Economic Insect Pests of *Brassica*

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Abstract

Brassica is a genus of plants in the mustard family that includes cauliflower, sprouts, broccoli and cabbage. Plants of the *brassica* family are rich sources of biologically active substance. The beneficial effects of *brassica* vegetables on human health have been somewhat linked to phytochemicals. They prevent oxidative stress, induce detoxification enzymes, stimulate immune system and decrease the risk of cancers. Crucifers are the important winter crops grown widely in tropical and temperate regions of the world, giving yield of 50.7 million tons. It is cultivated around the year over an area of 8263 hectares in Karnataka with production of 23.63 tons per hectare. Cauliflower and cabbage are the most common crops throughout the world. Diamondback moth (DBM) caused losses of about 16 million dollars by causing a 2.5% damage annually. There are many insect pests that attacked these crops and most common are diamondback moth, tobacco cutworm, aphid, jassid, cabbage worm and many others. The most important of these insect pests is the diamondback moth *Plutella xylostella* also called cabbage moth that belongs to Plutellidae. There are many controlled strategies including chemical control, biological control, physical control and many other methods. This study contributes to the literature offering understandings about the insect pests of *brassica* and their best management techniques.

Keywords: *brassica*, insect pests, DBM, bionomic, distribution, management

1. Introduction

Cruciferous family crops are economically important, and especially cabbage (*Brassica oleracea*) is one of the most important winter vegetables grown extensively in temperate and tropical areas of the world with an output of 50.7 million tons, of which India contributes 38.62 lakh metric tons, from an area of 2.18 lakh hectares [1]. The most important of cole crops, cabbage and cauliflower, are grown on 0.438 million hectares producing 6.335 million tons per annum in India [1]. In China, cruciferous family plants are also cultivated on large areas. The most damaging pest of cruciferous family plants is diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) because of its greater dispersal ability, per-year larger number of generation and development of resistance to most commonly used insecticides [2, 3]. *P. xylostella* is a serious pest of cauliflower, cabbage, lily, brussels, broccoli, sprouts and Chinese cabbage [2].

2. Bionomic of diamondback moth

2.1. Biology and ecology

DBM is a tiny brownish color moth having triangular markings on their forewing. Eggs are laid signally on the underside of leaves. The female of diamondback moth lays 300 eggs in her reproductive period. The female of DBM lays eggs on the lower and upper side of the leaf surface and the ratio is 3:2, and very little amount of eggs are laid on the stems of the leaf [4]. An egg hatching period is 2–4 days. As new tiny larvae emerge, they start feeding on the lower side of leaves. Larval duration is 10–15 days but it largely depends on the temperature and other environmental conditions. Color of young larvae is from whitish yellow to pale green. The life of an adult is 10–15 days. Larvae cause large defoliation of leaves [5]. Diamondback moth adult is a weak flier and the length of adult moth is about 5 mm and width is 2 mm [6].

After the emergence, the first instar makes mines in the spongy tissue and the second instar starts feeding on the lower side of the leaf and consumes all the tissue expect the waxy layer. When fourth instar feeding is complete, it converts into a cocoon-like structure that is called the pupal stage, and at this stage feeding stops [7]. The duration of this stage depends upon the temperature and mostly it is 4–10 days, but it can decrease in warm areas and increase in cold areas; after adults emerge who feed on water or dew drops, their adult life is short [8].

2.2. Diapause

In subtropical and tropical regions, where the cabbage and cauliflower or any other crops belonging to the Crucifers family are grown throughout the year, all the stages of diamondback moth are present at any time. In the temperate region, where the crucifers crop are not grown throughout the year, and in winter season, both pupal and adult stages of diamondback moth hibernate in plant debris [9]. A study was done in the New York state for the presence of diamondback moth during winter season using different pheromone traps and it found that no diamondback moths were caught [10].

2.3. Migration

Diamondback moths have great abilities to disperse and migrate over long distances. Mass migration of DBM occurs in Britain, and the adult of diamondback moth migrates from Baltic to Southern Finland and covers about 3000 km, and this study indicates that the adult of DBM remains in flight continuously for several days [11].

3. Distribution of diamondback moth

Plutella xylostella was for the first time recorded in Europe but later found throughout America, Australia, Southeast Asia and New Zealand. For the first time, it was observed in North America in 1854, in Illinois, and then spread to Florida and the Rocky Mountains in 1883 and in 1905, diamondback moth was reported in British Columbia [2].

Diamondback moth has been recorded all over the world and the largest number of this species was recorded in the USA. Seven species of this insect was recorded in South America and Argentina, Chile and Colombia recorded nine species and only two species of *Plutella* have been recorded in Europe. The world's most important five species include *P. annulatella* (Curt.) in Finland; *P. armoraclae* (Bus.) in Colorado, the USA; *P. antiphona* (Mey.) in New Zealand; *P. porrectella* (L.) in Ontario, Canada; and *P. xylostella* (L.). All these species are limited in their geographic distribution except *P. xylostella*. It is also suggested that this pest might have originated in South Africa because the presence of rich and diverse fauna [12].

4. Damaging history of diamondback moth

Diamondback moth is a serious pest of cruciferous plants worldwide and about 1 billion dollars of losses occur annually due to its larval damage [13]. It is reported that 90% of losses occur due to this pest [14] and also reported that 60% loss occurs in production and 2 billion dollars of losses occur when controlling this pest [15]. It is estimated that 16 million dollars of losses occur on the basis of a 2.5% damage on protective crops per annum by this pest [1]. The larvae of DBM caused damage to all cruciferous family crops especially cabbage in Southeast Asia.

The failure of DBM occurred when this insect became the most destructive pest of the Lepidopteran family. DBM damaged above-ground plant parts and reduced the yield except during rainy weather [16]. When the attack of diamondback moth is very serious the losses reach up to 80–90% [17].

4.1. Mode of damage

The larvae of diamondback moth *Plutella xylostella* feed on the foliage at their different larvae stages and reduce the yield and also decrease the quality of vegetables [18]. Larvae of DBM damage the cabbage and cauliflower leaves by making small holes on the surface of leaves, often leaving the epidermis of leaves that is called Feeding Window; also, inside broccoli florets and cauliflower curds, contamination occurs due to this insect.

5. Chemical control of diamondback moth

There are many specific insecticides used for the control of DBM while certain chemicals are more effective against other pests as compared to DBM, so it is important to select appropriate chemicals according to insect pests. Some chemicals having longer residual action on later growth stages like prothiophos, cartap and fenvalerate mixtures are suitable for management of diamondback moth [19]. Organophosphates (OPs) have been considered as the most important group of compounds for the control of DBM. In OP groups, enough variations in chemical structures have contributed to the wide spectrum of efficacy and varied levels of resistance observed in DBM [20].

5.1. Pyrethoids

Many synthetic pyrethoids (permethrin constituting 0.01%, decamethrin of 0.004%, fenvalerate of 0.01% and cypermethrin of 0.005%) have no good results for controlling after 48 h of the treatment on adult diamondback moth while quinalphos constituting 0.05%, phosalone of 0.05%, endosulfan of 0.05%, monocrotophos of 0.05% and dichlovos of 0.05% have greater toxic effects on both adult and larval stages; after 6 h dichlovos and quinalphos recorded 100% mortality, endosulfan 93% and monocrotophos 63% [21]. Spinosad and permethrins caused 100% mortalities to diamondback moth adults and larvae in leaf dip and residual bioassays method after 72 h of treatment [22].

5.2. Organophosphates

Spinosad and fenvalerate provide good results for the control of diamondback moth larvae at various development stages. Novalurin at 6–12 oz./acre is effective for the control of DBM as compared to non-treated plants, and spinosad is superior to all other insecticides for controlling DBM [23]. Emamectin benzoate with trademark PROCLAIM^{R} is extensively used in the USA and has great degradation on leaf surface and provides good control of DBM larvae and other pest species [24]. Benzoyl phenyl urea and chitin synthesis inhibitors also show good results for controlling resistance-developed population of diamondback moth [25, 26].

5.3. Neem-based insecticides

Neem-based insecticides are most effectively used for the management of *P. xylostella* and other insect pests of Crucifer crops [27, 28]. This type of insecticide, that is, AlignTM (3% formerly agri dyne, Salt Lake City, axadirachtin, Utah), was applied on Lepidopterous pests, mainly *P. xylostella* and other Crucifers crop pests in Texas by [27]. They get results that this insecticide significantly decreases the attack of *P. xylostella* and other insect pests of cabbages and Crucifer crops. Three plant extracts, Annona muricata seeds, *Annona saquamosa* seeds and *Stemona collinsae* roots, are also used at 20 mg/ml concentration and showed high toxic effects, that is, 100% mortality of larvae [29]. The ethyl acetate extracted from *Phytolacca americama* root and extract of Pseudolarix kaempferi, that is, petroleum, is used for the control of DBM larvae; acetate shows stronger insecticidal effects on the second and third instar larvae of *P. xylostella* having LC_{50} values of 225 and 335 ppm [30].

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6. Biological control of DBM

There are many biological control agents used for the control of diamondback moth including parasitoids and bio-pesticides [31]. In 1998, the main focus was on introducing the two important species of parasitoids, that is, *Diadegma semiclausum* (Ds) and *Diadromus collaris* (Dc), which were introduced from Malaysia by programme for private sector development (PPSD) with the help of FAO Regional Vegetable IPM and CAB International. The parasitoids are successfully established in high-land areas in Vietnam. In particular areas, the lake of effectiveness of parasite or predator control is due to the ability of diamondback moth to migrate and is also established in new planted vegetable areas, and the second important reason for the failure of biological control is the use of highly toxic pesticides in large amounts [32].

Mixture of some chemical and Bt products is very useful for the control of diamondback moth. There is belief that such mixtures are also useful and have large potential for the control of Crucifer insect pests. Similar results was reported as mention above by the use of mixture of typically 20 chemicals formulations [33]. The mixture of Bt products and parasitoids *Diadegma semiclausum* (Ds) and *Diadromus collaris* (Dc) provides effective control of *Plutella xylostella* and other Crucifers crops; the control ranges from 50 to 85% [34]. These mixtures decrease the use of insecticides by 80% in dry season and 55% during rainy season [33]. Mostly, farmers used *Bt* when the attack of DBM larvae exceeded 10/m^2 of crop; farmers used six or seven applications during dry conditions and three or four applications during rainy conditions [35].

6.1. Egg parasitoids

Trichogrammatoidea bactrae is the egg parasitoid of diamondback present naturally in Thailand. This parasite was reared and mass released in the field in mid-1880s and 1990s by the Department of Agriculture, Thailand, and the range of parasitism in unsprayed experimental field is 16–45% of diamondback moth eggs; results show that this parasite controlled DBM but was killed due to chemical spray [36].

6.2. Larval parasitoids

Cotesia plutellae is the larval parasitoid used for the control of diamondback moth (DBM). *Plutella xylostella* L. released without applying insecticides in the glass house has a great effect on the larval stage in Taiwan [37]. In tropical and subtropical areas, where the temperature is greater than 35°C and cauliflower and cabbage are grown, the parasitism of *C. Plutella* was less than 30% [38].

6.3. Pupal parasitoids

Diadromus collaris is the pupal parasite having 6–7 mm of size and only deposits their eggs in the pupa cocoon, having a life cycle of 15 days. This species naturally occurs in Thailand in the province of Chiang Mai and Petchaboon. The parasitism on the pupa of diamondback was studied at the University of Maejo that is 9–30%. Many species like this was observed in February and March in 1990 in Maejo University [36].

7. Bacterial control of DBM

Bacillus thuringiensis as a biopesticide is very good practice to reduce the pest population pressure to cultivate the cruciferous vegetables in cool seasons of many tropical regions [39, 40]. The advantage of *Bt* toxin is that it is extremely precise to its target host especially to DBM. Dry flowable (DF) formulations of Dipel are most compatible with many other insecticides and fungicides. This product is also harmless to the bio-control agents, which are available commercially [41]. Development of resistance in insects is a serious problem against various viruses and *Bt* biopesticide [42]. In many cases, resistance has been observed by DBM against *Bt* toxins. Transgenic Crucifer plants can be used to improve the strategies of resistance management which are applicable broadly to other crops and insects [42]. Three regions of Florida used genetically improved strains of *Bt* and have obtained good results for controlling diamondback moth [43].

8. Nematodial control of diamondback moth

Entomopathogenic nematodes in families Steinernematidae and Heterorhabditidae have great effects for controlling the Lepidopteran pest and the best alternative control by insecticides [44]. It is reported that Steinernematidae, *Steinernema carpocapsae*, is used for the control of diamondback moth [45, 46]. Cell of *X. nematophila* that is present in *S. carpocapsae* is used for the control of diamondback moth larvae [47, 48]. Cell-free solution that contains bacterial cell suspension or nematodes toxins has the best ability for control of diamondback moth larvae [49].

9. Viral control of diamondback moth

Granulosis virus (PxGV), *Autographa californica* nuclear polyhedrosis virus (AcMNPV) and nuclear polyhedrosis virus (GmMNPV) are used for the control of diamondback moth and other cruciferous family crops in Malaysia [50]. Many baculoviruses have been reported for the control of diamondback moth; Granulosis virus (GV) is used for the control of *Plutella xylostella* [51].

10. Resistance against different control strategies

One of the major reasons for the development of resistance to insecticides by DBM is the increasing of number of sprays and thereby increasing cultivation costs. Eco-friendly and less-toxic new chemicals are also available in the market but the farmers are still using broad-spectrum pyrethroids, organophosphates, organochlorines and many other conventional insecticides diamondback moth has developed resistance against these insecticides [52]. Thiodicarb, fipronil, lufenuron, spinosad, carbosulfan and indoxicarb are still performing well

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as compared to malathion [53]. In Malaysia, high uses of abamectin in Crucifer crops against diamondback moth develop serious problems of resistance [14].

High rate of resistance developed in many insecticides such as cypermethrin, pyrethroids, fenvalerate, organophosphate, deltamethrin and quinalphos was found in DBM population, collected from areas where farmer used mostly pyrethroids at heavy doses [54]. Diamondback moth has developed resistance against fenvalerate, cypermethrin and deltamethrin in the Indian province of Punjab [55]. A new chemical cartap hydrochloride is a successful insecticide for controlling resistance population of DBM. A 170-fold resistance to quinalphos developed in DBM [55].

In some part of the world, DBM became most difficult insects to control because of development of resistance due to the use of extensively toxic chemicals [56, 57]. The extensive use of toxic commercial insecticides against DBM in India is the one of the major constrains in the profitable cultivation of cole crops because these chemicals in heavy and toxic doses developed resistance in DBM [58]. Both mechanisms of resistance and baseline susceptibility are necessary for the effective management of location-specific resistance strategies [59, 60].

Resistances developed 144-fold against diamondback moth due to the use of cyperpethrin at Panipat (Haryana) in India [54]. In DBM, resistance persisted longer in Taiwan against pyrethroids [61]. It is reported that *P. xylostella* is the only pest that develops resistance in the field. OP resistance is not fully investigated and appears probably additional to metabolic resistance mechanisms [62, 63]. The insect growth regulator (IGR) resistance observed in Taiwan DBM populations is significantly affected by piperonyl butoxide action. The synergistic ratios were 7.9:10.4 in three DBM populations for teflubenzuron [64].

The larvae of South Texas strain were less susceptible to indoxacarb than that of the Minnesota strain, and mortality increased with the time of exposure [65]. It is reported that there is no significant difference in the laboratory strain and field population when comparing the resistance [66]. Outside Southeast Asia, it has been reported that there is great development of resistance in this insect pest in several countries, for example, Japan, the USA, Honduras and Australia [67]. In some regions it has been also detected that DBM developed resistance against IGRs which are so-called benzoylphenyl urea (BPUs) [68].

It is documented that difference between two populations of DBM at LC_{50} was 2.9 fold and high levels of resistance developed in DBM against lambda-cyhalothrin and lufenuron [69]. In China, LC_{50} of 1.22, 0.61 and 0.004 ppm against emamectin benzoate from His-Hu strain and Lu-Chu strain and susceptible strain [70].

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