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Dr. Pratap A Divekar
(1) Division of Crop Protection, ICAR- Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India
(2) ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar, India

Sampat Kumar Patel
ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar, India

Manimurugan C
(1) ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar, India
(2) Division of Crop Improvement, ICAR-Indian Institute of Oilseeds research, Hyderabad, India

Motilal Kushwaha
ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar, India

Vikas Singh
ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar, India

Corresponding Author:
Dr. Pratap A Divekar
(1) Division of Crop Protection, ICAR- Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India
(2) ICAR-IIVR, Regional Research Station, Sargatia, Kushinagar, India

Bio-efficacy of newer insecticides cyantraniliprole and flonicamid for the management of mustard aphid *Lipaphis erysimi* (Kaltenbach) in cabbage

Dr. Pratap A Divekar, Sampat Kumar Patel, Manimurugan C, Motilal Kushwaha and Vikas Singh

Abstract
Mustard aphid, *Lipaphis erysimi* (Kalt.) is a serious insect pest on cabbage. The field experiments were carried out to study the efficacy of insecticides against mustard aphid in cabbage. The efficacy of insecticides namely, cyantraniliprole; flonicamid; diafenthiruon, thiamethoxam, acetamiprid; imidacloprid; thiacloprid and dimethoate were evaluated against mustard aphid, *Lipaphis erysimi* under field conditions at ICAR-Indian Institute of Vegetable Research, Regional Research Station, Sargatia, Kushinagar, India. Over the untreated control, all insecticides were found to be more effective in reducing the aphid population. Diafenthiuron, flonicamid, and cyantraniliprole were found to significantly superior to other insecticides and untreated control in lowering the number of aphids at all the interval of observation giving 80.63, 79.79 and 78.58 percent reduction over control. The insecticides like imidacloprid, thiacloprid and acetamiprid were found relatively less effective causing 65.68, 66.70, 67.79 percent reduction over control. Therefore, we recommend the use of newer molecules cyantraniliprole and flonicamid as an alternative option for effective management of the mustard aphid, *Lipaphis erysimi* (Kalt.) in cabbage.

Keywords: Cabbage, *Lipaphis erysimi*, insecticides, bioefficacy, cyantraniliprole, flonicamid

Introduction
Cabbage (*Brassica oleracea* var. capitata L.) is one of the widely cultivated species of the Brassicaceae family, which is generally consumed as a leafy green vegetable. Although low in calories, cabbage is a good source of dietary fibre, vitamins and minerals. It also stands out for having high concentrations of calcium, iron, iodine, potassium, sulphur and phosphorus. Cabbage is a remarkable nutritional remedy for battling the dreaded disease of cancer because of its anti-cancer features (USDA 2009) [17]. Despite the economic as well as nutritional importance of cabbage, the major bottleneck in cabbage production is the qualitative as well as quantitative losses incurred by the severe infestation of insect pests (Alula and Tesfaye 2021) [1].

The mustard aphid (*Lipaphis erysimi*) (Kalt.) which is prevalent in Eastern Uttar Pradesh, India, cause severe damage to the cabbage crop (Yadav *et al*. 2015) [18]. The most predominant pest of cole crops in India is thought to be the mustard aphid, *Lipaphis erysimi* (Kaltenbach) (Gautam *et al*., 2019) [9]. *Lipaphis erysimi* (Kalt), an aphid that is reportedly a significant pest of cabbage, is one of the pests destroying the crop (Sharma and Bhalla, 1964) [14]. Aphid *Lipaphis erysimi* (Kalt) was assessed to be responsible for a yield loss of 47.1 to 96.0 percent in the cabbage crop (Suri *et al*. 1988) [16]. Despite the existence of environmentally beneficial and sustainable insect control measures like host plant resistance (HPR) (Divekar *et al*. 2019a,b) [3, 4], plant secondary metabolites (Divekar *et al*. 2022a) [6], bio-control agents (Dukare *et al*. 2021) [8] and defence proteins (Divekar *et al*. 2022b) [7], the farmers prefer synthetic insecticides over other options. Due to the lack of access to sustainable management methods, small-scale farmers are finding it difficult to deal with the pests' mounting threat (Divekar *et al*., 2022c) [5].

Selective biodegradable pesticides with minimal negative effects on people and the environment are now more important than ever because of the challenges raised by agrochemicals and their residues (Stevenson *et al*. 2012) [15]. The use of microbial pesticides, plant products, and insecticides that are often safer, more environmentally friendly, and less likely to acquire resistance has increased in recent years (Yadav *et al*. 2015) [18].

It is crucial to use selective insecticides that are also less hazardous to the non-target organisms. It is necessary to look at other strategies, such as the use of biopesticides that are environmentally friendly, effective against a limited number of pest species, and suitable for use in holistic pest control programs (Gupta and Dikshit 2010) [10].

Therefore, in order to manage the mustard aphid in cabbage and reduce the obstacles associated with insect pests and pesticides, it is urgently necessary to identify an effective and environmentally friendly insecticide for sustainable crop protection. The current study aimed to investigate the bio-efficacy of several pesticide compounds against the mustard aphid, *Lipaphis erysimi*, in the cabbage ecosystem.

Materials and Methods

Field efficacy of insecticides against mustard aphid, *L. erysimi* in cabbage

The field experiment was carried out with the cultivation of cabbage variety Golden Acre during the 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). The experiments were performed in a randomized block design (plot size: 4 m ×3 m) with nine treatments including untreated control and the same set of experiments was repeated three times. The crop was grown according to the recommended package of measures, with the exception of protection measures. The treatment details are given in Table 1. In both seasons, 35-day-old cabbage seedlings were transplanted. Insecticidal spray treatments were applied 25 and 40 days after transplantation (DAT) when crossing the ETL of mustard aphids (Opfer and McGrath 2013) [21].

The number of insect pests before treatment was noted one day before insecticide application. The aphid population was estimated using a numerical count (Lal 1998) [10]. Five cabbage plants were randomly selected from each plot and marked. Using a magnifying glass, the total number of aphids on five plants was visually counted and converted into aphids per plant. To count the number of aphids at an early stage of the plant, the leaves were grasped by the petiole with the thumb and four fingers and rotated until the entire underside of the leaf was clearly visible. In the advanced plant growth stage, these observations were only made on the outer bracts. The MA population was recorded on days 1, 3, 7 and 14 after spray application. The percentage reduction in pest population versus control was calculated using the formula of Henderson and Tilton (1955) [19].

Table 1: Insecticide selected for the bioefficacy studies against mustard aphid in cabbage

Sr. No.	Description	Dose (g a.i./ha)	Trade Name	Manufacturer
1	Acetamiprid 20% SP	15	Ekka	Adama India Pvt Ltd
2	Diafenthiuron 50 WP	300	Agas	Syngenta
3	Imidacloprid 17.8% SL	25	Josh	Krishi Rasayan Exports Pvt Ltd
4	Cyantraniliprole 10.26%	60	Benevia	FMC India Pvt Ltd
5	Dimethoate 30% EC	200	Sagar	Aroxa Crop Science Pvt. Ltd.
6	Thiamethoxam 25% WG	25	Actara	Syngenta
7	Thiacloprid 21.7 % SC	72	Gunwaan	Mahadeo Agro
8	Flonicamid 50 % WG	75	Ulala	UPL

Result and Discussion

Efficacy of insecticides against mustard aphid, *Lipaphis erysimi*

The results of the bio-efficacy of selected insecticides against mustard aphid in cabbage are presented in Tables 2-6. The number of mustard aphid populations before treatment was not significant and ranged from 73.13 to 89.80 (F=2.78, p=0.034) during the first season. For the mean mustard aphid population, significant differences were observed between treatments after the first spray and second spray application (F=40.82, p<0.001) and (F=385.80, p<0.001) respectively (Tables 2 and 3). Flonicamid, cyantraniliprole and diafenthiuron were found effective in reducing the population to 18.63, 16.67, 17.85 aphids per plant after first spray and 4.27, 3.68, 3.92 aphids per plant after second spray, respectively. Higher reduction in mustard aphid population was noted after the application of cyantraniliprole 10.26% OD (82.42%) followed by diafenthiuron 20% SP (81.36%) followed by flonicamid 50% WG (80.34%) and over the untreated control during season 1. The less reduction in mustard aphid population was recorded after the application of thiacloprid 21.70% SC (64.60%) followed by Imidacloprid 17.8 % SL (64.73%), followed by acetamiprid 20% SP (66.83%) in comparison to untreated control during season 1.

The results of the bio efficacy of selected insecticides against mustard aphids in cabbage during season 2 are presented in Tables 4 and 5. The number of mustard aphids before treatment was not significant and ranged from 69.73 to 75.13 (F=1.42, p=0.254) during season 2. Significant differences were observed for the mean mustard aphid population between treatments after the first and second spray application (F=101.48, p<0.001) and (F=349.25, p<0.001) (Tables 4 and 5). Flonicamid, cyantraniliprole and diafenthiuron were found effective in reducing the population to 14.08, 16.70, 17.47 after first spray and 3.43, 3.82, 5.03 aphids per plant, respectively. Higher percent reduction in mustard aphid population was noted after the application of flonicamid 50% WG (79.23%), followed by cyantraniliprole 10.26% OD (78.83%) followed by diafenthiuron 20% SP (75.81%) over the untreated control during season 2. The less reduction in mustard aphid population was recorded after the application of Imidacloprid 17.8 % SL (66.63%) followed by acetamiprid 20% SP (68.75%) followed by thiacloprid 21.70% SC (68.80%) in comparison to untreated control during season 2.

All the insecticides were found effective in reducing the aphid population over the untreated control. Results of pooled data clearly revealed that the reduction of mustard aphid after the application of cyantraniprole 10.26% OD (80.63 percent reduction over control) and flonicamid 50% WG (79.97 percent reduction over control) treatments found significantly superior to control at all the interval of observation. Insecticides namely, imidacloprid 17.8% SL (65.68 percent reduction over control), acetamiprid 20% SP (65.68 percent reduction over control) are found less effective in managing

the mustard aphid in cabbage (Table 6).

Flonicamid 50 WG was found effective aginst sucking pest like jassids, whiteflies in comparison to conventional pesticides namely dimethoate, imidacloprid, thiamethoxam (Kodandaram et al., 2017a) [12]. Cyantraniliprole 10 OD @ 90 and 75 g a.i. ha-1 recorded the lowest mean population of sucking pests (thrips, whiteflies and aphids) after two rounds of spraying ten days apart on potatoes compared to dimethoate and thiamethoxam. Cyantraniliprole 10 OD at 90 and 75 g a.i. ha-1 recorded a yield increase of 34.11 and 32.42% respectively compared to the untreated control (Bhojan, 2021) [2]. Patel *et al*., 2014 [13] reported that cyantraniliprole 10% OD @ 90 and 105 g a.i./ha, has been shown to be extremely effective in controlling the population of sucking pests such as aphids, thrips and whitefly in cotton. Cottonseed yield was also significantly higher with cyantraniliprole 10% OD treatments at 90 (31.97 q/ha) and 105 (33.33 q/ha) g a.i./ha, an increase of 50.80 and 52.81, respectively percent compared to the untreated control. Kodandaram et al., 2017b [11] reported that cyantraniliprole 10 OD @ 60 g ai/ha was highly effective in controlling DBM, Plutella xylostella; painted bug, Bagrada hilaris and all the aphid species namely, Brevicorne brassicae, Myzus persicae and Lipaphis erysimi in cruciferous vegetables.

Table 2: Effect of insecticides on the mustard aphid, L. erysimi in terms of reduction in population in cabbage during season 1 after first spray

Treatment	Dose (a.i. g/ha)	PTC	Mustard aphid, *Lipaphis erysimi* population				Mean*	Percent Reduction over Control (PROC)				Mean PROC**
			1 DAS	3 DAS	7 DAS	14 DAS		1 DAS	3 DAS	7 DAS	14 DAS	
Acetamiprid 20% SP	15	85.00a	20.60ab	14.67bc	29.60c	39.00d	25.97a	73.59	82.09	65.94	56.38	69.50
Diafenthiuron 50 WP	300	79.40a	17.87a	10.40ab	18.07a	25.07a	17.85a	75.48	86.41	77.74	69.99	77.40
Imidacloprid 17.8% SL	25	82.93a	27.00d	18.33a	25.20bc	34.60cd	26.28a	64.52	77.06	70.28	60.34	68.05
Cyantraniliprole 10.26%	60	85.07a	17.80a	9.47a	17.13a	22.27a	16.67a	77.20	88.45	80.30	75.12	80.27
Dimethoate 30% EC	200	73.13a	23.20bc	17.07c	22.20ab	30.07bc	23.13a	65.43	75.78	70.31	60.92	68.11
Thiamethoxam 25% WG	25	88.27a	25.53cd	15.13bc	26.67bc	30.53bc	24.47a	68.47	82.21	70.45	67.12	72.06
Thiacloprid 21.7 % SC	72	75.80a	25.40cd	17.80c	28.40c	36.93d	27.13a	63.48	75.63	63.35	53.68	64.04
Flonicamid 50 % WG	75	82.73a	20.20ab	8.00a	20.13a	26.20ab	18.63a	73.39	89.97	76.19	64.38	75.98
Untreated Control	-	89.80a	82.40e	86.53d	91.80d	94.47e	88.80b	-	-	-	-	-
F		2.784	301.84	239.92	215.66	209.397	40.82	-	-	-	-	-
P		0.034	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	-

PTC-Pre-treatment Count, PROC-percent reduction over control, * Mean aphid population after 1, 3, 7 and 14 days after spraying, **PROC after 1, 3, 7 and 14 days after spraying. Data are means of three replications. Means in the same column followed by different letters differ significantly ($p< 0.05$) on the basis Duncan's Multiple Range Test (DMRT) test.

Table 3: Effect of insecticides on the mustard aphid, *L. erysimi* in terms of reduction in population in cabbage during season 1 after second spray

Treatment	Dose (a.i. g/ha)	Mustard aphid, *Lipaphis erysimi* population				Mean*	Percent Reduction over Control (PROC)				Mean PROC**
		1 DAS	3 DAS	7 DAS	14 DAS		1 DAS	3 DAS	7 DAS	14 DAS	
Acetamiprid 20% SP	15	14.60c	12.77c	14.77c	16.87bc	14.75c	62.22	68.85	64.93	60.67	64.17
Diafenthiuron 50 WP	300	3.40a	1.73a	4.00a	6.53a	3.92a	86.31	93.42	85.22	76.29	85.31
Imidacloprid 17.8% SL	25	14.07c	11.47c	14.33c	16.53bc	14.10bc	58.97	68.46	61.63	56.54	61.40
Cyantraniliprole 10.26%	60	2.20a	1.47a	3.47a	7.60a	3.68a	90.03	93.73	85.58	68.96	84.57
Dimethoate 30% EC	200	9.00b	6.60b	9.53b	13.93b	9.77b	69.79	79.11	70.63	57.85	69.35
Thiamethoxam 25% WG	25	9.53b	6.80b	8.80b	16.27bc	10.35bc	68.49	78.81	73.31	51.55	68.04
Thiacloprid 21.7 % SC	72	12.20bc	10.27bc	12.27bc	19.80c	13.63bc	66.66	73.55	69.24	51.24	65.17
Flonicamid 50 % WG	75	3.53a	2.20a	4.33a	7.00a	4.27a	86.39	92.01	84.68	75.70	84.70
Untreated Control	-	93.60d	99.27d	102.00d	103.87d	99.68d	-	-	-	-	-
F		727.07	681.42	629.62	456.19	385.802	-	-	-	-	-
P		<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	-

PROC-percent reduction over control, * Mean aphid population after 1, 3, 7 and 14 days after spraying, **PROC after 1, 3, 7 and 14 days after spraying. Data are means of three replications. Means in the same column followed by different letters differ significantly ($p< 0.05$) on the basis Duncan's Multiple Range Test (DMRT) test.

Table 4: Effect of insecticides on the mustard aphid, *L. erysimi* in terms of reduction in population in cabbage during season 2 after first spray

Treatment	Dose (a.i. g/ha)	PTC	Mustard aphid, *Lipaphis erysimi* population				Mean*	Percent Reduction over Control (PROC)				Mean PROC**
			1 DAS	3 DAS	7 DAS	14 DAS		1 DAS	3 DAS	7 DAS	14 DAS	
Acetamiprid 20% SP	15	70.20a	24.60b	17.27b	21.80cd	26.80c	22.62cd	63.15	75.38	70.58	64.69	68.45
Diafenthiuron 50 WP	300	70.93a	21.67ab	11.60a	16.47b	20.13b	17.47abc	67.88	83.63	78.00	73.75	75.82
Imidacloprid 17.8% SL	25	71.00a	24.73b	19.60b	23.40cd	27.07c	23.70d	63.36	72.37	68.77	64.74	67.31

Cyantraniliprole 10.26%	60	72.00a	20.73ab	11.40a	15.87b	18.80b	16.70ab	69.72	84.15	79.12	75.85	77.21
Dimethoate 30% EC	200	72.47a	23.40b	19.53b	23.80d	25.93c	23.17cd	66.04	73.02	68.88	66.90	68.71
Thiamethoxam 25% WG	25	75.13a	23.80b	16.20b	20.60c	25.00c	21.40bcd	66.69	78.42	74.02	69.23	72.09
Thiacloprid 21.7 % SC	72	69.73a	22.87b	19.07b	24.13d	26.53c	23.15cd	65.51	72.63	67.21	64.81	67.54
Flonicamid 50 % WG	75	70.40a	18.40a	9.80a	13.00a	15.13a	14.08a	72.51	86.07	82.50	80.12	80.30
Untreated Control	-	74.60a	70.93c	74.53c	78.73e	80.67d	76.22e	-	-	-	-	-
F		1.422	185.04	365.32	484.13	302.68	101.489	-	-	-	-	-
P		0.254	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	-

PTC-Pre-treatment Count, PROC-percent reduction over control, * Mean aphid population after 1, 3, 7 and 14 days after spraying, **PROC after 1, 3, 7 and 14 days after spraying. Data are means of three replications. Means in the same column followed by different letters differ significantly ($p< 0.05$) on the basis Duncan's Multiple Range Test (DMRT) test.

Table 5: Effect of insecticides on the mustard aphid, *L. erysimi* in terms of reduction in population in cabbage during season 2 after second spray

Treatment	Dose (a.i. g/ha)	Mustard aphid, *Lipaphis erysimi* population				Mean*	Percent Protection over Control				Mean PROC**
		1 DAS	3 DAS	7 DAS	14 DAS		1 DAS	3 DAS	7 DAS	14 DAS	
Acetamiprid 20% SP	15	9.13b	5.67cd	7.53e	12.00b	8.58bc	64.48	79.68	73.59	58.44	69.05
Diafenthiuron 50 WP	300	5.67a	3.13ab	4.60bc	6.73a	5.03ab	70.67	85.04	78.54	68.96	75.80
Imidacloprid 17.8% SL	25	10.73b	6.60d	8.33e	12.40b	9.52c	58.67	76.56	71.08	57.48	65.95
Cyantraniliprole 10.26%	60	3.80a	1.87a	3.20ab	6.40a	3.82a	78.93	90.46	84.01	68.40	80.45
Dimethoate 30% EC	200	8.53b	4.00bc	5.53cd	11.87b	7.48abc	65.71	85.17	79.95	57.53	72.09
Thiamethoxam 25% WG	25	8.60b	4.93bcd	6.80de	13.93b	8.57bc	64.15	81.03	74.45	48.27	66.97
Thiacloprid 21.7 % SC	72	8.20b	5.60cd	7.73e	11.40b	8.23bc	67.79	79.71	72.62	60.12	70.06
Flonicamid 50 % WG	75	3.40a	1.53a	2.80a	6.00a	3.43a	76.58	90.26	82.62	63.20	78.17
Untreated Control	-	77.40c	80.73e	82.60f	83.60e	81.08d	-	-	-	-	-
F		815.92	1879.66	2242.82	708.94	349.259	-	-	-	-	-
P		<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	-

PROC-percent reduction over control, * Mean aphid population after 1, 3, 7 and 14 days after spraying, **PROC after 1, 3, 7 and 14 days after spraying. Data are means of three replications. Means in the same column followed by different letters differ significantly ($p<0.05$) on the basis Duncan's Multiple Range Test (DMRT) test.

Table 6: Pooled data of insecticides showing percent protection over control during season 1 and season 2.

Treatment	Season 1		Average*	Season 2		Average*	Pooled mean**
	First spray	Second spray		First spray	Second spray		
Acetamiprid 20% SP	69.50	64.17	66.83	68.45	69.05	68.75	67.79
Diafenthiuron 50 WP	77.40	85.31	81.36	75.82	75.80	75.81	78.58
Imidacloprid 17.8% SL	68.05	61.40	64.73	67.31	65.95	66.63	65.68
Cyantraniliprole 10.26%	80.27	84.57	82.42	77.21	80.45	78.83	80.63
Dimethoate 30% EC	68.11	69.35	68.73	68.71	72.09	70.40	69.56
Thiamethoxam 25% WG	72.06	68.04	70.05	72.09	66.97	69.53	69.79
Thiacloprid 21.7 % SC	64.04	65.17	64.60	67.54	70.06	68.80	66.70
Flonicamid 50 % WG	75.98	84.70	80.34	80.30	78.17	79.23	79.79
Untreated Control	-	-	-	-	-	-	-

*Mean PROC after first and second spray. ** Mean PROC after two sprays of the study duration.

Conclusion

Insecticides molecules namely cyantraniliprole 10.26% OD and flonicamid 50% WG were found highly effectivce against the mustard aphid, *Lipaphis erysimi* in cabbage ecosystem. The conventional insecticides like acetamiprid 20% SP, imidacloprid 17.8 % SL and thiacloprid 21.7 % SC were found less effective against *L. erysimi* in comparison to the newer molecules cyantraniliprole and flonicamid. Therefore, we recommend the application of cyantraniliprole 10.26% OD and flonicamid 50% WG alternative for the management of mustard aphid, *Lipaphis erysimi* in cabbage.

Author Contributions

Conceptualization: PAD; formal analysis: PAD; investigation: PAD, MK and SKP; data curation: PAD and MC; writing-original draft preparation: PAD and SKP; writing review and editing: PAD, MC and VS; supervision: MC, VS. All authors have read and agreed to the published version of the manuscript.

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