International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(7): 458-468
www.biochemjournal.com
Received: 08-04-2024
Accepted: 13-05-2024

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A review on application of integrated pest management tactics for aphid complex on crop ecosystem

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DOI: https://doi.org/10.33545/26174693.2024.v8.i7f.1505

Abstract
Integrated Pest Management (IPM) is an essential approach for managing pest populations in crop ecosystems. The application of various IPM tactics specifically targets to the aphid complex which causes significant damage to various crops. Aphids have delicate pear-shaped bodies with long legs and antennae and belong to hemimetabolous insects which consist of various stages like egg, nymph and adults. Aphids are a highly adaptable and prolific pest group and out of all the species, 10% of species feed on multiple host crops. Damage is caused by the aphids in the form of extracting sap from plants at growth stages of mustard such as vegetative stage 6.50%, flowering stage 76.50%, and pod-forming stage 17.00%. Apart from that stunted growth, wilting and reduced vigor. It acts as vector to transmit various diseases such as mosaic viruses, leaf curl viruses and yellowing diseases, which produce different symptoms like sooty mould, leaf curling, stunting and dead shoots. Effective management of aphid populations (Nymph and adult) through a combination of different methods such as cultural, mechanical, biological, nano-pesticides and biorational pesticides in integrated pest management strategies. This review provides an overview of the key IPM tactics applicable against aphid infesta tions, highlighting their effectiveness, advantages and limitations. Additionally, the ecological implications and sustainability of IPM approaches are discussed.

Keywords: Aphid, biology, economic threshold levels (ETL), integrated pest management (IPM) strategies, nymph, adult, vector, disease

1. Introduction

Aphids, also known as plant lice or greenflies are small, soft-bodied insects belonging to the family Aphididae suborder Homoptera. They are one of the most destructive and widespread groups of pests that affect crops worldwide. Aphids are highly adaptable and have a broad host range, infesting a wide variety of plants, including fruits, vegetables, grains, ornamentals and field crops [1, 2]. These tiny insects possess a significant threat to crop ecosystems, causing substantial economic losses and compromising food security. Aphids can reproduce rapidly and can adapt to changing environmental conditions [3]. Female aphids can give birth directly as nymphs and each nymph can reach at maturity within a week, leading to exponential population growth, having a rapid reproductive rate to quickly establish large colonies on plants, causing extensive damage. The feeding behaviour of aphids is particularly detrimental to plants, through their specialized mouth parts called stylets which penetrate the plant tissues and feed on the phloem sap which causing the extract of essential nutrients from the plants leading to poor growth, reduced vigour and decreased crop yields. Moreover, aphids can transmit a wide range of plant viruses and pathogens while they are feeding which results in crop damage up to the vegetative stage (6.50%), flowering stage (76.50%) and pod-forming stage (17.00%) and yield losses up to 50 to75% due to mustard aphids [4, 5, 6, 7].

Around 4,000 species of aphids have been discovered, out of which 250 species are reported as pests of crops and ornamental plants. Such as *Aphis pomi*, *Brevicoryne brassicae*, *Adelges cooleyi*, *Anuraphis maidi radicis*, *Adelges abietis*, *Toxoptera graminum*, *Myzus persicae*, *Aphis gossypii*, *Acyrthosiphon pisum*, *Macrosiphum euphorbiae*, *Macrosiphum rosae*, *Dysaphis plantaginea*, *Eriosoma lanigerum* [8]. Morphology of wingless female aphids having two rows of black bands on the thorax and abdomen with yellowish-green or light green in colour, antennae are dark in colour, cornicles are pale with black tips and the legs have dark at joints. The body is thinly covered with white powder. The winged female is similar in size to the wingless female [9].

2. Life cycle of Mustard Aphid

2.1 Host Plants

Host-seeking behaviour of aphids search the resource for selection can be carried out in three steps: habitat location, host location, and host acceptance [10]. Aphids typically use visual signals (Colours, contrasts) and smell to locate hosts [11]. Some species are reported as monophagous and polyphagous in nature, an example is the green peach aphid which consumes hundreds of different plant species from different genera. Approximately 10% of species feed on various plants at different times of the year [12]. In addition to cabbage, cauliflower, broccoli, brussels sprouts, kale, kohlrabi, radish and turnips, cruciferous weeds such as shepherd's purse and wild mustard serve as hosts for this pest [13]. Several kinds of aphids and their host plants are compared in (Table. 1) in terms of yield and Economic threshold levels (ETL).

2.2 Nature of Damage

Aphids cause the infestation of the host plant which produces symptoms like the turning of leaves from green to yellow, curling and eventually drying up, which produces tiny, frail pods [31]. It produces honeydew, which promotes the growth of sooty mould which causes to inhibit photo synthesis [32]. Aphids can damage their hosts by sucking the plants phloem with their mouthparts. Aphids serve as vectors for a variety of plant viruses, such as mosaic viruses, leaf curl viruses and yellowing diseases. In severe cases, virus transmission can result in reduced crop quality, lower yields or even complete crop loss [33]. Aphids can spread various diseases to the plants, here some examples of the diseases caused by aphids are shown in (Table. 2), and the reduction of seed yield of mustard due to aphid infestation at different stages of crop growth are given in the (Table. 3).

2.3 Morphology

Aphids are soft, pear-shaped insects that are between 1-2 mm in size [37]. They frequently have a waxy or powdery covering on their body. The head, thorax and abdomen are the three primary parts of their bodies. A pair of long antennae, compound eyes and mouthparts designed for piercing and sucking sap are present on the head [38]. Most common aphid species have soft bodies and are green in color but some hard-bodied species are dark with a different colour. Nymphs are similar to apterous adults according to external morphology but they are smaller and do not have wings. On the posterior dorsum of the abdomen, two tube-like structures known as siphunculi or cornicles are capable of releasing alarm pheromones. The cauda, a posterior protrusion on the tip of the abdomen is another feature that makes aphids unusual. Generally, wax secretions by the aphids are used for protection purposes [39] and Malpighian tubules are absent [40]. The morphology of aphids is shown in (Fig. 2).

2.4 Life cycle

Aphids normally go through only three stages of metamorphosis: egg, nymph and adult. Nymphs resemble adults but are smaller and lacking of wings. They undergo several moults before reaching adulthood. Formation of wings may develop in response to environmental cues, facilitating dispersal [41]. It reproduces asexually as well as sexually, female aphids without wings, known as stem mothers, can have progeny without mating (Known as parthenogenesis) in the summer season. Unlike many other insects that lay eggs, these stem mothers give birth to progeny (Known as viviparity) [42]. The average duration of each life stage for several aphid species is shown in (Table. 4) and the life cycle of the mustard aphid is shown in (Fig. 3).

2.4.1 Eggs

Adult females of aphids lay eggs on host plants, generally in the bark crevices, leaf buds or other plant parts [1]. Eggs are typically oval or elongated in shape and their color ranges from yellowish to dark brown or black, depending on the species [46]. The different factors like temperature, relative humidity and photoperiod, etc., which are impact on the hatching of eggs [47] and the pattern of the laying eggs are row parallel to the leaf veins [48].

2.4.2 Nymph

After hatching from eggs, aphids go through several nymphal instar stages before becoming adults. Nymphs resemble adults, but are smaller and lack wings. They feed on plant sap with their piercing-sucking mouth parts and undergo moulting at matured stage [46]. The nymph passes through four distinct instars before reaching the adult stage. The instars were determined from their exuviae cast of fat each moult. Newly borne 1st instar was wingless, elongated, transparent and pale yellowish or light greenish in colour, then 2nd instar was bigger than the first instar, 3rd instar was dark yellowish in colour and the last instar was dark in colour with elongated in shape. The duration of 1st, 2nd, 3rd and 4th were 1-2, 1-2, 0.5-4 and 1-4 days, respectively and the total nymphal period was 6 to 9 days [49].

2.4.3 Adult

The apterate adults had elongated with a dark to deep olive-green in colour. The compound eyes were swollen and dark black in colour, antennae were six segments which are shorter than the length of the body. Legs were rather long, thick and covered with hairs. The third pair of legs is larger as compared to the first and second pair of legs. The abdomen was swollen, shiny and dark to nearly black in colour. A pair of cornicles are present in long tube-like structures with green in colour which is used as a distinguishing characteristic of adult aphids. An alate is similar to the apterate adult except in the presence of wings. Both the fore and hind wings are translucent and rectangular in shape, but the forewing is longer and wider than the hind wing. The life span of adults ranges from 2.0 to 9.0 days [49].

3. Integrated Pest Management (IPM)

Aphids cause big problems for different crop cultivation in India, leading to less production in terms of both quality and quantity. Integrated pest management is the best option to manage the aphids. It was introduced in 1970, which included cultural, mechanical, biological and chemical methods, which help to maintain the balance of ecosystems and reduce dependence on and excessive use of synthetic chemical pesticides [50]. The aim to keep pest populations below economic injury levels through the decreasing the use of pesticides and effective implementation of IPM programs for to reduce the management of costs for farmers and minimize the impact on the ecosystem [51].

3.1 Cultural Management Practices

A cultural method is one of the most important in the management of pests which helps to cause economic losses [52]. The numerous cultural practices have been categorized as follows.

3.1.1 Soil characteristics and climatic conditions

The aphid population is greatly impacted by soil properties and climatic conditions. Sufficient soil moisture is necessary for plant health and can indirectly affect the aphid populations by influencing the vigor and susceptibility of host plants. Additionally, excessive moisture can promote the formation of fungi that could harm aphids [53]. Both hot and cold temperatures may reduce aphid activity and population [54]. Aphids can survive in high-humidity conditions while died in low humidity [55]. Indian mustard is a cool-seaso00n crop that may be grown in both tropical and temperate climates. It functions best with a temperature range of 6 to 27 °C and soil pH of 4.3 to 8.3 and harvesting is completed in the dry season [56].

3.1.2 Date of sowing

Early sowing of crops facilitates their earlier emergence and establishment, allowing them to escape conditions favourable for aphid development. This approach aids in minimizing aphid infestation by disrupting their reproductive cycle and reducing their population [57]. Late sowing helps in the management of aphid populations by increasing coordination between plant growth stages and natural enemy activity [58]. Sowing the crop before October 20^{th} can reduce the infestation of mustard aphids [31]. Early-sown crops showed less infestation compared to late-sown crops [59].

3.1.3 Manures and fertilizers

Manures and fertilizers increase plant health and vigor but it indirectly influences the aphid population. Organic manures, such as compost and Farm Yard Manure (FYM), can improve soil properties and microbial activity, which helps in better plant growth and improved resistance capacity against aphid infestations [60]. Proper fertilizer application may help to plants recover from aphid damage and improve tolerant capacity, leading to minimizing the overall impact of aphid infestations [46]. Nutrient management in crops is the most important key to high production and affects the response of plants against insects, pests and diseases. The application of 80 kg/ha Muriate of Potash (MOP) on mustard crops recorded the lowest aphid population [61]. A balanced ratio of N:P:K which is 69:46:25 kg/acre to improve wheat production and minimizes the aphid population [62].

3.1.4 Crop rotation

Crop rotation is an effective cultural practice against the aphid populations, in the form of disruption of the life cycles of aphids and hence minimizing the population of insects present in the soil and breaking the cycle of host-specific diseases. It helps to disturb the life cycles of aphids by removing their preferred host plants and due to that the reproduction rate of aphids decreases significantly [10]. However, a cropping system that includes rice followed by mustard can help decrease the aphid population. Hence, it is an essential component of integrated pest management [63].

3.1.5 Resistance variety

Using of resistant varieties is an important method for managing the population of aphids in *in vitro* conditions. The main goal of breeding programs is used to make resistance varieties of different plants with specific genetic characteristics that provide tolerance or resistance against aphids. Different varieties can manage the aphids in different ways, like using systemic insecticides, physical barriers, etc., which helps to prevent aphids from feeding and reproduction. Planting resistant varieties can significantly reduce aphid populations and minimize yield losses as compared to susceptible varieties [64]. Based on aphid infestation on the mustard crop at 100% flowering and pod formation stages, varieties like Varuna and Vaibhav were found most susceptible to mustard aphid (*Lipaphis erysimi*) incidence, while Vardan, Uravasi, Maya, Ashirvad, and Pitambari were found moderately resistant against mustard aphid (*Lipaphis erysimi*) incidence and variety Rohini was found resistant [65].

3.2 Mechanical control

In mechanical control, aphid populations are managed physically without the need for pesticides. The main aim is to prevent or control the population of aphids from the damaged plants.

3.2.1 Trap crop

Trap cropping helps to protect the main crop from pest attack, where trap crops are cultivation or growing of plants at the border of the main crop and the main aim is to manage the pest in the form of attraction to insects-pest and other organisms like nematodes [66, 67]. Many cruciferous crops like cabbage, cauliflower, knol-khol, broccoli, radish, turnip, beet root are a few examples of trap crops used against aphids, these vegetables are used to destroy or control different aphid species such as *Lipaphis erysimi*, *Brevicoryne brassicae* and *Myzus persicae* [68]. Cabbage is a trap crop used against the aphid and observed that the red coloured cabbage showed lesser aphid infestation (13.9 aphids) compared to green coloured cabbage varieties (15.1 aphids) [69].

3.2.2 Sticky trap

Sticky traps play a crucial role in integrated pest management (IPM) programs, which help to minimize the use of synthetic pesticides and promote sustainable pest control strategies. It is the best method to monitor the pest population and to know the early indication of pest infestation [70]. Aphids are attracted to yellow or other related colours with wavelengths reflecting between 500 and 580 nm and monitoring of aphids through the yellow and green colour traps [71, 72] experimented with the management of mustard aphids through sticky traps, result concluded that the maximum trapping of alate mustard aphids (*Lipaphis erysimi*) is between 305-457 per trap in the month of the last week of February. Another research was conducted by [73] they mainly worked on a different colour of traps such as yellow, white, orange, green, red and black were used the manage the aphid population up to 91.67%, 78.79%, 75.05%, 73.81%, 71.93% and 65.70% at 7 days after installation of the trap.

3.3 Biological control

The most important component of integrated pest management (IPM) is the biological control for the management of insect pests. Essentially, biocontrol refers to the use of live creatures to suppress the pest population to avoid economic losses. Different biocontrol agents like predators, parasitoids and entomopathogens, etc., to maintain pest populations below economic injury level through by introducing a new bioagent in the field to increase the population that is already present in the field [52].

3.3.1 Predator

Predators are the insect that feeds on the other living organism, it always feeds on the smaller host, examples include various spider species, dragonflies, damselflies, ladybird beetles, *Chrysoperla* species, birds and other living organisms [52]. Now a days use of different natural enemies in pest management has increased due to different synthetic insecticides. Various predator species were observed against *Lipaphis erysimi* such as *Coccinella septempunctata*, *Chilomenes sexmaculatus*, *Chrysoperla carnea*, *Chrysoperla zastrow*, *Geocoris ochropterus*, *Crematogaster wroughtonii*, *Pheidole indica*, *Componatus compresses*, *Lycosa pseudoannulata* and *Coccinella Septempunctata* are found in significantly [74]. Larvae of seven spotted ladybird beetles vigorously feed on aphids, it is the best alternative to synthetic chemicals [75, 76] studied on the feeding ability of the ladybird beetle and concluded that the ability of a hundred *coccinellids* can control the aphids up to 66 to 88% between the year 1994 and 1995. Hoverfly is also another important natural enemies against aphids and it is also known as the syrphid fly or flower fly, this species maggots are frequently utilized in biological control against aphids [77]. Predation rates on aphids at different phases of development are shown in (Table. 5).

3.3.2 Parasitoids

Parasitoids is a kind of living organisms that kill the host in the form of laying eggs in or on the body of the host and reaching the adult hood on the single host which causing the death of the host [82]. It can be classified into various types based on the host developmental stage at which they complete their life cycle and include egg, larval, pupal, adult, egg-larval, and larval pupal stages. Various types of parasitoids which helps to effectively manage the pest population, examples include *Trichogramma* sp., *Apanteles* sp., *Bracon* sp., *Chelonus* sp., *Brachemeria* sp., and *Pseudogonotopus* sp. [52]. The total developmental time of *Diaeretiella rapae* against cabbage aphid (*Brevicoryne brassicae*) is about 13.36 and 12.58 days, while the time from egg to mummification is 8.36 and 8.11 days [83]. The highest Parasitization rate of *Diaeretiella rapae* is 88% against *Lipaphis erysimi* in field conditions [84]. Lists of various aphids and their parasitoids are shown in (Table. 6) [85]. The life cycle of *Aphidius* parasitoid is shown in (Fig. 4)

3.4 Bio-pesticides

Biopesticides derived from natural sources such as plants, microbes and minerals provide eco-friendly alternatives to chemical pesticides for controlling aphids. Insecticidal properties of chemicals which derived from plant extracts are the source of botanical biopesticides. The different bio-pesticides used against for the management of pests effectively and ecologically. Garlic clove extracts, pyrethrum, and neem oil are a few examples of botanicals [86]. Fungi, viruses and bacteria are the three major groups of pathogens. Some nematodes also cause diseases in certain insect pests. Among viruses, the most important example is Nuclear Polyhedrosis Virus (NPV), among bacteria, *Bacillus thuringiensis* (Bt.) and *B. Papillae* are particularly common examples [52]. Recommend using the biopesticides *Beauveria bassiana*, *Verticillium lecanii* and azadirachtin separately or in combination to manage the mustard aphid (*Lipaphis erysimi*) as an eco-friendly and cost-effective alternative [87]. Entomopathogenic bacteria that cause the disease in insects and destroy it through septicemia and toxin production [88]. Plant-associated bacteria, such as rhizospheric, endophytic and phylloplane bacteria included in bio-control by producing defense compounds that help to induce systemic resistance [89]. Different bio-pesticides are discussed against the management of the aphid population shown in (Table. 7).

3.5 Nano Pesticides

Nanotechnology plays a judicious role in the agriculture sector. It is being used to develop genetically modified plants, pesticides, fertilizers and agricultural machines. In pesticides, the goal of nanotechnology is to reduce the quantity of pesticides consumed each year by transforming existing pesticides into nanopesticides. Nano-pesticide technology is reducing the quantity of pesticide which is used to control pests, indirectly it the cost of crop production [92]. Nanopesticides are 2 to 3 dimensional nano-structures with diameters ranging from 1 to 200 nm that are utilized to transport agrochemical ingredients (AcI). Compared to free insecticides, the incorporation of AcI into nanoparticles has advantages because of their special features. With the fast development of newly engineered nanoparticles for pest control, a new type of environmental waste is being produced [93]. Insecticides, pesticides, herbicides, fungicides, and other chemicals can be loaded onto nanoparticles (NPs), which can then be released at the target site [94], 2021). SiO_2, ZnO, TiO_2 (Anatase and rutile), and Al_2O_3 (α and γ) these nanoparticles (Nanocides) are hydrophilic, hydrophobic, and lipophilic. Nano TiO_2 was shown to be only moderately efficient against Mustard aphids (*Lipaphis pseudobrassicae*), whereas nano Al_2O_3 and amorphous nano SiO_2 were found to be very effective [95]. Bacteria, fungi, algae, and plant extracts are known to synthesize silver nanoparticles (AgNPs). Although all 25 isolates of the synthesized nano silver particles significantly reduced the mortality of the mustard aphid (*Lipaphis erysimi*), isolates B4 and B13 had the highest mortality 60.09% [96, 97].

3.6 Chemical practices

When other management practices fail to control the insect population below the Economic Threshold Levels (ETL) level, the use of chemical pesticides is the last option. Although there is a great advancement in pest management research, pesticides will continue to play an important role in crop protection given the complexity of pest problems. The use of pesticides is need-based and judicious, it is based on pest surveillance and economic threshold levels (ETL) and it helps to reduce the cost of production [52]. Systemic insecticides are absorbed by plants and translocated to various plant tissues, including leaves, stems and flowers. Aphids feeding on treated plants ingest the insecticide along with plant sap, resulting in mortality or reduced reproductive capacity [98]. Contact insecticides can eliminate aphids upon direct contact with the insecticide residue on plant surfaces. Such insecticides can offer immediate control of aphid populations due to their fast knockdown effect [99]. Some insecticides like cypermethrin and carbofuran are less harmful to the environment, botanical insecticides like neem oil and mahogany oil, are safe to the environment and traditional methods with non-chemical compounds such as wood ash and wood ash + lime used as insecticides to control the mustard aphid (*Lipaphis erysimi*) [100]. Imidacloprid 0.08%, thiamethoxam 0.01%, and acetamiprid 0.01% were highly effective insecticides against mustard aphids (*Lipaphis erysimi*) [101]. Acephate 75 SP at 350g a.i./ha reduces the aphid population (8.33 aphids/plant) and increases the yield of the crop (16.35 q/ha) [102]. The highest cost-benefit ratio (1:9.54) is obtained from imidacloprid 17.8 SL @ 150 ml/ha [103]. Among the insecticides tested against the mustard aphid (*Lipaphis erysimi*) imidacloprid 17.8 SL @ 0.2 g/litre showed the highest control, reducing mustard aphid incidence by 87.53% [104].

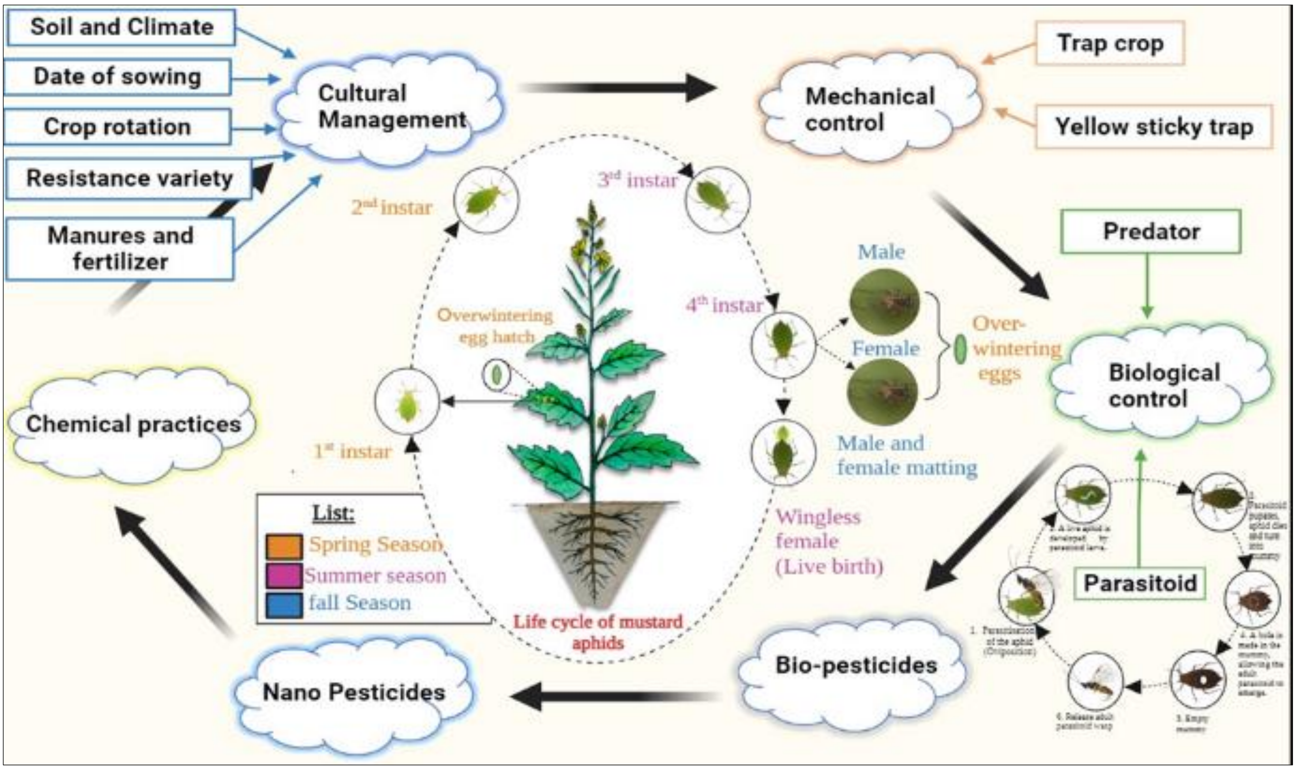

Fig 1: Graphical abstract

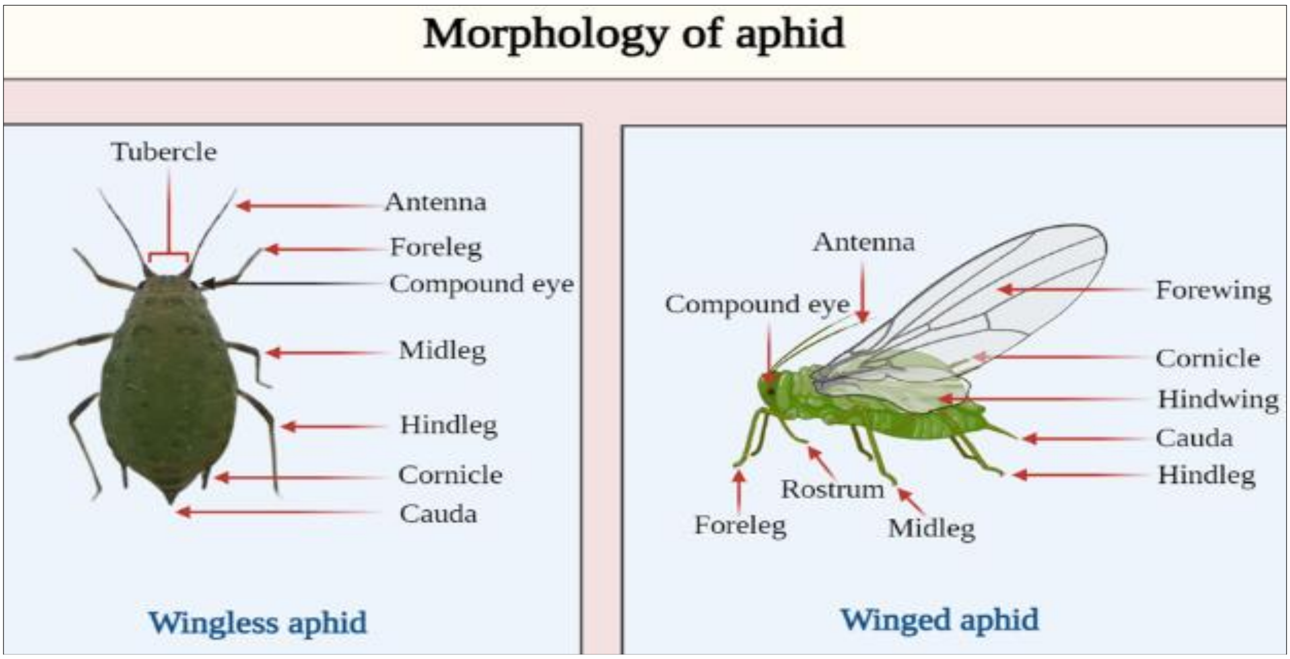

Fig 2: Morphology of aphid

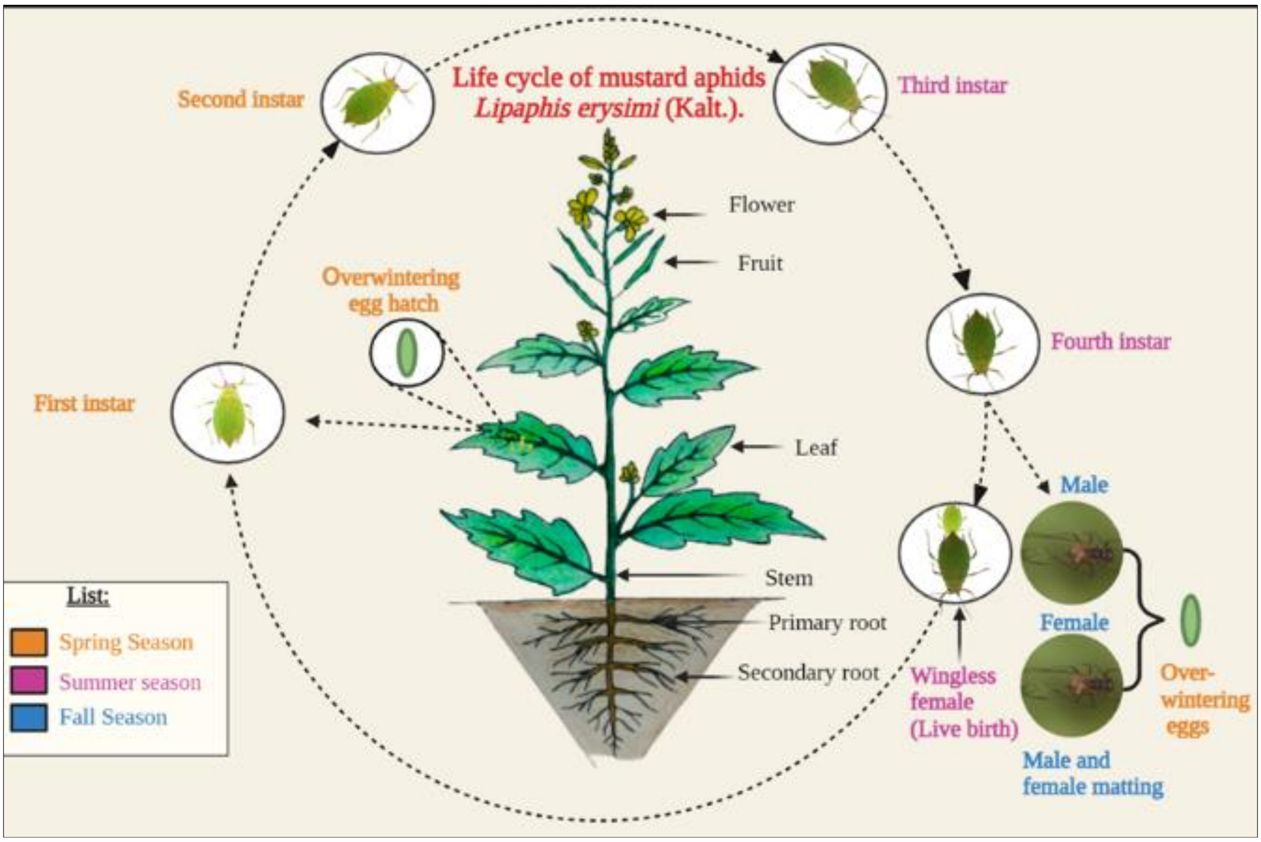

Fig 3: Life cycle of mustard aphids Lipaphis erysimi.

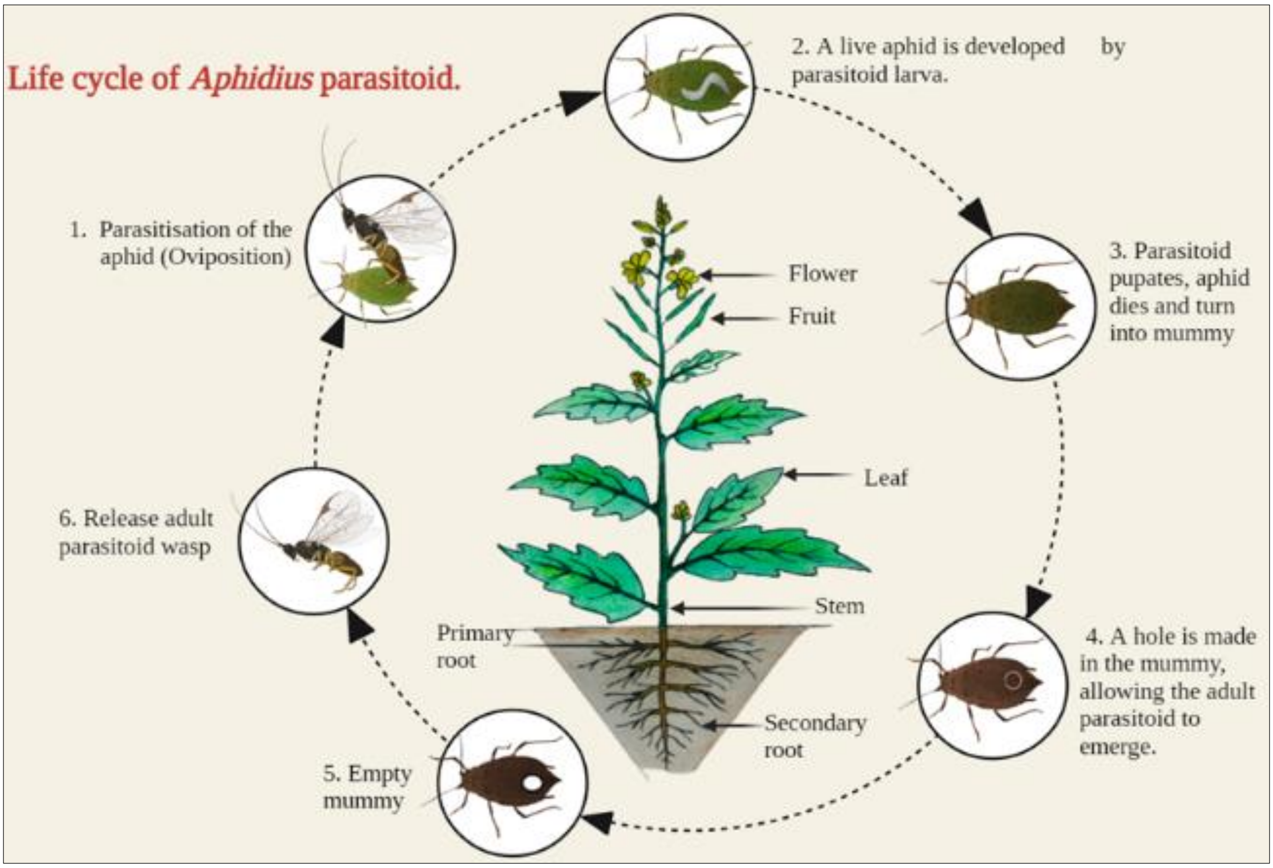

Fig 4: Life cycle of Aphidius parasitoid

Table 1: Yield and Economic threshold levels (ETL) of various aphid species in their respective host plants.

Sr. No.	Scientific name, Order, Family	Host name	Yield losses	ETL level
1.	*Lipaphis erysimi* (Kalt.) (Hemiptera: Aphididae)	Mustard	10.2–61.1% yield losses. [14]	40 aphids per 10 cm length of the twig on the top portion of the central shoot. [15]
2.	*Aphis gossypii* (Glover) (Hemiptera: Aphididae)	Cotton	12% yield loss. [16]	66 to 272 aphids per leaf. [17]
3.	*Acyrthosiphon pisum* (Harris) (Hemiptera: Aphididae)	Pea	230 kg/ha. [18]	85 aphids per stem. [19]
4.	*Aphis glycines* (Hemiptera: Aphididae)	soybean	75%. [20]	250 aphids per plant. [21]
5.	*Myzus persicae* (Sulzer) (Hemiptera: Aphididae)	Chinese Cabbage	13%. [22]	20 aphids per plant. [22]
6.	*Sitobion avenae* (Fabricius) (Hemiptera: Aphididae)	Wheat	35-40%. [23]	6-10 aphids per tiller up to the milky ripe stage. [24]
7.	*Aphis craccivora* (Koch) (Hemiptera: Aphididae)	Cowpea	2000 to 500 kg/ha. [25]	15.37 nymphs per m row in cowpea. [26]
8.	*Aphis fabae* (Scop) (Hemiptera: Aphididae)	bean	50%. [27]	50-100 aphids per plant. [28]
9.	*Myzus persicae* (Sulzer) (Hemiptera: Aphididae)	Potato	90% yield losses caused by viruses. [29]	10 aphids per leaf. [30]

Table 2: Aphids can spread various diseases to the plants, here some examples of the diseases caused by aphids

Sr. No.	Viral diseases	Vector (Species of aphids)	References
1	Banana Bunchy Top Virus (BBTV)	*Pentalonia nigronervosa*	[34]
2	Citrus Tristeza Virus (CTV)	*Aphis gossypi, Aphis spiraecola, Toxoptera aurantii, Toxoptera citricida*	
3	Potato leaf roll virus/potato viruses Y(PVY)	*Myzus persicae*	
4	Sugarcane yellow leaf virus (SCYLV)	*Ceratovacuna lanigera, Melanaphis sacchari, Rhopalosiphum maidis, Rhopalosiphum rufiabdominalis*	
5	Sugarcane mosaic disease	Several species of aphids	
6	Barley yellow dwarf (BYD) virus	*Rhopalosiphum padi, Sitobion avenae, Metopolophium dirhodum*	
7	Cardamum kattee/foorkey/chirkey virus	*Pentalonia nigronervosa*	[35]
8	Cardamom mosaic virus	*Pentalonia nigronervosa, Aphis craccivora*	
9	Cow pea mosaic virus	*Aphis craccivora*	
10	Watermelon mosaic virus	*Myzus persicae*	
11	Garlic mosaic virus	*Aphis craccivora, Myzus persicae*	
13	Turnip mosaic virus	*Lipaphis erysimi, Myzus persicae*	
13	Papaya ringspot virus (PRSV)	*Aphis gossypii, Aphis craccivora, Myzus persicae*	[36]

Table 3: %Yield loss due to aphid infestation at different growth stages of mustard.

Sr. No	Growth stages	% yield losses	References
1.	Vegetative Stage	6.50	[6]
2.	Flowering Stage	76.50	
3.	Pod forming Stage	17.00	

Table 4: Duration of different stages of the lifecycle in different aphid species.

Sr. No	Name of Aphid	Oviposition period (Days)	Nymphal period				Adult logitivity (Days)	Reference
			1st instar (Days)	2nd instar (Days)	3rd instar (Days)	4th instar (Days)		
1.	*Lipaphis erysimi* (Kalt.)	1-2	1-2	2.0	2.0	3.0	5-10	[43]
2.	*Aphis craccivora* (Koch)	1-1.6	1.47	1.36	1.19	1.41	10-12	[44]
3.	*Aphis fabae* (Scop)	Nil	2.0	2.0	1.5	2.5	3-6	[9]
4.	*Aphis gossypii* (Glover)	Nil	1.6	1.4	1.2	1.3	11.4	[45]
5.	*Myzus persicae* (Sulzer)	Nil	1.4	1.2	1.0	0.8	24.1	

Table 5: List of predators with their aphid consumption rate at different stages.

Sr. No	Predators	Grub/ Maggot /Larval Stage				Adult (Aphid/day)	Mean (Aphid/day)	Reference
		1st Instar (Aphid/day)	2nd Instar (Aphid/day)	3rd Instar (Aphid/day)	4th Instar (Aphid/day)			
1.	Seven-spotted ladybird beetle, *Coccinella septempunctata* (Linnaeus)	2.00	19.00	34.00	48.00	40.00	28.00	[78]
2.	Syrphid fly, *Xanthogramma scutellarae*	27.82	174.21	253.15	-	Free-living	151.72	[79]
3.	Green lacewing, *Chrysoperla carnea* (Stephens)	6.00	25.00	43.00	-	Free-living	24.6	[80]
4.	*Syrphus confrater* (Weid.)	6.90-6.20	55.90-55.	86.10-86.50	-	Free-living	49.63-49.23	[81]
5.	*Syrphus balteatus* (Deg.)	8.00-7.21	23.33-23.90	91.66-95.00	-	Free-living	41.00-42.07	
6.	*Ischiodon scutellaris* (Fab.)	6.66-5.99	34.10-33.87	72.00-71.90	-	Free-living	37.59-37.25	

Table 6: Lists of various aphids with their parasitoids [85].

Sr. No.	Common Name	Scientific Name	Parasitoids
1.	Mustard aphid	*Lipaphis erysimi*	*Trioxys* sp., *Aphidius* sp., *Aphidius rosae*
2.	Pea aphid	*Acrythosiphon pisum*	*Binodoxys anglicae, Aphidius* sp., *Aphidius absenti, Aphidius smithi, Aphidius urticae*
3.	Black bean aphid	*Aphis fabae*	*Trioxys* sp., *Binodoxys anglicae, Aphidius* sp., *Binodoxys indicus*
4.	Cotton aphid	*Aphis gossypii*	*Trioxys* sp., *Binodoxys anglicae, Aphidius sp., Binodoxys indicus*
5.	Green peach aphid	*Myzus persicae*	*Aphidius* sp., *Diaretiella rapae, Aphidius ribis*
6.	Wheat aphid	*Schizaphis graminum*	*Diaretiella rapae, Aphidius colemani*
7.	Cabbage aphid	*Brevicoryne brassicae*	*Diaretiella rapae*
8.	Bird cherry-oat aphid	*Rhopalosiphum padi*	*Aphidius colemani*

Table 7: List of Bio-pesticides that are effective against mustard aphids.

Sr. No.	Pathogen	Bio-pesticides	Discover by	% Effective against mustard aphid	References
1.	Fungi	*Metarhizium anisopliae*	Metschnikoff, 1879	83.23	[90]
2.	Fungi	*Beauveria bassiana*	Vuill, 1912	78.33	
3.	Bacterium	*Bacillus thuringiensis*	Berliner, 1915	73.00	
4.	Fungi	*Lecanicillium lecanii*	Zimmermann, 1898	98-83	[91]
5.	Fungi	*Paecilomyces lilacinus*	Charles Thom, 1910	100-73	

4. Conclusion

In this review, discusses on integrated pest management (IPM) strategies that provide a comprehensive approach to managing aphid populations in crop ecosystems. The key practices for successful aphid control include early sowing of crops and implementing cultural methods like crop rotation and sowing resistant varieties. Crop rotation with resistant cultivars is crucial in affecting aphid life cycles and reducing susceptibility attack of aphids, which is an essential component of sustainable pest management. The application of biopesticides is eco-friendly and has minimal impact on human health and the environment. While chemical pesticides should be used as a last resort, their judicious use based on pest surveillance and economic threshold levels can provide effective management of aphid populations when necessary. In summary, a combination of these strategies customized to specific crop ecosystems and pest pressures can contribute to successful aphid management, protect crop yields, and promote environmental sustainability in agricultural practices.

5. Acknowledgement

The author is grateful thanks to the Department of Entomology, School of Agriculture, Lovely Professional University, Punjab (India), for providing the required resources and helpful suggestions during the work.

6. Future aspects

This paper explores sustainable strategies for managing aphid populations in agriculture through different methods including resistant crop varieties, biological control, sustainable pest management and precision agriculture technologies, etc., for the need to consider climate change and promote eco-friendly and economically viable solutions against the management of aphids.

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