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Population dynamics and management of diamond back moth *Plutella xylostella* (L.) in cabbage ecosystem of West Bengal

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Abstract
An experiment was conducted in cabbage ecosystem of West Bengal in 2013-2014 and 2014-2015 to study the population fluctuation of diamond back moth (DBM) with abiotic factors along with efficacy of eight novel insecticides and bio-pesticides on DBM and subsequent effect on natural enemies. Results revealed that, DBM population had a positive correlation with temperature and sunshine hours and negative correlation to relative humidity and rainfall. Bio-efficacy studies showed that rynaxypyr was most effective in reducing larval population (96.41%) closely followed by flubendiamide (94.86%) and spinetorum (92.62%). Combination of novaluron and indoxacarb also provided good reduction of larval population (92.04%). Bio-pesticides *Bacillus thuringiensis* var kurstaki and *Beauveria bassiana* gave 55.82% and 32.24% reduction of DBM larvae respectively. All the imposed test molecules were found soft to prevailing natural enemies. Yield of cabbage was found to be highest in plots treated with rynaxypyr (550.50q/ha) followed by flubendiamide (535.65q/ha) and spinetorum (530.55q/ha).

Keywords: cabbage, DBM, natural enemies, abiotic factors, bio-pesticides

Introduction
Cabbage, *Brassica oleracea* var. capitata an herbaceous plant of Family Brassicacea, is a widely cultivated vegetable throughout the world as a longstanding dietary supplement. It has numerous health benefits that have increased its popularity all over the world [1]. In India, cabbage is cultivated over 0.245 M with an average production of 5.6 M mt and a productivity of 22.9mt/ha out of which West Bengal contributes to about 1.9 M mt of cabbage from over 65 k ha. However, the set back to optimum cabbage production is the attack of insect pests, the most important of which is the diamond back moth (DBM), *Plutella xylostella* which has become a single limiting factor in the production of quality heads [2]. It is one of the most destructive insect pests of cruciferous vegetables, currently accounting for US$2.7 billion worth of annual worldwide crop losses. Management of this pest depends largely on imposing heavy quantities of synthetic chemical pesticides all over the world. However, this moth has developed multifold resistance to almost all the recommended insecticides in many parts of the world which has added to more woes as it is becoming increasingly difficult to control [3]. So the time has come to relook over the bio-ecology of the pest and revise the available management options to set the best package of practices for successful management of this pest. Keeping in view the above factors the present study is based on the population dynamics of DBM and its management using novel insecticides and bio-pesticides to find the best fit in IPM package of practices.

Materials and Methods
Population fluctuation of DBM with abiotic factors
Population of DBM larvae was recorded from 10 randomly selected plants of untreated plot having plot size of 3mx3m with a spacing 40cmx30cm along with meteorological data from November - February of 2013-2014 and 2014-2015. The data collected were then analyzed statistically to draw the conclusion.

Bio-efficacy of novel insecticides and bio-pesticides
The present experiment was arranged in Randomized Block Design with nine treatments viz. T1- Rynaxypyr 18.5% SC @ 30 g a.i/ ha, T2- Flubendiamide 20% WG @ 40 g a.i/ ha,

T3- Spinetoram 12% SC @ 50g a.i/ ha, T4- Indoxacarb 14.5% SC @ 60 g a.i/ ha, T5- Novaluron 10% EC @ 75 g a.i/ha, T6- Indoxacarb (4.5%SC)+Novaluron (5.25%SC), T7- *Bacillus thuringiensis* var kurstaki @ 1000g/ha, T8- *Beauveria bassiana* @ 1000g/ha and T9-untreated check all of which were replicated four times. The seedlings of variety Pusa Snowball were transplanted in plot size of 3mx3m with a spacing 50cmx40cm during 1st week of November in the year 2013 and 2014. All recommended agronomic practices were followed to raise the crop under irrigated condition. The target pest was DBM and the defenders coccinellids and hymenopteran parasitoids most importantly *Cotesia plutellae*. Two rounds of sprays were imposed on coinciding with the ETL (3larvae/plant) with a high volume of knapsack sprayer. The data on population of pest was counted as number of DBM larvae from 5 randomly selected plants from each plot. Pre-treatment count was taken 1 day before spraying which was followed by observations on pest incidence at 5^{th} and 10^{th} days after spraying (DAS). The larval mortality in each plot was calculated and was subjected to arc sine transformation to normalize the data for statistical analysis.

Effect on defenders in the ecosystem

The population count of important predators like *Coccinella septempunctata* and *Coccinella transversalis;* and parasitized DBM larvae by *Cotesia plutellae* were recorded from same plants on respective dates of observation. Important larval parasitoids, *Cotesia plutellae* were taken at 1 day before treatment and 7 days after treatment from five metre row length and subsequently transformed into $\sqrt{x+0.5}$ for statistical interpretations.

The yield of cabbage was recorded at harvest from each plot and was further calculated to quintals per hectare. The cost benefit ratio was further calculated using the data on yield and that of expenditures.

The mean values after suitable transformation were subjected to ANOVA for interpretation of the results [4]. The data thus collected were subjected to analysis of variance after necessary transformation where ever required.

Results and Discussion

Population fluctuation of DBM with abiotic factors

Table 1 shows the variation in DBM population throughout the season in different weeks after transplanting starting from the first week till the 12^{th} week after transplanting along with that of abiotic factors like temperature (max and min), relative humidity (RH), rainfall and bright sunshine hours (BSSH).

Table 2 gives the correlation coefficient value for abiotic factors and population fluctuation of DBM which revealed that the interaction between DBM x Temp (Max), DBM x Temp (min), DBM x BSSH (hour) were all positively correlated. However, DBM x RH and DBM x total rainfall (mm) were negatively correlated.

Rainfall was reported to dwindle down the population of DBM and so did high humidity [5]. Further, a peak activity of DBM was reported during mid February [6] and this lay support with the finding of present author.

Table 1: Population fluctuation of DBM with abiotic factors over two seasons (2013-2014 and 2014-2015) in cabbage ecosystem of West Bengal RH- Relative humidity BSSH- Bright sunshine hours

Time of observation	2013-2014						2014-2015					
	Max Temp (^{0}C)	Min Temp (^{0}C)	RH (%)	Total Rainfall (mm)	BSSH (hr.)	DBM larva/plant	Max Temp (^{0}C)	Min Temp (^{0}C)	RH (%)	Total Rainfall (mm)	BSSH (hr.)	DBM larva/plant
1WAT	17.49	7.98	91.07	0	8.09	2.75	20.56	10.32	92.04	0	8.05	3.27
2 WAT	18.91	8.17	92.02	0	8.27	3.32	23.41	12.59	92.76	0	8.32	4.12
3 WAT	19.43	8.22	92.17	0	8.29	3.98	25.98	13.81	93.61	0	8.91	5.79
4 WAT	24.37	10.18	94.50	0	8.35	4.75	26.33	14.93	94.90	0	8.45	6.31
5 WAT	27.2	10.84	96.00	0	8.69	6.75	26.80	14.06	96.34	0	8.42	6.78
6 WAT	27.9	14.71	93.86	0	8.56	10.25	27.88	14.97	95.15	0	8.99	8.56
7 WAT	24.4	13.43	96.86	2.77	6.76	4.00	28.02	15.21	94.19	0	8.78	10.13
8 WAT	28.74	16.09	94.86	0	7.2	7.75	29.32	15.76	94.04	0	8.56	12.78
9 WAT	29.01	16.03	94.71	0	8.76	12.75	29.04	16.04	93.41	0	8.90	13.82
10 WAT	32.14	17.33	90.29	0	8.44	13.50	31.21	16.84	93.92	0	8.64	14.09
11 WAT	34.33	18.07	86.86	0	9.33	15.00	27.27	17.29	96.88	1.76	7.01	8.81
12 WAT	34.69	21.31	96.40	0	7.88	12.50	25.02	18.41	97.04	2.61	6.61	7.23

Table 2: Correlation of DBM incidence with abiotic factors (2013-2014 and 2014-2015)

Pest studied	2013-2014					2013-2014				
	Temperature		RH (%)	Total Rainfall (mm)	BSSH (hr)	Temperature		RH (%)	Total Rainfall (mm)	BSSH (hr)
	Max Temp (^{0}C)	Min Temp (^{0}C)				Max Temp (^{0}C)	Min Temp (^{0}C)			
Diamond back moth (*Plutella xylostella* Linn)	0.90	0.78	-0.67	-0.53	0.61	0.91	0.65	- 0.56	- 0.76	0.26

Table 3: Evaluation of relative toxicity of novel insecticides and bio-pesticides against DBM in cabbage (2013-2014 and 2014-2015)

Treatments	Dose g/ g a.i/ha	2013-2014						2014-2015						Overall mean % increase or decrease
		Pretreatment count (no. of DBM larvae/plant)*	First spray Percent reduction/increase (+) after spray**		Second spray Percent reduction/increase(+) after spray**		Mean Percent reduction/increase(+) after spray	Pretreatment count(no. of DBM larvae/plant)*	First spray Percent reduction/increase (+) after spray**		Second spray Percent reduction/increase (+) after spray**		Mean Percent reduction/ increase (+) after spray	
			5 DAS	10 DAS	5 DAS	10 DAS			5 DAS	10 DAS	5 DAS	10 DAS		
Rynaxypyr 18.5% SC	30	6.53 (2.65)	95.60 (77.89)	92.80 (74.44)	100.00 (90.00)	97.21 (80.39)	96.40	10.24 (3.28)	92.19 (88.43)	88.43 (70.09)	98.17 (82.19)	95.18 (77.29)	93.49	94.95
Flubendiamide 20% WG	40	6.17 (2.58)	93.40 (75.11)	89.90 (71.47)	100.00 (90.00)	96.12 (78.64)	94.86	13.66 (3.76)	86.63 (79.09)	79.09 (62.76)	96.92 (79.86)	91.53 (73.05)	88.54	91.70
Spinetoram 11.7 % SC	50	6.75 (2.69)	89.20 (70.81)	90.50 (72.05)	96.43 (79.11)	94.34 (76.24)	92.62	11.21 (3.42)	82.09 (81.54)	81.54 (64.53)	92.76 (74.36)	91.08 (72.59)	86.87	90.75
Indoxacarb 14.5% SC	60	6.37 (2.62)	81.65 (64.64)	83.55 (66.07)	86.27 (68.25)	84.14 (66.53)	83.90	14.15 (3.83)	72.84 (73.12)	73.12 (58.75)	79.16 (62.81)	78.42 (62.29)	75.89	79.90
Novaluron 10% EC	75	6.63 (2.67)	77.60 (61.75)	81.20 (64.30)	65.40 (53.97)	70.80 (57.29)	73.75	11.38 (3.45)	72.23 (78.69)	78.69 (62.48)	73.87 (59.23)	76.49 (60.97)	75.32	74.54
Indoxacarb (4.5%SC)+Novaluron (5.25%SC)	80	6.27 (2.60)	92.50 (74.11)	90.30 (71.85)	93.25 (74.94)	92.10 (73.68)	92.04	9.65 (3.19)	89.12 (88.71)	88.71 (70.34)	94.12 (75.94)	94.05 (75.85)	91.50	91.77
Bacillus thuringiensis var kurstaki	1000g	6.03 (2.56)	54.67 (47.68)	46.55 (43.02)	59.50 (50.48)	62.56 (52.27)	55.82	8.79 (3.05)	51.87 (45.91)	45.91 (42.64)	57.94 (49.55)	61.98 (51.91)	54.35	55.09
Beauveria bassiana	1000g	5.93 (2.54)	32.02 (34.46)	29.74 (33.05)	33.13 (35.14)	34.05 (35.70)	32.24	12.09 (3.55)	28.76 (23.85)	23.85 (29.22)	29.05 (32.60)	31.37 (34.05)	28.26	30.25
Untreated control	-	6.17 (2.58)	(+)25.30 (0.00)	(+)36.80 (0.00)	(+)27.50 (0.00)	(+)35.31(0.00)	(+)31.23	13.01 (3.68)	(+)21.09 (0.00)	(+)32.63 (0.00)	(+)31.99 (0.00)	(+)38.18 (0.00)	(+)30.97	(+)31.10
S.Em ±	-	-	3.48	4.03	2.45	1.89								
CD at 5%	-	NS	1.32	0.97	1.57	1.03								

*- square root transformed values in parentheses **- angular transformed values in parentheses

Table 4: Effect of test chemicals and biopesticides on natural enemies of cabbage ecosystem (2013-2014 and 2014-2015)

Treatments	Dose g or g a.i/ha	2013-2014								2014-2015							
		Pretreatment count of natural enemies/ 5 metres row length				Population of natural enemies/5 metre row length 7 days after treatment				Pretreatment count of natural enemies/ 5 metres row length				Population of natural enemies/5 metre row length 7 days after treatment			
		Predators*			Parasitoid**	Predators*			Parasitoid**	Predators*			Parasitoid**	Predators*			Parasitoids**
		Coccinellid	Spider	Syrphid	% parasitization	Coccinellid	Spider	Syrphid	% parasitizati-on	Coccinellid	Spider	Syrphid	% parasitization	Coccinellid	Spider	Syrphid	% parasitizati-on
Rynaxypyr 18.5% SC	30	5.67 (2.48)	3.00 (1.87)	1.33 (1.35)	5.63 (13.72)	6.00 (2.55)	2.33 (1.68)	1.67 (1.47)	5.09 (13.03)	8.00 (2.92)	1.33 (1.35)	0.33 (0.91)	4.08 (11.65)	6.67 (2.68)	1.67 (1.47)	0.67 (1.08)	3.67 (11.04)
Flubendiamide 20% WG	40	6.33 (2.61)	7.33 (2.80)	2.00 (1.58)	7.67 (16.07)	6.00 (2.55)	6.67 (2.68)	1.67 (1.47)	6.21 (14.42)	6.67 (2.68)	2.67 (1.78)	0.67 (1.08)	2.78 (9.59)	6.00 (2.55)	2.33 (1.68)	0.33 (0.91)	2.66 (9.38)
Spinetoram 11.7% SC	50	4.67 (2.27)	6.67 (2.68)	1.00 (1.22)	3.00 (9.97)	4.33 (2.20)	6.33 (2.61)	1.00 (1.22)	2.33 (8.78)	7.33 (2.80)	1.00 (1.22)	0.33 (0.91)	3.56 (10.87)	6.33 (2.61)	0.67 (1.08)	0.00 (0.71)	3.47 (10.73)
Indoxacarb 14.5% SC	60	7.33 (2.80)	4.00 (2.12)	2.33 (1.68)	2.67 (9.40)	7.00 (2.74)	3.67 (2.04)	2.00 (1.58)	2.87 (9.75)	4.00 (2.12)	3.33 (1.96)	0.00 (0.71)	3.67 (11.04)	4.33 (2.20)	3.67 (2.04)	0.33 (0.91)	4.01 (11.55)
Novaluron 10% EC	75	5.00 (2.35)	7.00 (2.74)	2.00 (1.58)	4.00 (11.53)	5.67 (2.48)	7.33 (2.80)	2.33 (1.68)	3.70 (11.09)	5.67 (2.48)	2.00 (1.58)	1.33 (1.35)	4.61 (12.39)	6.00 (2.55)	2.00 (1.58)	1.33 (1.35)	4.67 (12.48)
Indoxacarb (4.5%SC)+Novaluron (5.25%SC)	80	5.33 (2.41)	2.33 (1.68)	3.00 (1.87)	5.33 (13.34)	4.67 (2.27)	2.00 (1.58)	1.67 (1.47)	4.21 (11.84)	8.33 (2.97)	1.67 (1.47)	0.67 (1.08)	3.89 (11.37)	7.00 (2.74)	2.00 (1.58)	0.00 (0.71)	3.61 (10.95)
Bacillus thuringiensis var kurstaki	1000g	6.00 (2.55)	3.67 (2.04)	1.33 (1.35)	3.39 (10.61)	6.67 (2.68)	4.33 (2.20)	2.67 (1.78)	4.89 (12.77)	4.67 (2.27)	3.00 (1.87)	1.67 (1.47)	4.32 (11.99)	6.33 (2.61)	3.67 (2.04)	2.00 (1.58)	4.56 (12.33)
Beauveria bassiana	1000g	2.67 (1.78)	6.33 (2.61)	0.67 (1.08)	4.67 (12.48)	4.33 (2.20)	6.33 (2.61)	1.33 (1.35)	2.67 (9.40)	5.00 (2.35)	3.33 (1.96)	0.00 (0.71)	1.67 (7.42)	5.33 (2.41)	4.33 (1.67)	1.67 (1.47)	2.67 (9.40)
Untreated control	-	4.33 (2.20)	5.00 (2.35)	2.33 (1.68)	3.23 (10.35)	5.67 (2.48)	6.00 (2.55)	3.00 (1.87)	5.00 (12.92)	5.33 (2.41)	2.00 (1.58)	1.33 (1.35)	2.03 (8.19)	7.00 (2.74)	3.67 (2.33)	2.33 (1.68)	3.69 (11.07)
S.Em ±	-																
CD at 5%	-																

*- square root transformed values in parentheses **- angular transformed values in parentheses

Table 5: Yield of cabbage and economics of different treatment schedules of novel insecticides and biopesticides against DBM during 2013-2014 and 2014-2015

Treatments	Dose (g or g a.i/ha)	Cabbage yield (quintals/ha)								Cost of treatments including labour charges (`/ha)	Gross realization (`/ha)	Net realization (`/ha)	Net profit (`/ha)	Benefit Cost Ratio
		2013-2014			2014-2015			Mean marketable yield	Percentage increase in yield over control					
		Total yield	Marketable yield	% yield reduction	Total yield	Marketable yield	% yield reduction							
Rynaxypyr 18.5% SC	30	550.50 (23.47)	542.60 (23.30)	1.44	543.20 (23.32)	531.09 (23.06)	2.23	536.85	76.02	49250	586095	536845	487595	9.90:1
Flubendiamide 20% WG	40	535.65 (23.15)	521.40 (22.85)	2.66	522.68 (22.87)	502.65 (22.43)	3.83	512.03	74.85	51200	563225	512025	460825	9.00:1
Spinetoram 11.7% SC	50	530.55 (23.04)	513.65 (22.67)	3.19	519.13 (22.80)	497.96 (22.33)	4.08	505.81	74.55	48000	553805	505805	457805	9.54:1
Indoxacarb 14.5% SC	60	500.40 (22.38)	459.40 (21.45)	8.19	490.32 (22.15)	448.88 (21.20)	8.45	454.14	71.65	47400	501540	454140	406740	8.58:1
Novaluron 10% EC	75	463.50 (21.54)	389.50 (19.75)	15.97	441.90 (21.03)	373.05 (19.33)	15.58	381.28	66.23	47500	428775	381275	333775	7.03:1
Indoxacarb (14.5%SC)+Novaluron (5.25%SC)	80	521.60 (22.85)	496.90 (22.30)	4.74	498.04 (22.33)	469.12 (21.67)	5.81	483.01	73.34	46250	529260	483010	436760	9.44:1
Bacillus thuringiensis var kurstaki	1000g	408.00 (20.21)	278.75 (16.71)	31.67	380.92 (19.53)	278.91 (16.72)	26.78	278.83	53.82	46000	324830	278830	232830	5.06:1
Beauveria bassiana	1000g	375.50 (19.39)	225.50 (15.03)	39.94	365.48 (19.13)	236.46 (15.39)	35.30	230.98	44.26	46000	276980	230980	184980	4.02:1
Untreated control	-	175.75 (13.28)	108.60 (10.45)	38.21	256.32 (16.03)	148.89 (12.22)	41.91	128.75	-	44000	172745	128750	84745	1.93:1
S.Em ±	-													
CD at 5%	-													

Data in parentheses are square root transformed values

Market price of cabbage: 1000.00 per quintal (As of 16 March, 2015, Govt. of India. http:// http://agmarknet.nic.in/)

Labour charges (skilled): 222.00 day as per govt. of W.B. Labour Commission Cicular, 2014

Bio-efficacy of novel insecticides and bio-pesticides

The relative toxicity of different insecticides and biopesticides imposed on cabbage has been represented in table 3. The pre-treatment population of DBM larvae varied from 5.93-6.75 per plant in first season and 8.79-14.15 per plant in the second season. The overall mean percentage of larval population reduction reveals that rynaxypyr 18.5% SC @ 30 g a.i/ha provided the highest reduction of DBM larval population upto 10 days (94.95%), closely followed by premix combination formulation of indoxacarb (4.5%SC)+novaluron (5.25%SC) @ 80 g a.i/ha giving 91.77% reduction of population further followed by flubendiamide 20% WG @ 40 g a.i/ha giving 91.70% reduction respectively. The next best management of DBM larvae was achieved from spinetorum 11.7% SC @ 50 g a.i/ha i.e., 90.75% reduction. Indoxacarb and novaluron in combination performed better than when used singly giving 79.90% and 74.54% respectively. Bio-pesticides *Bacillus thuringiensis* var kurstaki and *Beauveria bassiana* were found to give only 55.09% and 30.25% reduction of larval population. Untreated control was found to have an increase of 31.10% larval population.

This observation is supported by the finding in which rynaxypyr is reported as an exceptionally commanding molecule against *Plutella xylostella* [7]. Flubendiamide was reported to perform excellently against *Plutella xylostella, Spodoptera and Helicoverpa* which lends support to present study [8]. Spinetoram 12% SC at 56g a.i., was reported to be very much effective against spotted boll worm followed by high seed and lint yield [9]. These reports are also in conformity with the present findings.

Effect on defenders in the ecosystem

The effect of natural enemies like coccinellids, spiders and syrphids have been studied along with effect on DBM larval parasitoid Cotesia plutellae and has been represented in Table 4. All the imposed test chemicals and bio-pesticides were found to be very soft on natural enemies having little or no effect. Flubendiamide and rynaxypyr were reported to be highly effective against lepidopterans [10, 11] and safe to non-target organisms which are in support of the present findings.

Effect on yield

Yield of green cabbage heads was found to be the maximum in plots treated with rynaxypyr 18.5% SC giving almost 76 % increase in yield over control followed by that of flubendiamide 20%WG >spinetorum 11.7%SC > indoxacarb (14.5%SC)+novaluron (5.25%SC)> indoxacarb 14.5% SC> novaluron 10% EC> *Bacillus thuringiensis* var kurstaki> *Beauveria bassiana*. The highest benefit cost ratio was obtained from rynaxypyr 18.5% SC followed by flubendiamide 20% WG and the least was obtained from that of *Beauveria bassiana*.

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