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Insecticidal resistance in diamondback moth (*Plutella xylostella*): A review

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Abstract

Diamondback Moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), has become the world's most devastating insect pest of the Brassicaceae family. This study provides an overview of insecticidal resistance in DBM, as well as an outline of resistance development and monitoring, which will aid in the formulation of new tactics to address the pest's problems in horticultural ecosystems around the world. DBM has become one of the most challenging pests to control, owing to irrational and non-judicious application of insecticides belonging to different groups, which has resulted in higher application rates, reduced effectiveness, and control efficiency breakdown. DDT was the first insecticide to which resistance was discovered in Lembang in 1953. This paper will assist us in providing a better control towards its hostile behaviour.

Keywords: *Plutella xylostella,* Insecticidal resistance, resistance development, resistance monitoring, IRM

Introduction

From the Mediterranean origin (Huaripata and Sánchez, 2019) [18], diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is one of the most damaging major pest in Brassicaceae crops, which is oligophagous is nature (Farias *et al.*, 2020) [11]. Throughout the world, six species of the genus *Plutella* have been recorded on *Brassica* with limited geographical distribution except the cosmopolitan pest *Plutella xylostella* (Kfir, 1998) [23]. On cruciferous vegetables, diamondback moth was first recorded in India in 1914 (Fletcher, 1914) [13], which is now found to be the most destructive pest of the crops in various Indian states like Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, Maharashtra, Tamil Nadu and Karnataka. Severity of this pest can be different and increase in many regions of the country due to climatic changes (Dhaliwal *et al.*, 2010) [7]. Thus, it has become an economic threat to the crops and a major pest status of national importance, which can cause an economic loss up to 90% (Furlong et al. 2013) [13]. Diamondback moth is adaptable to harsh weather conditions with an excellent ability to spread out with a short life cycle (Duarte *et al.*, 2016) [9]. It is a multivoltine insect which can complete 4 to 20 generations per year in temperate and tropical regions respectively (Harcourt, 1986; Vickers *et al.*, 2004) [16]. The shorter generation time, lack of effective natural enemies (Huaripata and Sánchez, 2019) [18] and insecticidal resistance are the foremost reasons for increase in the pest status of *P. xylostella* in different parts of the world (Lim, 1986., Talekar and Shelton, 1993).

The most preferred host plant for diamondback moth are cabbage and cauliflower among all the crucifer vegetables, because they both possess fleshy and succulent leaves having glucosides and glucosinolates that stimulates feeding and oviposition. The damage to the crop is caused by larval feedings. The larvae of diamondback moths have a chewing type of mouthpart (Li *et al.*, 2018) [26] and are gregarious feeders that are continuously feeding on the leaves causing heavy defoliation (Farias *et al.*, 2020) [11]. The larvae feed by mining and scrapping off the under surface of leaf tissues, resulting in formation of windows or holes and also complete removal of foliar tissue except for the leaf midrib and veins. It will mainly affect the seedlings and may disrupt head formation in cabbage, broccoli, and cauliflower. DBM damages above the ground parts and causes reduction in yield. Its damage can continue throughout the year except in rainy season (Talekar, 1996) [56]. It is estimated that its annual management costs and associated crop losses are $ 4-5 billion globally (Shen *et al.*, 2020) [47]. In Southeast Asia, *Plutella xylostella* outbreaks often cause crop losses of more than 90% (Marak *et al.*, 2017) [28]. Losses caused by DBM is estimated to be $16 million annually in a cultivated area of 0.5 million ha in India (Mojan and Gujar, 2003) [31].

Insecticidal resistance

Resistance has been defined as "the inherent ability of a strain of some organisms to survive doses of a toxicant that would kill the majority of individuals in a normal population of the same species". The major problem in DBM management is the development of insecticidal resistance. Due to unwise and untenable application of synthetic insecticides from the past 50 years, *P. xylostella* has become one of the stubborn insect pests to control in the world, first and foremost because of the evolution of resistance to every class of insecticide that has been used extensively against it (Sarfraz and Keddie, 2005) [41]. Throughout the world, DBM management is mainly done with the use of insecticides (Sakomoto *et al*. 2003) [42] and relying on this single approach has led to increase in the application rates, decline in effectiveness and gradual breakdown of control efficiency.

DDT was the first insecticide to show resistance by the diamondback moth, which was discovered in Lembang, Indonesia, in 1953. (Sayyed *et al*., 2002) [44]. Till now, DBM has developed resistance to about 97 active chemicals (Shen *et al*., 2020) [47], putting it first among the 20 most insecticide resistant insect species. The interplay between the gut microbiota and the insect immune system has been discovered to result in increased chemical pesticide resistance (Xia *et al*., 2018) [59]. Between 1953 and 2014, DBM demonstrated resistance to 91 active components of agricultural pesticides, including 12 strains of *Bacillus thuringiensis* (*Bt*) (IRAC, 2005; Legwaila *et al*., 2014; Xia *et al*., 2014) [25, 60]. Resistance to fundamental pesticide classes such as organochlorides (OC), organophosphates (OP), synthetic pyrethroids, and carbamates has emerged in *P. xylostella* (Mahmoudvand *et al*., 2011) [30]. Diamondback moth has also been reported to be resistant against the new classes of insecticides such as Abamectin, chlorantraniliprole, cyantraniliprole, flubendiamide, betacypermethrin, Spinosad, fipronil, phoxim, chlorfenapyr and chlorfluazuron (Chen *et al*., 2010; Shakeel *et al*., 2017) [6, 46]. Resistance to cypermethrin, decamethrin, and quinalphos was also found to be greater in this notorious pest (Gautam *et al*., 2018) [14]. In India, DBM has gained its resistance against insecticides and the most of the conventional insecticides have become ineffective against it. The following table represents the reports of several groups of insecticide resistance in different parts of India.

Table 1: Insecticide resistance in DBM in India

Insecticides	State	References
DDT, parathion	Punjab	Varma and Sandhu (1968) [57]
Fenitrothion, malathion, monocrotophos	Punjab	Chawla and Kalra (1976) [4]
Permethrin, fenvalerate	Karnataka	Krishnakumar *et al*. (1986) [24]
Cypermethrin, fenvalerate	Haryana,	Saxena *et al*. (1989) [43]
deltamethrin, quinalphos	Uttar Pradesh, Delhi	
Deltamethrin, quinalphos	Punjab	Chawla and Joia (1991 and 1992) [3]
Bacillus thuringiensis (B.t.)	Tamil Nadu	Rabindra *et al*. (1995) [36]
Cypermethrin, fenvalerate	Uttar Pradesh	Raju and Singh (1995) [37]; Raju (1997)
Endosulfan, quinalphos, Monocrotophos, quinalphos, fenvalerate	Tamil Nadu	Chandrasekaran and Regupathy (1996) [1] Renuka and Regupathy (1996) [38]
Endosulfan, chlorpyriphos, methylparathion, quinalphos, methomyl, monocrotophos, carbaryl, alphamethrin, fenvalerate, cypermethrin, deltamethrin, cartap hydrochloride, B.t.	Karnataka	Sannaveerappanavar (1995) [40]
Monocrotophos, malathion, endosulfan, dichlorvos	Haryana	Kalra *et al*. (1997) [22]

Resistance development in diamondback moth

The studies regarding the resistance development of diamondback moth against conventional insecticides have revealed that it has the ability to develop resistance to new class of insecticides in a very short time of exposure (Fahmy *et al*., 1991) [10]. Diamondback moth has become highly resistive to a wide range of insecticides mainly because of the presence of detoxifying enzymes inside their body. The quantitative or qualitative changes in these enzymes can metabolize or sequester the insecticides before they reach their target sites. In insects, the esterase enzyme patterns have shown high rates of intraspecific and interspecific variations (Nascimento and Campos Buicudo, 2002) [33]. Several studies have been conducted in order to isolate and identify the detoxifying enzymes from DBM. For instance, Maa *et al.* (1990) [27] were able to detect 17 esterase isozymes from a soluble fraction of the larval homogenate of diamondback moth. Chemicals such as DEF (S,S,S-tributylphosphorolhioate), TPP (triphenyl phosphate) and IBP (S-benzyl O.O-diisopropylphosphorothionate) which are carboxylesterase inhibitors can be used as synergist to detect the involvement of esterase and to elucidate the role of carboxylesterase in insecticide resistance studies (Hemingway, 1982) [17]. When these synergists were used in bioassays, loss in the resistance was observed in resistant insects with an esterase-based mechanism (Georghiou and Pasteur, 1978) [15]. A resistant population of *P. xylostella* for malathion and phenthoate showed increased esterase activity (Noppun *et al*., 1987) [35]. Pesticides containing organophosphates and indoxacarbs were found to have a positive relationship with enhanced esterase activity (Doichuanngam and Thornhill 1989) [8]. The organophosphorous insecticides and indoxocarb resistant insects showed an increase in esterase activity (Sayyed and Wright 2006) [45].

Glutathione-s-transferase (GST) has also been linked to *P. xylostella* resistance against abamectin and β-cypermethrin (Pei *et al*., 2003). According to Moharil (2004) [29], cypermethrin resistant DBM had a 3.83-fold higher GST activity than the cypermethrin susceptible DBM. GSTs have been implicated in resistance to pesticides such as acephate, indoxocarb and chlorofluazuron, according to Sonoda and Tsumuki (2005) [50]. GSTs have been linked to pesticide resistance in *P. xylostella*, including acephate, indoxocarb, and chlorofluazuron (Nehare *et al*., 2010; Sonoda and Igaki, 2010) [34, 51].

Resistance monitoring in diamondback moth

Monitoring of insecticide resistance is a necessary criterion for any Insecticide Resistance Management (IRM) programme. Monitoring method should be designed in such a way in order to detect resistant individuals at a frequency of 1% of the population which is the practical limit in most of the cases with available techniques (Tabashnik and Croft, 1982) [55]. To measure insecticidal resistance in DBM, several bioassay procedures have been developed and applied, including the glass vial technique, paper impregiation method, topical application, larval dip, spray methods, etc. In Tamil Nadu, the vial residue assay approach is successfully employed for continuous DBM resistance monitoring (Renuka and Regupathy, 1996) [38]. The discriminating dosage is used to differentiate between resistant and susceptible strains with pinpoint accuracy. On cabbage and cauliflower, Chandrasekaran and Regupathy (1996) [1] established discriminating dosages for routinely used insecticides. According to Roush and Miller (1986) [39], the optimal monitoring strategy in most practical cases is to apply a dose that kills 99 percent of vulnerable individuals. Discriminating doses of 140, 115, 3, 4 and 5 ppm for monocrotophos, fenvalerate, quinalphos, cartap hydrochloride and carbosulfan, respectively, to monitor the insecticide resistance in field populations of DBM in Tamil Nadu were suggested by Chandrasekaran and Regupathy (1996) [1].

Insecticide resistance management (IRM)

Insecticide resistance has become a severe and widespread issue among many crop pests. It comes at a high price in terms of economic, social, and environmental repercussions. Furthermore, in many situations, the problem has become so severe that the insects can now survive any chemical dose applied on them for their management. Because DBM has a limited mobility and a high reproductive capacity (up to 25 generations per year), resistance development is quick in this pest. The widespread presence of multiple resistance in this insect necessitates immediate attention to the development of successful IRM techniques that may be implemented as a key component of an IPM programme for this pest.

For positive outcomes, Sivapragasam *et al*. (1984) [48] proposed using an economic threshold, combining *Bt*., parasitoids, pheromone traps and permethrin in DBM management. According to simulated management measures, limiting spray frequencies to less than two per cabbage season and spray concentrations of less than LC_{75} of vulnerable larvae under tropical conditions have been reported to be beneficial in delaying resistance development (Tabashnik, 1986) [54]. Srinivasan and Krishnamoorthy (1991) [53] from India reported the usefulness of mustard as trap crop, whereby the need for insecticides application was greatly reduced. Chandrasekaran (1994) [5] suggested the use of *Bt*. (750>500g of Biobit/ha), cartap hydrochloride (250g a.i./ha) or carbosulfan (250>125g a.i./ha) for the management of DBM in cabbage and cauliflower. According to Sannaveerappanavar and Viraktamath (1997a) [49], four Bet. products were particularly efficient in reducing the DBM population in cabbage, followed by two acylurea compounds (flufenoxuron and teflubenzuron) and aqueous neem seed kernel extract (4%). (Biobit, Delfin, Dipel 8L and Centari). The most effective pesticides for the treatment of DBM, according to Nagesh and Verma (1997) [32], were cartap, lufenuron, and Bet.

To conserve natural enemies and avoid insecticide resistance, Zuhua and Shusheng (1998) [61] advised selective use of avermectin, *Bt.* and virus mixture, diafenthiuron, and chlorfluazuron for the management of DBM.

Conclusion

There is a growing concern that the diamondback moth will develop resistance to new classes of insecticides in a short period of time, despite the fact that it has a long history of resistance to almost all synthetic insecticides, making it one of the most resistant insect species (Whalon *et al*. 2016; Sparks and Nauen 2015) [58, 52]. In this context, an effective IRM system for continuous monitoring of insecticidal resistance should be an inherent aspect of chemical management to allow early detection of resistance and avoid its economic, toxicological and biological repercussions. For the control of DBM, temporal and spatial constraints on the use of pesticides should be implemented. The use of insecticides on an indiscriminate basis must be avoided, instead bio-pesticides and plant products should be used for reducing the DBM population and hence the number of chemical treatments and concomitant resistance risk.

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