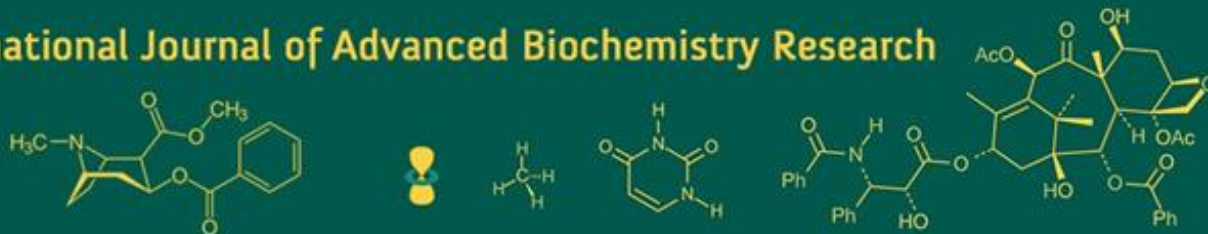


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Efficacy of biopesticides against mustard aphid *Lipaphis erysimi* (Kaltenbach) on mustard

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Abstract

The present investigation evaluated the bio-efficacy of different biopesticides against mustard aphid, *Lipaphis erysimi* (Kaltenbach), in the field during Rabi 2023-24 and 2024-25 at Navsari, Gujarat. Seven biopesticides, viz., *Metarhizium anisopliae*, *Beauveria bassiana*, *Lecanicillium lecanii*, custard apple leaf extract, azadirachtin, neem seed kernel extract (NSKE) and Novel Plus, were evaluated along with an untreated control. Among all treatments, azadirachtin (1500 ppm) @ 0.00075 percent was the most effective treatment, recording the lowest aphid population (46.83 aphids/10 cm central twig), followed by NSKE @ 5 percent (54.41 aphids/10 cm central twig) and *L. lecanii* @ 0.007 percent (54.85 aphids/10 cm central twig). Azadirachtin also recorded the highest pooled seed yield (1600.00 kg/ha), followed by NSKE (1586.33 kg/ha) and *L. lecanii* (1557.00 kg/ha), compared with 928.50 kg/ha in the control. The highest increase in seed yield over control was recorded with azadirachtin (72.31%), followed by NSKE (70.91%) and *L. lecanii* (67.78%). The pooled avoidable yield loss was 41.96, 41.49 and 40.40 percent with azadirachtin, NSKE and *L. lecanii*, respectively. Overall, azadirachtin, NSKE and *L. lecanii* emerged as the most promising biopesticides for effective and sustainable management of mustard aphid in the field.

Keywords: *Lipaphis erysimi*, mustard, aphid, biopesticides, azadirachtin, management, neem seed kernel extract

1. Introduction

Oilseed crops constitute an important component of Indian agriculture and contribute substantially to the country's agricultural production and edible oil requirements (Dodiya and Barad, 2022)^[1, 2]. Among the oilseed crops, rapeseed-mustard occupies a prominent position and is cultivated extensively during the Rabi season under both irrigated and rainfed conditions. Indian mustard, *Brassica juncea* L. (Zern. & Coss ex Coss), is one of the major cultivated species of the rapeseed-mustard group and is widely grown in different parts of India. The crop requires cool and dry weather during its growing period and is generally cultivated from September-October to February-March ([4] Rahman, 2002; [1] Khavse et al., 2014; [6] Anonymous, 2024)^[3, 5, 6]. Mustard is an important source of edible oil and provides considerable nutritional and economic value. Its seeds generally contain about 37-49 percent oil, while mustard oil is widely used as an edible oil, condiment and in several industrial and pharmaceutical applications ([7] Bhowmik et al., 2014; [8] Barfa et al., 2016; [9] [10] Dharavath et al., 2017 Dodiya et al., 2025)^[7, 8, 9]. However, productivity of mustard is constrained by several biotic factors, particularly insect pests, which attack the crop at different stages of growth. More than 38 insect pest species have been reported to be associated with mustard in India. Among these, the mustard aphid, *Lipaphis erysimi* (Kaltenbach), is considered one of the most destructive and economically important pests ([11] Bakhietia and Sekhon, 1989; [5] Patel et al., 2019)^[11, 12].

The mustard aphid, *L. erysimi* (Hemiptera: Aphididae), is an important yield-limiting pest of mustard and has been reported to cause avoidable yield losses ranging from 10.20 to 61.10 percent (Dhillon et al., 2022)^[13]. Depending upon the crop growth stage, aphid population buildup and prevailing agroclimatic conditions, the extent of damage may vary considerably ([15] Rana, 2005; [17] Singh and Sharma, 2009; [18] Chaudhary et al., 2022; [20] Patel et al., 2024; [1] Dodiya et al., 2024)^[16, 18, 19, 21, 14]. Management of mustard aphid is essential for minimizing yield losses. Although synthetic insecticides provide effective control, their repeated use may adversely affect non-target organisms and the environment (Dodiya et al., 2023)^[10, 14]. Therefore, biopesticides have gained importance as eco-friendly alternatives that can reduce dependence on conventional repeated use may adversely affect non-target organisms and the environment (Dodiya et al., 2023)^[10, 14].

Therefore, biopesticides have gained importance as eco-friendly alternatives that can reduce dependence on conventional insecticides and support sustainable integrated pest management. The efficacy of biopesticides against *L. erysimi* may vary with the type and concentration of biopesticide, environmental conditions and pest population. Hence, field evaluation of different biopesticides is necessary to identify effective treatments for aphid suppression. Therefore, the present investigation was undertaken to evaluate the bio-efficacy of different biopesticides against mustard aphid, *L. erysimi*, under field conditions.

2. Materials and Methods

A field experiment was conducted to evaluate the bio-efficacy of different biopesticides against mustard aphid, *Lipaphis erysimi* (Kaltenbach), at the College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, during *Rabi* 2023-24 and 2024-25. Mustard variety GDM 4 was used for the experiment. The experiment was laid out in a Randomized Complete Block Design (RCBD) with eight treatments and three replications.

2.1 Biopesticide treatments and application

Eight treatments comprising seven biopesticides and an untreated control were evaluated. The treatments included *Metarhizium anisopliae* 1.15 WP (1 × 10⁶ cfu/g)^[22] @ 0.007 percent (60 g/10 L water), *Beauveria bassiana* 1.15 WP (1 × 10⁶ cfu/g) @ 0.007 per* cent (60 g/10 L), *Lecanicillium lecanii* 1.15 WP (1 × 10⁶ cfu/g) @ 0.007 percent (60 g/10^[22] L), custard apple leaf extract (*Annona reticulata* L.) @ 10 percent (1000 ml/10 L), azadirachtin (1500 ppm) @ 0.00075 percent (50 ml/10 L), neem seed kernel extract @ 5 percent (500 g/10 L), Novel plus @ 2 percent (200 ml/10 L) and water spray as control.

The crop was sown on 27th November 2023 and 20th November 2024 during *Rabi* 2023-24 and 2024-25, respectively. All recommended agronomic practices were followed throughout the crop period. Biopesticides were applied as foliar sprays using a 15 L capacity knapsack sprayer. The first spray was applied at the appearance of the aphid population, followed by a second spray 15 days after the first application. Care was taken to avoid spray drift and ensure uniform coverage of the crop.

2.2 Assessment of aphid population

The efficacy of the treatments was assessed by recording the aphid population before spraying and at 1, 3, 7 and 14 days after each spray. Five randomly selected and tagged plants were used for observations in each net plot. Aphids were counted on the top 10 cm portion of the central twig of each selected plant, following the method described by Pradhan *et al.* (1960)^[23, 24] and Mathur and Singh (1986)^[25, 26]. The observations were recorded with minimum disturbance to the aphid population.

2.3 Seed yield and avoidable yield loss

At physiological maturity, each plot was harvested separately and the produce was threshed and cleaned. Seed yield was recorded on a net plot basis and converted to kg/ha. The percentage increase in seed yield over control was calculated as:

$$\text{Yield increase over control (\%)} = \frac{T - C}{C} \times 100$$

where T = seed yield of the respective treatment (kg/ha) and C = seed yield in control (kg/ha).

The avoidable yield loss due to mustard aphid was estimated according to Khosla (1977)^[20, 21] using:

$$\text{Avoidable yield loss} = \frac{Y_t - Y_c}{Y_t} \times 100$$

where Y_t = seed yield in the effective treatment and Y_c = seed yield in the control.

2.4 Statistical analysis

The data on aphid population recorded before treatment and at 1, 3, 7 and 14 days after application were subjected to analysis of variance following the RCBD procedure. Aphid population data were subjected to square-root transformation before statistical analysis. Treatment-wise observations were analysed for individual observation periods as well as pooled over observation periods and years. The experimental data were analysed using the analysis of variance procedure described by Steel and Torrie (1980)^[27, 28].

3. Results and Discussion

3.1 Bio-efficacy of biopesticides against mustard aphid, *L. erysimi*

3.1.1 First season (*Rabi* 2023-24)

The results of the bio-efficacy of different biopesticides against *L. erysimi* during the first spray and second spray of *Rabi* 2023-24 are presented in Table 1 and illustrated in Fig. 1. The pre-treatment aphid population was statistically comparable among the treatments, indicating uniform pest infestation before application. Following both sprays, all the biopesticide treatments significantly reduced the aphid population compared with the untreated control, although their efficacy varied among treatments and observation periods. The data for the first spray are presented in Table 1, while the second-spray observations are included in the same table for comparison.

Among the treatments, azadirachtin (1500 ppm) @ 0.00075% consistently recorded the lowest aphid population, followed by neem seed kernel extract (NSKE) @ 5% and *L. lecanii* 1.15 WP @ 0.007%. During the first spray, azadirachtin recorded 113.33, 78.33, 57.00 and 76.33 aphids per 10 cm central twig at 1, 3, 7 and 14 DAS, respectively, compared with 173.33, 175.00, 190.33 and 241.67 aphids in the untreated control. A similar trend was observed after the second spray, where azadirachtin remained the most effective treatment. *L. lecanii* and NSKE were the next most effective treatments, whereas custard apple leaf extract @ 10% was comparatively less effective.

The pooled analysis over the two sprays during 2023-24 further confirmed the superiority of azadirachtin, which recorded the lowest aphid population (45.33 aphids/10 cm central twig), followed by NSKE (54.56 aphids/10 cm central twig) and *L. lecanii* (55.90 aphids/10 cm central twig). Novel plus, *B. bassiana* and *M. anisopliae* recorded 95.74, 103.13 and 105.80 aphids per 10 cm central twig, respectively, while custard apple leaf extract recorded 142.30 aphids. The untreated control recorded the highest population (217.06 aphids/10 cm central twig). These pooled results are presented in Table 1 and Fig. 1.

3.1.2 Second season (*Rabi* 2024-25)

The results obtained during *Rabi* 2024-25 are presented in Table 2 and Fig. 1. The pretreatment aphid population during the first

spray ranged from 140.67 to 190.67 aphids per 10 cm central twig and did not differ significantly among treatments, indicating uniform infestation before spraying.

Similar to the previous season, all the biopesticide treatments significantly suppressed the aphid population after both sprays. Azadirachtin @ 0.00075% was consistently the most effective treatment, followed by *L. lecanii* @ 0.007% and NSKE @ 5%. After the second spray, azadirachtin recorded only 47.67 aphids/10 cm central twig at 1 DAS, followed by *L. lecanii* (50.33 aphids/10 cm central twig) and NSKE (52.33), whereas the untreated control recorded 239.67 aphids. At 3 DAS, azadirachtin further reduced the population to 24.67 aphids, while *L. lecanii* and NSKE recorded 32.33 and 33.00 aphids, respectively.

The comparatively moderate efficacy of *M. anisopliae* and *B. bassiana* may be associated with differences in fungal infectivity and the prevailing environmental conditions affecting establishment and infection of the aphid population.

Nevertheless, these treatments provided significantly better suppression than the untreated control.

3.1.3 Pooled analysis of two years

The pooled results of Rabi 2023–24 and 2024–25 are presented in Table 3 and Fig. 1. Significant differences were observed among the biopesticide treatments in suppressing *L. erysimi*. Azadirachtin (1500 ppm) @ 0.00075 per cent recorded the lowest pooled aphid population (46.83 aphids/10 cm central twig) and was significantly superior to the other treatments, whereas NSKE @ 5 per cent (54.41 aphids/10 cm central twig) and *L. lecanii* @ 0.007 per cent (54.85 aphids/10 cm central twig) were statistically at par with each other. Novel plus, *B. bassiana* and *M. anisopliae* recorded 96.33, 103.34 and 105.59 aphids per 10 cm central twig, respectively, while custard apple leaf extract recorded 144.22 aphids. The untreated control recorded the highest population (219.73 aphids/10 cm central twig).

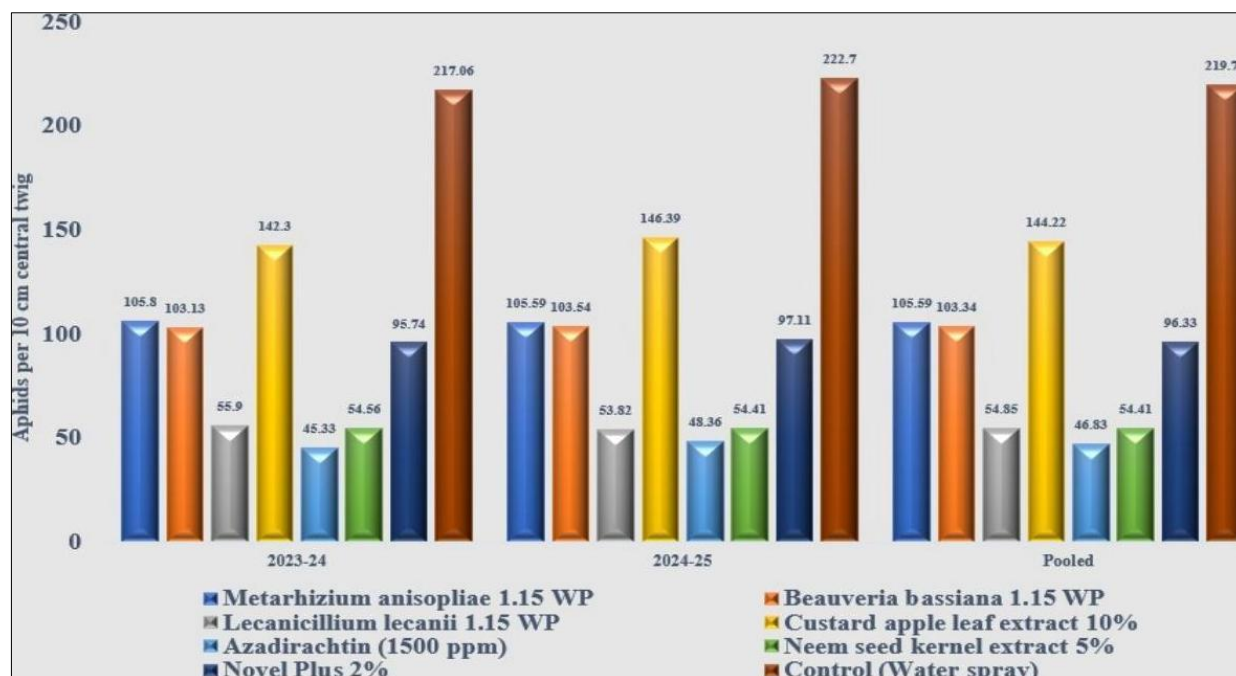


Fig 1: Bio-efficacy of biopesticides against *L. erysimi*

Table 1: Bio-efficacy of biopesticides against *L. erysimi* during Rabi 2023-24

Tr. No.	Treatments	Aphids per 10 cm central twig											
		DBS	1 st Spray				Pooled	2 nd Spray				Pooled	Pooled over periods and sprays
			1 DAS	3 DAS	7 DAS	14 DAS		1 DAS	3 DAS	7 DAS	14 DAS		
T ₁	<i>Metarhizium anisopliae</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	12.94 (167.33)	13.02 ^b (169.67)	11.25 ^{bc} (126.33)	10.29 ^b (106.00)	11.30 ^b (128.33)	11.46 ^c (130.83)	10.27 ^b (105.00)	9.29 ^b (86.00)	8.80 ^b (77.00)	8.25 ^b (67.66)	9.16 ^c (83.41)	10.31 ^c (105.80)
T ₂	<i>Beauveria bassiana</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	12.90 (166.33)	13.04 ^b (171.33)	11.20 ^{bc} (125.33)	10.05 ^b (101.50)	11.25 ^b (126.33)	11.38 ^c (129.00)	10.13 ^b (103.00)	9.18 ^b (84.00)	8.68 ^b (75.00)	7.92 ^b (62.33)	8.98 ^c (80.14)	10.18 ^c (103.13)
T ₃	<i>Lecanicillium lecanii</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	12.31 (151.67)	12.22 ^{ab} (149.33)	9.41 ^a (88.33)	8.28 ^a (68.33)	9.25 ^a (85.33)	9.79 ^b (95.34)	7.12 ^a (50.33)	5.69 ^a (32.33)	4.64 ^a (21.33)	3.52 ^a (12.00)	5.25 ^b (27.06)	7.51 ^b (55.90)
T ₄	Custard apple leaf extract (<i>Annona reticulata</i> L.) @	13.27 (176.00)	13.02 ^b (169.67)	12.74 ^c (162.00)	12.42 ^c (154.00)	13.05 ^c (170.00)	12.80 ^d (163.34)	12.23 ^c (149.33)	11.51 ^c (132.00)	10.88 ^c (118.00)	9.79 ^c (95.67)	11.11 ^d (122.93)	11.95 ^d (142.30)

	10%												
T ₅	Azadirachtin (1500 ppm) @ 0.00075%	12.44 (154.67)	10.66 ^a (113.33)	8.78 ^a (78.33)	7.50 ^a (57.00)	8.75 ^a (76.33)	8.92 ^a (79.07)	6.90 ^a (47.67)	5.01 ^a (24.67)	3.93 ^a (15.00)	2.67 ^a (6.67)	4.63 ^a (20.94)	6.77 ^a (45.33)
T ₆	Neem seed kernel extract @ 5 %	12.30 (151.33)	11.13 ^a (124.33)	9.51 ^a (90.33)	8.41 ^a (70.67)	9.31 ^a (86.33)	9.59 ^{ab} (91.47)	7.25 ^a (52.33)	5.78 ^a (33.00)	4.45 ^a (20.33)	3.56 ^a (12.33)	5.26 ^b (27.17)	7.42 ^b (54.56)
T ₇	Novel plus @ 2 %	12.41 (156.00)	11.97 ^a (143.23)	11.09 ^b (123.00)	10.04 ^b (100.67)	11.01 ^b (121.00)	11.03 ^c (121.16)	9.62 ^b (92.33)	8.79 ^b (77.00)	8.39 ^b (70.00)	7.58 ^b (57.00)	8.60 ^c (73.46)	9.81 ^c (95.74)
T ₈	Control (Water spray)	12.67 (161.00)	13.13 ^b (173.33)	14.70 ^d (216.00)	15.12 ^d (228.33)	15.51 ^d (241.67)	14.61 ^e (212.95)	15.44 ^d (239.67)	15.07 ^d (228.33)	14.86 ^d (221.00)	14.20 ^d (202.33)	14.90 ^e (221.51)	14.75 ^e (217.06)
S.Em. ± Treatment(T)		0.60	0.57	0.52	0.52	0.54	0.26	0.53	0.46	0.39	0.35	0.21	0.17
Period (P)		-	-	-	-	-	0.18	-	-	-	-	0.15	0.12
Spray (S)		-	-	-	-	-	-	-	-	-	-	-	0.08
T × P		-	-	-	-	-	0.53	-	-	-	-	0.42	0.34
T × S		-	-	-	-	-	-	-	-	-	-	-	0.24
P × S		-	-	-	-	-	-	-	-	-	-	-	0.17
T × P × S		-	-	-	-	-	-	-	-	-	-	-	0.48
CD at 5% T		N.S.	1.74	1.57	1.57	1.65	0.75	1.59	1.40	1.17	1.05	0.60	0.47
P		-	-	-	-	-	0.53	-	-	-	-	0.42	0.33
S		-	-	-	-	-	-	-	-	-	-	-	0.23
T × P		-	-	-	-	-	1.50	-	-	-	-	NS	0.95
T × S		-	-	-	-	-	-	-	-	-	-	-	0.67
P × S		-	-	-	-	-	-	-	-	-	-	-	0.47
T × P × S		-	-	-	-	-	-	-	-	-	-	-	NS
CV %		8.20	8.09	8.11	8.75	8.43	8.22	9.22	9.09	8.26	8.38	8.75	8.48

Note: 1. Figures outside the parentheses are $\sqrt{(x + 0.5)}$ transformed values and those inside the parentheses are the retransformed values, 2. DAS- Days after spray, DBS- Day before spray, NS- non-significant and Sig.: significant 3. Treatment mean(s) with the letter(s) in common are not differing significantly by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

Table 2: Bio-efficacy of biopesticides against *L. erysimi* during Rabi 2024-25

Tr. No.	Treatments	Aphids per 10 cm central twig											
		DBS	1 st Spray				Pooled	2 nd Spray				Pooled	Pooled over periods and sprays
			1 DAS	3 DAS	7 DAS	14 DAS		1 DAS	3 DAS	7 DAS	14 DAS		
T ₁	<i>Metarhizium anisopliae</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	12.61 (159.00)	12.53 ^{ab} (156.67)	11.37 ^b (129.67)	10.09 ^b (102.00)	11.22 ^b (126.00)	11.30 ^b (127.19)	10.38 ^b (107.50)	9.48 ^b (90.30)	9.04 ^b (81.67)	8.35 ^b (69.67)	9.32 ^b (86.36)	10.30 ^b (105.59)
T ₂	<i>Beauveria bassiana</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	12.87 (166.00)	12.73 ^{ab} (163.33)	11.28 ^b (128.5)	9.87 ^b (97.00)	11.07 ^b (122.67)	11.23 ^b (125.61)	10.28 ^b (106.33)	9.40 ^b (88.33)	8.88 ^b (78.67)	8.11 ^b (65.67)	9.17 ^b (83.59)	10.20 ^b (103.54)
T ₃	<i>Lecanicillium lecanii</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	12.14 (147.00)	11.96 ^a (142.67)	9.60 ^a (92.00)	8.08 ^a (65.00)	8.95 ^a (81.00)	9.64 ^a (92.43)	7.43 ^a (55.00)	5.32 ^a (28.00)	4.36 ^a (18.67)	3.31 ^a (10.50)	5.11 ^a (25.61)	7.37 ^a (53.82)
T ₄	Custard apple leaf extract (<i>Annona reticulata</i> L.) @ 10%	13.82 (190.67)	13.67 ^b (187.33)	12.90 ^{bc} (166.00)	12.55 ^c (158.00)	12.96 ^c (168.00)	13.01 ^c (168.76)	12.34 ^c (152.00)	11.62 ^c (135.67)	11.03 ^c (121.33)	9.92 ^c (98.00)	11.23 ^c (125.61)	12.12 ^c (146.39)
T ₅	Azadirachtin (1500 ppm) @ 0.00075%	12.29 (150.67)	11.12 ^a (124.00)	8.66 ^a (75.00)	7.86 ^a (61.50)	8.89 ^a (79.00)	9.13 ^a (82.86)	7.02 ^a (49.00)	5.22 ^a (27.00)	4.13 ^a (17.00)	3.03 ^a (9.00)	4.86 ^a (23.12)	6.99 ^a (48.36)
T ₆	Neem seed kernel extract @ 5 %	11.79 (140.67)	11.48 ^a (132.00)	9.40 ^a (88.33)	8.20 ^a (67.00)	9.14 ^a (83.33)	9.55 ^a (90.70)	7.54 ^a (56.67)	5.51 ^a (30.00)	4.66 ^a (22.33)	3.36 ^a (11.33)	5.27 ^a (27.27)	7.41 ^a (54.41)
T ₇	Novel plus @ 2 %	12.05 (145.00)	11.92 ^{ab} (142.33)	11.22 ^{ab} (125.67)	9.79 ^b (96.33)	10.82 ^b (117.00)	10.93 ^b (118.96)	9.80 ^b (96.00)	9.15 ^b (83.33)	8.54 ^b (73.67)	7.82 ^b (61.00)	8.83 ^b (77.47)	9.88 ^b (97.11)
T ₈	Control (Water spray)	13.15 (174.00)	13.73 ^b (189.33)	14.80 ^d (219.00)	15.22 ^d (232.00)	15.70 ^d (246.00)	14.86 ^d (220.32)	15.61 ^d (244.00)	15.14 ^d (231.00)	14.99 ^d (225.00)	14.35 ^d (206.33)	15.03 ^d (225.40)	14.94 ^d (222.70)
S.Em. ± Treatment(T)		0.59	0.57	0.54	0.51	0.53	0.27	0.52	0.55	0.57	0.45	0.25	0.19
Period (P)		-	-	-	-	-	0.19	-	-	-	-	0.18	0.13
Spray (S)		-	-	-	-	-	-	-	-	-	-	-	0.09
T × P		-	-	-	-	-	0.55	-	-	-	-	0.51	0.38
T × S		-	-	-	-	-	-	-	-	-	-	-	0.27
P × S		-	-	-	-	-	-	-	-	-	-	-	0.19
T × P × S		-	-	-	-	-	-	-	-	-	-	-	0.54
CD at 5% T		NS	1.74	1.65	1.53	1.62	0.78	1.57	1.68	1.72	1.35	0.72	0.53
P		-	-	-	-	-	0.55	-	-	-	-	0.51	0.37
S		-	-	-	-	-	-	-	-	-	-	-	0.26

T × P	-	-	-	-	-	1.56	-	-	-	-	NS	1.06
T × S	-	-	-	-	-	-	-	-	-	-	-	0.75
P × S	-	-	-	-	-	-	-	-	-	-	-	0.53
T × P × S	-	-	-	-	-	-	-	-	-	-	-	NS
CV %	8.18	8.03	8.44	8.57	8.32	8.56	8.94	10.85	11.97	10.59	10.36	9.44

Note: 1. Figures outside the parentheses are $\sqrt{(x + 0.5)}$ transformed values and those inside the parentheses are the retransformed values, 2. DAS- Days after spray, DBS- Day before spray, NS- non-significant and Sig.: significant 3. Treatment mean(s) with the letter(s) in common are not differing significantly by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

Table 3: Bio-efficacy of biopesticides against *L. erysimi* (Pooled)

Tr. No.	Treatments	Aphids per 10 cm central twig		
		Pooled over period and sprays		Pooled over periods and sprays
		2023-24	2024-25	
T ₁	<i>Metarhizium anisopliae</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	10.31 ^c (105.80)	10.30 ^b (105.59)	10.30 ^d (105.59)
T ₂	<i>Beauveria bassiana</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	10.18 ^c (103.13)	10.20 ^b (103.54)	10.19 ^{cd} (103.34)
T ₃	<i>Lecanicillium lecanii</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	7.51 ^b (55.90)	7.37 ^a (53.82)	7.44 ^b (54.85)
T ₄	Custard apple leaf extract (<i>Annona reticulata</i> L.) @ 10%	11.95 ^d (142.30)	12.12 ^c (146.39)	12.03 ^c (144.22)
T ₅	Azadirachtin (1500 ppm) @ 0.00075%	6.77 ^a (45.33)	6.99 ^a (48.36)	6.88 ^a (46.83)
T ₆	Neem seed kernel extract @ 5 %	7.42 ^b (54.56)	7.41 ^a (54.41)	7.41 ^b (54.41)
T ₇	Novel plus @ 2 %	9.81 ^c (95.74)	9.88 ^b (97.11)	9.84 ^c (96.33)
T ₈	Control (Water spray)	14.75 ^e (217.06)	14.94 ^d (222.70)	14.84 ^f (219.73)
	S.E.m. ± Treatment (T)	0.17	0.19	0.12
	Period (P)	0.12	0.13	0.09
	Spray (S)	0.08	0.09	0.06
	Year (Y)	-	-	0.06
	Y × S	-	-	0.09
	Y × P	-	-	0.12
	Y × T	-	-	0.18
	S × P	0.17	0.19	0.12
	S × T	0.24	0.27	0.18
	P × T	0.34	0.38	0.25
	Y × S × P	-	-	0.18
	Y × S × T	-	-	0.25
	S × P × T	0.48	0.54	0.36
	Y × P × T	-	-	0.36
	Y × S × P × T	-	-	0.50
	CD at 5% T	0.47	0.53	0.35
	P	0.33	0.37	0.25
	S	0.23	0.26	0.17
	Y	-	-	NS
	Y × S	-	-	NS
	Y × P	-	-	NS
	Y × T	-	-	NS
	S × P	0.47	0.53	0.35
	S × T	0.66	0.75	0.50
	P × T	0.95	1.06	0.71
	Y × S × P	-	-	NS
	Y × S × T	-	-	NS
	S × P × T	NS	NS	NS
	Y × P × T	-	-	NS
	Y × S × P × T	-	-	NS
	CV %	8.48	9.44	9.02

Note: 1. Figures outside the parentheses are $\sqrt{(x + 0.5)}$ transformed values and those inside the parentheses are the retransformed values, 2. DAS- Days after spray, DBS- Day before spray, NS- non-significant and Sig.: significant. 3. Treatment mean(s) with the letter(s) in common are not differing significantly by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

The significant effects of treatment, spray and observation period indicated differences in the efficacy of the biopesticides across spray schedules and observation periods. However, the non-significant interactions involving year and treatment indicated that the relative efficacy of the tested biopesticides remained generally consistent across the two seasons. Significant spray × period, spray × treatment and period × treatment interactions indicated variation in aphid population and treatment efficacy across sprays and observation periods.

However, the year and its interactions with spray, period and treatment were nonsignificant, indicating that the relative efficacy of the biopesticides remained consistent across both years. The nonsignificant higher-order interactions further confirmed the overall stability of treatment performance across seasons. The pooled analysis revealed that azadirachtin (1500 ppm) @ 0.00075% recorded the lowest aphid population (46.83 aphids/10 cm central twig) and was significantly superior to NSKE @ 5% (54.41) and *L. lecanii* 1.15 WP @ 0.007% (54.85),

whereas NSKE and *L. lecanii* were statistically at par with each other. The consistent performance of these treatments over two consecutive years indicated their stable bio-efficacy against *L. erysimi*. The superior performance of neem-based treatments is supported by Prasad (1997) [28, 25], who reported 73-83 percent reduction in mustard aphid population with neem extract and neem oil. Similarly, Kumar *et al.* (2020) [29, 14], Yadav (2020) [30, 3] and Arvind *et al.* (2025) [31] reported high efficacy of azadirachtin and neem-based formulations against mustard aphid, supporting the present findings. Among the microbial biopesticides, *L. lecanii* showed comparatively higher efficacy and was statistically at par with NSKE, whereas azadirachtin recorded a significantly lower aphid population than both treatments *Beauveria bassiana* and *M. anisopliae* showed moderate suppression. This agrees with Meena *et al.* (2013) [4, 32], who reported effective suppression of mustard aphid with NSKE, *B. bassiana*, *L. lecanii* and *M. anisopliae*. The strong performance of *L. lecanii* is further supported by Singh *et al.* (2008) [33, 23], Janu *et al.* (2018) [32, 2] and Pradhan *et al.* (2020) [17, 20], who reported substantial reduction in aphid population with *V. lecanii*/*L. lecanii* under field conditions. Similarly, Pal *et al.* (2020) [15, 5] and Yadav and Singh (2021) [34, 35] reported

effective suppression of *L. erysimi* with azadirachtin, *B. bassiana*, NSKE and neem based treatments. The present results were partially consistent with Pradhan *et al.* (2020) [17], who reported *L. lecanii* as superior to azadirachtin, whereas in the present study azadirachtin recorded the lowest pooled aphid population and was significantly superior to *L. lecanii*, whereas *L. lecanii* was statistically at par with NSKE. Such differences may be associated with variation in fungal strains, formulations, mustard cultivars, aphid pressure and prevailing agro-climatic conditions. The comparatively lower efficacy of *B. bassiana* and *M. anisopliae* under field conditions also differed from the laboratory findings of Deka *et al.* (2017) [22]; Sajid *et al.* (2017) [36, 19]; Barad *et al.*, (2023) [26, 37] and Dodiya *et al.*, (2024) [21], who reported higher mortality with these fungi. This variation may be attributed to differences in temperature, relative humidity, solar radiation, fungal strain, inoculum concentration and the contrasting environmental conditions of laboratory and field experiments. The custard apple leaf extract @ 10% was the least effective treatment, recording 144.22 aphids per 10 cm central twig. Similar lower efficacy of non-neem botanicals has been reported by Kumar (2025) [38, 10] and Aswitha and Yadav (2023) [39]. Overall, the present findings demonstrate that

Table 4: Impact of biopesticides against mustard aphid on yield parameter

Tr. No.	Treatments	Yield (Kg/ha)			Increase in yield over control (%)			Avoidable yield loss (%)		
		2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T ₁	<i>Metarhizium anisopliae</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	1340.00 ^b	1344.00 ^b	1342.00 ^b	43.21	45.88	44.61	30.17	31.45	30.85
T ₂	<i>Beauveria bassiana</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	1353.00 ^b	1338.00 ^b	1345.50 ^b	44.60	45.22	44.94	30.85	31.14	31.00
T ₃	<i>Lecanicillium lecanii</i> 1.15 WP (1 x 10 ⁸ cfu/g) @ 0.007%	1559.67 ^{ab}	1554.33 ^a	1557.00 ^a	66.69	68.70	67.78	40.01	40.72	40.40
T ₄	Custard apple leaf extract (<i>Annona reticulata</i> L.) @ 10 %	1138.00 ^c	1127.00 ^c	1132.50 ^c	21.62	22.32	21.98	17.78	18.25	18.02
T ₅	Azadirachtin (1500 ppm) @ 0.00075%	1607.67 ^a	1592.00 ^a	1600.00 ^a	71.82	72.79	72.31	41.80	42.13	41.96
T ₆	Neem seed kernel extract @ 5 %	1588.67 ^a	1584.00 ^a	1586.33 ^a	69.79	71.92	70.91	41.10	41.84	41.49
T ₇	Novel plus @ 2 %	1384.33 ^b	1349.00 ^b	1367.00 ^b	47.95	46.42	47.20	32.41	31.70	32.06
T ₈	Control (Water spray)	935.67 ^e	921.33 ^d	928.50 ^d	-	-	-	-	-	-
S. Em. ± Treatment (T)		65.00	66.74	45.00	--					
Year (Y)		-	-	22.50						
T × Y		-	-	63.65						
CD at 5% T		197.17	202.44	130.00						
Y		-	-	NS						
T × Y		-	-	NS						
CV %		8.26	8.56	8.12						

Note: 1. NS- non-significant. 2. Treatment mean(s) with the letter(s) in common are not differing significantly by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance

3.2 Effect of biopesticides on seed yield

The effect of different biopesticides on seed yield during Rabi 2023-24, 2024-25 and their pooled analysis is presented in Table 4. Treatments that effectively suppressed *L. erysimi* generally recorded higher seed yield than the untreated control. During both seasons, azadirachtin @ 0.00075% recorded the highest seed yield, followed by NSKE @ 5% and *L. lecanii* @ 0.007%. In the pooled analysis, azadirachtin recorded the highest seed yield (1600.00 kg/ha), followed by NSKE (1586.33 kg/ha) and *L. lecanii* (1557.00 kg/ha), whereas the untreated control recorded only 928.50 kg/ha. The higher seed yield under these treatments may be attributed to their effective suppression of aphid infestation, resulting in reduced feeding damage and better seed development.

The present findings are in agreement with Yadav and Singh (2015) [40, 41], who reported higher mustard seed yield with bio-intensive management involving *V. lecanii* and NSKE. Similarly, Sharma *et al.* (2017) [42, 12] observed significant improvement in seed yield with *L. lecanii* + NSKE and *B. bassiana* + NSKE. The present results are also consistent with Arvind *et al.* (2025) [31], who reported the highest seed yield with azadirachtin followed by NSKE and other biopesticides, supporting the superior performance of azadirachtin and neem-based treatments observed in the present study. The present findings were partially in agreement with Kumar (2025) [38], who reported *V. lecanii* as the most effective biopesticide, whereas azadirachtin recorded the highest seed yield in the

present investigation and remained statistically at par with NSKE and *L. lecanii*. Conversely, Deka *et al.* (2017)^[22, 6] and Sajid *et al.* (2017)^[36, 19] reported greater efficacy of *M. anisopliae* under laboratory or *in vitro* conditions. The comparatively moderate performance of *M. anisopliae* in the present field study may be attributed to differences in fungal strains, environmental conditions and field-level factors affecting fungal efficacy.

3.3 Increase in seed yield over control

The percentage increase in seed yield over the untreated control is presented in Table 4. All biopesticide treatments resulted in an increase in seed yield over the control, although the magnitude varied among treatments. In the pooled analysis, azadirachtin recorded the highest increase in seed yield over control (72.31%), followed by NSKE (70.91%) and *L. lecanii* (67.78%). Novel plus, *B. bassiana* and *M. anisopliae* recorded comparatively moderate increases, while custard apple leaf extract recorded the lowest increase among the biopesticide treatments.

3.4 Avoidable yield loss

The avoidable yield loss due to mustard aphid infestation under different biopesticide treatments is presented in Table 4. The pooled results showed that the highest avoidable yield loss was recorded with azadirachtin (41.96%), followed by NSKE (41.49%) and *L. lecanii* (40.40%). The corresponding values for Novel plus, *B. bassiana* and *M. anisopliae* were 32.06, 31.00 and 30.85%, respectively, whereas custard apple leaf extract recorded 18.02%. The higher avoidable yield loss associated with the more effective treatments indicates that effective suppression of mustard aphid can substantially protect the yield potential of mustard. Thus, the present findings demonstrate the importance of incorporating effective biopesticides into an integrated pest management programme against *L. erysimi*. The higher avoidable yield loss associated with effective treatments indicates the magnitude of yield that could be protected through effective management of mustard aphid.

Conclusion

The two-year field study demonstrated that biopesticides differed significantly in their effectiveness against mustard aphid, *L. erysimi*. Azadirachtin was significantly superior to NSKE and *L. lecanii*, whereas NSKE and *L. lecanii* were statistically at par with consistently lower aphid populations across both seasons. These treatments also resulted in higher seed yield, with azadirachtin recording the highest pooled yield (1600.00 kg/ha) and an increase in yield over control (72.31%). Thus, azadirachtin, NSKE and *L. lecanii* can be considered promising biopesticides for incorporation into an eco-friendly and sustainable integrated pest management programme against mustard aphid.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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