The Bioscan 11(3): 1609-1613, 2016 (Supplement on Agronomy)
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.com

EFFICACY AND COMPATIBILITY OF NEWER INSECTICIDES AND COMMON FUNGICIDES AGAINST DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA (L.)* (PLUTELLIDAE; LEPIDOPTERA)

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KEYWORDS
Compatibility
diamondback moth
antagonism
synergism.

Received on :
07.08.2015

Accepted on :
20.07.2016

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ABSTRACT

Studies were conducted in the laboratory to evaluate the compatibility of insecticides *viz* ., Emamectin benzoate SG, Flubendiamide 480 SC, Chlorantraniliprole 18.5 SC, Spinosad 45 SC, Diafenthiuron 50 WP, Novaluron 10 EC, Indoxacarb 15.8 EC, Chlorfenapyr 10 SC and Fenvalrate 20 EC in combination with two fungicides Mancozeb 75 WP and Difenconazole 25 EC against cabbage diamondback moth, *Plutella xylostella*. Among the nine insecticides evaluated, based on LC_{50} values, Chloranraniliprole was the most toxic (24.22 ppm) whereas Fenvalrate was least toxic (148.12 ppm) insecticide against *P. xylostella*. The fungicides alone, difenconazole and mancozeb at 200 ppm each caused highest diamond back moth larval mortality of 14.88 and 11.11 per cent, respectively. Among the tank mixed combinations, chlorantraniliprole was highly compatible with difenconazole and mancozeb by recording lowest LC_{50} values of 17.38 and 21.60 ppm, respectively and recorded highest relative toxicity of 13.95 and 11.12 times more toxic than fenvalrate + mancozeb aginst *P. xylostella* .

INTRODUCTION

Cole crops are important group of winter vegetables consumed all over the world and grown in temperate and tropical regions of the world. Among them cabbage and cauliflower are economically important vegetables in India. Caterpillars of the 'diamondback moth' (DBM), *Plutella xylostella* (Linnaeus), are the dominant and most damaging pest of cabbage and cauliflower vegetable crops in India. In India that losses of cabbage and cauliflower due to diamondback to the tune of 90 per cent when no control measures taken (Sujith Sandur., 2004)

In recent years, the production of crucifers has been seriously affected by steady increase in insect pest infestation, especially the diamondback moth and the leaf spot disease caused by the fungus, *Alternaria brassicae* (Srinivasan and Krishnamoorthy, 1992). Among the insect pests, diamondback moth, *P. xylostella* has become a severe pest on cabbage because of its high reproductive potential, short life cycle and ability to develop resistance to insecticides and intensive cultivation of crucifers involving more number of crops in sequence during a year.

The number of chemicals involved in plant protection are too many and the information on compatibility of insecticides with the fungicides is scattered. With the present problem of labour scarcity, the farmers have started mixing insecticides and fungicides without due consideration of their compatibility. However, the mixing of pesticides may result in incompatibility not only in terms of physical nature but also may alter efficacy. This basic knowledge is useful for growers whether to use the insecticides and fungicides alone or in combination. Common people find difficulty in ascertaining the compatibility of agro-chemicals. Hence, based on experience Gray (1914) prepared a chart showing compatibility of some insecticides and fungicides. Later several charts were developed or updated by Frear (1948), Gruzdyed *et al.*(1983), Sreedhar (2006), Siddartha (2013) for the chemicals in use with the additional information regarding incompatibility under certain crops, season, aging of mixtures and many other factors. Scanning of literature revealed that compatibility of newer insecticides with fungicides is scanty. Hence, an attempt has been made to know the compatibility of fungicides with insecticides and their influence on the bioefficacy of insecticides against *Plutella xylostella* (L.) in cabbage ecosystem.

MATERIALS AND METHODS

Laboratory culture of *Plutella xylostella*

Laboratory experiments were carried out at Department of Entomology, College of Agriculture, GKVK, Bangalore. All the bioassay and bio-efficacy experiments were carried out under laboratory conditions on the F_1 progeny reared from field collected *P. xylostella* population. The insect was reared on mustard seedlings by employing the method of Liu and Sun (1984) with suitable modifications. The later instar larvae and pupae were collected from infested cabbage fields around Bangalore and were reared to pupal stage on mustard seedlings raised in plastic petridishes (10 x 1.5 cm). Pupae were placed in the oviposition cage (35 x l0x 35 cm) for adult emergence. One day-old moths were provided with three to four days old mustard seedlings to facilitate oviposition. Ten per cent sugar solution on cotton wads was given to moths during oviposition as adult food. After 24 hours, seedlings were transferred to rearing trays placed on wooden stands. Fresh seedlings were provided every day for oviposition. The insects were reared on mustard seedlings, methods used to rear larvae and adults were essentially as described by Liu and Sun (1984).

Insecticidal action of fungicides against *Plutella xylostella*

A study was carried out to know the insecticidal property of selected fungicides. The third instar larvae were exposed to the systemic and a contact fungicides *viz*., difenconazole 25EC and mancozeb 75 WP respectively each at different concentration *viz*., 10, 25, 50, 75, 100 and 200 ppm of the formulation.

Leaf dip method of bioassay as described by Tabashnik *et al.* (1987) was adopted in the present studies. Fresh, uniform sized cabbage leaves were dipped in aqueous fungicides dilution containing 0.1 per cent liquid soap for ten seconds and then air dried under shade for about an hour. The petiole cut end of treated leaves were provided with wet cotton wads and wrapped with aluminum foil to retain the succulence. The treated cabbage leaves were placed in petridishes. For control, leaves were dipped in water with 0.1 per cent soap. Fifteen early third instar larvae of the test insect were released on treated leaves in each petridish and each treatment was replicated thrice. The treated larvae were maintained at $25 \pm 1°C$ in BOD incubator and the mortality counts were recorded at 24 and 48 hours after the treatment.

Effect of fungicides on the bio-efficacy of insecticides against *Plutella xylostella*

The toxicity of individual insecticides, fungicides as well as the mixtures of insecticide and fungicide on the test insect was assessed in the laboratory based on the median lethal concentration by employing 'leaf-dip' method of bioassay. The median lethal concentrations were determined for insecticides alone and for insecticide-fungicide mixtures. The insecticides and fungicides used in this study were emamectin benzoate 5 SG, flubendiamide 480 SC, chlorantranilliprole 18.5 SC, spinosad 45 SC, diafenthiuron 50 WP, novaluron 10 EC, indoxacarb 15.8 EC, chlorfenapyr 10 SC, fenvalrate 20 EC in combination with two fungicides difenconazole 25 EC and mancozeb 75 WP, respectively.

Bioassay

For every insecticide and fungicide mixture and individual insecticide, six concentrations of the test products in geometric progression were used for each bioassay. For every dose, three batches of 15 third instar larvae were maintained and the mortality counts were recorded at 24 and 48 hours after the treatment.

Observed mortality data were converted to percentage and corrected for control mortality according to Abbott (1925). The corrected mortality values were subjected to probit analysis (Finney, 1971) for obtaining regression equations for dosage mortality response and to determine the LC_{50} value.

Determination of co-toxicity co-efficient (CC)

Co-toxicity co-efficients were worked out to ascertain the level of potentiation (synergism) or antagonism of toxicity of insecticide and fungicide mixtures using the formula suggested by Sarup *et al.* (1980).

$$CC = \frac{LC_{50} \text{ of insecticide} + \text{fungicide combination}}{LC_{50} \text{ of insecticide} + \text{fungicide combitation}}$$

Determination of relative toxicity:

The relative toxicity of the insecticide and fungicide combinations and individual insecticide to the test insect was calculated taking the LC_{50} of the least toxic chemical (highest LC_{50} value) as unity.

$$\text{Relative toxity} = \frac{\text{LC of the least toxic individual insecticide or combination with fungicide}}{LC_{50} \text{ of the other individual insectic or combination with fungicide}}$$

RESULTS AND DISCUSSION

Insecticidal activity of selected fungicides against *Plutella xylostella*

The results revealed that among two fungicides, difenconazole at 200 ppm concentration caused highest mortality of 18.51 per cent at 48 h of treatment. While, mancozeb at the same concentration and duration recorded lower toxicity (12.59 per cent mortality). However, mancozeb was almost non toxic at lower dosages (Table 1). Scanning of literature reveals that the information on insecticidal activity of fungicides against *P.*

Table 1 : Insecticidal activity of selected fungicides against third instar larvae of *Plutella xylostella* under laboratory condition

	Concentration (ppm) and Larval mortality (%) for													
Fungicides	24hr						Mean	48hr						Mean
	10	25	50	75	100	200		10	25	50	75	100	200	
Difenconazole	0	5.2	7.4	8.31	9.62	14.88	7.56	2.22	6.06	8.14	9.04	11.11	18.51	9.16
(25 EC)	(0.00)^{a}	(9.33)^{c}	(15.79)^{d}	(16.25)^{e}	(18.05)^{g}	(22.71)^{i}	-13.68	(8.53)^{b}	(10.22)^{c}	(16.54)^{d}	(17.89)^{f}	(19.46)^{h}	(25.48)^{j}	-16.35
Mancozeb	0	0	0	2.75	4.4	11.11	3.04	0	0	0	3.21	5.18	12.59	5.83
(75 WP)	(0.00)^{a}	(0.00)^{a}	(0.00)^{a}	(6.05)^{b}	(12.11)^{d}	(19.46)^{f}	-6.27	(0.00)^{a}	(0.00)^{a}	(0.00)^{a}	(8.04)^{c}	(13.05)^{e}	(20.79)^{g}	-6.98
Mean	0	2.6	3.7	5.53	7.01	12.99	5.3	1.11	3.01	4.07	13.12	8.14	15.55	7.5
	0	-4.66	-7.89	-11.15	-15.08	-21.08	-9.97	-4.26	-5.11	-8.27	-12.96	-16.25	-23.13	-11.66
	Fungicides		Concentration		-	-	-	Fungicides		Concentration		-	-	-
F test	*		*		-	-	-	*		*		-	-	-
S.Em±	2.11		4.8		-	-	-	2.59		3.95		-	-	-
CD @ 5%	6.58		15		-	-	-	7.25		12.96		-	-	-

Note: Figures in parthenses are arc sine " per cent transformed values; Mean denoted by the same letter on each column are not significantly different by (p = 0.05) DMRT

Table 2: The probit analysis co-toxicity co-efficient and relative toxicity of *Plutella xylostella* to selected insecticides alone and in combination with fungicides Difenconazole and Mancozeb

Sl. No	Insecticides	X^2	Regression equation Y =	LC_{50} (ppm)	Fiducial limits at 95 % (ppm)	CC	Relative toxicity
1	Chlorantraniliprole (18.5 SC)	1.2	-3.12 + 2.25 x	24.22	19.64 - 28.83	—	6.11
2	Spinosad (45 SC)	10.13	-4.21 + 2.89 x	28.78	19.25 - 40.14	—	5.14
3	Emamectin benzoate (5% SG)	3.84	-3.17 + 2.10 x	32.13	26.41 - 38.48	—	4.6
4	Chlorfenapyr (10 SC)	1.42	-2.75 + 1.62 x	49.82	38.61 - 62.96	—	2.97
5	Flubendiamide (480 SC)	10.79	-3.21 + 1.90 x	56.78	32.58 - 98.79	—	2.6
6	Novaluron (10 EC)	3.56	-3.89 + 2.09 x	71.53	58.92 - 86.93	—	2.07
7	Indoxacarb (15.8 EC)	5.86	-2.94 + 1.57 x	74.16	56.31 - 94.05	—	1.99
8	Diafenthiuron (50 WP)	2.43	-2.85 + 1.41 x	103.27	77.56 - 135.01	—	1.43
9	Fenvalrate[#] (20 EC)	0.87	-2.68 + 1.23 x	148.12	109.40- 204.47	—	1
10	Chlorantraniliprole (18.5 SC) + Difenconazole (25 EC)	12	-1.62 + 1.31 x	17.38	1.58 - 36.06	1.39	13.95
11	Spinosad (45 SC) + Difenconazole (25 EC)	12.4	-3.15 + 2.21 x	26.43	13.55 - 42.60	1.08	9.17
12	Emamectin benzoate(5% SG) + Difenconazole (25 EC)	3.53	-2.94 + 2.01 x	29.15	23.63 - 35.14	1.1	8.32
13	Novaluron (10 EC) + Difenconazole (25 EC)	5.49	-2.39 + 1.53 x	36.70	27.29 - 47.11	1.94	6.61
14	Flubendiamide (480 SC) + Difenconazole (25 EC)	12.08	-3.06 + 1.91 x	39.59	19.08 - 67.38	1.43	6.12
15	Diafenthiuron (50 WP) + Difenconazole (25 EC)	3.92	-2.69 + 1.38 x	87.83	64.68 - 115.38	1.17	2.76
16	Chlorfenapyr (10 SC) + Difenconazole (25 EC)	2.44	-2.57 + 1.31 x	90.16	68.11 - 126.14	0.55	2.69
17	Indoxacarb (15.8 EC) + Difenconazole (25 EC)	7.73	-3.23 + 1.65 x	90.50	52.02 - 146.77	0.81	2.68
18	Fenvalrate (20 EC) + Difenconazole (25 EC)	9.11	-2.75 + 1.29 x	134.03	68.17 - 360.32	1.1	1.81
19	Chlorantraniliprole (18.5 SC) + Mancozeb (75 WP)	0.47	-2.80 + 2.09 x	21.60	16.95 - 26.14	1.11	11.22
20	Spinosad (45 SC) + Mancozeb (75 WP)	5.64	-3.47 + 2.36 x	28.57	24.69 - 34.84	1.04	8.49
21	Emamectin benzoate (5% SG) + Mancozeb (75 WP)	3.59	-3.06 + 2.05 x	31.23	25.58 - 37.53	1.02	1.76
22	Flubendiamide (480 SC) + Mancozeb (75 WP)	10.07	-3.08 + 1.87 x	44.19	23.76 - 72.24	1.28	5.49
23	Indoxacarb (15.8 EC) + Mancozeb (75 WP)	4.193	-3.16 + 1.56 x	59.22	43.21 - 80.68	1.25	4.09
24	Chlorfenapyr (10 SC) + Mancozeb (75 WP)	1.38	-2.16 + 1.22 x	59.22	43.21 - 80.68	0.84	4.09
25	Novaluron (10 EC) + Mancozeb (75 WP)	6.3	-3.54 + 1.99 x	59.34	48.30 - 72.45	1.2	4.09
26	Diafenthiuron (50 WP) + Mancozeb (75 WP)	31.3	-2.23+ 1.23 x	64.36	64.68 - 115.38	1.17	3.75
27	Fenvalrate (20 EC) + Mancozeb[*] (75 WP)	1.72	-3.10 + 1.30 x	242.48	180.53 - 349.34	0.61	1

Note: CC-Co-toxicity Co- efficient (LC_{50} of insecticide alone /LC_{50} of insecticide and fungicide combination);[#]Taken LC_{50} of Fenvalrate as unity; [*]Taken LC_{50} of Fenvalrate +;Mancozeb as unity

Table 3: Compatibility of Insecticides with Fungicides

Sl.No.	Pesticides	Difenconazole	Mancozeb
1	Emamectin benzoate	+	+
2	Flubendiamide	+	+
3	Chlorantranilliprole	+	+
4	Spinosad	+	+
5	Diafenthiuron	+	+
6	Novaluron	+	+
7	Indoxacarb	-	+
8	Chlorfenapyr	-	-
9	Fenvalrate	+	-

+ = Compatible;- = Incompatible

xylostella is scanty. So in comparison with other insect pests mancozeb nine kg toxicant per hectare was found to be effective in controlling only nymphs of *Psylla pyricola* on pear (Mcmullan and Jong, 1971), *Phyllocoptruta oleivora* on citrus (Hanna and Abdelhafez, 1977). Kamin *et al.* (2012) reported that *Beauveria bassiana* was found to be superior over control and average net mortality of 70 to 100% was recorded when the DBM larvae treated with *B. bassiana*. Siddartha *et al.* (2013) reported that mancozeb + carbendazim at 1875 ppm caused the highest mortality of diamond back moth (28.91 %).

Influence of fungicides on the bio-efficacy of insecticides

Compatibility of pesticides reveals the behaviour of combination with reference to active component that is, whether it has maintained, reduced or potentiated its pesticidal activity.

The results clearly revealed that in some combinations toxicity was enhanced while in others the toxicity was lowered. Among nine insecticides, lower median lethal concentration (24.22 ppm) was found in chlorantraniliprole and the highest LC_{50} was noticed in fenvalrate (148.11 ppm). These results are in line with the findings of Meena *et al.* (2014) reported that Chlorantraniliprole found highly toxic to *Spodoptera litura* in soyabean ecosystem. Among the combinations with difenconazole, the lowest LC_{50} value (17.38 ppm) was observed in chlorantraniliprole + difenconazole combination. While, higher LC_{50} value was recorded in combinations of indoxacarb + difenconazole and chlorfenapyr + difenconazole of 90.50 and 90.16 ppm, respectively (Table 2). The present study is corroborated with the findings of Sreedhar (2006), who reported that combination of chlorothalonil with seven insecticides, median lethal concentrations of five insecticides were reduced *viz.*, endosulfan, fipronil, indoxacarb, profenophos and spinosad were reduced to 2013.1, 8.7, 2.9, 681.8 and 2.1, ppm respectively. But chlorothalonil acted antagonistically over novaluron and thiodicarb by increasing the LC_{50} values to 9.8 and 80.3 ppm, respectively.Combination product of imidacloprid + ethiprole @ 0.8 g/l + hexaconazole @ 2.0 ml/l has recorded less sheath blight incidence (7.3%) severity (14.4%) and also lesser number of plant-hoppers (Bhuvaneswari and Krishnam Raju, 2013)

Later the extent of loss or gain in toxicity of test insecticides when mixed with fungicides was quantified based on the co-toxicity co-efficient to ascertain the compatibility. The results revealed that some combinations were more toxic and some were less toxic to the test insect compared to insecticides alone with co-toxicity values of more than or less than one. As noticed from the earlier trials inherent insecticidal property possessed by all the fungicides contributed to the larval mortality.Thus additive effect of these fungicides with insecticides accounted for increase in mortality over insecticides alone and the antagonistic effect may be due to in-sensitization of insecticidal target sites, resulted in decrease in the susceptibility of pest species involved. With regard to combining effect of difenconazole with insecticides, highest level of toxicity potentiation was observed in case of novaluron + difenconazole with co-toxicity co efficient (CC) value of 1.94 followed by flubendiamide + difenconazole (1.43) and chlorantranilliprole + difenconazole (1.39), while toxicity slightly enhanced in case of diafenthiuron + difenconazole (1.17), emamectin benzoate + difenconazole (1.10), fenvalrate + difenconazole (1.10) and spinosad + difenconazole (1.08). The combination of indoxacarb + difenconazole and chlorfenapyr + difenconazole exhibited antagonistic action with CC values of 0.55 and 0.81 respectively (Table 2). It is also interesting to note that level of potentiation varies with different insecticides involved in the study and these results is corroborated with the findings of Sreedhar (2006), who reported that enhanced toxicity in endosulfan + chlorothalonil with co-toxicity co-efficient value of 1.32 followed by fipronil + chlorothalonil (1.31) and profenophos + chlorothalonil (1.26). While toxicity slightly enhanced in case of indoxacarb + chlorothalonil (1.17), spinosad + chlorothalonil (1.14). The combination of novaluron + chlorothalonil and thiodicarb + chlorothalonil exhibited antagonistic action with CC values of 0.81 and 0.97 respectively. From the above results it is clear that the combinations in which the co-toxicity co-efficient was more than one or equal to one will be treated as compatible because the insecticidal property was increased or not changed. Hence, excluding indoxacarb and chlorfenapyr all other insecticides are compatible with difenconazole (Table 3).

While in combination with mancozeb the least LC_{50} value was recorded in chlorantranilliprole + mancozeb treatment (21.60 ppm). While, higher LC_{50} value was recorded in combinations of chlorfenapyr + mancozeb (59.22 ppm) and fenvalrate + mancozeb (242.48 ppm). Regarding interaction of mancozeb with insecticides, increased level of toxicity was noticed in by flubendiamide + mancozeb with co-toxicity co efficient value of 1.28, followed by other insecticides indoxacarb (1.25), novaluron (1.20), diafenthiuron (1.17) chlorantranilliprole (1.11), spinosad (1.04), emamectin benzoate (1.02). However, its toxicity was lowered when mixed with chlorfenapyr and fenvalrate with CC values of 0.84 and 0.61 ppm, respectively (Table 2). It is evident from the available literature that mancozeb potentiated the toxicity of some insecticides. Laboratory investigations by Aly (1997) revealed that mancozeb was more compatible with the insecticide karate (Lambda-cyhalothrin) and turadacupral against the adults of *Tribolium confusum*. Similarly, Abbaih (1985) reported synergistic action of mancozeb with monocrotophos against *Drosophila melanogaster*. From the above studies it is clear that excluding chlorfenapyr and fenvalrate all other insecticides are compatible with mancozeb (Table 3).

Relative toxicity of insecticide + fungicide combinations and individual insecticides

Based on the LC_{50} values the relative toxicity of insecticide + fungicide combinations to the field strain of *P. xylostella* was worked out by taking LC_{50} of fenvalrate + mancozeb (242.48 ppm) as unity (Table 2). The combination of chlorantranilliprole + difenconazole and chlorantranilliprole + mancozeb recorded high LC_{50} values with relative toxicity of 13.95 and 11.22 respectively. The other best combinations were spinosad + difenconazole (9.17), spinosad + mancozeb (8.49),emamectin benzoate + difenconazole (8.32), emamectin benzoate + mancozeb (7.76), novaluron + difenconazole (6.61), flubendiamide + difenconazole (6.12) and flubendiamide + mancozeb (5.49). The remaining combinations possessed low relative toxic values (Table 2).

The relative toxicity of individual insecticides to the larvae of *P. xylostella* was also evaluated by taking LC_{50} of fenvalrate as unity. Among the individual compounds chlorantraniliprole (6.11) was the most toxic insecticide followed by spinosad (5.14), emamectin benzoate (4.60), chlorfenapyr (2.97) and flubendiamide (2.60) (Table 2). These results were found to be similar with the findings of Sreedhar (2006), who reported that the combination of spinosad + mancozeb and spinosad + chlorothalonil was highly toxic with relative toxicity values of 1065.38 ppm, for both the combinations. The other best combinations are indoxacarb+ quintal (860.5), spinosad + quintal (828.62), indoxacarb + chlorothalonil (771.48), indoxacarb + mancozeb (545.68), nuvaluron + quintal (399.51), nuvaluron + mancozeb (315.11), fipronil + chlorothalonil (215.16), fipronil + quintal (238.01), novaluron + chlorothalonil (228.29) and fipronil + mancozeb (217.21).

From the above study, it can be concluded that chlorantranilliprole with minimum LC_{50} values proved to be most toxic to all the tested insecticides against *Plutella xylostella*. Among the different combination, chlorantraniliprole + difenconazole found to be highly toxic in recording lower LC_{50} with high co-toxicity coefficient and relative toxicity. The LC_{50} values obtained for various insecticides, insecticide + fungicide combination would serve as ready reckoner for the selection of insecticides, fungicides which helps in pest and disease management programmes.

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be distinguished in the text and in the references by letter arranged alphabetically followed by the citation of the years eg. 2004a, 2004b.

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