Insecticide resistance in diamondback moth (DBM), *Plutella xylostella* (L.): status and prospects for its management in India

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Abstract

Insecticide resistance and concomittant field failure to control the diamondback moth (DBM), *Plutella xylostella* were first recorded in 1968 in Punjab. Studies carried out in different states like Tamil Nadu, Karnataka, Madhya Pradesh, Punjab, indicate that fenvalerate, quinalphos and monocrotophos resistance are now ubiquitous in *Plutella xylostella*. In Tamil Nadu, the discriminating dose technique by vial assay is used to routinely monitor resistance in cabbage and cauliflower growing areas. Very high levels of resistance to fenvalerate (66–100%), significant OP resistance (quinalphos 45–81%; monocrotophos 33–86%) and low levels of resistance to cartap hydrochloride (18–53%) and carbosulfan (14–55%) are a feature of all regions monitored. The problems encountered in effective management of *P. xylostella* under Indian conditions are: 1. indiscriminate and over use of pesticides; 2. carry over of pest aided by staggered and repeated monocropping of cabbage and cauliflower and 3. nonavailability of effective biocontrol agents such as *Cotesia plutella* (Kurdjumov), *Diadegma semiclausum* (Horstmann), granulosis virus, etc. in sufficient quantities and high cost of B.t. formulations.

The extent of natural parasitisation of *P. xylostella* by *C. plutellae* varied from 16 to 75% in tropical plains and that of *D. semiclausum* to the extent of 80% in hill/highland areas. The occurrence of granulosis virus (GV) highly pathogenic to *P. xylostella* was observed in lab. culture. Attempts are being made to mass multiply this virus.

The following strategies are discussed: 1. create a network on resistance monitoring and management on the lines developed recently for *Helicoverpa armigera*, 2. obtaining base-line data for site specific IRM tactics and 3. developing and popularising available alternative control agents like parasitoids and the GV.

Key words: Diamondback moth, insecticide resistance, management strategies

Introduction

In India, diamondback moth (DBM) *P. xylostella* (L.) was first recorded in 1914 (Fletcher, 1914) on cruciferous vegetables. This species is now distributed all over India wherever crucifers are grown. Though DBM infests important crucifers viz. cabbage, cauliflower radish, knol khol, turnip, beet root, mustard, *Brassica campestris* var. *toria* and *B. campestris* var. *sarson* (Chand and Choudary, 1977; Dube and Chand, 1977; Jayarathnam, 1977; and Singh and Singh, 1982) and non cruciferous crops like *Amaranthus viridis* L. (Vishakantaiah and Visweswara Gowda, 1975), the pest exhibits a marked preference for cauliflower and cabbage. Perhaps these crops with fleshy and succulent leaves provide olfactory and gustatory stimuli for successful selection and development (Chand and Choudary, 1977; Dube and Chand, 1977; Jayarathnam, 1977; and Singh and Singh, 1982). The crop loss is estimated to vary from 52 (Krishnakumar *et al.*, 1984) to 100 per cent (Calderson and Hare, 1986)

DBM as a major pest of crucifers

The reasons for DBM assuming the status of major pests of crucifers in India are:

1. Continuous cropping of susceptible crops (cabbage and cauliflower) throughout the year and monocropping (mustard and rape) in larger areas.
2. Diversity and abundance of natural enemies (*Cotesia plutellae, Diadegma semiclausum*) is reduced by redundant and free use of synthetic non-selective insecticides (monocrotophos, quinalphos etc.)
3. Greater competitive ability of the pest over its natural enemy in establishing itself in newer areas.
4. Ability to migrate longer distances.
5. Out-dated application technology resulting in inefficient targeting of sprayings against DBM.
6. High rate of multiplication: DBM has a capacity to multiply 3.18, 3.38 and 2.5 times every week on cauliflower, cabbage and mustard, respectively (Justin, 1996) and as many as 16 generations are completed per year (Jayarathnam, 1977)

Resistance Development

A number of insecticides have been evaluated and reported effective against DBM; endosulfan,
Table 1. Discriminating doses (LC99) used for assessing resistance in field population

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>LC99 (ug/ml)</th>
<th>Method of assay</th>
<th>Vial</th>
<th>PST</th>
<th>Larval dip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbosulfan</td>
<td>4.0</td>
<td>20.0</td>
<td>15.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cartap hydrochloride</td>
<td>5.0</td>
<td>10.0</td>
<td>10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fenvalerate</td>
<td>115.0</td>
<td>170.0</td>
<td>130.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monocrotophos</td>
<td>140.0</td>
<td>170.0</td>
<td>150.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quinalphos</td>
<td>3.0</td>
<td>10.0</td>
<td>10.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Insecticide resistance frequency of P. xylostella in different sampling locations of Tamil Nadu

<table>
<thead>
<tr>
<th>Collection site</th>
<th>Fenvalerate 15 ppm</th>
<th>Quinalphos 3 ppm</th>
<th>Monocrotophos (6 ppm)</th>
<th>Cartap hydrochloride (5 ppm)</th>
<th>Carbasulfan (4 ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coimbatore</td>
<td>76 (100%)</td>
<td>792 (100%)</td>
<td>754 (100%)</td>
<td>664 (100%)</td>
<td>672 (100%)</td>
</tr>
<tr>
<td>Ooty</td>
<td>741 (100%)</td>
<td>693 (100%)</td>
<td>648 (100%)</td>
<td>594 (100%)</td>
<td>649 (100%)</td>
</tr>
<tr>
<td>Oddanchatram</td>
<td>781 (100%)</td>
<td>810 (100%)</td>
<td>784 (100%)</td>
<td>669 (100%)</td>
<td>734 (100%)</td>
</tr>
</tbody>
</table>

fenitrothion, fenthion, dichlorvos, quinalphos, methamidophos, chlorpyriphos, phosalone, phenthoate, methylparathion, monocrotophos, sulprofos, prothiophos, carbaryl, cypermethrin, fenvalerate, permethrin, carbosulfan, and cartap hydrochloride (Chawla and Kalra, 1976; Singh et al., 1976; Rajamohan and Jayarat, 1978; Krishnakumar et al., 1978; Regupathy and Paranjoti, 1980; Srinivasan and Krishnakumar, 1982; Shah et al., 1984; Chelliah and Srinivasan, 1986; Chandrasekaran et al., 1994; and Rabindra et al., 1995).

In India, the first report of DBM resistance to insecticides (DDT and parathion) was made by Varma and Sandhu (1968) in Ludhiana (Punjab). Subsequently this was confirmed by Deshmukh and Saramma (1973). They also observed the DBM resistance to ethyl parathion in Jalandhar (Punjab). Chawla and Kalra (1976) reported the extension of DBM resistance to fenitrothion and malathion. A high degree of resistance to cypermethrin, decamethrin and quinalphos was reported by Saxena et al., (1989). The resistance to quinalphos was found to be stable (Chawla and Joia, 1992). The current status of DBM resistance to quinalphos (70X), fenvalerate (2700X) and cypermethrin (2880X) and cross resistance status to insecticides with different mode of action (cartap hydrochloride, diafenthiuron and flufenexuron) and had been reported by Joia and Chawla (1995) and by Joia et al., (1996).

Rabindra et al., (1995) reported that DBM populations from different parts of Tamil Nadu exhibited differential susceptibility to fenvalerate, monocrotophos, chlorpyriphos and B.t. (LC50 values ; Oddanchatram population > Coimbatore population) indicating that some populations in Tamil Nadu were already on the road to resistance selection. Chandrasekaran and Regupathy (1996) fixed discriminating doses using F26 lab. reared population without exposure to insecticides for quinalphos, fenvalerate, carbosulfan and monocrotophos by different bioassay methods using third instar larvae (Table 1).

Of the different methods, the vial residue bioassay was found to be preferred and was used for assessing the resistance levels in different DBM populations (Table 2). Renuka and Regupathy (1996) took up monitoring of DBM resistance since June, 1995. The extent of resistance varied from 66.7–100.0% for fenvalerate, 45.5–92.3% for quinalphos, 32.6 to 85.7% for monocrotophos, 14.3 to 55.2% for carbosulfan and 17.9 to 52.4% for cartap hydrochloride. Oddanchatram population showed high degree of resistance to fenvalerate. Irrespective of the locations high frequency of resistance was observed to fenvalerate > quinalphos, monocrotophos > cartap hydrochloride > carbosulfan. Insecticide resistance and DBM control failures are now common in other states like Karnataka. [Veerappanavar (1996) UAS, Bangalore] and Uttar Pradesh [Raju, (1996) Banaras Hindu University, Varanasi].
Proposed IRM strategy for *P. xylostella* in India.
1. Crop scouting as a means of ensuring correct application timing to minimise the number of insecticide applications.
2. Resistance monitoring to determine the extent of the resistance problem and to monitor if the strategy is achieving any real benefit in reducing insecticide resistance.
3. Large temporal and or spatial restrictions on the use of insecticide groups with resistance risk potential.
4. Maximising efficiency of insecticide application to ensure coverage of the target eg. Primordia head formation.
5. Maximising advantage of biological and cultural methods to decrease DBM populations and these by the need for insecticide intervention.

Pest surveillance
A pest surveillance programme is in operation in the Centre for Plant Protection Studies (CPPS) in Tamil Nadu Agricultural University (TNAU) for major field crops. The scouting system has been implemented as a collaborative venture between TNAU and the State Department of Agriculture (SDA) since 1984. The concerted efforts taken by TNAU and SDA in implementing IPM, by applying more emphasis on insecticide application through economic threshold levels (ETLs) significantly reduced the number of insecticide applications applied by local farmers on cotton, rice, sugarcane etc. Such collaborative exercise between TNAU and State Department of Horticulture (SDH) is needed.

Resistance monitoring
The continuous monitoring of insecticide resistance in DBM must form an integral part of chemical control to enable the detection of resistance as early as possible so that its economic, toxicological and biological consequences may be obviated. In India, for the first time, a collaborative programme involving Natural Resources Institute (NRI), U.K., International Crop Research Institute for the Semi Arid Tropics (ICRISAT), Hyderabad, India and the Indian Council of Agricultural Research (ICAR), New Delhi, is successfully implemented to monitor seasonal changes in insecticide resistance in *H. armigera* in different regions and cropping systems in India and to develop regional insecticide resistance management strategy for *H. armigera*. Under this programme eight monitoring laboratories have been set up (Regupathy, 1995) and monitoring is done continuously since 1993.

At present the research on DBM is carried out in various states like Tamil Nadu, Karnataka, Uttar Pradesh, Madhya Pradesh, Haryana and Punjab funded by ICAR, New Delhi. However the co-ordination among scientists working on DBM is lacking. There is a need for a network programme on the lines of collaborative project on *H. armigera*. Chandrasekaran and Regupathy (1996) have established discriminating doses for commonly used insecticides on cabbage and cauliflower (*Table 1*). The vial residue assay technique is successfully used in Tamil Nadu for continuous monitoring of DBM resistance (Renuka and Regupathy, 1996). These may be used in other laboratories to have uniformity. Based on this, a field kit has been developed and tested in adoptive trials with farmers and extension functionaries in order to make an informed choice as to the most appropriate insecticide to use at specific times in the season.

Temporal and spatial restrictions on the use of insecticides
At present the constraints identified in the implementation of temporal and spatial restrictions on the use of insecticides for the control of DBM in India are:
1. Farm holdings are small and generally literacy rate is low among users.
2. The first line contact for most farmers wanting advice on pest control is the pesticide dealer. Dealers are rarely impartial and will invariably advise farmers to pesticide even when none is required.
3. Poor participation by the chemical industry in educating the farmers.
4. Asynchrony of planting times and succession of cabbage and cauliflower crops.
5. The demand by the consumer for unblemished cabbage and cauliflower heads.

Regulation of application rate
Indiscriminate application of insecticides must be discouraged. After the application of blanket spray to protect the primordia/head formation stage, further spraying could be restricted to the number necessary to keep damage to no more than one hole an average per wrapper leaf of the cabbage. This approach is reported to be an effective alternative to reliance on regular weekly or fortnightly sprays (Srinivasan, 1984). He is of the opinion that the larval populations causing damage to either outer leaves, or to leaves about to cover the head, do not reduce marketable yield significantly.

Utilising biological control
The exploitation of biological and plant products to decrease the DBM population and thereby the number of chemical treatments and concurrent resistance risks should be considered.

Parasitoids
A large number of parasitoids have been recorded on DBM (*Chellia* and *Srinivasan*, 1986 and Chandramohan, 1996 and the references there in). Among these, the egg parasitoids of *Trichogramma confusum* and *Trichogrammaeidea bactrae* accepted the eggs of DBM in the lab but failed to parasite DBM in the field (Wuhrer and Hasan, 1993). The activity of a larval parasitoid *D. semiclausum* is noticed throughout year in Nilgiris with maximum parasitism (77%) during September.
C. plutellae is the predominant larval parasitoid of DBM in almost all the tracts of India (Chelliah and Srinivasan, 1986 and Srinivasan and Krishnakumar, 1982). It exhibits clear density dependent relationship with high level of parasitism ranging from 46.9% in Bangalore, 77.1% in Gujarat (Chelliah and Srinivasan, 1986) and 83.7% in Tamil Nadu (Chandramohan, 1994). In South India a high level parasitism of 68.5% by the gregarious larval pupal parasitoid Tetrastichus sokolowskii (Eulophidae) had been recorded in November (Cherian and Basheer, 1939). The pupal parasitoid Didromus (=Thyrella) collaris which is common in Malaysia, Indonesia, New Zealand, Figi and Taiwan (2.70%) is recorded in Shillong (Chacko, 1968).

**Predators**

The bird yellow wagtails (Motacilla flava) were found to feed on DBM larvae, and the ants, Tapinoma melanocephalum, Pheidole spp and Camponotus sericeus were found to carry away DBM larvae in the field (Jayarathnam, 1977).

**Pathogen**

The larvae and less frequently the pupa are attacked by two entomopathogenic fungi, Erynia and Zoophthora radicans. Nagarkatti and Jayanth (1982) collected two diseased larvae affected by nuclear polyhedrosis virus (NPV) in Bangalore. Recently, Renuka and Regupathy (unpublished) observed epizootics of granulosis virus (GV) affecting field populations maintained for monitoring insecticide resistance. The virulence of different isolates are being assessed (Rabindra et al., 1996). The effectiveness of Bacillus thuringiensis (Berliner) (B.t) formulations had been reported as early as in 1969 by Narayanana and subsequently by Chandrasekaran et al. (1994) and Justin (1996). Some of the constraints identified in promoting biocontrol agents in India are indicated below with a view to take up further research.

1. Mass multiplication and speedy distribution to the large number of cabbage and cauliflower growers. The effective larval parasitoids D. semiclausum and C. plutellae are solitary endo larval parasitoids of DBM. In India 25% field parasitism by C. plutellae was reported in Trichoplusia ni. The possibility of mass multiplication of C. plutellae on amenable host like Corcyra larvae need consideration.

2. Performance of parasitoids in field has been restricted. Egg parasitoids (T. chilonis) are not found to have potential for field release.

3. Adaptability of parasitoids. The pest DBM has better reproductive characteristics than its parasitoids. It reproduces under extremely varied conditions. The pest could breed and develop between 10°C–40°C (Hardy, 1938). The ideal temperature range for D. semiclausum is 15–25°C. At temperature approaching 30°C parasitism drops sharply (Chandramohan, 1994). The optimum temperature range for C. plutellae (Chua and Ooi, 1986; Hsu and Wang, 1971) is 20–30°C. Heavy rain will annihilate C. plutellae population.

**Lack of information**

In India, field evaluation is done only to D. semiclausum and C. plutellae under the AVDC (Asian Vegetable Research Development Centre) – IIHR (Indian Institute of Horticultural Research, Bangalore) – TNAU IPM Programme in Western Ghat region of Tamil Nadu. The information on the early inundative release of C. plutellae is not available. The evaluation of the potential pupal parasitoid, Didromus (=Thyrella) collaris (Ichneumonidae), has not been done. The extrinsic superiority of C. plutellae over D. semiclausum under field condition and vice versa in laboratory condition is not understood clearly.

**Scope of development of resistance to B.t.k.**

DBM is the most susceptible insect to B.t. However the continued use of B.t. is likely to result in the development of resistance in DBM to B.t., (Hama, 1992 and Tabashnik et al., 1990). Recent studies by Chandrasekaran and Regupathy (1996) and Justin (1996) revealed that different DBM populations exhibited differential susceptibility to B.t. This indicates resistance selection to B.t. Genetic analysis showed that the resistance to B.t. products HD 1 isolate of kurstaki serotype is autosomal, recessive and controlled by one or few loci (Tabashnik et al., 1990). The lack of cross resistance to aizawai serotype which has additional toxins offers some hope for managing resistance to B.t.

The low out turn of NPV and GV and limitation in mass multiplication of DBM on which these pathogens multiplied make use of these pathogen far from practical. Any breakthrough made in mass multiplication method (cell line cultures?) may be for future consideration.

**Best-Bet Packages:**

On farm trials to validate a ‘Best Bet’ management strategy for insecticide resistance DBM are to be conducted considering the following components:

1. **Avoid pre-heading sprays of insecticides to retain natural enemies.**

   DBM infestation at 55 days after planting has the maximum effect in reducing the yield (Krishnakumar et al., 1984). However, blanket spray of insecticide is needed to protect the primordia/head formation stage.

2. **Grow trap crop**

   Tomato, when intercropped with cabbage reduced DBM – egg laying (Vostrikov, 1915; Burandy and Raros, 1973 and Sivapragasam et al., 1982). The problem is that late crop stages of tomato only inhibited DBM oviposition (Srinivasan, 1984) necessitating early planting of tomato 30 days prior to cabbage. This is not attractive to the...
farmers. Srinivasan (1984) later successfully demonstrated the usefulness of mustard as trap crop. However, asynchrony in planting main crop (cabbage) and trap crop (sowing mustard crop 15 days prior to cabbage planting or planting 20 days old mustard seedling at the time of cabbage plantings) is considered difficult by farmers to adopt. To make it more attractive suitable mustard variety for synchronous planting needs to be selected/developed.

3. Application of neem based formulations.
Two neem extracts viz., AZT (30 mg azadirachtin/ml) and Neem-Azal (3 mg azadirachtin/ml) recorded a mortality of 50 and 90 percent, respectively, after 13 days. Though there was no morphogenetic abnormalities, there was antifeedant and repellent effect apart from ovicidal action (Verkerk and Wright, 1994).

The neem formulations (Neem-Azal and Nimbecidine) and aqueous extracts of NSKE, V. negundo, T. terrestis and M. azarach reduced the fecundity, longevity and leaf area consumption of DBM. A low ovicidal action was observed in all the neem formulations (Justin 1996). The neem products could be utilised in conjunction with trap crop.

4. Application of biopesticides like B.t.
Spraying of B.t. (500g/ha) at the primordial stage is most effective. Repeat application of same serotype may be avoided.

5. Inundative release of parasitoids
Release of larval parasitoids D. semiclausum in high altitude regions and C. plutellae in plains commencing from 30 days after planting @ 20,000 in each of five releases at 20 days interval.

6. Application of insecticides
Most appropriate insecticides at the recommended rate and alternating chemical groups of insecticides. As very high level of natural parasitism of D. semiclausum and C. plutellae in field are observed less selective insecticides like quinalphos (Mani and Krishna moorthy, 1984) may be avoided at peak period of parasitism. Avoiding repeat application of insecticides of same group or with similar mode of action and having cross resistance like cartap hydrochloride, diafenthiuron and flufenexuron (Joia et al., 1996) will delay the insect resistance.

References


