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Assessing susceptibility of diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) population of different geographic region to selected newer insecticides

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Abstract
The Study was conducted to assess the variations in relative susceptibility levels among the populations of diamondback moth in major cabbage growing areas of South Karnataka. The LC_{50} values were varied across insecticides for single population and also across the populations of geographical locations. The LC_{50}value of Bengaluru, Kolar and Chikkaballapura populations recorded highest for 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. xylostella.* This clearly indicated that the rate of evolution of resistance in *P. xylostella* was varied across insecticides and also across geographical locations.

Keywords: DBM, *Plutella xylostella,* insecticides, bioassay, resistance

1. Introduction
Cole crops are important group of winter vegetables consumed all over the world and grown in tropical and temperate regions of the world. Cole crops like cabbage, cauliflower, turnip, kale, broccoli, brussel sprouts *etc.* are grown in hills and plains of India. Among them, cabbage and cauliflower are economically more important vegetables in India.

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 [2].

Most of the cruciferous vegetables are vulnerable to many insect pests whereas diamondback moth (DBM), *Plutella xylostella* Linnaeus, cabbage butterfly, *Pieris brassicae* Linnaeus, cabbage semilooper, *Trichoplusia ni* Hubner, Head borer, *Hellula undalis* Fabricius, Tobacco caterpiller, *Spodoptera litura* (Fabricius), Cabbage aphid, *Brevicorneae brassicae* (Linnaeus) and Green peach aphid, *Myzus persicae* (Green) are the major productive constraints. Among these, diamondback moth is the most serious in causing economic loss. Though, the moth originated in the Mediterranean area, it has surpassed all the natural barriers and is believed to have become a cosmopolitan pest [20].

The Diamondback moth (DBM), Plutella *xylostella* (L.), is one of the major hurdles for the cultivation of cabbage all over the world. This insect was first recorded on cruciferous vegetable [11]. This species is distributed all over India wherever crucifers are grown. It is a major pest on crucifers *viz.* cabbage, cauliflower, radish, knol khol, turnip, beet root, mustard, *Brassica campestris* var. *toria* and *B. campestris* var. *sarson* [5, 9, 14, 35] and non-cruciferous crops like *Amaranthus viridis* L [41].

This pest exhibits a marked preference for cauliflower and cabbage crops. Perhaps these crops with fleshy and succulent leave provide olfactory and gustatory stimuli for successful selection and development [5, 9, 35]. The crop loss due to infestation by DBM is estimated to vary from 52 to 100 percent [18, 4].

Major reasons for DBM assuming the status of major pest of crucifers in India may be due to continuous cropping of preferred crops (cauliflower and cabbage) all round the year and

mono-cropping rapeseed and mustard in larger areas, reduction in diversity and abundance of natural enemies (*Cotesia plutellae, Diadegma semiclausum*) due to redundant and free use of synthetic non-selective insecticides, greater competitive ability of the pest over its natural enemy in establishing itself in newer areas, abilty of the insect for long distance migration, out-dated application technology resulting in inefficient targeting of sprayings [29] and High reproductive potential, (as it has a capacity to multiply 3.18, 3.38 and 2.5 times every week on cauliflower, cabbage and mustard, respectively [15] and shorter life cycle with 16 generations per year [14].

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 [36]. The reliance on this single approach has led to ever increasing application rates, decreased effectiveness and eventual breakdown of control efficiency [12]. Farmers often increase the dose of insecticides and taken up spray up to 25 times within a cropping season [17, 16].

The excessive dependency on chemical control led to development of resistance to all major group of insecticides used extensively against it [39]. As a result, every new insecticide is expected to have potential effectiveness for just two or three years [31, 25, 44, 39]

DBM developed resistance to as many as 69 insecticides, which is maximum for any other insect pest [3]. It was the first insect to have developed resistance to *Bt* under field conditions [38, 28]. In India, insecticide resistance in *P. xylostella* was documented for the first time in 1966 when parathion and DDT failed to control DBM around Ludhiana of Punjab [40]. Subsequently it was confirmed [8]. Who also observed DBM resistance to ethyl parathion in Jalandhar area of Punjab?

A high degree of resistance to cypermethrin, decamethrin and quinalphos was reported [33]. Resistance has also been reported against many groups of insecticides *viz.,* organochlorines, organophosphates, carbamates, synthetic pyrethroids, *Bt* products [32, 6 and 34]. Failure of new groups of insecticides *viz*., chlorantraniliprole and flubendiamide as foliar applications was recently reported [2].

The reported failure of wide group of insecticides to control DBM indicates that insecticide resistance in DBM has become a major limiting factor in the cultivation of crucifers in India. DBM being a weak flier acquired local importance depending upon the cropping systems and agro-ecological conditions [13]. Insecticide usage pattern varied widely and attributed to differences in their susceptibility levels.

Significant variation in susceptibility of larvae of *P. xylostella* against permethrin was reported in Taiwan [7] and against DDT, diazinon, fenvalerate and permethrin in Hawaii [38]. The susceptibility pattern of different geographical populations of DBM will provide basis for developing appropriate and effective resistance management strategies.

2. Material and Method

The present investigations on evolution of resistance in Diamondback moth (DBM), *Plutella xylostella* populations to newer insecticide molecules were carried out at Department of Entomology, College of Horticulture, University of Horticultural Sciences campus, GKVK, Bengaluru, Karnataka during 2016-17. The station is located in northern part of the city at 12°.58' N and 77°. 38'E longitude with an altitude of 920 meters above mean sea level. The materials used and methods employed in the research to achieve the target objectives of the study are briefly described in this chapter.

The DBM populations were collected from different cabbage growing areas of Karnataka *viz.,* Bengaluru rural, Kolar and Chikkaballapura districts. The collected populations were reared to F_1 generation to avail sufficient number of uniform age. The populations of F_1 generation were used in the study the geographical variation in resistance to different new insecticide molecules.

2.1 Mass rearing of *P. xylostella*

All the experiments pertaining to estimation of resistance in different populations of DBM were carried out on laboratory reared field populations. The different stages such as larvae and pupae of DBM were collected from cabbage fields of Bengaluru, Kolar and Chikkaballapura districts. These places represent the predominantly cabbage growing regions of Sothern Karnataka. The field collected populations were brought to the laboratory and reared separately on mustard seedlings.

The DBM population was reared on mustard seedlings raised in plastic cups

(8× 4 cm) by adopting the method described[19] with suitable modifications. The cups were filled with well soaked vermiculite to a depth of 1.5 cm as a growth medium. Seeds of bold type mustard were spread evenly over the vermiculite surface and watered. The seeds germinated within three days at room temperature and the seedlings were watered as and when required. Four days old seedlings were used for rearing of DBM larvae. The larvae were picked up with the help of a soft camel hair brush and transferred on four days old mustard seedlings and rearing continued till they attain pupal stage.

The neonate larvae feed on the mustard leaves by mining. The larvae were transferred to fresh seedlings by gently tapping the old seedlings gently with a Camel® hairbrush. On completion of larval period, fully grown larvae were allowed to pupate on the seedlings. Pupae were transferred to a Petri dish and kept in a cage for moth emergence. Moths were provided with three to four days-old mustard seedlings for oviposition. The cotton swabs with 10 per cent honey solution were provided for moth feeding. After 24 hours, mustard seedlings with eggs were taken out and kept in rearing trays. Three to four days old seedlings were placed inside the oviposition cage every day for oviposition.

This rearing procedure was continued for at least one generation till sufficient number of larvae was available for bioassay studies. The rearing trays, oviposition cages and the culture room were disinfected regularly with 4 per cent formaldehyde solution to prevent any entomopathogenic infection.

2.2 Insecticides

The details of insecticides used in the bioassay studies are listed in Table 1. All the insecticides used in the bioassay studies were procured from the market.

Table 1: Details of insecticides used in the studies

Sl. No.	Common Name	Insecticide Group
1.	Chlorantraniliprole18.5 SC	Anthranilicdiamide
2.	Cyantraniliprole10.26 OD	Anthranilicdiamide
3.	Emamectin benzoate 5 SG	Semisyntheticanalogue of abamectin
4.	Spinosad 45 SC	Actinomycetesgroup
5.	Novaluron 10 EC	Acylureacompounds
6.	Fenvalerate 20 EC	Pyrethroid
7.	Dichlorvos 76 EC	Organophosphate

2.3 Bio-assay

The "leaf dip" bioassay method was used in the present investigation for determination of median lethal concentrations (LC_{50}values). Bioassays were carried out for insecticides *viz.,* chlorantraniliprole, spinosad, emamectin benzoate, cyantraniliprole, fenvalerate, novaluron and dichlorovos. Bracketing was done for each insecticide to fix appropriate range of doses or concentration for different levels of mortality ranging from 10 per cent to 90 per cent.

For each insecticide, bioassay was carried out with minimum six concentrations. For each concentration three replications were maintained with thirty larvae per replication. Uniform size, fresh and healthy mustard leaf discs were dipped in diluted concentration of an insecticide. The excess insecticide fluid on leaf discs was allowed to drip off and then discs were air dried under shade using filter paper. The treated leaf discs were placed in Petri-dishes (10 × 1.5 cm). Thirty fresh third instar larvae were released to each plate and three replications were maintained. The observations on mortality of larvae were recorded at 24 h post treatment intervals. The mortality in the control was corrected following Abbott's formula [1]. The obtained data in bioassay was subjected to probit analysis [10] following SPSS ver.16 statistical software.

Resistance levels in DBM populations collected from different cabbage growing regions was determined by comparing with LC_{50}value for a given insecticides.

3. Results

3.1 The probit analysis of concentration-mortality responses of the resistance (field) population of *P. xylostella* to selected insecticides

Seven insecticides were selected to test their toxicity against third instar larvae of *P. xylostella* of three different regions of Karnataka i.e., Bengaluru, Kolar and Chikkballapura districts. The data on mortality of larvae was recorded at 24 h post treatment intervals, however, the data at 72 hours post treatment was used for estimation median lethal concentration (LC_{50}) values. The mortality range of larvae was sufficient enough to estimate median lethal concentrations for these selected insecticides at 72 h post treatment. The Chi- square analysis for the tested insecticides was non-significant (df=4), which indicates the homogeneity in the test insect population and the response of the population followed the concentration fixed in the experiment. The regression equations obtained from probit analysis of seven insecticides are presented in the table. The equations are helpful for calculating the LC_{50} value for the varied concentrations of the respective insecticide. The regression equation shows the different toxicity levels among insecticides. The more gradient of linear graph, means more toxic insecticide. The less gradient of linear graph the insecticide is less toxic due to the big change in dose (X-axis) small number of insect killed are changed in Y-axis.

3.1.1 The probit analysis of concentration-mortality response of *P. xylostella* of the resistance (field) population of Bengaluru to the selected insecticides

Among insecticides tested, the insecticide, emamectin benzoate 5 SG was found to record the LC_{50} of 3.130 µg a.i. ml^{-1}, with fuducial limits ranging from 1.219 to 5.286µg a.i. ml^{-1}. The toxicity (LC50) of other six insecticides are 4.220 µg a.i. ml-1 (spinosad 45 SC), 4.435 µg a.i. µg a.i. ml^{-1} (cyantraniliprole 10.26 OD), 6.705 µg a.i. ml^{-1} (chlorantraniliprole 18.5 SC), 8.910 µg a.i. ml^{-1} (novaluron 10 EC), 13.651 µg a.i. ml^{-1} (fenvalerate 20 EC) and 15.630 µg a.i. ml^{-1} (dichlorvos 76 EC) (Table 2; Fig.1).

The lower LC50 value, the more toxic the chemical is because only a small amount of active ingredient can give higher percentage of the insect mortality. Thus, emamectin benzoate 5 SG is highly toxic to larvae with lower LC_{50} value than rest of the other six chemicals.

The probit regression lines of concentration-mortality response of insecticides were found varied between the insecticides. The regression equation of emamectin benzoate 5 SSG showed the more gradient in their slopes and more toxic to *P. xylostella*. Thus, the result from the probit analysis showed, the emamectin benzoate 5 SG was the most effective on the mortality of larvae for *P. xylostella* L. followed by spinosad 45 SC and lastly insecticide dichlorvos. The sequence is emamectin benzoate 5 SG> spinosad 45 SC> cyantraniliprole 10.26 OD> chlorantraniliprole 18.5 SC> novaluron 10 EC> fenvalerate 20 EC> dichlorvos 76 EC.

3.1.2 The probit analysis of concentration -mortality response of *P. xylostella* of the of the resistance (field) population of Kolar to selected insecticides

Among insecticides tested, the insecticide, cyantraniliprole 10.26 OD was found to record the LC_{50} of 4.489 µg a.i. ml^{-1}, with fuducial limits ranging from 3.614 to 5.431 µg a.i. ml^{-1}. The toxicity (LC_{50}) of other six insecticides are 5.782 µg a.i. ml^{-1} (Spinosad 45 SC), 5.863 µg a.i. ml^{-1}(emamectin benzoate 5 SG), 9.614 µg a.i. ml^{-1} (novaluron 10 EC), 13.871 µg a.i. ml^{-1} (fenvalerate 20 EC), 16.042 µg a.i. ml^{-1} (chlorantraniliprole 18.5 SC) and 45.162 µg a.i. ml^{-1}(dichlorvos 76 EC). (Table 3; Fig. 2).

The lower LC_{50} value, the more toxic the chemical is because only a small amount of active ingredient can give higher percentage of the insect mortality. Thus, cyantraniliprole 10.26 OD is highly toxic to larvae with lower LC_{50} value than rest of the other six chemicals.

The probit regression lines of concentration-mortality response of insecticides were found varied between the insecticides. The regression equation of cyantraniliprole 10.26 OD showed the more gradient in their slopes and more toxic to *P. xylostella*. Thus, the result from the probit analysis showed, the cyantraniliprole 10.26 OD was the most effective on the mortality of larvae for *P. xylostella* L. followedby cyantraniliprole 10.26 OD and lastly insecticide dichlorvos 76 EC. The sequence is cyantraniliprole 18.5 SC> spinosad 45 SC> emamectin benzoate 5 SG > novaluron 10 EC > fenvalerate 20 EC> chlorontraniliprole 18.5 SC> dichlorvos 76 EC.

3.1.3 The probit analysis of concentration-mortality response of *P. xylostella* of the of the resistance (field) population of Chikkaballapur to selected insecticides

Among insecticides tested, the insecticide, spinosad 45 SC was found to record the LC_{50} of 2.484 µg a.i. ml^{-1}, with fuducial limits ranging from 30.783 to 4.321µg a.i. ml^{-1}. The toxicity (LC_{50}) of other six insecticides are 3.427 µg a.i. ml^{-1} (emamectin benzoate 5 SG), 4.489µg a.i. ml^{-1}(cyantraniliprole 10.26 OD), 6.031µg a.i. ml^{-1}(novaluron 10 EC), 6.244 µg a.i. ml^{-1} (fenvalerate 20 EC), 6.446 µg a.i. ml^{-1} (chlorantraniliprole 18.5 SC) and 22.519 µg a.i. ml^{-1}(dichlorvos 76 EC). (Table 4; Fig. 3).

The lower LC_{50} value, the more toxic the chemical is because only a small amount of active ingredient can give higher percentage of the insect mortality. Thus, spinosad is highly toxic to larvae with lower LC_{50} value than rest of the other six chemicals.

The probit regression lines of concentration-mortality response of insecticides were found varied between the insecticides. The regression equation of spinosad 45 SC

showed the more gradient in their slopes and more toxic to *P. xylostella*. Thus, the result from the probit analysis shows the spinosad was the most effective on the mortality of larvae for *P. xylostella* L. followed by emamectin benzoate 5 SG and lastly insecticide dichlorvos 76 EC. The sequence is spinosad 45 SC > emamectin benzoate 5 SG> cyantraniliprole 10.26 OD> novaluron 10 EC> fenvalerate 20 EC> chlorantraniliprole 18.5 SC> dichlorvos 76 EC.

Table 2: The probit analysis of concentration -mortality responses of the Bengaluru population of *P. xylostella*field strain at 72 h post treatment

Insecticides	χ^2 (df=4)	y=a+bx	LC_{50} (µga.i. ml^{-1})	Fiducial limit (95%) (µga.i. ml^{-1})	LC_{99} (µga.i. ml^{-1})	*Resistanceratio (RR)
Chlorantraniliprole 18.5 SC	9.10	-1.27+1.54x	6.70	3.83- 9.82	215.03	2.14
Spinosad 45 SC	4.04	-0.72+1.15x	4.22	3.22- 5.29	438.78	1.34
Emamectin benzoate 5 SG	14.05	-0.66+1.34x	3.13	1.21-5.28	166.76	1.00
Cyantraniliprole 10.26 OD	5.23	-0.82+1.27x	4.43	3.48- 5.45	301.42	1.41
Dichlorvos 76 EC	4.43	-1.05+0.88x	15.63	9.42-22.19	6770.17	4.99
Fenvalerate 20 EC	6.43	-1.05+0.92x	13.65	9.31- 18.25	4473.22	4.36
Novaluron 10 EC	6.62	-1.31+1.37x	8.91	6.69- 11.16	433.20	2.84

*Resistance ratio was calculated using lowest LC_{50} value among the populations

Table 3: The probit analysis of concentration -mortality responses of the Kolar population of *P. xylostella*field strain at 72 h post treatment

Insecticides	χ^2 (df=4)	y=a+bx	LC_{50} (µga.i. ml^{-1})	Fiducial limit (95%) (µga.i. ml^{-1})	LC_{99} (µga.i. ml^{-1})	*Resistanceratio (RR)
Chlorantraniliprole 18.5 SC	3.97	-1.59+1.32x	16.04	13.21-19.40	914.93	3.57
Spinosad 45 SC	6.70	-0.91+1.20x	5.78	4.59- 7.11	497.15	1.28
Emamectin benzoate 5 SG	15.89	-0.91+1.19x	5.86	1.47-10.91	528.90	1.30
Cyantraniliprole 10.26 OD	4.64	-0.91+1.39x	4.48	3.61- 5.43	208.70	1.00
Dichlorvos 76EC	4.49	-1.18+0.79x	31.82	21.33-43.48	28044.64	7.08
Fenvalerate 20 EC	5.58	-1.25+1.09x	13.87	10.12-17.81	1830.96	3.08
Novaluron 10 EC	5.23	-1.43+1.46x	9.61	7.42- 11.84	374.57	2.14

*Resistance ratio was calculated using lowest LC_{50} value among the populations

Table 4: The probit analysis of concentration -mortality responses of the Chikkaballapur population of *P. xylostella*field strain at 72 h post treatment

Insecticides	χ^2 (df=4)	y=a+bx	LC_{50} (µga.i. ml^{-1})	Fiducial limit (95%) (µga.i. ml^{-1})	LC_{99} (µga.i. ml-1)	*Resistanceratio (RR)
Chlorantraniliprole 18.5 SC	11.12	-0.84+1.04x	6.44	2.06- 11.52	1088.78	2.59
Spinosad 45 SC	13.87	-0.52+1.33x	2.48	0.78- 4.32	137.64	1.00
Emamectin benzoate 5 SG	7.56	-0.73+1.37x	3.42	1.40-5.52	170.62	1.37
Cyantraniliprole 10.26 OD	4.64	-0.91+1.39x	4.48	3.61- 5.43	208.70	1.80
Dichlorvos 76 EC	6.80	-1.55+1.15x	22.51	11.49-34.61	2378.04	9.06
Fenvalerate 20 EC	2.69	-0.59+ 0.75x	6.24	2.96- 9.88	7916.65	2.51
Novaluron 10 EC	8.68	-0.96+1.23x	6.03	1.97- 10.39	457.20	2.42

*Resistance ratio was calculated using lowest LC_{50} value among the populations

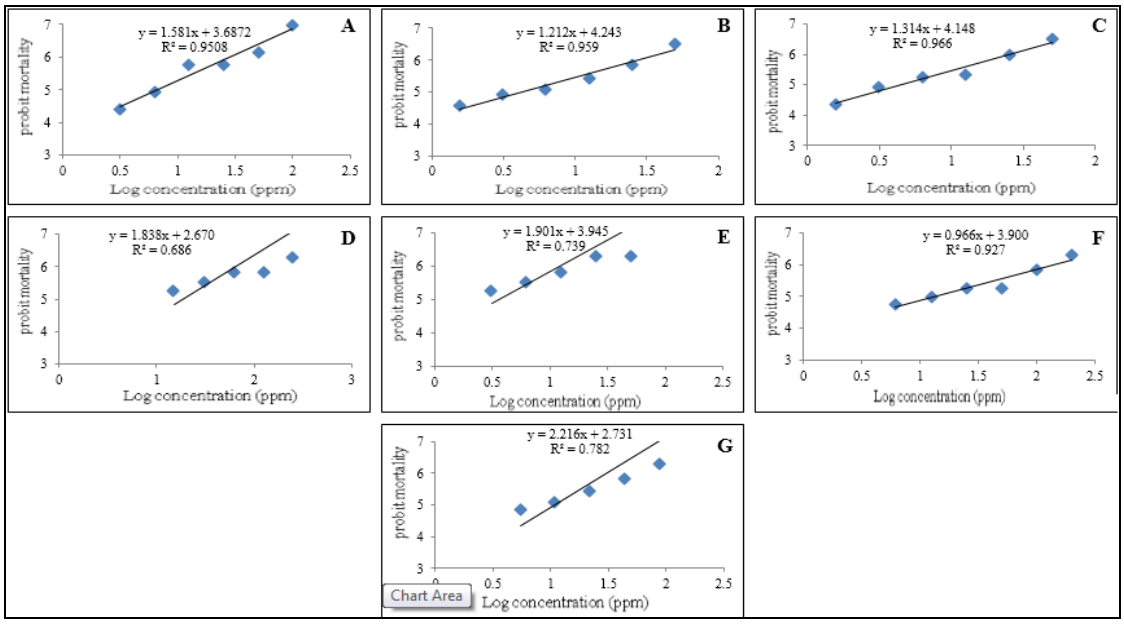

Fig 1: Probit regression lines showing dosage-mortality response of *P. xylostella* at 72hrs of interval for field population of Bengaluru to (A) chlorantraniliprole 18.5 SC, (B) spinosad 45 SC, (C) cyantraniliprole 10.26 OD, (D) dichlorvos 76 EC, (E) emamectin brnzoate 5 SG, (F)fenvalerate 20 EC and (G) novaluron 10 EC

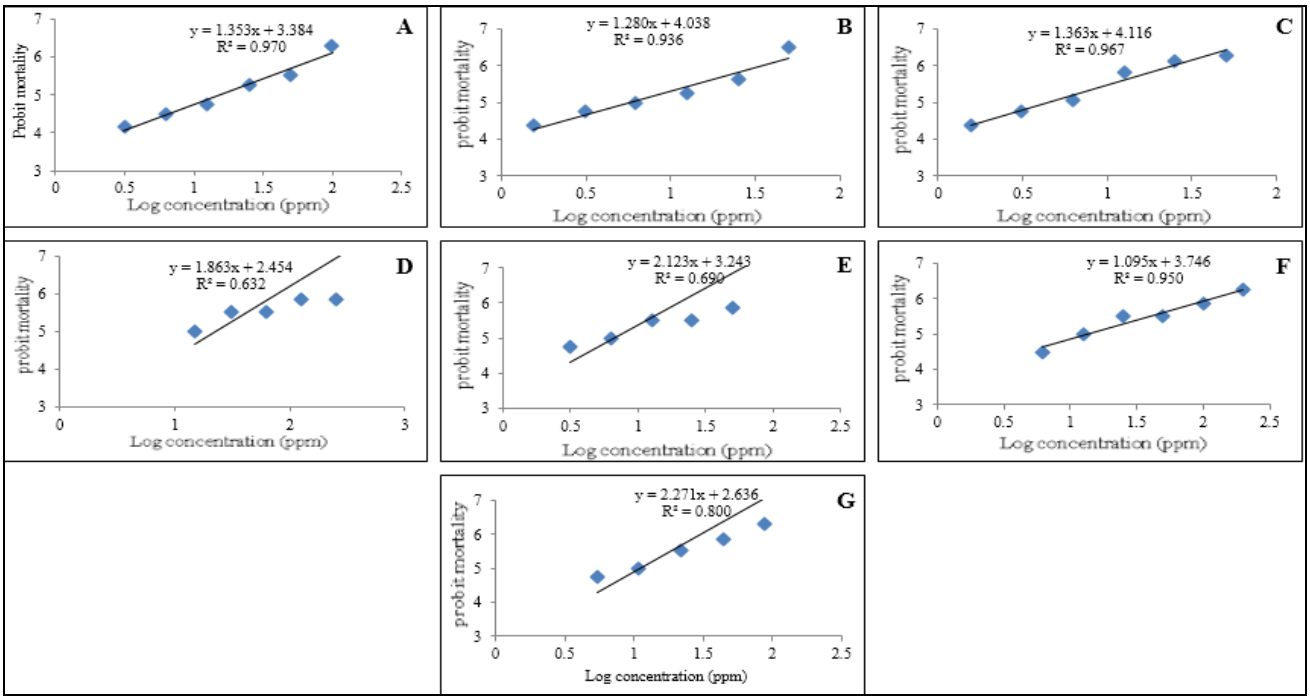

Fig 2: Probit regression lines showing dosage-mortality response of *P. xylostella* at 72hrs of interval for field population of Kolar to(A) chlorantraniliprole 18.5 SC, (B) spinosad 45 SC, (C) cyantraniliprole 10.26 OD, (D) dichlorvos 76 EC, (E) emamectin brnzoate 5 SG, (F) fenvalerate 20 EC and (G) novaluron 10 EC

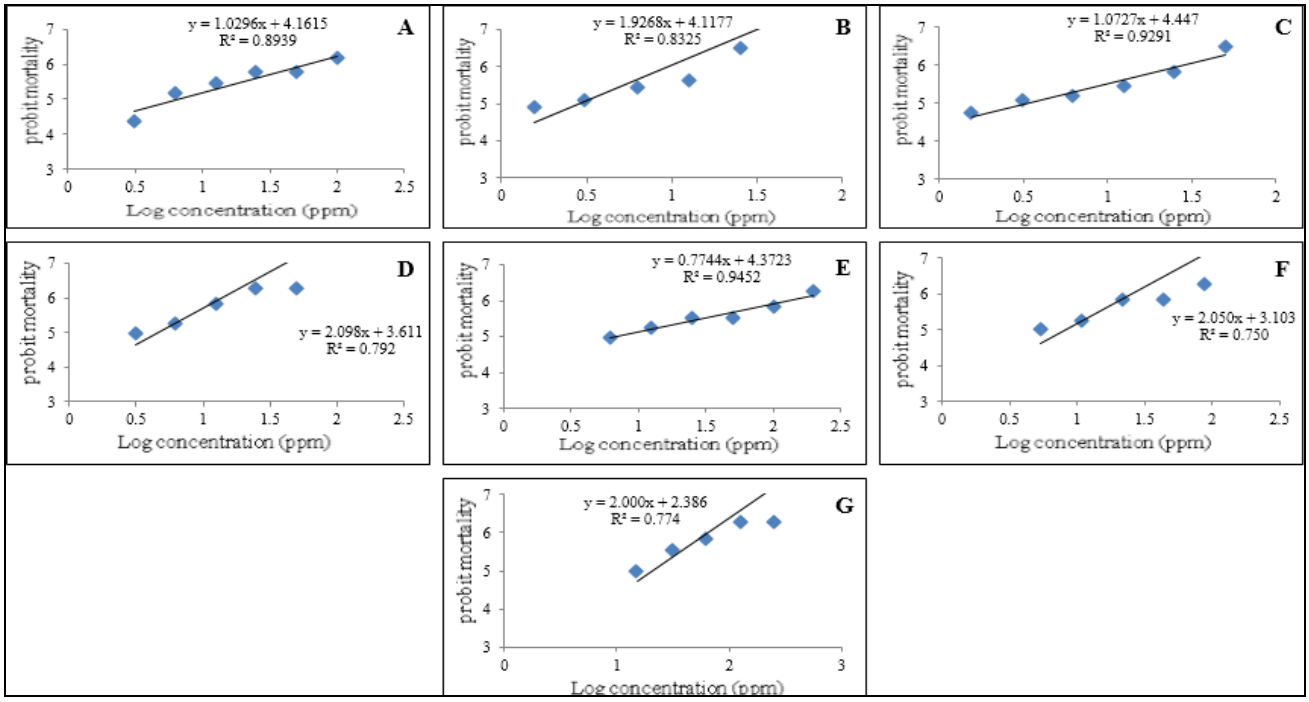

Fig 3: Probit regression lines showing dosage-mortality response of *P. xylostella* at 72hrs of interval for field population of Chikkaballapura to (A) chlorantraniliprole 18.5 SC, (B) spinosad 45 SC, (C) cyantraniliprole 10.26 OD, (D) emamectin brnzoate 5 SG, (E) fenvalerate 20 EC, (F) dichlorvos 76 EC and (G) novaluron 10 EC

4. Discussion

Akin to the reported cases of resistance to insecticides in various parts of the country, study was undertaken to assess current status of resistance and relative susceptibility of different populations of DBM to newer insecticide molecules in Karnataka. A total of three field populations were collected from different locations of Karnataka (Bangalore rural, Kolar, and Chikkaballapura) and were investigated to assess the relative susceptibility levels of these populations and extent of resistance to newer insecticides. The locations represented major cabbage growing areas of South Karnataka with varied levels of pesticide applications in cabbage system.

Development of resistance is mainly influenced by frequency of application of insecticides, which imparts selection pressure. During the course of investigation it was observed that the frequency of pesticide application by the cabbage growers of Bengaluru, Kolar and Chikkaballapura locations were more. In addition to higher insecticide applications,

these areas are also known for continuous and year round cultivation of cole crops. Consequently, the populations collected from Bengaluru, Kolar and Chikkaballapura were expected to show higher levels of resistance to insecticides. During the course of investigation it was found that the different populations showed considerable variations with regard to susceptibility to selected insecticides. The present study clearly indicated that the populations from Kolar and Bengaluru exhibited greater levels of resistance to most of the insecticides tested compared to Chikkaballapura population. This variation in susceptibility levels across the populations might be due to several factors such as difference in the insecticides usage pattern, cropping intensity and even inherent genetic variation existed in the parent populations. And also depends on pesticide usage pattern. The DBM populations from Bengaluru, Kolar and Chikkaballapura locations showed lowest susceptibility levels where incidentally the pesticide application was maximum on cabbage crop.

The determined median LC_{50} of chlorantraniliprole against susceptible strain of *P. xylostella* larvae for F_1 population was 20.06 ppm and LC_{95} was 835.68 ppm, whereas onF_{25} population the LC_{50} for was 0.91 ppm and LC_{95} was 23.11 ppm. The susceptibility increased up to F_{22} population without exposure to insecticides. The susceptibility index (SI) after F_{25} generation over F_1 generation was 22.02 and 36.15 based on LC_{50} and LC_{95}, respectively. Chlorantraniliprole 18.5SC at 23 ppm recorded low level of resistance with Udaghamandalam (53.83 %), Coimbatore (58.83 %) and Oddanchatram (64.00 %) populations compared to other insecticides [18].

Irrespective of the geographical locations, the DBM *P. xylostella* population exhibited higher levels of resistance to the dichlorvos 76 EC followed by fenvalerate 20EC, novaluron 10 EC and chlorantraniliprole 18.5 SC. Among these insecticides, highest resistance ratio was recorded for dichlorvos 76 EC (7.08 to 9.06 folds) followed by fenvalerate 20 EC (2.51 to 4.36). The field populations showed moderate levels of resistance to spinosad 45 SC, very low to moderate levels of resistance to emamectin benzoate 5 SG and cyantraniliprole 10.26 OD.

The level of resistance ratio of chlorantraniliprole 18.5 SC was ranged from 2.14 to 3.57 folds. The susceptibility of 16 field populations and seven laboratory maintained strains of *P. xylostella* to chlorantraniliprole 18.5 SC were determined through leaf dip bioassay. Similar study was conducted for, 16 field populations and median lethal concentrations were varied from 0.221 to 1.104 mg/l. However, wider ranges of variation in LC50 values (10-fold) were observed among seven laboratory strains. Low level tolerance (6 to 10 fold) was detected in two laboratory-selected strains and three field-collected populations when compared with the susceptible strain [44].

The field populations showed moderate levels of resistance to spinosad 45 SC, the resistance ratio was varied from 1.00 to 1.34 folds and for emamectin benzoate 5 SG from 1.00 to 1.37 folds for three cabbage growing regions of Karnataka. [45] reported the results, which are closely related to present investigation *viz.,* resistance to semi-synthetic toxin, emamectin benzoate 5 SG (150 to 300 fold) was observed in Taiwan and moderate levels of resistance against spinosad were observed with the ratio 6.5 to 19.4 folds in central china population of DBM.

The level of resistance ratio in diamondback moth against cyantaniliprole 10.26 OD ranges from 1.00 to 1.80 folds. [45] Reported the development of resistance and concluded that moderate to low resistance levels were found with the ratio 3.1-23.1 fold among five field population of DBM collected from the central China.

The levels of resistance in diamondback moth against fenvalerate 20 EC and novaluron 10 EC ranged from 2.51 to 4.36 folds and 2.14 to 2.84 folds for three cabbage growing regions of Karnataka reapectively. The resistance to fenvalerate in Malaysia (27848 fold) [20]. Diamondback moth showed low level of resistance to novaluron in Taiwan [17].

The field populations showed high levels of resistance to dichlorvos 76 EC with minimum of 4.99 to maximum of 9.065 folds. [4] Reported in 15 to 172 folds of resistance in population of Philippines and in India, 5-15 fold resistance was reported by various workers [17, 45, 38].

5. Conclusion

Because of widespread resistance in diamondback moth, there is an urgency of insecticides with a different mode of action and that do not select for cross resistance to conventional insecticides. To preserve the efficacy of such insecticides as long as possible, all causal factors of resistance occurring locally should be investigated. This knowledge could be applied to prevent severe damage caused by the resistant diamondback moth in the future. Introduction of IRM strategies to farmers is necessary to mitigate the resistance of the diamondback moth to insecticides. Monitoring insecticide resistance status is important for forecasting the failure of insecticide control. The information obtained can be used for planning insecticide resistance management strategies for the diamondback moth.

The Diamondback moth (DBM), *Plutella xylostella* is one such serious insect pests of crucifers all over across the globe gifted with battery of resistance genes. The pest has drawn a lot of attention due to its persistence and cause severe damage in very acute proportions on cabbage and cauliflower. The DBM has inherent ability to develop resistance rapidly to the conventional and also to newer insecticides with unique mode of action and target site within a short span of its exposure. However, the study on rate of evolution of resistance in DBM or can susceptibility be regained in the population are very meager. In this context the present investigation was undertake and obtained results are summarized in brief in this chapter.

The susceptible population of *P. xylostella* was established in the laboratory without exposing to any insecticides for more than 15 generations and the population was used in the bioassay to assess the susceptibility to different insecticides. The toxicity was measured in terms of median lethal concentration (LC_{50}) which is an index of toxicity.

The LC_{50} values were varied across insecticides for single population and also across the populations of geographical locations. The LC_{50}value of Bengaluru population recorded was highest for fenvalerate 20 EC (11.902 µg a.i. ml^{-1}) and lowest for emamectin benzoate 5 SG (2.05 µg a.i. $ml^{-1)}$. Similarly, it is highest for dichlorvos 76 EC and noluron 10 EC (9.61 µg a.i. ml^{-1}and5.91 µg a.i. ml^{-1}) and lowest for spinosad 45 SC (3.08 µg a.i. ml^{-1}) was found to be highly toxic to the third instar larvae of *P. xylostella.* The dichlorvos 76 ECregistered highest LC_{50} value of 13.932 µg a.i. ml^{-1} and emamectin benzoate 5 SG recorded lowest LC_{50} value of 1.538 µg a.i. ml^{-1}. The regression lines of log concentration-mortality response of the DBM were varied across seven insecticides and across geographical locations *viz.,* Bengaluru, Kolar and Chikkaballapura.

The result from the probit analysis showed that, the emamectin benzoate was the most effective on the mortality of larvae for *P. xylostella* L. followed by spinosad 45 SC and lastly the insecticide dichlorvos 76 EC. The order of sequence based of degree of toxicity is emamectin benzoate 5 SG> spinosad 45 SC> cyantraniliprole 10.26 OD> chlorantraniliprole 18.5 SC> novaluron 10 EC> fenvalerate 20 EC > dichlorvos 76 EC for Bengaluru population.

The cyantraniliprole 10.26 OD was the most effective on the mortality of larvae for *P. xylostella* L. followed by cyantraniliprole 10.26 OD and lastly insecticide dichlorvos 76 EC. The order of sequence based of degree of toxicity is cyantraniliprole 10.26 OD> spinosad 45 SC> emamectin benzoate 5 SG > novaluron 10 EC > fenvalerate 20 EC > chlorantraniliprole 18.5 SC> dichlorvos 76 EC for Kolar population.

The spinosad 45 SC was the most effective on the mortality of larvae for *P. xylostella* L. followed by emamectin benzoate 5 SG and lastly insecticide dichlorvos 76 EC. The order of sequence based of degree of toxicity is spinosad 45 SC> emamectin benzoate 5 SG> cyantraniliprole 10.26 OD> novaluron 10 EC>fenvalerate 20 EC > chlorantraniliprole 18.5 SC> dichlorvos 76 EC for Chikkaballapura.

The resistance ratio was worked out by dividing LC_{50} values of field/ resistance population by LC_{50} values of laboratory (susceptible) populations of *Plutella xylostella*. The susceptible population reared under laboratory has completed over 15 generations without exposing to any insecticides.

The resistance ratio calculated was found to varied across insecticides for *P. xylostella* population of Bengaluru, Kolar and Chikkaballapura. The high resistance ratio was observed for chlorantraniliprole 18.5 SC(2.84 folds) and least resistance ratio was reported to dichlorvos 76 EC (1.12 folds) for DBM population of Bengaluru.

The highest resistance ratio was observed for chlorantraniliprole 18.5 SC with resistance ratio of 4.208 folds and lowest to fenvalarate 20 EC (1.146 folds) for population sampled from Kolar. The mean resistance ratios for Bengaluru, Kolar and Chikkaballapura were 1.789±0.636, 1.93±1.09 and 1.499±0.493 folds respectively. In brief, this clearly indicated that the rate of evolution of resistance in *P. xylostella* was varied across insecticides for single population and also across geographical locations.

6. Reference

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