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**Research Article**

# Efficacy of biorationals against mustard aphid, *Lipaphis erysimi* Kalt.

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**ABSTRACT:** Field experiments were conducted to assess the effectiveness of various biopesticides and plant-derived products in controlling infestation of aphid, *Lipaphis erysimi* Kalt. in mustard crop through two rounds of spraying. Treatments included *Metarhizium anisopliae*, *Beauveria bassiana*, *Lecanicillium lecanii*, Azadirachtin, NSKE (5.0%), neem oil (1.0%), karanj oil (1.0%), karanj seed extract (5.0%), and a standard check involving alternate spray of dimethoate (0.03%)/malathion (0.05%). Results indicated that among biorationals, azadirachtin, NSKE and neem oil were most effective. Though biorationals were relatively less efficacious than standard check, considering their safety to environment and residue free food production, these can be included in IPM of mustard. Similarly, these treatments exhibited the highest yield increase and net profit, with dimethoate/malathion having the highest benefit-cost ratio (15.09) compared to other treatments.

**KEYWORDS:** Aphids, biopesticides, benefit-cost ratio, mustard, plant extracts

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## INTRODUCTION

Mustard, *Brassica juncea* (Linn.) Czern and Coss is an important oilseed crop of the *rabi* season, belonging to the Brassicaceae family. Known as a key oilseed crop, mustard ranks first in India's oilseed production (131.61 lakh tons), contributing ≈33.24% of all oilseeds produced (Government of India, 3rd Advance Estimate, 2023-2024). In addition to having high oil content (32-40%), mustard seeds are rich in calcium, phosphorus, and magnesium. It also contains enough of the essential fatty acids linolenic and linoleic. Due to its high nutritional content, mustard plays a significant role in Indian cooking as well as the pharmaceutical and cosmetic industries. Mustard oil is also used to lubricate, soften leather, and manufacture soap and detergent. Mustard cake seems to be a viable protein substitute for groundnut and soybean cakes in fish and poultry feeds because of its comparatively low level of anti-nutritional components. Also, it is extensively utilized for enhancing soil fertility and rehabilitating salt-affected soils.

Insects such as mustard aphids, *Lipaphis erysimi* (Kalt.), painted bugs, *Bagrada cruciferarum* Kirk., mustard sawflies, *Athalia lugens proxima* Klug., leaf miners, *Phytomyza horticola* Meign, cabbage leaf webbers, *Crocidolomia binotalis* and flea beetles, *Phyllotreta cruciferae* pose significant threats to mustard crops, severely impacting their production. Mustard aphids alone can cause losses ranging from 66.0 to 99.0% in *B. campestris* and 27.0 to 28.0 % in *B. juncea*, accompanied by a 15.0% decrease in oil content (Bakhetia, 1979; Rohilla *et al.,* 1987; Singh & Sachan, 1994; Verma & Singh, 1987). Mustard aphid is classified as a major pest based on the monetary losses it causes (Bakhetia & Sekhon, 1989; Dhillon *et al*., 2018). Both nymphs and mature individuals extract sap from tender leaves, buds, and pods, inducing leaf curling and, in extreme instances, plant wilting and mortality. Infested plants exhibited several deformities including vigour and growth retardation (Khan *et al.,* 2015). Moreover, the honeydew on aphid-infested plants favours the proliferation of sooty mold on plant surfaces, impeding photosynthesis and diminishing crop productivity (Samal *et al*., 2021; Aswathi, 2002). Favourable weather conditions facilitate the rapid proliferation and spread of mustard aphids, necessitating farmers to resort to insecticide applications.

In order to mitigate infestation caused by *L. erysimi* and ensure the production of superior-quality rapeseed-mustard, it is imperative to meticulously administer pest population management strategies utilizing suitable control methodologies at optimal timings. It emphasizes need-based and selective insecticidal application at recommended doses only when all other non-insecticidal measures fail to keep the pest population below ETL. The application of chemical insecticides through seed treatment showed promising

potential in managing insect pests, even at lower doses (Arvind *et al.,* 2023). But their injudicious and indiscriminate use offered a lot of problems such as environmental pollution, increased cost of production, food poisoning and pest resurgence. Biological control also holds promising potential in mustard aphid management. But owing to associated social and institutional constraints, the integration of bio-control, to its best potential, in pest management is yet to be achieved (Arvind *et al.,* 2023). Considering all the pros and cons of available pest management approaches, the research focus is to devise a noble, eco-friendly pest management strategy which would prove ecologically safe, economically feasible and field applicable. The potential alternatives include the use of bio-control agents, plant products, newer safe insecticide molecules and IPM-based strategies, which entails all possible means of pest management economically and ecologically (Deka *et al.,* 2017; Sahu *et al.,* 2018). Various entomopathogenic fungi exhibit pathogenicity towards various insect pests, including aphids (Asi *et al.,* 2009; Nirmala *et al*., 2006. Thus, this study incorporates the utilization of biopesticides and botanical agents in the management of mustard aphid aiming to control the pest while minimizing adverse impacts on natural predators and pollinators.

## MATERIALS AND METHODS

The present investigation was conducted at the Agronomy Farm, S. K. N. College of Agriculture, Jobner Rajasthan (26.26°N, 78.28°E) during the *rabi*, 2020–2021. Geographically, Jobner is situated within agro-climatic zone III A, identified as Rajasthan's "Semi-arid Eastern Plain," which is characterized by sandy-loam soil. The soil exhibits mild alkalinity and is non-calcareous. The field experiment aimed to assess the effectiveness of biopesticides and plant products through two rounds of spraying on aphid-infested mustard crops.

The experiment evaluating the efficacy of biopesticides and plant extracts was performed twice using ten treatments with three replications under a randomized block design (Table 1). The Bio-902 variety was sown on October 30, 2020, across thirty plots measuring 2×2 square meters with plant spacing 30×10 cm (R-R×P-P).

*$1\times10^8$ spores or CFU per gram (minimum)

### Determination of parameters

### Population of mustard aphid

Mustard aphid *L. erysimi* population was recorded firstly at one day prior to spraying, subsequently, at intervals of one, three, seven, and ten days of post-treatment. These observations were noted from 10 cm terminal shoots of five randomly chosen and labelled plants within each experimental plot. The insect population was recorded during the early morning hours.

### Bio-efficacy of biopesticides and plant products

The percentage reduction in population was calculated after each spray at various intervals using the equation developed by Henderson, 1955.

$$\text{Per cent reduction in pest population} = 1 - \frac{Ta \times Cb}{Tb \times Ca} \times 100$$

where,

$T_a$ = Post-treatment pest population

$T_b$ = Pre-treatment pest population

$C_a$ = Pest population in untreated plots (post-treatment)

$C_b$ = Pest population in untreated plots (pre-treatment)

The percentage data obtained were analyzed after being converted into angular values (Bliss, 1937).

### Per cent avoidable loss

The avoidable loss and yield increase of grain over the control were computed for each treatment utilizing the following formula:

**Table 1.** Experimental interventions utilized in the study

| S. No. | Treatment details | Formulations | Doses |
|---|---|---|---|
| 1 | *Metarhizium anisopliae* | 1.15 WP* | 1.0 g/l Water |
| 2 | *Beauveria bassiana* | 1.15 WP* | 1.0 g/l Water |
| 3 | *Lecanicillium lecanii* | 1.15 WP* | 1.0 g/l Water |
| 4 | Azadirachtin | 0.03 EC | 5.0 ml/l Water |
| 5 | NSKE | Lab prepared | 5.0 % |
| 6 | Neem oil | Lab prepared | 1.0 % |
| 7 | Karanj oil | Lab prepared | 1.0 % |
| 8 | Karanj seed extract | Lab prepared | 5.0 % |
| 9 | Dimethoate/malathion (Standard check) | 30 EC/50 EC | 0.03 %/0.05 % |
| 10 | Untreated control | - | - |

Per cent avoidable yield loss = $\frac{Yield\ in\ treated\ plot - Yield\ in\ untreated\ plot}{Yield\ in\ treated\ plot}$ x 100

**Percent increase in yield**

To quantify the proportional reduction in yield caused by mustard aphid across different treatments was calculated by incorporating the following formula (Pradhan, 1964):

Increase in yield (%) = $\frac{Yield\ in\ treated\ plot - Yield\ in\ control\ plot}{Yield\ in\ control\ plot}$ x 100

**Statistical analysis**

The data were collected on aphid population across the treatments at pre-defined intervals and further subjected to Analysis of Variance (Fischer,1958). The obtained data were subjected to transformation into square root (√X+0.5) values for homogeneity (p=0.05) by using 'OPSTAT' software of CCS Haryana Agricultural University, Hisar. We determined the treatment with the highest efficiency and cost-effectiveness by analyzing net profit and the Net Incremental Cost Benefit Ratio (NICBR), taking into account the expenses incurred from each insecticide or botanical treatment and their corresponding yields. Moreover, we evaluated the economic viability of different treatments by considering both the cost of insecticides and their application. The gross income was determined by multiplying the yield by the current wholesale price of mustard during the harvest period in the market.

**RESULTS AND DISCUSSION**

The field experiment was designed to evaluate the bio-efficacy as well as cost-effectiveness of different biopesticides and plant extracts on mustard aphid during the *rabi*, 2020-21. Two spray applications of different treatments were undertaken, the first upon reaching a significant aphid population level and the second 21 days after the initial spray. Observations were analysed for percentage reduction compared to an untreated control at one, three, seven, and ten days post-spraying, and seed yield data were collected at harvest (Table 2 and Figure 1).

**First spray**

The data indicated that all biopesticide treatments and botanical products displayed notably superior efficacy compared to the untreated control throughout all observation intervals. However, there were significant variances in efficacy among them (Table 2). One day after the initial application, the percentage decrease in aphid population ranged from 30.41% to 90.48%. The greatest reduction in pest population, *i.e.*, 90.48%, was observed in the standard check treatment utilizing dimethoate 30 EC, followed by Azadirachtin 0.03 EC, NSKE, and neem oil, which demonstrated reductions of 83.68%, 80.31%, and 75.24%, respectively. These treatments exhibited statistically comparable efficacy among each other but differed significantly with dimethoate 30 EC in terms of effectiveness. Treatments involving entomopathogenic fungi, specifically *M. anisopliae* 1.15 WP, *L. lecanii* 1.15 WP and *B. bassiana* 1.15 WP, were identified as the subsequent most effective, showcasing reductions of 35.14%, 33.34%, and 30.54% in the aphid population, respectively, and were statistically comparable. The lowest effectiveness was observed in the karanj oil treatment (30.41%), followed by karanj seed extract (31.36%), with no significant disparity noted between them.

Three days post-spraying, the highest effectiveness was observed in the treatment employing dimethoate 30 EC, resulting in a decrease of 94.48%. Following this, Azadirachtin 0.03 EC, NSKE, and neem oil showed reductions of 86.68%, 78.84%, and 75.55%, respectively. Nonetheless, these treatments exhibited significant differences from one another, except for the latter two, which were comparable. Among the entomopathogenic fungi, *M. anisopliae* demonstrated the highest efficacy, achieving a reduction of 59.34%; after that, *L. lecanii* and *B. bassiana*, with reductions of 55.24% and 53.67%, respectively. These three biopesticides constituted a group of moderately effective treatments, with no significant differences observed between them. Conversely, treatments involving karanj oil and karanj seed extract exhibited the lowest reductions in aphid population, at 44.82% and 52.11%, respectively, and varied non-significantly.

The dimethoate 30 EC treatment exhibited the highest efficacy, surpassing other treatments with an 86.61% reduction in aphid population even after seven days post-spraying. Following this, Azadirachtin (81.68%), NSKE (80.84%), and neem oil (75.25%) demonstrated statistically comparable effectiveness. Among treatments of moderate efficacy, *M. anisopliae* displayed the highest effectiveness, yielding a 60.52% reduction in aphid population, followed by *L. lecanii* and *B. bassiana* with reductions of 59.14% and 58.24%, respectively. These treatments did not exhibit significant differences from one another. The lowest reduction, at 44.48%, was recorded in the karanj oil treatment, after that karanj seed extract at 51.26%, and both treatments were statistically equivalent to each other.

Ten days after the application of insecticides, the dimethoate 30 EC treatment remained the most effective, resulting in a 79.00% reduction in aphid population. This was followed by Azadirachtin (74.67%), NSKE (73.34%) and Neem oil (68.75%). The NSKE and neem oil treatments showed no statistical difference in efficacy, while dimethoate 30 EC differed significantly from Azadirachtin. Among

the treatments displaying moderate efficacy, *M. anisopliae* demonstrated the highest effectiveness with a reduction of 65.81%, succeeded by *L. lecanii* and *B. bassiana*, which achieved reductions of 62.61% and 62.04%, respectively. However, these treatments differ insignificantly in terms of their effectiveness. The lowest reduction, at 59.26%, was observed in the karanj oil treatment, followed by karanj seed extract at 60.58%, with no statistically significant difference between them.

The mean data regarding the percentage reduction in aphid population from all observations revealed that the standard check, dimethoate 30 EC, was the most effective, showing an 87.64% reduction, followed by Azadirachtin 0.03 EC (81.68%), NSKE (78.33%), and neem oil (73.70%). The NSKE and neem oil treatments showed no statistical difference between them, while dimethoate 30 EC significantly differed from Azadirachtin. Among the EPF, *M. anisopliae* exhibited the highest efficacy, with a reduction of 55.20%, followed by *L. lecanii* and *B. bassiana* with reductions of 52.58% and 51.12%, respectively (Fig. 2). These treatments were moderately effective and did not significantly differ from each other. These results are supported by the findings (Patel & Patel, 2010: Sachin & Kumar, 2016; Sahu *et al.,* 2018) who reported various entomo-pathogenic fungi to be less effective than chemical insecticides and neem-based insecticidal formulations in reducing aphid population.

The treatment with karanj oil exhibited the lowest reduction at 44.74%, followed by karanj seed extract at 48.83%, and both showed no statistical difference between them. However, their efficacy was also comparable to that of *L. lecanii* and *B. bassiana*.

The effectiveness of biorational treatments after the initial application was in the descending order of Azadirachtin, NSKE, neem oil, *M. anisopliae*, *L. lecanii*, *B. bassiana*, karanj seed extract, and karanj oil. This observation corroborates with prior investigations (Harjindra *et al*., 2017; Patel & Patel, 2010; Sahu *et al*., 2018; Singh *et al.,* 2007; Yadav & Singh, 2015; Zorempuii and Kumar, 2019), which consistently demonstrated that all treatments exhibited superior efficacy compared to the untreated control.

**Second spray**

The data indicated that all treatments employing biopesticides and botanical products exhibited markedly higher effectiveness compared to the untreated control across all observation intervals. Nevertheless, notable differences in efficacy were observed among these treatments. This consistency in efficacy trends was observed for various pesticides during both the initial and subsequent spray applications (Table 2). The effectiveness of insecticides following the second spray was observed in the following descending order: malathion 50 EC, Azadirachtin, NSKE, neem oil, *M. anisopliae*, *L. lecanii*, *B. bassiana*, karanj seed extract, and karanj oil.

**Effect of biopesticides and plant products on the seed yield of mustard**

The data depicted in Table 3 reveal that all plots treated with biopesticides and botanical products displayed significantly higher seed yields compared to the untreated control (7.10 q/ha). The highest seed yield, reaching 14.15 q/ha, was attained in plots treated with the standard check, alternating between sprays of dimethoate 30 EC and malathion 50 EC, followed by Azadirachtin (12.15 q/ha), NSKE (11.85 q/ha), and neem oil (10.99 q/ha). All three neem-based treatments exhibited non-significant differences in seed yield, whereas the standard check demonstrated significant superiority over other treatments. The plots treated with karanj oil, after that karanj seed extract, at 9.33 and 9.39 q/ha, respectively, experienced the lowest seed yield with no significant difference between them. Treatments with *M. anisopliae*, *L. lecanii*, and *B. bassiana* yielded 10.78, 10.59, and 10.35 q/ha, respectively, with no significant differences observed between them. The neem oil treatment showed comparable seed yields to those of *M. anisopliae*, *L. lecanii* and *B. bassiana*. Additionally, treatments with karanj oil and karanj seed extract exhibited comparable seed yields to that of *B. bassiana*. Furthermore, the NSKE treatment (11.85 q/ha) displayed comparable seed yields to those of neem oil (10.99 q/ha) and *M. anisopliae* (10.78 q/ha). The ranking of insecticides based on their effectiveness in enhancing mustard seed yield was as follows: the standard check involving alternating sprays of dimethoate 30 EC and malathion 50 EC, Azadirachtin 0.03 EC, NSKE, neem oil, *M. anisopliae*, *L. lecanii*, *B. bassiana*, karanj seed extract, and karanj oil. These results are consistent with prior research (Harjindra *et al*., 2017; Sahu *et al*., 2018; Singh *et al*., 2007; Yadav & Singh, 2015), which illustrated that the plots treated with dimethoate exhibited the highest mustard seed yield. Additionally, another study indicated superior seed yield in plots treated with Nimbicidine compared to the control (Harjindra *et al.,* 2017)

**Evaluation of losses and enhancements in yield**

Considering the yield obtained in dimethoate 30 EC/ malathion 50 EC as highest, the total avoidable losses in plots treated with Azadirachtin, NSKE, and neem oil, were 2.0, 2.30, and 3.16 q/ha, with corresponding percentage avoidable losses of 14.13%, 16.25%, and 22.33%, respectively (Table 3). The maximum total avoidable losses of 4.82 and 4.76 q/ha, along with percentage avoidable losses of 34.06% and 33.64%, were observed in plots treated with karanj oil and karanj seed extract, respectively. For treatments involving *M.*

**Table 2.** Assessing the effectiveness of biopesticides and plant-based products against the mustard crop pest, *Lipaphis erysimi* Kalt., during *rabi* 2020-21

| S.No. | Treatments | Conc. (%)/ dose | Per cent reduction in aphid population days after spray | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | First spray | | | | | Second spray | | | | |
| | | | One | Three | Seven | Ten | Mean | One | Three | Seven | Ten | Mean |
| 1 | *M. anisopliae*1.15 WP | 1.0 g/ l | 35.14 (36.36) | 59.34 (50.38) | 60.52 (51.07) | 65.81 (54.22) | 55.20 (47.99) | 33.87 (36.69) | 60.25 (50.91) | 60.92 (51.33) | 66.05 (54.36) | 55.27 (48.03) |
| 2 | *B. bassiana*1.15 WP | 1.0 g/ l | 30.54 (33.55) | 53.67 (47.10) | 58.24 (48.74) | 62.04 (51.97) | 51.12 (45.64) | 32.84 (34.96) | 57.67 (49.41) | 58.33 (49.80) | 62.14 (52.03) | 52.75 (46.57) |
| 3 | *L. lecanii*1.15 WP | 1.0 g/ l | 33.34 (35.27) | 55.24 (48.01) | 59.14 (50.27) | 62.61 (52.30) | 52.58 (46.48) | 33.11 (35.13) | 58.61 (49.96) | 59.64 (50.56) | 62.73 (52.37) | 53.52 (47.02) |
| 4 | Azadirachtin 0.03 EC | 5.0 ml/ l | 83.68 | 86.68 | 81.68 | 74.67 | 81.68 | 84.41 | 87.68 | 81.92 | 74.81 | 82.21 |
| | | | (66.17) | (68.59) | (64.66) | (59.78) | (64.66) | (66.74) | (69.45) | (64.84) | (59.87) | (65.05) |
| 5 | NSKE | 5.0 % | 80.31 | 78.84 | 80.84 | 73.34 | 78.33 | 81.21 | 79.04 | 81.12 | 73.46 | 78.71 |
| | | | (63.66) | (62.61) | (64.04) | (58.91) | (62.26) | (64.31) | (62.75) | (64.25) | (58.99) | (62.52) |
| 6 | Neem oil | 1.0 % | 75.24 | 75.55 | 75.25 | 68.75 | 73.70 | 75.86 | 73.35 | 74.77 | 68.50 | 73.12 |
| | | | (60.16) | (60.37) | (60.17) | (56.01) | (59.15) | (60.57) | (58.92) | (59.85) | (55.86) | (58.77) |
| 7 | Karanj oil | 1.0 % | 30.41 | 44.82 | 44.48 | 59.26 | 44.74 | 26.65 | 46.87 | 49.81 | 59.42 | 45.69 |
| | | | (33.47) | (42.03) | (41.83) | (50.34) | (41.98) | (31.08) | (43.21) | (44.89) | (50.43) | (42.53) |
| 8 | Karanj seed extract | 5.0 % | 31.36 | 52.11 | 51.26 | 60.58 | 48.83 | 32.58 | 53.61 | 50.45 | 60.71 | 49.34 |
| | | | (34.06) | (46.21) | (45.72) | (51.11) | (44.33) | (34.81) | (47.07) | (45.26) | (51.18) | (44.62) |
| 9 | Dimethoate 30 EC/ malathion 50 EC* | 0.03 %/ 0.05 % | 90.48 (72.03) | 94.48 (76.41) | 86.61 (68.54) | 79.00 (62.73) | 87.64 (69.42) | 91.08 (72.62) | 94.61 (76.58) | 87.62 (69.40) | 79.45 (63.04) | 88.19 (69.90) |
| 10 | Untreated control | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| | SEm± | | 1.27 | 1.99 | 1.29 | 0.96 | 1.03 | 1.33 | 1.26 | 1.47 | 1.04 | 0.96 |
| | CD (p=0.05) | | 3.82 | 5.97 | 3.85 | 2.88 | 3.08 | 4.00 | 3.77 | 4.39 | 3.12 | 2.88 |
| | CV (%) | | 6.56 | 5.97 | 7.10 | 8.32 | 6.98 | 6.23 | 7.87 | 8.35 | 8.12 | 6.95 |

Figures in parentheses are angular transformed values * Standard check

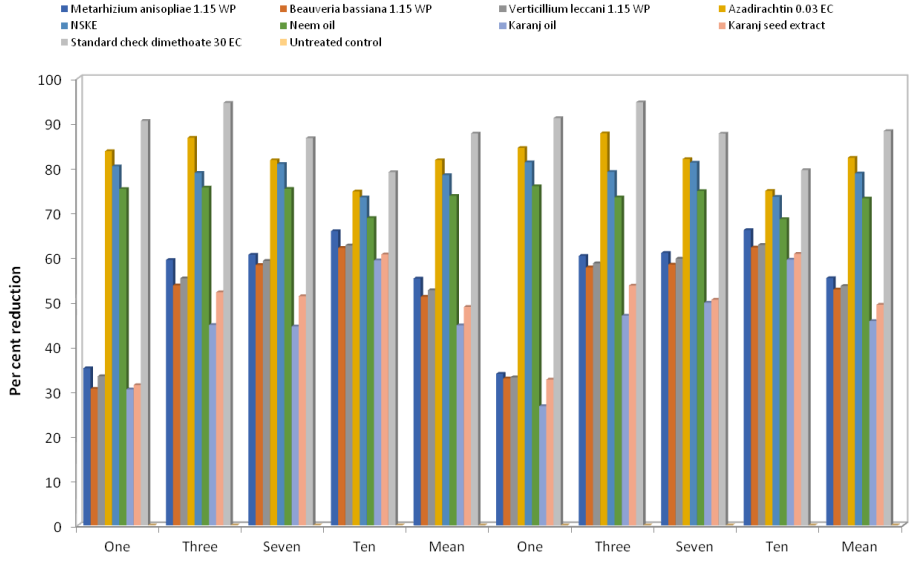



**Figure 1.** Assessing the effectiveness of biopesticides and plant extracts against the mustard aphid, *Lipaphis erysimi* Kalt., during the *rabi* 2020-21.

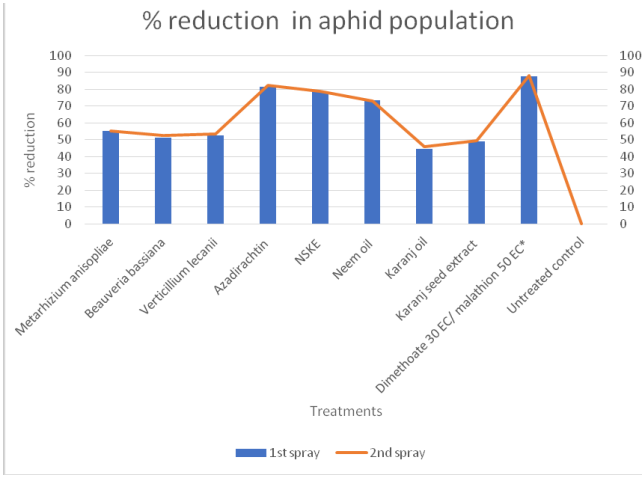



**Figure 2.** Average percentage reduction in the aphid population across various spray treatments.

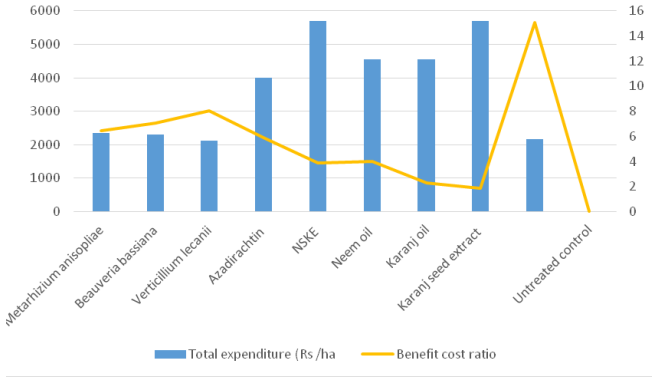



**Figure 3.** Details of expenditure per treatment and the benefit-cost ratio.

**Table 3.** Economic analysis of biopesticides and plant-based products used to control *Lipaphis erysimi* Kalt. on Indian mustard during the *rabi* 2020-21

| S. No. | Treatments | Conc. (%)/ dosage (ml/g) | Yield (q ha$^{-1}$) | Total avoidable losses (q ha$^{-1}$) | Avoidable losses (%) | Increase in yield over control (q ha$^{-1}$) | Increase in yield over control (%) | Gross returns (Rs ha$^{-1}$) | Total expenditure (Rs ha$^{-1}$) * | Net returns (Rs ha$^{-1}$) | Benefit cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Metarhizium anisopliae* | 1.0 g/ l | 10.78 | 3.37 | 23.82 | 3.68 | 51.83 | 15113 | 2350 | 12763 | 6.43 |
| 2 | *Beauveria bassiana* | 1.0 g/ l | 10.35 | 3.80 | 26.86 | 3.25 | 45.77 | 16229 | 2295 | 13934 | 7.07 |
| 3 | *L. lecanii* | 1.0 g/ l | 10.59 | 3.56 | 25.16 | 3.49 | 49.15 | 17112 | 2130 | 14982 | 8.03 |
| 4 | Azadirachtin | 5.0 ml/ l | 12.15 | 2.00 | 14.13 | 5.05 | 71.13 | 23483 | 4000 | 19483 | 5.87 |
| 5 | NSKE | 5.0 % | 11.85 | 2.30 | 16.25 | 4.75 | 66.90 | 22088 | 5700 | 16388 | 3.88 |
| 6 | Neem oil | 1.0 % | 10.99 | 3.16 | 22.33 | 3.89 | 54.79 | 18089 | 4550 | 13539 | 3.98 |
| 7 | Karanj oil | 1.0 % | 9.33 | 4.82 | 34.06 | 2.23 | 31.41 | 10370 | 4550 | 5819.5 | 2.28 |
| 8 | Karanj seed extract | 5.0 % | 9.39 | 4.76 | 33.64 | 2.29 | 32.25 | 10649 | 5700 | 4948.5 | 1.87 |
| 9 | Dimethoate 30 EC/ malathion 50 EC** | 0.03 %/ 0.05% | 14.15 | 0.00 | 0.00 | 7.05 | 99.30 | 32783 | 2172 | 30611 | 15.09 |
| 10 | Untreated control | - | 7.1 | 7.05 | 49.82 | - | - | - | - | - | - |
| | SEm± | - | 0.36 | - | - | - | - | - | - | - | - |
| | CD (P=00.05) | - | 1.17 | - | - | - | - | - | - | - | - |

Price of mustard seed was Rs. 4650 q ha-1 * It comprises the expenses for insecticides and labour charges **Standard check

*anisopliae*, *L. lecanii*, and *B. bassiana*, the total avoidable losses and percentage avoidable losses were 3.37, 3.56, and 3.80 q/ha, with corresponding percentages of 23.82%, 25.16%, and 26.86%, respectively. The untreated plots displayed the highest total avoidable losses and percentage avoidable losses, at 7.05 q/ha and 49.82%, respectively.

The plots treated with the standard check, followed by three neem-based treatments, demonstrated the greatest total increase in yield compared to the untreated control (7.05 q/ ha), resulting in a percentage increase of 99.30%. Within these

plots, the yield increase ranged from 5.05 to 3.89 q/ha, with corresponding percentage increases ranging from 71.13% to 54.79%. Conversely, plots treated with karanj oil and karanj seed extract exhibited the minimum total increase in yield over the untreated control, at 2.23 and 2.29q/ha, respectively, with percentage increases of 31.41% and 32.25%. The treatments involving entomopathogenic fungus demonstrated total increases in yield over the untreated control range from 3.68 to 3.25 q/ha, with percentage increases ranging from 51.83% to 45.77%. These outcomes align with the report that the mustard aphid caused an avoidable loss of 41.14% (Dotasara *et al*., 2018).

### Economics of biopesticides and plant products

#### Net profit

The data in Table 3 illustrates that the treatment, including the standard check, followed by Azadirachtin and NSKE, generated the highest net profit, amounting to Rs. 30,611/ha, Rs 19,483/ha, and Rs 16,388/ha, respectively. Conversely, the lowest net profit was observed in treatments involving karanj oil (Rs 4,948/ha), followed by karanj seed extract (Rs 5,819/ha). The net returns of Rs 12,763/ha, Rs 14,982/ha, and Rs 13,934/ha were recorded in treatments with *M. anisopliae*, *L. lecanii*, and *B. bassiana*, respectively (Fig. 3). These findings align with those of Meena *et al.* (2013), who reported that the most effective treatment was dimethoate 30 EC at a rate of 300 g a.i $ha^{-1}$, followed by NSKE (5%).

#### Benefit cost ratio

The data displayed in Table 3 indicate that the treatment exhibiting the highest benefit-cost ratio of 15.09 was associated with the standard check employing dimethoate 30 EC/malathion 50 EC, followed by *L. lecanii* (8.03) and *B. bassiana* (7.07). Furthermore, treatments with *M. anisopliae*, Azadirachtin, neem oil, and NSKE yielded higher benefit-cost ratios of 6.43, 5.87, 3.98, and 3.88, respectively. Conversely, the lowest benefit-cost ratios were observed in the treatments with karanj seed extract (1.87), followed by karanj oil (2.28). These findings are consistent with previous studies (Dotsara *et al*., 2018; Patel & Patel, 2010; Yadav & Singh, 2015), which observed the highest cost-benefit ratio in treatments involving dimethoate. However, the outcomes of the current investigation are in opposition to the conclusions drawn by Parmar & Kapadia (2007), who identified *B. bassiana* as the most effective treatment in terms of the cost-benefit ratio.

## CONCLUSION

The study has revealed that biopesticides and botanicals have greater potential in effectively reducing mustard aphid population compared to control. Though their efficacy was less compared to insecticide treatments, considering their safety to environment and natural enemies and also their role in residue free food production, biopesticides can form an important component of IPM of mustard.

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