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Review article

Integrated approaches to manage mustard aphid Lipaphis erysimi (Kaltenbach): An update

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Abstract

Importance of the work: This review paper compared and elaborated on recent updates about various effective approaches to control mustard aphid.
Objectives: To promote environmentally friendly and ecologically beneficial research in the field of pest control without compromising production in field crops.
Materials & Methods: Various important and economically effective approaches against mustard aphid were compiled. Different approaches were compared from an economic viewpoint. Promotion of integrated approaches was based on the research findings of various scientists in respective fields.
Results: Comparative management of aphids through various approaches is a keen area of interest to farmers as well as researchers. Undoubtedly, chemical approaches offer most effective control compared to all other approaches; however, the toxicity and residual effects of chemicals disturb the ecological balance. The tendency of researchers to move to integrated approaches was notable and could be an effective way to reduce the chemical loads on the environment. The use of cultural, mechanical, biological, botanicals and chemical controls in combination are long-term and sustainable approaches to manage the impact of mustard aphid in mustard fields. Therefore, a sound integrated pest management module should be developed with the objective of integrating all possible management practices that are environmentally vibrant and effective to manage the aphid catastrophe in mustard fields.
Main finding: Chemical insecticides should only be applied in situations where the aphid population is far above the economic threshold level, and if so, only systemic insecticides at recommended dosages should be used as these pose minimum harm to natural enemies in the mustard ecosystem.

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Introduction

Rapeseed-mustard belongs to the genus *Brassica* and the family Cruciferae. It accounts for up to 30% of whole oilseed production in India and is the second-most important edible oil crop after groundnuts (Anonymous, 2019). Thirteen states dominate its production, of which Rajasthan (45%), Uttar Pradesh (13%), Haryana (11%) and West-Bengal (8%) account for 77% of the total crop (Kaur, 2017). The Indian mustard, yellow sarson, brown sarson, raya and toria crops are in that order the widely farmed rapeseed-mustard groups (Shekhawat et al., 2012). Each part of rapeseed, such as the seed, flower, leaf, stem and root, can be used for cosmetics, food, medicine and other industrial applications. In particular, the most useful part is the seed as it contains oil (36–45%) in addition to protein (Raboanatahiry et al., 2021).

For oilseed *Brassica*, India stands second in planted area and third in production after China and Brazil, respectively, producing up to 72.37 million t from 33.64 million ha during the 2019–2020 season (Anonymous, 2021). India's rapeseed and mustard productivity is less than that of other mustard-producing countries, such as Germany (3,811 kg/ha), France (3,240 kg/ha), China (1,834 kg/ha) and Canada (1,769 kg/ha), as well as the global average (1,849 kg/ha) (Kaur and Grover, 2020). This low productivity is attributed to the fact that the crops suffer from heavy yield losses due to various biotic and abiotic stresses (Patel et al., 2017). More than 43 species of insect pests have been reported in rapeseed-mustard crops in India, of which the most important are aphid (*L. erysimi*), sawfly (*Athalia lugens proxima*), painted bug (*Bagrada hilaris*) and leaf miner (*Phytomyza horticola*). Among these, the mustard aphid, *L. erysimi* (Hemiptera: Aphididae) is the major pest causing up to 96% yield losses and 5–6% reduction in the oil content (Sahoo, 2012; Lal et al., 2018). Therefore, the present review aimed to summarize recent research work related to the integrated pest management of mustard aphid.

Nature and extent of loss

The activity of aphid in a mustard crop usually starts from November to March with the peak population during mid-February to mid-March (Sreedhar et al., 2019). The highly efficient colonization and settlement of *L. erysimi* directly impacts its economic importance. Plants become weaker due to the continuous sucking of the sap by aphid colonies which reduces the economic return. Heavy infestation of aphid colonies is accompanied by symptoms of yellowing, curling and drying of the leaves, resulting in the development of small, feeble seeds in the mustard pods. It also reduces the photosynthetic rate and secretes honeydew which is responsible for sooty mold growth (Patel et al., 2017). In the past few years, researchers have reported yield losses in the range 4–81% (Yadav and Rathee, 2020). Different species vary in estimated yield loss with reported ranges of 10.0–90.0% (Rana, 2005), 35.4–96.0% (Deka et al., 2017) and 76.0–100.0% (Patel et al., 2004). Observations recorded on different genotypes for the aphid population per plant were in the range 2.1–32.4 aphids/plant, with the maximum population (32.4 aphids/plant) registered on *Brassica rapa* (Kular and Kumar, 2011).

Management of L. erysimi

Control of the aphid control is difficult due to its fast multiplication, parthenogenetic reproduction mode, polymorphic nature and quick adaptability to diverse environments. Several chemical insecticides have been found effective against mustard aphid in different parts of India. Though highly effective, these chemical insecticides are not only toxic to the natural enemies of aphids, such as *Diaeretiella rapae*, *Chrysoperla zastrowi arabica*, coccinellids and syrphid flies (Singh et al., 2007), but also responsible for environmental pollution, health hazards to human beings, toxicity to pollinators and residue in oil and cake (Singh and Sharma, 2002). Therefore, researchers and farmer communities are keenly interested in integrating the ecologically friendly approaches discussed below.

Cultural practices

Sowing time

In many parts of India, early sowing of mustard results in minimized incidence of mustard aphid as the cold and cloudy weather in later months favors pest multiplication. During December and January, the chance of infestation due to mustard aphid increases substantially. Therefore, regular monitoring of crop fields is required to avoid resultant high losses, particularly during these months.

Table 1 Effect of date of sowing on aphid infestation and other yield parameters

Recommended planting time	Observed impact	Reference
10 November	Highest growth attributes, such as plant height, dry matter accumulation, days taken to 50% flowering, number of tillers, leaf area index and yield and yield attributes such as number of siliqua per plant, length of siliqua, test weight, seed yield, grain yield, stover yield, biological yield and harvest index	Tripathi et al. (2021)
20 October	Early planted: (7.06 aphids/plant)	Dinda et al. (2018)
5 November	Mid planted, (66.89 aphids/plant)	
20 November	Late planted, (121.30 aphids/plant)	
25 October	Highest oil content (41.62 %) and economic return compared to very early planting on 25 September (33.93%)	Singh et al. (2017)
Mid-October	Early sown crops (mid-October) in each year had significantly lowest number of key aphids (14.09 aphids/plant) compared to late sown crops in early November (16.82 aphids/plant) and mid-November (20.87 aphids/plant)	Saeed and Razaq (2014)
20 October	Recorded lowest aphid infestation (9–11.5 aphids/plant)	Chandra et al. (2013)

Clipping of infested twigs

Heavily infested twigs can be clipped after every 15 d, starting from the first appearance of aphids. Three such rounds of clipping will be effective, subject to the availability of cheap labor (Yadav and Rathee, 2020). The effectivity increases when clipping is combined with other measures. Neem oil and neem seed kernel extract (NSKE) at 5% after clipping of infested twigs may be recommended as an eco-friendly and effective alternative to chemical control of aphid on Indian mustard (Yadav et al., 2021).

Optimum fertilization

A high dosage of nitrogenous fertilizers increases major growth of plants which, in turn, attracts dense aphid populations (Khattak et al., 1996). However, the increased application of sulfur is negatively correlated with the population of aphids (Bakhetia and Brar, 1988). Similarly, aphid incidence decrease with higher dosages of phosphorus and potassium (Ram and Gupta, 1992). Based on reports of NPK fertilization and its correlation with aphids (*L. erysimi* and *Myzus persicae*) it has been concluded that increased fertilizer doses increased the incidence of aphids on the crop (Choudhary et al., 2001). An increase in the nitrogen level up to 60 kg N/ha consistently and significantly increased the number of primary branches, number of seeds per siliqua and 1,000 seed weight (Shekhawat et al., 2012). Further increases in the nitrogen level up to 90 kg/ha increased the number of secondary branches per plant, the number of siliquae per plant and the seed and straw yields, as well making the crop highly susceptible to mustard aphid infestation.

Intercropping

Most companion crops, usually planted as mixed crops with Indian mustard, operate as deterrents and barriers to *L. erysimi* migration across mustard fields.

Use of traps

The winged morphs of aphid initiate infestation as these are attracted toward yellow-colored mustard flowers (Pal et al., 2018). The two peak incidences of alate forms have been observed at 34.6 aphids/trap and 94.9 aphids/trap (Kumar, 2015). Populations of winged adults can be monitored with the use of yellow sticky traps at 12/ha (Yadav and Rathee, 2020). Researchers have recorded the various populations in mustard of winged adults/trap such as 30 (Sundar et al., 2015) and 35.4 ± 2.9 (Kumar, 2015). In a study in Karachi, Pakistan the catches per trap on yellow-, blue-, green- and white-colored traps were 168, 132, 109 and 71, respectively (Khanzada et al., 2016).

Table 2 Management of *Lipaphis erysimi* through intercropping

Intercrop	Ratio	Effect recorded	References
Coriander, Radhuni Garlic	Similar distance was maintained when all seeds were sown (50cm inter-row)	Intercrops showed lower aphid population levels (14.98 to 15.40 aphids/plant)	Afrin et al. (2017)
Spinach, beans, or dill	4 mustard :1	Reduced aphid infestation.	Seif and Nyambo (2013)
Onion	4 lines/plot of $1m^2$	Cost-benefit ratio was 1:2.81.	Sarker et al. (2009)
Garlic	4 lines/plot of $1m^2$	Cost-benefit ratio was 1:2.96 compared to mustard alone (1:2.06)	
Chickpea	4 mustard :1 chickpea	Nodule number, dry weight, grain yield was higher in the intercrop	Singh and Rathi (2003)
Chilli	26% mustard + 100% chilli	Higher yield and profit than sole crop	Mamun et al. (2002)
Chickpea	75% mustard + 25% chickpea	Higher yield and economic returns than sole crop	Samsuzzaman et al. (1995)

Host plant resistance

Plants that are resistant to insects have unique characteristics that enable them to resist insect attack (Muhammad and Khan, 2022). The three modalities of plant resistance to insects are: tolerance, antibiosis and antixenosis (Acquaah, 2009). Antixenosis modulates pest behavior in such a way that it moves away or chooses to feed on susceptible alternative. Antibiosis negatively affects the biology of the pest, often resulting in reduced longevity and fecundity/reproduction or death in certain cases. The main concern in developing genotypes with strong antibiosis is the selection pressure on insects, which might result in potential breakdown of resistant evolutions of the fresh pest's biotype (Dhaliwal et al., 2004). In contrast, where a pest shows tolerance, so that selection pressure cannot be imposed on the pest population, there is the potential to integrate with other management techniques to provide a more sustainable solution to pest problems. Due to consumer acceptance and market demand, varietal resistance has received priority in integrated pest management programs.

Cultivation of resistant or tolerant varieties is very effective and is the cheapest method of cultural control against insect-pests. Utilization of resistant varieties/germplasms against aphids results in increased production and the reduction of harmful pesticides residue in the environment. The program of breeding resistant varieties of *Brassica* to the mustard aphid aims to tap into the best source of resistance in this genetically heterogeneous species (Rohilla et al., 1993). Various biochemical constituents such as total phenols, ortho-dihydroxy phenols and glucosinolates, showed a significant negative correlation with aphid whereas, flavonols did not exhibit any significant correlation with aphid population (Kumar and Sangha, 2013). Comparing the role of individual components in reducing aphid populations in the field, it is surmised that glucosinolates, orthodihydroxy phenols and total phenols are important in that order. Table 3 presents the genotypes released with their resistance intensity.

Mechanical control methods

There is very little information available on mustard aphid management through mechanical means. The high pressure of water being sprayed through a hollow cone nozzle with a single opening produced the highest aphid population reduction by immediately dislodging 90.8% of them (Nawaz et al., 2016).

Botanicals

Tannins, sitosterol, glycosides, phenols, flavonoids, terpenoids and alkaloids are some of the numerous secondary metabolites found in plants (Gulzar et al., 2018). In certain insect species, these chemical plant extracts exhibit lethal, anti-feedant and growth-disturbing properties through inhibiting molting (Al-Fifi, 2009). Recent years have seen a rise in the use of botanicals for pest control, since they are eco-friendly, cheap, more readily available and less poisonous to natural enemies. Table 4 shows the effective concentrations of the different plant parts used.

Table 3 Promising mustard genotypes showing host plant resistance to *Lipaphis erysimi*

Genotype	Resistance category	Reference
RSPN-28, CNH-11-13, RL-1359, HNS-1101, GSC-101, CNH-11-2 and HNS-1102	MR	Tiwari et al. (2023)
KS 75, Zahoor (Pakistan)	R	Muhammad and Khan (2022)
RP 09, RCM-202, RCM-84, RCM-198, RLM 84, C 294, Laha 101 and Pusa Kalyani	R	Yadav and Rathee (2020)
UCD-1202	R	Shah (2020)
NPJ-194	HR	Sreedhar et al. (2019)
Divya-88, RL-JEB-52, DRMRIJ-1585, Ganga, RGN-385, SVJ-64, Sitara-sreenagar, RH-0923, JMM-927-RC, RGN-389, RGN-384, PRD-2013-9, RH-1202, KM-126, NPJ-196, RMM-0910, RB-77, RL-JEB-84, RH-1209, PR-2012-12	R	
CS 2009–154, KMR (E) 16–1, NIMH-23 and NPJ-202	R	Yadav and Kumar (2018)
Vardan	R	Chaudhary and Patel (2016)
RWAR-842, RH-9020, RH-7847 and RH-7846	R	Shekhawat et al. (2012)
Kranti, Maya, MYSL-203, PCR-7, Pusa Agrani, Pusa Swarnim, NDYS-2, and YST-151 (AII<1)	HR	Ali and Rizvi (2011)
BSH-1, Alankar, Krishna, Pusa Bahar,Pusa Bold, Vardan, GSL-1, PT-30, B-9, PS-66 (AII=1)	MR	
Laha 101 and *Brasicca juncea* 6105	HR	Lal (2009)
Genotypes; 294, R.T. 11, *B. juncea* 5976 and B.R. 13	MR	

R = resistant; MR = moderately resistant; HR = highly resistant

Table 4 Effective concentration of different plant parts in management of *Lipaphis erysimi*

Common (Scientific name)	Plant parts commonly used (Active ingredient)	Effective concentration/ mortality	Reference
Neem (*A. indica*)	Leaves (azadirachtin)	Only 17.28 aphids per 10 cm terminal shoot post treatment with 10000 ppm @ 500 mL/ha	Vinyas et al. (2022)
Neem leaf extract (*Azidirachta indica*)	Leaves (azadirachtin)	4 ± 0.84 aphids at 36 days after spraying (DAS) with 250g/L water	Angala et al. (2022)
Mahogany seed dust (*Swietenia mahagoni*)	Seed (catechin, gallic acid, and rutin)	4 ± 1.30 aphids at 36 DAS with 100g/L water	
Neem seed extract (*A. indica*)	Seed (azadirachtin)	87.75% mortality @ 270.08g/L	Essani et al. (2020)
Neem oil (*A. indica*)	Fruits (azadirachtin)	76.02% mortality @ 50ml/L	
Tobacco extract (*Nicotiana tabacum*)	Leaves (nicotine)	71.38% mortality @ 300g/L	
Aak (*Calotropis procera*)	Stem, roots, and Leaves (calotropin, calotoxin and uscharin)	68.57% mortality @ 352g/L	
Azadirachtin 10000 ppm (*A. indica*)	Leaves (azadirachtin)	82.2% mortality @ 1.0 mL/L water	Kumar et al. (2020)
Azadirachtin 1500 ppm (*A. indica*)	Leaves (azadirachtin)	79.1% mortality @ 1.0 mL/L water	
Neem oil 3% (*A. indica*)	Fruit (azadirachtin)	78.7% mortality at 1.0 mL/L	
Neem (*A. indica*)	Leaves (azadirachtin)	88.6% mortality @ 5%	Bhatta et al. (2019)
Tobacco (*N. tabacum*)	Leaves (nicotine)	88.16% mortality @ 5%	
Titepati (*Artimesia vulgaris*)	Leaves (monoterpenoids and sesquiterpenoids)	75.99% mortality @ 5%	
Marigold (*Tagetes erecta*)	Leaves (Monoterpenoids, carotenoids, and flavonoids)	75.55% mortality @ 5%	
Aak (*C. procera*)	Stem and leaves (calotropin, calotoxin and uscharin)	54.91% mortality @ 2%	Akbar et al. (2016)
Gul-e-daudi (*Chrysanthemum indicum*)	Leaves (pyrethrin)	49.55% mortality @ 2%	
Neem leaf extract (*A. indica*)	Leaves (azadirachtin)	92.85% mortality @20%	Chattree et al. (2016)
Neem oil (*A. indica*)	Fruit (azadirachtin)	100% mortality after @ 2.5%	Aziz et al. (2014)
Neem seed cake extract (*A. indica*)	Seed (azadirachtin)	86.13% mortality @ 10%	
Neem seed kernel extract (*A. indica*)	Seed (azadirachtin)	77.41% mortality @ 10%	
Neem seed kernel extract (*A. indica*)	Seed (azadirachtin)	70.82% mortality @ 5%	Chandel et al. (2012)
Neem leaf extract (*A. indica*)	Leaves (azadirachtin)	Up to 77.33% mortality	Singh and Lal (2012)
Punch phuli leaf extract (*Lantana camara*)	Leaves (Phytol, Pyrroline, Paromomycin and Pyrrolizin)	74.35% mortality	
Garlic leaf extract (*Allium sativum*)	Bulb (dimethyl trisulfide, diallyl disulfide and diallyl sulfide)	73.19% mortality	
Mexican marigold (*T. erecta*)	Leaves, flowers, and root extracts (Monoterpenoids, carotenoids, and flavonoids)	96.4% mortality @ 1:2.5 g/ml	Ali et al. (2010)
Indian neem (*A. indica*)	Leaves (azadirachtin)	100% mortality @ 1: 1.5 w/v	

Biological control

Use of predators and parasitoids

The cornerstone to on-site control of mustard aphids is the preservation of natural enemies that feast on them. These include: ladybird beetles, such as *Coccinella septempunctata*, *C. transversalis*, *Monochillus sexmaculata*, *Hippodamia variegata* and *Cheilomones vicina*; green lacewings, such as *Chrysoperla zastrowi sillemi*; and many syrphid/hoverfly species, such as *Syrphus torvus, Episyrphus balteatus, Sphaerophoria* spp., *Sphaerophoria scripta* and *Xanthogramma* spp. (Yadav and Rathee, 2020). The braconid parasitoid, *Diaetriella rapae* was reported to have naturally parasitized 48.0–62.0% of aphid populations (Yadav and Rathee, 2020). The Hymenoptera Braconidae; *Aphidius* spp., *Praon* spp., *Tryoxis* spp., *Diaeretiella* spp. and Chalcidoide; *Aphelinus* spp. are other aphid parasitoids (Guerrieri and Digilio, 2008). The initial application of NSKE at 5%, followed by the release of *Chrysoperla carnea* (parasitized eggs at 150,000/ha) effectively managed a mustard aphid population (Singh and Singh, 2013). Table 5 presents the feeding potential of predators on aphid populations.

Table 5 Feeding potential of different instars of predators on aphids

Predator	1st instar	2nd instar	3rd instar	4th instar	Reference
C. septempunctata	21.62	48.03	73.37	102.64	Singh and Singh (2013)
C. septempunctata	24.57±6.50	48.73±11.38	110.70±20.69	179.06±32.71	Khanday et al. (2016)
Syrphus confrater	7.38	41.32	55.73	-	Singh and Singh (2013)
Syrphus balteatus	8.57	25.45	62.75	-	
Ischiodon scutellaris	7.29	33.25	42.73	-	

The overall feeding efficiency of *C. septempunctata* was highly effective on *L. eysimi* aphids compared to other aphid species (Arshad and Parvez, 2007).

Use of entomopathogens

Several entomophagous fungi are known to infect aphids, including *Beauveria bassiana* (Green Heal), *Metarhizium anisopliae* (Bio Metaz), *Verticillium lecanii* (Varunastra), *Bacillus thuringiensis* (Thuricide), *Lecanicillium lecanii* (Biovert), *Paecilomyces lilacinus* (Bioniconema) and *Nomuraea rileyi*. Table 6 presents the efficacy of entomopathogens against *L. erysimi*.

Chemical control

For management of mustard aphid, insecticides must be applied only if in at least 10% of the plant population, there are 23–25 aphids per 10 cm of the main stalk—the economic threshold level or ETL (Chattopadhyay et al., 2005). Application of any one of the insecticides listed in table 7 at the ETL has proven effective, while imparting minimum harm to the ecosystem balance.

Economics of management options for L. erysimi

In addition to successfully managing aphid populations, the selected control strategy should also be economically justifiable in terms of increased yield per cost incurred. Though not ecologically sound, several chemical insecticides usually provide a higher benefit-cost ratio compared to biological and botanical control measures. Furthermore, botanicals are not usually available in the large quantities needed for large-scale management of aphids in field conditions. Table 8 shows the incremental cost-benefit ratios of different management strategies to manage the aphid.

Table 6 Entomopathogenic management of *Lipaphis erysimi*

Entomopathogens	Effective concentration/mortality >50%	Reference
B. thuringiensis	57.02% mortality	Sairam and Kumar, (2022)
B. bassiana	55.76% mortality	
M. anisopliae	50.46% mortality at 106–108 spore load/g	
L. lecanii	Only 20.28aphids per10 cm terminal shoots recorded after application @ 2 kg/ha.	Vinyas et al. (2022)
B. bassiana	22.08 aphids per 10 cm terminal shoot after application @ 2 kg/ha	
M. anisopliae	71.67 ± 6.16% mortality post 96 hr spray with 1 × 10^9 spores/mL @ 3mL/L water	Khanal et al. (2020)
B. bassiana	70.84 ± 5.16 % mortality post 96 hr spray with 1 × 10^9 spores/mL @ 3.3 mL/L water	
V. lecanii	58.33 ± 5.18% mortality post 96 hr spray with 2 ×10^8 CFU/ mL @ 6 mL/L water	
B. thuringiensis var. kurstaki, 0.5% W.P.	37.50 ± 4.79% mortality post 96 hr spray @ 6 g/L	
Azadirachtin followed by *B. bassiana* after 15 d	95.61% mortality @ 2g/L	Pal et al. (2020)
B. bassiana followed by second spraying after 15 d	90.65% mortality @ 2g/L	
Azadirachtin followed by *V. leccanii* @ 2g/l after 15 d	96.38% mortality @ 2g/L	
V. leccanii followed by second spraying after 15 d	91.52% mortality @ 2g/L	
V. lecanii	75.24% mortality @ 2.7 ×10^7 spores/ml	Janu et al. (2018)
B. bassiana	74.06% mortality @ 2.4 × 10^8 spores/ml	
M. anisopliae	50% mortality @ 1.71 × 10^7 spores /ml	Deka et al. (2017)
N. releyi	50% mortality @ 2.8 × 10^8 spores /ml	
B. bassiana	50% mortality @ 2.8 × 10^8 spores /ml	
V. lecanii	50% mortality @ 5.1 × 10^8 spores /ml	
M. anisopliae	83.23% mortality @ 25% concentration	Sajid et al. (2017)
B. bassiana	78.33% mortality @ 25% concentration	
B. thuringiensis	73% mortality @ 25% concentration	
L. lecanii isolate PDRL922	100% mortality @5.0x10^9 spores /ml	Ujjan and Shahzad (2012)
B. bassiana isolate PDRL1187	100% mortality @ 2.7x10^9 spores /ml	
P. lilacinus isolate PDRL812	100% mortality @ 5.1x10^7 spores /ml	
M. anisopliae isolate PDRL526	96.8% mortality @ 3.0x10^9 spores /ml	
B. bassiana, strain CG001	90% mortality and 4.4 days median lethal time	Araujo et al. (2009)
M. anisopliae, strain CG30	64% mortality and 3.8 d median lethal time	

Table 7 Effective chemical insecticides to control mustard aphid

Chemical	Effective concentration/mortality	Reference
Fipronil 5% SC	65.11% mortality	Sairam and Kumar (2022)
Spinosad 45% SC	61.85% mortality	
MECH 333	57.98% mortality	
Dimethoate 30 EC	84.63% mortality @ 625 mL/ha	Yadav et al. (2021)
Oxydemeton methyl 25	250–400 mL in 250–400 L of water per acre	Yadav and Rathee (2020)
EC or Dimethoate 30 EC	250– 400 mL in 250–400 L of water per acre	
Malathion 50 EC		
Thiamethoxam 25 WG	100% mortality @ 0.25g/L	Patel et al. (2020)
Imidacloprid 17.8% SL	100% mortality @ 0.25mL/L	
Dimethoate 30 EC	100% mortality @1mL/L	
Clothianidine 50 WDP	100% mortality @ 0.3 g/L	
Acetamiprid 20SP	100% mortality @0.15 g/L	
Acephate 75 SP	100% mortality @1mL/L	
Oxy-demeton methyl 25 EC	100% mortality @1mL/L	
Fipronil 5 SC	98.3% mortality @ 2 mL/L	
Flonicamid 50% WG	84.9 to 94.7% mortality @30 g active ingredient (a.i.)/ha	Debashis et al. (2018)
Pyriproxyfen 10% EC	81.7 to 93.00% mortality @50 g a.i./ha	
Imidacloprid 17.8% SL,	77.5 to 89.00% mortality @25 g a.i./ha	
Thiacloprid 21.7% SC	71.9 to 85.8% mortality @30 g a.i./ha	
Carbosulfan 20EC	98.7% mortality after 168 hr spraying @ 500mL/ac	Ahmed et al. (2018)
Pymetrozine 50%WG	96.6% mortality after 168 hr spraying @ 0.16kg/ac	
Dinotefuran 200SG	87.1% mortality after 168 hr spraying @ 100 mg/ac	
Thiamethoxam 25 WG	100% mortality @ 0.25g/L	Patel et al. (2017)
Imidacloprid 17.8% SL	99.8% mortality @ 1 mL/L	
Dimethoate 30 EC	99.68% mortality @ 1 mL/L	
Imidacloprid 17.8% SL	87.53% mortality @ 0.2 g/L	Dotasara et al. (2017)
Fipronil 5 SC	83.565 mortality @1.0 mL/L	
Imidacloprid 17.8	72.86% mortality @20 g a.i./ha	Sen et al. (2017)
Thiamethoxam 25 WG	69.42% mortality @ 25 g a.i /ha	
Diafenthiuron 50 WP	67.55% @ 50 g a.i./ha	
Buprofezin 40 EC	93.27% mortality @ 0.5 ml/l water	Dutta et al. (2016)
Indoxacarb 145 SC	75.08% mortality @ 1ml/l	
Diafenthiuron 500 SC	92.57% mortality @ 1ml/l	
Azidirachtin 1 EC	77.55% mortality @ 1ml/l	

WG = Wettable Granules; SL = Soluble Liquid; EC = Emulsifiable Concentrate; WP = Wettable Powder, SP = Soluble Powder; SC = Soluble Concentrate; WDP = Water Dispersible Powder

Table 8 Economics of different management strategies of mustard aphid

Treatment	Incremental cost-benefit ratio	Reference
Imidacloprid 17.8 SL	1:7.24,1:14.62, 1:10.36	(Sen et al., 2017; Vishal et al., 2019; Raju and Tayde, 2022)
Thiamethoxam 25 WG	1:5.24, 1: 14.35, 1:8.33	(Sen et al., 2017; Vishal et al., 2019; Raju and Tayde, 2022)
Acephate 75 SP	1: 6.1, 1:6.96	(Sahoo, 2012; Vishal et al., 2019)
Dimethoate 30EC	1: 7.6, 1: 19.8, 1:37.6	(Sahoo, 2012; Kumar et al., 2020; Pal et al., 2020)
Oxydemeton-methyl 25EC	1: 15.8	(Sahoo, 2012)
Fipronil 5SC	1:4.64, 1: 4.8	(Sahoo, 2012; Raju and Tayde, 2022)
Diafenthiuron 50WP	1: 13.40	(Sen et al., 2017)
Difenthurion 50%WP	1:6.43	(Raju and Tayde, 2022)
Profenophos 50% EC	1:3.94	(Raju and Tayde, 2022)
Azadirachtin 1500 ppm	1: 5.4	(Kumar et al., 2020)
NSKE 5%	1:3.90, 1: 3.1	(Sahoo, 2012; Raju and Tayde, 2022)
V. leccani	1: 10.6	(Pal et al., 2020)
B. bassiana	1: 08.9, 1:6.64	(Vishal et al., 2019; Pal et al., 2020)

Define all terms here in a footnote, using the same formatting as for the previous table.

WG = Wettable Granules; SL = Soluble Liquid; EC = Emulsifiable Concentrate; WP = Wettable Powder, SP = Soluble Powder; SC = Soluble Concentrate; ppm = parts per million

Conclusion and perspectives

Key Findings: The major findings of this review combine various approaches as follows:

1) Early sowing up to mid October will help to decrease the aphid infestation and increase the economic returns.

2) Neem oil and NSKE (neem seed kernel extract at 5%) after clipping of infested twigs are ecofriendly and an effective alternative to chemical control.

3) Higher doses of nitrogen fertilizer should be avoided to decrease the incidence of aphid populations, while phosphorous and potassium application decreases aphid populations.

4) Intercropping mustard with various crops, such as chickpea, chilli, beans, garlic and onion, reduces the aphid infestation and increases the cost-benefit ratio.

5) Botanicals such as neem extract (leaf, kernel, seed, oil), mahogany seed, tobacco, aak (*Calotropis*), artemesia, garlic and marigold have 50–96% mortality of aphid populations and these may be ranked as an alternative approach to chemical control.

6) The most effective bioagent against aphid populations is *Verticillim lecanii*, followed by *Beauveria bassiana, Metarhizum anisopliae and Bacillus thuringiensis*, respectively.

7) The use of novel insecticides, such as Thiamethoxam, Bifinthrin, Acephate, Pymetrozine and Clothianidine, in judicious dosages along with other approaches has been reported as economical and sustainable.

Contribution of study: Vertical growth in mustard production can be realized by exploiting the available genetic resources with breeding and biotechnological tools to identify more varieties that can withstand aphid infestations, have high repellant properties and show antibiosis effects. For horizontal growth in production, several high-yielding varieties that have already been proved to withstand high aphid populations should be deployed in major rapeseed mustard-producing states. Biological control should be encouraged with major emphasis on conservation of already existing niches of effective natural enemies of the aphid; pathogens that can cause epizootics in aphid populations have been identified and should be adopted alone or in combination with chemical sprays to manage aphid in an eco-friendlier manner. India is endowed with several botanicals that can be used by farmers to replace persistent broad-spectrum insecticides. Effective dosages should be elucidated of these botanicals and their combination ratios if needed. Timely planting, intercropping, mechanical weeding, clipping, optimum fertilization and the use of blue and yellow sticky traps to monitor aphid populations are such other cultural practices that can be adopted to develop a robust integrated pest management (IPM) module for this devastating pest. Chemical insecticides should only be applied in situations where the aphid population far exceeds the ETL, and then only systemic insecticides should be used at recommended dosages, as these should pose no or minimal harm to natural enemies in the mustard ecosystem.

Avenues for future research: The production gap needs to be bridged through management techniques that can meet the ever-growing demand for mustard-rapeseed oil in India. To address this biotic stress, a sound IPM module should be developed with the goal of integrating several equally effective and environmentally sound management techniques.

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