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Spinetoram, a Selective Novel Insecticide Able to Check Key Lepidopteran Pests in Cabbage Ecosystem

Pratap A. Divekar[1,2]*, Sampat K Patel[2], Guru Pirasanna Pandi G[3], Manimurugan C[2,4], Vikas Singh[2] and Jagdish Singh[1]

[1]*Division of Crop Protection, ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi-221305, India.*
[2]*ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar-274406, India.*
[3]*Division of Crop Protection, ICAR-National Rice Research Institute, Cuttack-753006, India.*
[4]*Division of Crop Improvement, ICAR-Indian Institute of Oilseeds Research, Hyderabad-500030, India.*

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Key words
***Plutella xylostella, Pieris brassicae*, Cabbage, Spinetoram, Novel insecticides, Bioefficacy, Safety**

ABSTRACT

Diamondback moth (DBM) and cabbage butterfly (CB) are serious cabbage yield limiting factors in India. Considering insecticide resistance development in these pests, a study was conducted to find out the effective chemical molecule for managing these pests. Several novel insecticides were evaluated against Diamon back moth (DBM) and CB during spring season of 2019 and 2020. Efficacy of insecticides was determined by comparing larval densities of each insect species, immature and adult of natural enemies, crop damage ratings and marketable yield in insecticide treated versus untreated control plots. Spinetoram 45 and 60 g a.i. per ha recorded significantly higher larval population reduction (>80%) with least crop damage ratings (< 2) for both the insect pest population. Spinosad, emamectin benzoate, indoxacarb and chlorantraniliprole were also the found best treatments in controlling DBM and CB. No phytotoxic symptoms were observed in any treatment after spray application. Chlorpyriphos, deltamethrin, lambda-cyhalothrin and flubendiamide were found adverse to natural enemies. Thus, spinetoram, spinosad, emamectin benzoate, indoxacarb and chlorantraniliprole are recommended to manage DBM and CB on rotational basis in the cabbage ecosystem.

INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata*) is one of the nutrient rich cole crops rich having vitamin C and essential minerals. Cabbage is used in salads, boiled vegetables, fried curries, pickles and vegetables which are dehydrated. Cabbage production in India is 8.76 million tonnes under 0.39 million ha area with productivity of 22.56 tonnes per ha. India's share in cabbage and other brassicas production is 12.3% and occupies second position in the world (Anonymous, 2018). The major yield-limiting factor for cabbage production is insect pest infestation, which causes both qualitative and quantitative loss. Diamondback moth (DBM) *Plutella xylostella* (Lepidoptera: Plutellidae) is the key pest of cabbage (Talekar and Shelton, 1993) which has high migratory nature and has attained cosmopolitan species status. The annual yield loss due to direct feeding injury and spoilage are estimated to the US $ 2.7 billion worldwide (Zalucki *et al*., 2012). Larva is the damaging stage in the case of DBM where first-instar larvae act as leaf miners. However, older larvae damage the lower leaf surface and usually devour all tissue except the adaxial wax layer, thus creating a window in the leaf (Samthoy *et al*., 1989) (Supplementary Fig. 1a). The cabbage butterfly (CB), *Pieris brassicae* (Linn.) (Lepidoptera: Pieridae), is a serious pest of cabbage and other cole crops across the globe (Feltwell, 1978). CB was identified as a major pest of *Brassica* oilseeds in eastern Uttar Pradesh and other parts of India (Lal and Ram, 2004). Generally, CB survives the winter in the plains and migrates to hilly regions as the temperature goes up during summer in India. Young caterpillars are gregarious feeders,

* Corresponding author: pratapento@gmail.com
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which on the severe attack, devour the plant completely (Ali and Rizvi, 2007) (Supplementary Fig. 1b). DBM and CB were reported as the limiting factors in the cabbage production in India causing yield losses to the extent of 52 % (Krishnamoorthy, 2004) and 40 % (Ali and Rizvi, 2007), respectively.

Though the pest management options like host plant resistance (HPR) (Divekar *et al*., 2019), plant secondary metabolites (Divekar *et al*., 2022) and bio-control agents (Dukare *et al*., 2020) are available to control the insect pests in an eco-friendly and sustainable manner, synthetic pesticides are the first choice of farmers. Farmers use insecticides inappropriately for managing insect pests, which involves applying pesticides more than the recommended dosage and applying calendar-based sprays. Across the various states of India, excessive use of pesticides was noticed in cabbage (Weinberger and Srinivasan, 2009). Various studies have reported the DBM resistance to commonly used insecticides like quinalphos, fenvalerate, and cypermethrin and cross resistance to insecticides with different modes of action like cartap hydrochloride, diafenthiuron (Joia and Chawla, 1995). Resistance to newer molecules like emamectin benzoate, indoxacarb, spinosad, flubendiamide and chlorantraniliprole has also been reported (Zhao *et al*., 2006; Troczka *et al*., 2017). Injudicious application of insecticides, several generations of insects and the availability of host plant throughout the year have created new challenges like development of insecticide resistance and multiple insect pest attacks in cabbage. To mitigate these challenges, there is an urgent need to find an effective and eco-friendly alternative insecticide that can singly or in combination with the other novel insecticides be used safely to manage lepidopteran insect pests in cabbage. The present investigation was aimed to study the potential of spinetoram and several other novel insecticides for their bioefficacy against lepidopteran insects, safety to natural enemies and phytotoxicity in cabbage ecosystem under field conditions.

MATERIALS AND METHODS

Field efficacy of insecticides against DBM and CB

The field experiment was conducted by growing cabbage var. Golden Acre during the spring season of 2019 (season 1) and 2020 (season 2) at ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar (Latitude NS 26˚ 43' 56.61 and Longitude EW 84˚11' 12.95). Experiments were performed in a randomised block design (plot size: 4m×3m) with twelve treatments including untreated control and the same set of experiment was replicated thrice. The crop was raised as per the recommended package of practices, except for the plant protection measures. The treatment details were given in Table I.

Cabbage seedlings of 35 days old were transplanted in both the seasons. Insecticide spray treatments were applied on 35, 50 and 65 days after transplanting (DAT) on crossing the ETL of lepidopteran pest population. Pre-treatment count of the insect pests was noted one day before insecticide application. Larval numbers of DBM and CB were assessed by visual counting from 5 randomly selected plants on 1, 3, 7, 10 and 14 days after each spray from lower and upper surface of the entire plant. The percentage reduction of the pest population over control was calculated by using the formula given by Henderson and Tilton (1955).

Table I. Insecticides used in evaluations of their efficacy against lepidopteran insects and safety to natural enemies in cabbage.

Insecticide	Brand name	Insecticide group	Primary site of action according to insecticide resistance action committee (IRAC)	Application rate (g a.i./ha)
Chlorpyriphos 20% EC	Dursban	Organo-phosphates	Acetylcholinesterase (AChE) inhibitors	600
Chlorantraniliprole 18.5% SC	Coragen	Diamides	Ryanodine receptor modulators	30
Deltamethrin 2.8% EC	Decis	Pyrethroids	Sodium channel modulators	12.5
Indoxacarb 14.5% SC	Avaunt	Oxadiazines	Voltage-dependent sodium channel blockers	50
Lambda-cyhalothrin 5% EC	Karate	Pyrethroids	Sodium channel modulators	11
Flubendiamide 39.35% SC	Fame	Diamides	Ryanodine receptor modulators	48
Emamectin benzoate 5% SG	Proclaim	Avermectins	Glutamate-gated chloride channel (GluCl) allosteric modulators	25
Spinosad 2.5 % SC	Success	Spinosyns	Nicotinic acetylcholine receptor (nAChR) allosteric modulators-Site I	17.5
Spinetoram 11.7% SC	Delegate	Spinosyns	Nicotinic acetylcholine receptor (nAChR) allosteric modulators-Site I	30
Spinetoram 11.7% SC	Delegate	Spinosyns	Nicotinic acetylcholine receptor (nAChR) allosteric modulators-Site I	45
Spinetoram 11.7% SC	Delegate	Spinosyns	Nicotinic acetylcholine receptor (nAChR) allosteric modulators-Site I	60

Phytotoxicity of insecticides on cabbage

The phytotoxic effects produced by spinetoram 11.7% SC and other insecticides on cabbage leaves and head were also studied. Five plants were selected at random in each plot and the plants were examined for phytotoxic symptoms viz., leaf tip burning, epinasty, hyponasty, necrosis, chlorosis, vein clearing, wilting and resetting on 1, 3, 7, 10 and 14 days after insecticide application. The phytotoxicity symptoms, if any, were graded based on the percent-injured leaves on the scale of 0-10 as per CIBRC, India and percent leaf injury was calculated by using a formula as described by Karthik *et al*. (2015).

Safety of insecticides to natural enemies

Natural enemies *viz*., coccinellid complex and spiders were observed and recorded before and after each insecticide application. Immature and adult stages were estimated by visual counting of individuals on lower and upper surface of the cabbage plant. Observations on the number of immature and adults of natural enemies were recorded from five plants per replication on 1, 3, 7, 10 and 14 days after each insecticidal spray application.

Crop damage rating and marketable yield

When plants were ready to harvest, ten plants per plot were scored for larval damage to the head of cabbage using a standard 1-6 scale (Greene *et al*., 1969). Harvesting was done at 80 DAT. Marketable yield was assessed from ten cabbage heads per plot.

Statistical analysis

The data on the population of lepidopteran insect pests and natural enemies were subjected to square root transformations (Snedecor and Cochran, 1967). The efficacy of different treatments in terms of larval population of DBM and CB, immature and adult of natural enemies, crop damage ratings and marketable yield were studied using one-way analysis of variance (ANOVA) through SPSS 22.0 software. When the F test was significant at 0.05 level, the treatment means were compared using the Tukey's honest significant difference (HSD) test. Additionally, principal component analysis (PCA) was done through SAS University Edition software by using pooled data to find out the affinities between the plant marketable yield, crop damage rating, percent protection over control and insects as well as natural enemy populations (Gowda *et al*., 2019).

RESULTS

Efficacy of insecticides against DBM, P. xylostella

The lepidopteran insect pests encountered in cabbage throughout the study period in open field conditions were DBM, *P. xylostella* and CB, *P. brassicae*. The incidence of DBM before and after three rounds of insecticide treatment during two seasons were summarized in Tables II and III.

Table II. Effect of insecticides on larval DBM population per plant in season 1.

Treatment	Dose (g a.i./ha)	PTC	I Spray	PROC	II Spray	PROC	III Spray	PROC	Mean*	PROC **
Chlorpyriphos 20% EC	600	5.87	4.80^{d} (2.30)	46.33	4.10^{cd} (2.14)	58.81	3.22^{c} (1.93)	64.01	4.04^{ef} (2.13)	59.29
Chlorantraniliprole 18.5% SC	30	6.20	3.63^{abcd} (2.03)	61.66	3.12^{abcd} (1.90)	70.34	2.56^{bc} (1.75)	72.92	3.10^{bcde} (1.90)	70.44
Deltamethrin 2.8% EC	12.5	6.33	4.73^{d} (2.29)	51.01	4.39^{d} (2.21)	59.15	3.64^{c} (2.04)	62.31	4.25^{e} (2.18)	60.30
Indoxacarb 14.5% SC	50	6.07	3.68^{abcd} (2.04)	60.24	2.72^{abc} (1.80)	73.55	2.42^{bc} (1.71)	73.84	2.94^{abcd} (1.85)	71.35
Lambda-cyhalothrin 5% EC	11	6.53	4.27^{cd} (2.18)	57.19	3.76^{bcd} (2.06)	66.08	3.22^{c} (1.93)	67.68	3.75^{ef} (2.06)	66.10
Flubendiamide 39.35% SC	48	6.40	4.00^{bcd} (2.12)	59.03	3.33^{abcd} (1.96)	69.34	3.05^{bc} (1.88)	68.75	3.45^{def} (1.99)	68.13
Emamectin Benzoate 5% SG	25	6.33	3.58^{abcd} (2.02)	62.91	3.15^{abcd} (1.91)	70.66	2.72^{bc} (1.79)	71.84	3.15^{bcde} (1.91)	70.60
Spinosad 2.5 % SC	17.5	5.87	3.05^{abc} (1.89)	65.88	2.38^{ab} (1.70)	76.13	1.90^{ab} (1.55)	78.76	2.44^{abc} (1.72)	75.38
Spinetoram 11.7% SC	30	6.00	2.82^{abc} (1.82)	69.19	2.38^{ab} (1.70)	76.62	1.86^{ab} (1.53)	79.67	2.35^{abc} (1.69)	76.81
Spinetoram 11.7% SC	45	6.40	2.72^{ab} (1.79)	72.17	2.22^{ab} (1.65)	79.53	1.12^{a} (1.26)	88.52	2.01^{ab} (1.59)	81.40
Spinetoram 11.7% SC	60	6.20	2.42^{a} (1.71)	74.41	1.76^{a} (1.50)	83.27	1.02^{a} (1.23)	89.21	1.73^{a} (1.49)	83.47
Control		6.40	9.76^{e} (3.20)		10.86^{e} (3.37)		11.86^{d} (3.52)		10.83^{f} (3.37)	
Tukey's HSD at 5%		NS	0.96		1.18		1.00		1.088	
df		11, 24	11, 24		11, 24		11, 24		11, 24	
F value		1.236	31.44		51.94		85.36		33.24	
P value		0.317	<0.001		<0.001		<0.001		<0.001	

PTC-Pre-treatment count, PROC-percent reduction over control, NS-Non-Significant, *Mean larval population after three sprays, **PROC after three sprays. Data are means of three replications. Figures in parentheses are $\sqrt{x+0.5}$ transformed values. Means in the same column followed by different letters differ significantly (P < 0.05) on the basis Tukey's honest significant different (HSD) test.

Table III. Effect of insecticides on larval DBM population per plant in season 2.

Treatment	Dose (g a.i./ha)	PTC	I Spray	PROC	II Spray	PROC	III Spray	PROC	Mean*	PROC
Chlorpyriphos 20% EC	600	9.00	7.32^{e} (2.80)	44.65	6.26^{d} (2.60)	58.20	5.39^{de} (2.43)	67.02	6.32^{e} (2.61)	57.40
Chlorantraniliprole 18.5% SC	30	8.93	5.02^{abcd} (2.35)	61.73	4.33^{bc} (2.20)	70.85	3.82^{abc} (2.08)	76.45	4.39^{bcd} (2.21)	70.20
Deltamethrin 2.8% EC	12.5	9.27	7.01^{e} (2.74)	48.50	6.31^{d} (2.61)	59.07	5.86^{e} (2.52)	65.20	6.39^{e} (2.63)	58.17
Indoxacarb 14.5% SC	50	9.07	5.12^{bcd} (2.37)	61.60	4.21^{bc} (2.17)	72.06	4.00^{bcd} (2.12)	75.71	4.44^{bcd} (2.22)	70.28
Lambda-cyhalothrin 5% EC	11	9.20	6.20^{de} (2.59)	54.14	5.32^{cd} (2.41)	65.21	4.76^{cde} (2.29)	71.51	5.43^{de} (2.43)	64.23
Flubendiamide 39.35% SC	48	8.87	5.86^{cde} (2.52)	55.02	4.39^{bc} (2.21)	70.23	4.26^{cd} (2.18)	73.54	4.84^{cd} (2.31)	66.92
Emamectin benzoate 5% SG	25	9.13	4.73^{abcd} (2.29)	64.76	4.23^{bc} (2.17)	72.17	3.79^{abc} (2.07)	77.15	4.25^{bcd} (2.17)	71.79
Spinosad 2.5 % SC	17.5	9.47	4.27^{abc} (2.18)	69.30	3.76^{abc} (2.06)	76.14	3.48^{abc} (1.99)	79.76	3.84^{abc} (2.08)	75.43
Spinetoram 11.7% SC	30	9.33	4.26^{abc} (2.18)	68.94	3.76^{abc} (2.06)	75.80	3.42^{abc} (1.98)	79.80	3.81^{abc} (2.07)	75.27
Spinetoram 11.7% SC	45	9.40	3.74^{ab} (2.06)	72.92	2.96^{ab} (1.86)	81.06	2.60^{ab} (1.76)	84.77	3.10^{ab} (1.90)	80.00
Spinetoram 11.7% SC	60	8.80	3.42^{a} (1.98)	73.58	2.51^{a} (1.73)	82.85	2.26^{a} (1.66)	85.88	2.73^{a} (1.79)	81.19
Control		8.73	12.83^{f} (3.65)		14.52^{e} (3.88)		15.86^{f} (4.04)		14.40^{f} (3.85)	
Tukey's HSD at 5%		NS	1.05		0.74		1.25		1.20	
df		11, 24	11, 24		11, 24		11, 24		11, 24	
F value		1.64	25.64		40.97		57.90		48.62	
P value		0.15	<0.001		<0.001		<0.001		<0.001	

PTC-Pre-treatment Count, PROC-percent reduction over control, NS-Non-Significant, *Mean larval population after three sprays, **PROC after three sprays. Data are means of three replications. Figures in parentheses are $\sqrt{x+0.5}$ transformed values. Means in the same column followed by different letters differ significantly ($P < 0.05$) on the basis Tukey's honest significant different (HSD) test.

Table IV. Effect of insecticides on larval CB population per plant in season 1.

Treatment	Dose (g a.i./ha)	PTC	I Spray	PROC	II Spray	PROC	III Spray	PROC	MEAN	PROC
Chlorpyriphos 20% EC	600	8.80	7.02^{f} (2.74)	46.28	6.03^{f}(2.55)	61.33	5.20^{e} (2.38)	68.56	6.08^{e} (2.57)	59.61
Chlorantraniliprole 18.5% SC	30	8.73	5.30^{cde} (2.41)	59.14	4.20^{cde} (2.16)	72.86	3.10^{cd} (1.89)	81.13	4.20^{cd} (2.17)	71.91
Deltamethrin 2.8% EC	12.5	8.13	6.62^{ef} (2.67)	50.80	5.40^{ef} (2.43)	66.36	4.12^{de} (2.15)	75.79	5.38^{de} (2.42)	65.31
Indoxacarb 14.5% SC	50	8.07	5.00^{cd} (2.35)	62.02	3.62^{bcd} (2.02)	76.95	3.10^{cd} (1.89)	81.36	3.91^{bcd} (2.10)	74.26
Lambda-cyhalothrin 5% EC	11	8.47	5.76^{def} (2.50)	56.73	5.10^{def}(2.36)	68.00	4.78^{e} (2.29)	71.69	5.22^{de} (2.39)	66.10
Flubendiamide 39.35% SC	48	8.20	6.10^{def} (2.56)	52.46	5.06^{def} (2.35)	67.06	4.12^{de} (2.15)	74.68	5.10^{de} (2.37)	65.63
Emamectin benzoate 5% SG	25	8.53	4.68^{bcd} (2.27)	64.71	4.28^{cde} (2.18)	72.95	3.12^{cd} (1.89)	81.42	4.03^{bcd} (2.13)	73.66
Spinosad 2.5 % SC	17.5	8.27	4.00^{abc} (2.12)	70.90	3.32^{abc} (1.94)	79.76	2.26^{abc} (1.65)	87.00	3.19^{abc} (1.92)	79.85
Spinetoram 11.7% SC	30	8.00	3.46^{ab} (1.98)	74.47	2.90^{abc} (1.83)	82.06	2.53^{bc} (1.74)	85.22	2.96^{abc} (1.86)	81.03
Spinetoram 11.7% SC	45	8.40	3.20^{ab} (1.92)	76.55	2.30^{ab} (1.67)	85.88	1.34^{ab} (1.36)	92.24	2.28^{ab} (1.67)	85.51
Spinetoram 11.7% SC	60	8.33	2.80^{a} (1.81)	78.09	2.05^{a} (1.60)	86.55	1.02^{a} (1.23)	93.69	1.96^{a} (1.57)	86.71
Control		8.60	12.68^{g} (3.63)		15.13^{g} (3.95)		16.04^{f} (4.06)		14.62^{f} (3.89)	
Tukey's HSD at 5%		NS	0.62		1.00		0.78		1.70	
df		11, 24	11, 24		11, 24		11, 24		11, 24	
F value		1.852	31.44		51.94		85.36		33.24	
P value		0.10	<0.001		<0.001		<0.001		<0.001	

PTC-Pre-treatment Count, PROC-percent reduction over control, NS-Non-Significant, * Mean larval population after three sprays, **PROC after three sprays. Data are means of three replications. Figures in parentheses are $\sqrt{x+0.5}$ transformed values. Means in the same column followed by different letters differ significantly ($P < 0.05$) on the basis Tukey's honest significant different (HSD) test.

Infestation of DBM was higher in the second season than the first. Pre-treatment count for DBM larval population was non-significant in both the seasons and was recorded in the range of 5.87 to 6.53 ($F_{(11, 24)}$ = 1.24, p= 0.32) and 8.73-9.47 (($F_{(11, 24)}$ =1.64, p=0.15) during season 1 and season 2, respectively. Significant differences were observed for the larval DBM population among the treatments and it was ranged in between 1.73-10.83 ($F_{(11, 24)}$ = 33.24, p<0.001) and 2.73-14.40 ($F_{(11, 24)}$ = 48.62, p<0.001) for the season 1 and 2, respectively. Application of spinetoram @ 60 g a.i./ha, resulted into the highest reduction of DBM in season 1 and 2. Spinetoram and spinosad caused the higher reduction of DBM larval population after three sprays in both season 1 and 2 than the untreated control. Chlorpyriphos produced the least reduction due to spray I (46.33%) and spray II (58.81%). Similarly, chlorpyriphos caused the least reduction after spray I (44.65%) and spray II (58.20%) during season 2. After spray III, least reduction of larval DBM population was recorded due to the application of deltamethrin in season 1 (62.31%) and season 2 (65.20%). DBM can be managed effectively by the application of chemical insecticides at proper time and against appropriate stage of insect.

Efficacy of insecticides against CB, P. brassicae

Results of insecticide evaluation against CB were presented in Tables IV and V. CB, *P. brassicae* infestation was higher in the first season as compared to the second. CB larval population was non-significant in both the seasons during pre-treatment count and it was observed in the range of 8.00-8.80 (F (11, 24) =1.85, p=0.10) and 5.00-6.07 ((F (11, 24) =1.91, p=0.09) during season 1 and season 2, respectively. Significant differences were noted among the treatments for larval population counts of CB and it was ranged in between 1.96-14.62 ($F_{(11, 24)}$ = 33.24, p<0.001) and 1.51-9.06 ($F_{(11, 24)}$ = 24.37, p<0.001) during season 1 and 2, respectively.

Highest reduction of CB was observed after application of spinetoram @ 60 g a.i./ha after spray I (78.09%), spray II (86.55%) and Spray III (93.69%) in season 1. Similarly, in season 2 spinetoram 60 g a.i. /ha was found responsible for highest reduction after spray I (72.29%), spray II (84.03%) and Spray III (90.98%). Spinetoram and spinosad were found responsible for higher reduction of CB larval population after three sprays in both the seasons. Chlorpyriphos caused the least reduction due to spray I (46.28%) and spray II (61.33%) and spray III (68.56%) during season 1. Similarly, in season 2 chlorpyriphos resulted into the least reduction after spray I (40.62%) and spray II (55.21%) spray III (64.23%). All the insecticide treatments were found effective against the larvae of CB, *P. brassicae* over untreated control.

Table V. Effect of insecticides on larval CB population per plant during season 2.

Treatment	Dose (g a.i./ha)	PTC	I Spray	PROC	II Spray	PROC	III Spray	PROC	MEAN	PROC
Chlorpyriphos 20% EC	600	5.73	4.68^{de} (2.27)	40.62	4.30^{d} (2.18)	55.21	3.76^{e} (2.06)	64.23	4.25^{d} (2.18)	54.50
Chlorantraniprole 18.5% SC	30	5.00	3.15^{abc} (1.91)	59.72	2.33^{abc} (1.67)	75.53	2.10^{bcd} (1.61)	79.84	2.53^{abc} (1.74)	72.73
Deltamethrin 2.8% EC	12.5	5.47	5.47^{e} (2.44)	32.68	3.85^{d} (2.08)	61.08	2.78^{d} (1.80)	74.31	3.78^{cd} (2.07)	60.70
Indoxacarb 14.5% SC	50	5.93	5.93^{e} (2.53)	25.37	2.40^{abc} (1.69)	75.17	1.82^{abcd} (1.51)	82.84	2.47^{abc} (1.72)	73.69
Lambda-cyhalothrin 5% EC	11	5.07	4.10^{cd} (2.14)	49.10	3.20^{bcd} (1.92)	67.42	2.54^{cd} (1.74)	76.36	3.28^{bcd} (1.94)	65.62
Flubendiamide 39.35% SC	48	6.07	3.78^{bcd} (2.06)	51.35	3.38^{cd} (1.96)	64.29	2.56^{cd} (1.75)	75.25	3.24^{bcd} (1.93)	64.76
Emamectin benzoate 5% SG	25	5.53	3.12^{abc} (1.89)	61.02	2.48^{abc} (1.73)	74.57	2.14^{bcd} (1.62)	79.91	2.58^{abc} (1.75)	72.76
Spinosad 2.5 % SC	17.5	5.20	2.62^{ab} (1.76)	68.38	2.07^{ab} (1.60)	79.48	1.49^{abc} (1.41)	86.55	2.06^{ab} (1.60)	79.02
Spinetoram 11.7% SC	30	5.93	2.50^{ab} (1.73)	69.39	2.04^{ab} (1.58)	79.53	1.40^{ab} (1.37)	87.16	1.98^{ab} (1.57)	79.54
Spinetoram 11.7% SC	45	5.27	2.30^{a} (1.67)	72.08	1.62^{a} (1.45)	83.86	1.11^{ab} (1.26)	89.89	1.68^{a} (1.45)	82.77
Spinetoram 11.7% SC	60	5.13	2.14^{a} (1.60)	72.29	1.50^{a} (1.41)	84.03	0.93^{a} (1.18)	90.98	1.51^{a} (1.42)	83.45
Control		5.73	7.65^{f} (2.85)		9.32^{e} (3.13)		10.20^{f} (3.27)		9.06^{e} (3.09)	
Tukey's HSD at 5%		NS	0.51		1.05		0.33		0.91	
df		11, 24	11, 24		11, 24		11, 24		11, 24	
F value		1.909	16.93		33.17		55.89		24.37	
P value		0.09	<0.001		<0.001		<0.001		<0.001	

PTC-Pre-treatment Count, PROC-percent reduction over control, NS-Non-Significant, * Mean larval population after three sprays, **PROC after three sprays. Data are means of three replications. Figures in parentheses are $\sqrt{x+0.5}$ transformed values. Means in the same column followed by different letters differ significantly (P < 0.05) on the basis Tukey's honest significant different (HSD) test.

Table VI. Effect of insecticides on crop damage rating and marketable yield during two seasons.

Treatment	Dose (g a.i./ha)	Crop damage rating scale (1-6)		Marketable yield (Kg per ten plants)	
		Season 1	Season 2	Season 1	Season 2
Chlorpyriphos 20% EC	600	4.17[e]	4.13[g]	4.80[b]	4.20[b]
Chlorantraniliprole 18.5% SC	30	2.80[cd]	3.17[def]	9.47[cd]	9.43[d]
Deltamethrin 2.8% EC	12.5	4.30[e]	4.50[g]	4.30[b]	3.83[b]
Indoxacarb 14.5% SC	50	2.63[bc]	2.80[bcd]	9.87[d]	9.68[d]
Lambda-cyhalothrin 5% EC	11	3.60[de]	3.80[f]	7.90[c]	7.80[c]
Flubendiamide 39.35% SC	48	3.50[de]	3.63[ef]	8.53[cd]	7.90[c]
Emamectin benzoate 5% SG	25	2.93[cd]	2.90[cde]	9.43[cd]	8.93[cd]
Spinosad 2.5 % SC	17.5	2.00[ab]	2.50[abc]	11.87[e]	11.30[e]
Spinetoram 11.7% SC	30	1.90[ab]	2.13[ab]	12.27[e]	11.90[ef]
Spinetoram 11.7% SC	45	1.43[a]	1.80[a]	13.40[ef]	12.30[ef]
Spinetoram 11.7% SC	60	1.30[a]	1.50[a]	14.93[f]	13.20[f]
Control		5.13[f]	5.30[g]	1.60[a]	1.20[a]
Tukey's HSD at 5%		0.55	0.58	1.35	1.33
df		11, 24	11, 24	11, 24	11, 24
F value		21.855	24.164	49.19	70.07
P value		<0.001	<0.001	<0.001	<0.001

Data are means of three replications. Means in the same column followed by different letters differ significantly ($P < 0.05$) on the basis of Tukey's HSD test.

Crop damage and marketable yield assessment

Crop damage done by larval feeding of DBM as well as CB and marketable yield obtained after the application of chemical insecticides are shown in Table VI. Insecticide treatments were significantly different with respect to crop damage rating during season 1 ($F_{(11, 24)} = 21.85$, $p<0.001$) and season 2 ($F_{(11, 24)} = 24.16$, $p<0.001$). The untreated control plots suffered the greatest damage from the larvae of DBM and CB. Crop damage rating was found least in spinetoram 60 g a.i. per ha in season 1 (1.30) and season 2 (1.50). However, amongst the insecticides evaluated, a higher crop damage rating was noted in deltamethrin treated plots during season 1(4.30) and season 2 (4.5).

Significant differences were found among the few insecticides in terms of marketable yield (season 1: $F_{(11, 24)} = 29.74$, $p<0.001$ and season 2: $F_{(11, 24)} = 34.43$, $p<0.001$). Application of spinetoram 60 g a.i. /ha resulted into greater marketable yield in both the seasons. Among the insecticides, least marketable yield was recorded in deltamethrin treated plots during season 1 (6.43 Kg per ten plants) and season 2 (6.13 Kg per ten plants). Untreated control plots suffered the most and recorded the least marketable yield in both the seasons.

Principal component analysis for mean larval population of DBM and CB, crop damage rating and marketable weight

Three principal components (PCs) were extracted for the different insecticidal treatments with relation to the pooled mean larval population of *P. xylostella* and *P. brassicae*, crop damage rating and marketable yield from scree plot with eigen value ≥ 1.0. The relations of the observed parameters on the different insecticidal treatments are presented in Figure 2. PC 1 depicted variation of 88.39% and PC 2 depicted variation of 11.14%, whereas PC 3 displayed only 0.47% variation. Component loadings of different factors governing natural enemy populations among tested chemicals are represented in Supplementary Table I. Among the tested chemicals in PC1, spinetoram 45 and 60 g a.i per ha treatment has a strong positive relation with all the observed parameters followed by spinosad, indoxacarb and chlorantraniliprole. Likewise, deltamethrin and chlorpyriphos have strong relation in components two and three, respectively. Three main groups, comprising different insecticides were identified based on positional proximity in the 2-D biplot. Insecticides such as chlorpyriphos, deltamethrin, flubendiamide and lambda-cyhalothrin, were forming one group as they located close to one another, whereas, spinetoram, indoxacarb, chlorantaniliprole and emamectin benzoate occupied a different location on the 2-D plot. Apart from these groups, control was only located in component two indicating a different trend compared to other parameters.

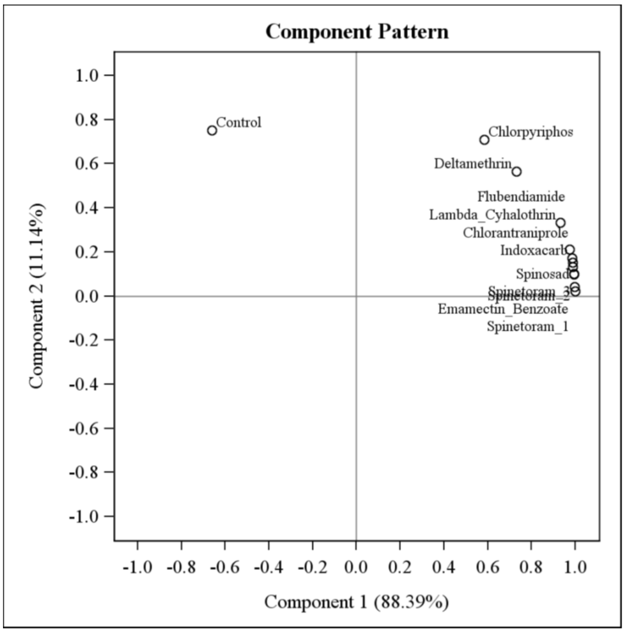

Fig. 1. 2-D plot of principal component analysis based on mean larval population of diamondback moth, cabbage butterfly, crop damage rating and marketable weight parameters among the insecticidal treatments.
*Note: Spinetoram_1 denotes Spinetoram 30 g a.i. per ha, Spinetoram_2 denotes Spinetoram 45 g a.i. per ha and Spinetoram_3 denotes Spinetoram 60 g a.i. per ha.

Effect of insecticides on natural enemies

Major natural enemies observed in cabbage ecosystem during the period of observation were coccinellids and spiders. Effect of application of insecticides on the natural enemies was presented in Table VII. The population of coccinellids and spiders were higher in untreated check as compared to the insecticide treated plots. Coccinellids population was found non-significant before insecticide spray application which was ranged in between 4.33 to 5.67 ($F_{(11, 24)}$ = 0.53, p=0.87) and 4.67-6.33 ($F_{(11, 24)}$ = 1.82, p=0.11) during season 1 and season 2, respectively. After three insecticide spray applications, coccinellids were noted with significant difference in the range of 4.03-7.42 ($F_{(11, 24)}$ = 6.54, p<0.001) and 2.72-6.80 ($F_{(11, 24)}$ = 17.12, p<0.001) during season 1 and season 2, respectively. Before imposing insecticide treatments spider population was non-significant which was observed in between 4.00-5.33 ($F_{(11, 24)}$ = 1.52, p=0.19) and 3.67-5.33 ($F_{(11, 24)}$ = 1.46, p=0.21) in season 1 and season 2, respectively. Significant differences were recorded in the population of spiders after of insecticide application during season 1 ($F_{(11, 24)}$ = 29.57, p<0.001) and season 2 ($F_{(11, 24)}$ = 11.54, p<0.001).

All the dosages of spinetoram were found safer as maximum number of adults as well as immature coccinellids and spiders were noted. Chorpyriphos and deltamethrin were found harmful as the minimum population of adults as well as immature of coccinellids and spiders were observed.

Table VII. Effect of insecticides on coccinellids and spiders per five plants during two seasons.

Treatment	Dose (a.i. g/ha)	Coccinellids				Spiders			
		Season 1		Season 2		Season 1		Season 2	
		PTC	Coccinellids*	PTC	Coccinellids*	PTC	spiders*	PTC	spiders*
Chlorpyriphos 20% EC	600	5.00	4.03^{a} (2.13)	6.00	2.72^{a} (1.79)	4.00	2.72^{a} (1.79)	4.33	4.04^{ab} (2.13)
Chlorantraniliprole 18.5% SC	30	4.00	5.53^{bc} (2.46)	4.67	5.38^{b} (2.42)	4.00	5.24^{bc} (2.40)	3.67	5.09^{cde} (2.36)
Deltamethrin 2.8% EC	12.5	5.00	4.21^{ab} (2.17)	6.33	2.84^{a} (1.83)	4.67	2.84^{a} (1.83)	4.00	3.40^{a} (1.97)
Indoxacarb 14.5% SC	50	4.33	5.12^{abc} (2.37)	4.67	5.14^{b} (2.37)	4.00	5.02^{b} (2.35)	4.00	5.17^{cde} (2.38)
Lambda-cyhalothrin 5% EC	11	4.67	3.92^{a} (2.10)	5.00	3.02^{a} (1.88)	5.00	3.02^{a} (1.88)	5.33	4.60^{bc} (2.26)
Flubendiamide 39.35% SC	48	4.67	4.20^{ab} (2.17)	5.67	3.06^{a} (1.89)	5.33	3.06^{a} (1.89)	4.67	4.58^{bc} (2.25)
Emamectin Benzoate 5% SG	25	4.67	5.65^{c} (2.48)	5.33	5.63^{b} (2.46)	4.67	5.16^{bc} (2.38)	4.67	4.97^{bcd} (2.34)
Spinosad 2.5 % SC	17.5	4.33	6.09^{cd} (2.57)	5.00	5.56^{b} (2.46)	4.33	5.88^{bcd} (2.53)	4.00	5.84^{def} (2.52)
Spinetoram 11.7% SC	30	4.33	6.48^{cd} (2.64)	4.67	6.19^{bc} (2.59)	4.33	5.95^{cd} (2.54)	4.67	6.16^{fg} (2.58)
Spinetoram 11.7% SC	45	5.33	6.27^{cd} (2.60)	5.67	6.05^{bc} (2.56)	4.00	6.14^{d} (2.58)	4.67	5.95^{ef} (2.54)
Spinetoram 11.7% SC	60	5.00	6.20^{cd} (2.59)	5.33	6.03^{bc} (2.56)	4.33	6.23^{de} (2.59)	4.33	6.02^{efg} (2.55)
Control		5.00	7.42^{d} (2.81)	5.67	6.80^{c} (2.70)	5.00	7.01^{e} (2.74)	5.00	6.91^{g} (2.72)
Tukey's HSD at 5%		NS	0.60	NS	0.45	NS	0.59	NS	0.43
df		11, 24	11, 24	11, 24	11, 24	11, 24	11, 24	11, 24	11, 24
F value		0.53	6.54	1.82	17.12	1.52	29.57	1.46	11.54
P value		0.87	<0.001	0.11	<0.001	0.19	<0.001	0.21	<0.001

PTC-Pre-treatment Count, NS-Non-Significant, * Mean immature and adult population after three sprays. Data are means of three replications. Figures in parentheses are $\sqrt{x+0.5}$ transformed values. Means in the same column followed by different letters differ significantly (P < 0.05) on the basis Tukey's HSD test.

Principal component analysis for pooled mean population of natural enemies

Three principal components (PCs) were extracted from the different insecticidal treatments with relation to spiders and coccinellids population for scree plot with eigenvalue ≥ 1.0. The coccinellid and spider population on different insecticidal treatments are presented in Figure 1. PC1 depicted a variation of 86.99% and PC2 depicted variation of 11.49%, whereas PC3 displayed 1.52% variation. Component loadings of different factors governing natural enemies populations among tested chemicals are represented in Supplementary Table II. Among the tested chemicals in PC1, chlorantraniliprole has strong positive relation followed by spinetoram. Likewise, lambda-cyhalothrin and spinetoram have strong relation in components two and three, respectively. Four main groups, comprising different insecticide parameters, were identified based on positional proximity in the 2-D biplot. Insecticides such as lambda-cyhalothrin, flubendiamide, deltamethrin were separated from other chemicals, whereas, indoxacarb, chlorantraniliprole occupied a different location from control on the 2-D plot. Apart from these groups, spinetoram and emamectin benzoate were only located close to control indicating a safer trend compared to other parameters.

Phytotoxicity of insecticides on cabbage leaves and head

None of the phytotoxic symptoms appeared on cabbage leaves and heads after the application of each insecticidal treatment.

DISCUSSION

DBM and CB were the lepidopteran insect species observed throughout the study period in cabbage. In the present investigation, applications of spinetoram, spinosad, chlorantraniliprole and indoxacarb were significantly effective in reducing the DBM and CB larval population on cabbage when sprayed thrice at 15 days interval providing significantly greater marketable yield with relatively safer to the natural enemies throughout the cropping season. Studies by Legwaila *et al.* (2014) wherein they reported a higher efficacy of spinosad against DBM egg and larvae under laboratory conditions. Muthukrishnan *et al.* (2013) reported that spinetoram at 45 and 54 g a.i./ha significantly reduced *Spodoptera litura* larval population in tomato. Chlorantraniliprole 52 mg a.i /L under field conditions was reported as effective as indoxacarb and spinosad furthermore significantly effective than emamectin benzoate in managing *Pieris rapae* giving marketable yield with three spray application (Su *et al.*, 2017). Our results showed that insecticides viz., chlorpyriphos, deltamethrin, flubendiamide and lambda-cyhalothrin were less effective in controlling the larval DBM and CB population in cabbage. Similarly, field trials conducted by Patra *et al.* (2017) revealed that chlorpyriphos was least effective against DBM in comparison to the novel molecules.

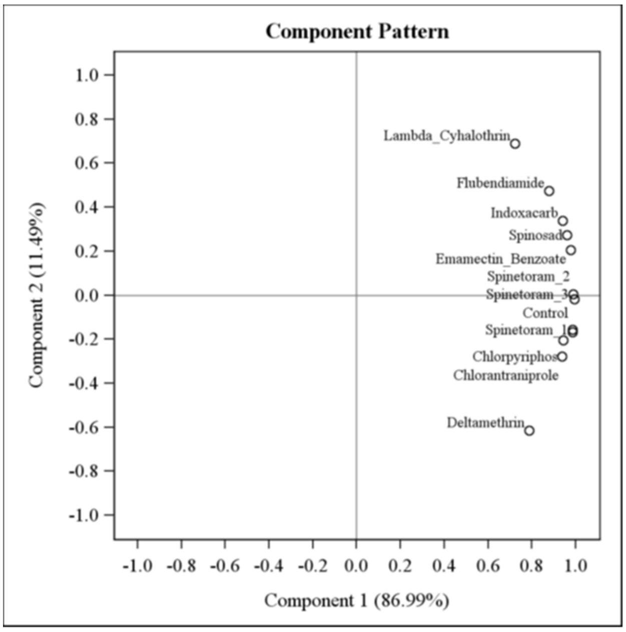

Fig. 2. 2-D plot of principal component analysis based on mean populations of coccinellid and spider numbers among the insecticidal treatments.
*Note: Spinetoram_1 denotes Spinetoram 30 g a.i. per ha, Spinetoram_2 denotes Spinetoram 45 g a.i. per ha and Spinetoram_3 denotes Spinetoram 60 g a.i. per ha.

Spinetoram showed highest efficacy in managing of DBM and CB with higher safety to natural enemies and without any visual symptoms of phytotoxicity (Fig. 2). This may be due to its unique mode of action *i.e.* stomach, contact, systemic and translaminar activity of this molecule. Similar findings were reported by Shimokawatoko *et al.* (2012). In comparison with conventional insecticides, novel molecules conserved natural enemies. However, as compared to untreated plots, populations of natural enemies were lower in insecticide treated plots. Apart from spinetoram, novel molecules namely spinosad, chlorantraniliprole, indoxacarb and emamectin benzoate were also safer to natural enemies. Dhanalakshmi and Mallapur (2008) reported that emamectin benzoate and spinosad were as safe as untreated control to natural enemies. Reduction in coccinellid and spider population following the application of chlorpyriphos, deltamethrin, flubendiamide and lambda-cyhalothrin might be due to the non-targeted impacts on their biology, growth and reproduction. Detrimental effects of chlorpyriphos on coccinellid predators were reported by El-Hawary *et al.* (2010). Adverse effects of lambda-cyhalothrin on seven spotted lady beetle, *Coccinella septumpunctata* were reported by Tengfei *et al.* (2019) under *in-vitro* conditions. Deltamethrin was reported as the most detrimental compound with 100 % mortality against two-spotted lady beetle, *Adalia bipunctata* (L.) (Coleoptera: Coccinellidae) (Garzon *et al.*, 2015).

CONCLUSION

Spinetoram can be effectively used to manage DBM and CB in cabbage ecosystem that is safer to the natural enemies like coccinellids and spiders. Apart from spinetoram, other novel molecules viz., spinosad, indoxacarb, chlorantraniliprole and emamectin benzoate were also effective in field conditions. Spinetoram can be incorporated into IPM programs and need to be used alternatively or sequentially in insecticide resistance management strategies.

DECLARATIONS

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Ethical approval

The research work does not contain any studies with human participants and animals performed by any of the authors.

Supplementary material

There is supplementary material associated with this article. Access the material online at: https://dx.doi.org/10.17582/journal.pjz/20220724130756

Statement of conflict of interest

The authors have declared no conflict of interest.

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