severe damage in cabbage production is the diamondback moth (DBM) [24]. In others words, for over three decades, the insecticide market has been dominated by organophosphates, carbamates and synthetic pyrethroids, while only 1% of the global insecticide market is occupied by the two bio-insecticides (*Bt* based products) and insecticides of plant origin (pyrethrum and neem based products) [17]. Toxicity and development of resistance issues have limited the use of these synthetic insecticides. Therefore, it is desirable to develop alternative methods for pest management based on biological pesticides, which are safe to both humans and the environment [40].
We want the DBM to co-exist with us and this paper deals with the India experience in coming up with DBM with fewer offspring causing only moderate to slight damage. This paper reviewed relevant literatures from the time DBM was first recorded. The relevant data of a survey on the current practices of cabbage growers and the kind of pesticides that are being sold for DBM by pesticide dealers were also presented. The researchers, mostly coming from the academe, conduct efficacy trials, not only in the laboratory or experimental plots but also

in farmer's fields while the Local Government Units (LGUs) conduct farmer training in collaboration with the academe and product developers. Judicious use of pesticides is emphasized by the industry staff during farmer training. Independently, sensitivity tests to monitor resistance levels against DBM were being conducted by some companies on their key products. They also decided to join together to combat resistance development.

Identification of diamondback moth, *Plutella xylostella*

Eggs are oval, somewhat flattened, approximately 0.4 mm long, 0.2 mm wide, and yellow to pale green. Eggs hatch in approximately five to six days under normal field conditions. Larvae develop through four instars and typically require from nine to 30 days to complete development. The early instars are tiny, colorless to yellow, and have a dark head capsule. Mid to later instars are green. Pupation occurs in a loose silk cocoon usually formed on the lower or outer leaves. The pupa is yellow to green and approximately 7 to 9 mm long. The pupal stage requires from five to 15 days to complete development. The DBM adult is a 6 mm long, slender, grayish-brown moth with pronounced antennae. The moth is marked with a broad cream or light-brown band along its back that is sometimes constricted to form one or more light-colored diamonds on the back, which is the basis for the common name of this moth. Adults can live for seven or eight weeks, but the usual life span is around two weeks. single female usually lays from18 to 356 eggs. The moth measures about 8-12 mm in length and are brown or grey, with conspicuous white spots on the fore wings, which appear like diamond patterns when the wings lie flat over the body. When full grown, the larvae measures about 8 mm in length and are pale yellowish green with fine black hair scattered all over the body [44].

Damage Symptom of diamondback moth, *Plutella xylostella*

A lot of damage is due to the construction of tunnels in the head as in cabbage and brussel sprouts. Furthermore, crop damage is usually first evident on plants growing on ridges in the crucifier field. The heavy population of *P. xylostella* can cause more than 90% crop loss and only few fourth stage larvae on a cabbage can make it unsalable [50].

Life Cycle of diamondback moth, *Plutella xylostella*

Diamondback moth adults become active at dusk and continue so into the night [15] Most adults emerge during the first 8 h of photophase [35] and mating occurs at dusk of the same day the adults emerge. Female moths start laying eggs soon after mating, and the oviposition period lasts 4 days, during which the female lays 11-188 eggs. The majority of eggs are laid before midnight with peak oviposition occurring between 7:00 and 8:00 PM [3]. Development time of egg is averages 5.6 days. The diamondback moth larve has four instars. Average and range of development time is about 4.5 (3–7), 4 (2–7), 4 (2–8), and 5 (2–10) days, respectively. Overall length of each instar rarely exceeds 1.7, 3.5, 7.0, and 11.2 mm. Pupation occurs in a loose silk cocoon, usually formed on the lower or mouter leaves. The yellowish pupa is 7 to 9 mm in length. The duration of the cocoon averages about 8.5 days (range five to 15 days). The adult is a small, slender, grayish-brown moth with pronounced antennae. It is about 6 mm long. Adult males and females live about 12 and 16 days [7]. DBM completed 13 to 14 generations per year in Bangalore, India. He also postulated that if the eggs were to be laid by the adults of each generation on the same day as emergence, up to 16 generations per year could be completed [19].

Economic Thresholds Level (ETL) of diamondback moth, *Plutella xylostella*

Seven weeks after transplanting, cabbage could sustain populations of 20 larvae/plant before significant economic injury and yield reduction were detected [33]. Based on crop loss estimation studies conducted in Bangalore, [19], found that a population of four or more medium sized larvae (3rd or 4th instar) could render a seedling untransplantable and 10 medium sized larvae/plant up to one month after planting and 20 medium sized larvae/plant between one and two months after planting necessitated insecticide application.

Effect of abiotic factor on population buildup of diamondback moth, *Plutella xylostella*

Minimum population 0.32 per cent recorded on second fortnight of Febuary and maximum population 5.98 per cent recorded on third fortnight of March. A study on the correlation studies indicated a significant positive correlation between larval population of diamondback moth and. the relative humidity (R.H), total rainfall and sunshine hours (SSH) had negative correlation with the larval population of diamondback moth [18]. Recorded the diamond back moth population was maximum in the first and second week of February (5th and 6th SW) [46]. recorded the infestation of *Plutella xylostella*, diamondback moth started from the 5th standard week (0.88 larvae plant-1) and reached peak (18.68 larvae plant-1) in a 14th standard week. The maximum and minimum temperature showed significant positive correlation with larval population of diamondback moth whereas, non-significant correlation with relative humidity and rainfall [34]. Recorded Peak population of diamond back moth (DBM) was recorded on 1st March and 23rd February with13.60 and 14.33 larvae /plant during 2011-12 and 2012-13 respectively [42]. Recorded that the infestation of diamondback moth started from the third week of November and reached peak (45.2 larvae /10 plants) in the first week of January. The maximum and minimum temperature showed significant negative correlation with larval population of diamondback moth whereas, non-significant correlation with relative humidity and sunshine hours [5]. Revealed that the maximum temperature had non-significant negative correlation (r = -0.005) with larval population but had positive correlation (r = 0.19) in year 2016-17. Minimum temperature had a positive correlation in both years (r = 0.24 and r = 0.21, respectively). Though, the relative humidity had negative and positive relation with the larval population of diamondback moth in both years (r = -0.26 and r = 0.11 respectively). Sunshine hours had negative but non-significant (r=-0.31) effect in 2015-16 while positive relation (r=0.38) was observed in 2016-2017. However rainfall had positive non-significant relation (r=-0.05 and r= -0.08 respectively), in both years.

Effect of biotic factor on population buildup of diamondback moth, *Plutella xylostella*

Major natural enemies recorded were coccinellids, *Coccinella septempunctata* (Fab.), *Cheilomenes sexmaculatus* (Fab.) (Coleoptera: Coccinellidae); common green lacewing, Chrysoperla sp. (Neuroptera: Chrysopidae); aphid parasitoid, Diaeretiella sp. (Hymenoptera: Braconnidae); diamond back moth and tobacco caterpillar on parasitoid of *Cotesia* sp. (Hymenoptera: Braconidae). However, their population were found fluctuate during the crop season [42]. Recorded that the coccinellid beetle was recorded as an important predator of aphid, which was maximum (20.2 /10 plants) in the fourth week of January [30]. Recorded that the parasitism rates of DBM were estimated with a larval parasitoid (*Cotesia plutellae*) and two pupal parasitoids (*Diadromus collaris* and *Macromalon orientale*). Mean percentage of DBM adult emergence was 73.30% on cabbage as a host plant, followed by 70.00% on cauliflower, 60.00% on broccoli and 53.30% on artificial diet. Hence, DBM development was better on cabbage compared to cauliflower, broccoli and artificial diet. Mean Percentage of DBM pupation on various media was 86.70% for aluminum foil, 83.30% for tissue paper and 73.30% for normal paper. Mean percentage of DBM parasitism rates were 73.30% by *C. plutellae*, 63.30% for D. *collaris* and 56.70% for *M. orientale*. Hence, parasitism rate of DBM larvae by the larval parasitoid (*C. plutellae*) was higher than the pupal parasitoids (*D. collaris* and *M. orientale*).

Genetic diversity of diamondback moth, *Plutella xylostella*

Along with species and ecosystem diversity, genetic diversity is a fundamental component of global biodiversity. The maintenance of genetic diversity is therefore considered to be one of the most important goals in biodiversity conservation. Genetic variation can affect the long-term survival of a species since it is a prerequisite for adaptation to environmental changes such as climatic change, pollution, novel diseases, competitors or predators [23]. revealed that the female from Palampur laid maximum eggs (368.93eggs/female). The innate capacity for increase (rc) was maximum in the The population (0.238) and Solan population had lowest (rc) value (0.209). The intrinsic rate of natural increase (rm) was estimated from (rc) values for different populations. The population had highest value of (rm) value (0.242) followed by the Palampur (0.236) and Fatehgarh (0.221). The least value of (rc) was observed in the Solan population (0.211). On comparing fertility parameters of *P. xylostella*, it was found that the Theog population was the most prolific among all the populations while the Solan population was the least prolific.

Insecticide resistance of diamondback moth, *Plutella xylostella*

In the past 50 years, *P. xylostella* has become one of the most difficult insects in the world to control. All over the world, management of DBM is mainly with the use of insecticides [40] reliance on this single approach has led to ever increasing application rates, decreased effectiveness and eventual breakdown of control efficiency [13]. Farmers often increase the dose of insecticides and taken up spray up to 25 times within a cropping season [20, 21]. The DBM has shown resistance to 91 active ingredients of agricultural chemicals worldwide, including 12 strains of Bacillus thuringiensis (Bt), between 1953 and 2014 (IRAC 2005), [25, 53]. In Punjab, [10] observed that populations of DBM collected from Jullundhar were less susceptible to parathion than those found in Ludhiana. Fairly high tolerance to parathion, fenitrothion, malathion, DDT and endrin was also reported from Punjab by Chawla and [21]. A high degree of resistance to cypermethrin, decamethrin and quinalphos was reported [38] Resistance has also been reported against many groups of insecticides *viz*., organochlorines, organophosphates, carbamates, synthetic pyrethroids, *Bt* products [37, 39] Failure of new groups of insecticides *viz*., chlorantraniliprole and flubendiamide as foliar applications was recently reported [1].

Table 1: List of insecticides for which the DBM resistance was monitored.

English Common Name	Active element
Alpha-cypermethrin	5.16%
Spinosad	2.50%
Fipronil	5.46%
Indoxacarb	15.00%
Abamection	2.00%
Chlorfluazuron	5.59%
Diafenthiuron	21.84%
Tebufenozide	10.64%
Chlorfenapyr	10.26%
Cartap	97.10%
Cry1Ac	3.00%

Source: Srinivasan, *et al.* (2011)

Integrated management of diamondback moth, *Plutella xylostella*

Cultural Practices

Pre-season cleanup

Remove all plant debris and weeds from the greenhouse. Many pests also occur on other crops or broadleaf weeds. For this reason, it is important to avoid growing other crops next to the greenhouse and to prevent heavy growths of broadleaf weeds around the outside edges of the greenhouse.

Balanced use of fertilizer

Fertilization schedules based on the balanced use of nutrients should be followed. Nitrogen should be applied only as needed for optimal growth. Periodic heavy applications set up nitrogen surpluses that cause excessive growth, which favor the population growth of aphids, and other pests. Application of potassium at desired levels has been found to reduce the incidence of insect-pests.

Pinching and Pruning

Pinching-off damaged plant parts, flowers, and spotted leaves (and those with insect larvae or egg deposits) can be a very effective way of reducing the spread of pests in the greenhouse. The plant debris should be placed immediately in a covered container before being disposed-off. This practice can be helpful in reducing the pest population of all the targeted pests.

Trap crop

For early detection and trapping of the target pests, some of the preferred hosts of the target pests can be used. Planting the marigold crop as a trap crop stop to increase the population of diamondback moth.

Rainfall has been identified as a major mortality factor for young larvae, so it is not surprising that crucifer crops with overhead sprinkle irrigation tend to have fewer diamondback moth larvae than drip or furrow-irrigated crops. Tomato, when intercropped with cabbage, has been reported to inhibit or reduce DBM egg-laying [52, 6, 45]. The reduction in oviposition and subsequent development of the pest was essentially due to emission of volatile compounds [46].

Genetic Control of diamondback moth, *Plutella xylostella*

Strategies for developing varietal resistance in brassicas against DBM have not yet been fully exploited. Modification of biochemical and morphological plant characteristics has also been Unsuccessful [11, 14]. Thus, despite its potential as an alternative non-chemical DBM control method,resistant variety development is still a huge challenge to biochemists and plant breeders in SA. We have not found any research identifying chemical compounds or genes that are necessary to manipulate and cause brassicas to be completely non-preferred hosts for DBM [28].

Botanical insecticide for diamondback moth, *Plutella xylostella*

A. sativum, A. indica and M. balsamina extracts significantly reduced *P. xylostella* populations, leaf and head damage of cabbage while increasing plant height and yield [9, 32] who reported that *Zingiber officinales, Piper retrofractum, Allium sativum, Solanum spp, Citrus sinensis* peels and turmeric rhizome were more effective against *P. xylostella* than synthetic insecticides.

Table 2: Aromatic plants and the part of plants used

Common name	Plant source	Family	Plant part
Neem	*Azadirachta indica*	Meliaceae	Whole plant
Karang	*Pongamia pinnata*	Fabaceae	leaves
Tobacco	*Nicotiana tabacum*	Solanaceae	leaves
Fennel	*Foeniculum vulgare*	Apiaceae	Fruit
levender	*Lavandula angustifolia*	Lamiaceae	Flowers
Mint	*Mentha* sp	Lamiaceae	Leaves
Lemongrass, Cochin grass	*Cymbopogon nardus*	Gramineae	Leaves
Ban baawaari	*Elsholtzia pubescens*	Labiatae	Leaves
Pomelo	*Citrus grandis*	Rutaceae	Peels
African marigold	*Tagetes erecta*	Asteraceae	Whole plant
Mediterranean cypress	*Cupressus sempervirens*	Cupressaceae	Leaves
Wild basil	*Ocimum americanum*	Labiatae	Seed
cinnamon	*Cinnamomum verum*	Lauraceae	Wood
citronella	*C. winterianus*	Gramineae	Leaves
Zinger	*Boesembergia pandurata*	Zingiberaceae	Rhizome
Babui basil	*O. basilium*	Labiatae	Leaves
Deadnettle	*Pogostemon cablim*	Lamiaceae	Leaves
Garden rue	*Ruta graveolens*	Rutaceae	Leaves
Lemongrass	*C. citratus*	Gramineae	Leaves
Jatiphala, Javitri	*Myristica fragrans*	Myristicaceae	Fruit

Chemical for diamondback moth, *Plutella xylostella*

LC_{50} value of dichlorvos 76 EC (15.63, 31.82 and 22.51 µg a.i. ml-1) and the lowest LC_{50} value of Bengaluru, Kolar and Chikkaballapura populations recorded for emamectin benzoate 5 SG (3.13 µg a.i. ml-1), cyantraniliprole 10.26 OD (4.48 µg a.i. ml-1) and Spinosad 45 SC (2.48 µg a.i. ml-1) was found to be highly toxic to the third instar larvae of *P. xylostellai* [30]. The activities of different compounds varied depending on the presence of different substituents at various positions of both the aromatic rings A and B. Among the tested compounds, 8, *N*-(3-bromo-4-methoxyphenethyl) cinnamamide showed best larvicidal activity with an LC_{50} = 62.13 mg/L followed by 6, *N*-(3′-bromophenethyl) cinnamamide (LC_{50}=128.49 mg/L) and 2 *N*-(4′-methoxyphenylethyl) cinnamamide (LC_{50} = 225.65 mg/L) [36]. Pyridalyl was least effective against *P. xylostella* on cabbage [8]. Fenvalerate showed higher efficacy against *P. xylostella* in reducing pest population. Mean population of *P. xylostella* after two sprays revealed that fenvalerate 0.004% was effective and superior [46]. Spinosad was found to be most effective reduced up to 94.33 percent population followed by indoxacarb (91.00%) and Flubendiamide (78.66%). The insecticides, *viz*., fipronil, emamection benzoate and chlorantraniliprole were found moderately effective as they resulted in 70.66, 70.33 and 68.66 percent reduction, respectively and chlorfenapyr, pyridalyl and acephate were proved least effective reduced up to 55.33, 56.66 and 56.00 percent, respectively [42]. Rynaxypyr was most effective in reducing larval population (96.41%) closely followed by flubendiamide (94.86%) and spinetorum (92.62%). Combination of novaluron and indoxacarb also provided good reduction of larval population (92.04%) [26]. Bio-pesticides *Bacillus thuringiensis* var kurstaki and *Beauveria bassiana* gave 55.82% and 32.24% reduction of DBM larvae respectively.

Table 3: Details of insecticides used and their concentrations for management for diamondback moth, *Plutella xylostella*

S. No.	Insecticides	Formulations (%)	Trade Name	Conc. (%)
1.	Spinosad	2.5 SC	Tracer	0.01
2.	Indoxacarb	14.5 SC	Avaunt	0.01
3.	Chlorantraniliprole	18.5 SC	Coragen	0.005
4.	Emamectin benzoate	5 SG	Proclaim	0.005
5.	Chlorfenapyr	10 SC	Lepido	0.01
6.	Fipronil	5 SC	Regent,Jump	0.01
7.	Flubendiamide	20WG	Fame	0.01
8.	Acephate	75 SP	Asataf	0.05
9.	Pyridalyl	10 EC	Pleo	0.015
10.	Cyantraniliprole	10.26 OD	DuPont	0.08
11.	Diafenthiuron	50 WP	Pegasus	0.03
12.	Fenvalerate	20 EC	Sumicidin	0.004
13.	Novaluron	10 EC	Rimon	0.001

Conclusion

Furthermore, there is a growing concern about the pollution of the environment and its resultant effects on the health of humans and animals arising from the continued use of these pesticides. Though the agro-climatic condition of Utter Pradesh is highly favorable for the successful cultivation of cabbage, this has not yet translated into higher yield mainly due to the attack of insect pests particularly diamondback moth. Though the pest has increasingly become a menace causing great economic losses, little work has been carried out and the information available at present is very meagre and of little relevance. Grounds for optimism that more effective and sustainable DBM management is achievable longer terms and the solutions are

- ✓ Dynamics of crop colonization and identity of source populations of DBM and key natural enemies
- ✓ Weather-based DBM outbreak predictive model
- ✓ Plant resistance
- ✓ More selective insecticides with different modes of action
- ✓ Improved spray application technologies

Future strategy

If we know when the population is reach peek period (Month), in case of DBM maximum population present in first week of March to middle march, then we apply control measures. And with knowing the biology of insect most susceptible stage control of insect pest is easy. The management practices are adopted which is most affected and give most cost benefits. Strong industry stewardship to ensure residue compliance. Compliance with new drift legislation, Improved application technology required to reduce spray drift and increase spray efficacy and The dynamics of DBM movement between India, crucifer vegetable and forage crops is the focus of a new Ph.D study.

Acknowledgements

Authors are thankful to Dr. Hem Singh, Sardar Vallabhbhai Patel University of Agriculture And Technology, Meerut for encouragement and constant support to write this article. All the author contributed equally in this article.

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