Management Strategies of Peach–Potato Aphid *Myzus persicae*

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The peach–potato aphid, *Myzus persicae* (Sulzer), is one of the most important pests of economic crops. It damages the plant directly by consuming nutrients and water and indirectly by transmitting plant viruses. This pest has the unenviable title of having resistance to more insecticides than any other herbivorous insect pest. Due to the development of its resistance to chemical pesticides, it is necessary to find other control options. Consequently, increased efforts worldwide have been undertaken to develop new management approaches for *M. persicae*.

Myzus persicae | biocontrol agents | integrated pest management | parasitoid | insecticide resistance | crop protection

1. Introduction

Aphids are one of the most economically important hemipteran pests, with about 100 aphid species being reported to cause significant agricultural losses worldwide [1][2]. Aphids are silent feeders that cause less tissue damage than chewing insects and, during feeding, release effector proteins in their saliva that suppress host plant defence responses [3]. Damage caused by aphids reduces plant fitness due to their feeding on phloem sap, which makes the plant nutritionally weaker compared to uninfested ones [4][5]. They also serve as important vectors for the transmission of plant viruses and produce honeydew that serves as a breeding medium for pathogens, which affect plant photosynthetic activities [2][3]. The peach–potato aphid, *M. persicae*, also known as the green peach aphid, is a highly polyphagous and cosmopolitan pest that has a global distribution, predominantly in North America, Europe, and Asia [3][6]. Winged adults measure up to 2.1 mm and reproduce parthenogenetically by a single sexual generation with a life cycle of 15 days [7]. In terms of damage, *M. persicae* causes direct and indirect damage to a wide range of crop plants [6][8][9][10].

The peach–potato aphid is considered one of the most destructive agricultural pests that feeds on over 40 plant families including Apiaceae (carrot, *Daucus carota* (Hoffmann)); Asteraceae (lettuce, *Lactuca sativa* (Linnaeus); artichoke, *Cynara cardunculus* (L.)); Amaranthaceae (beet, *Beta vulgaris* (L.); spinach, *Spinacia oleracea* (L.)); Brassicaceae (broccoli, *Brassica oleracea* var. *italica* (L.); brussels sprouts, *Brassica oleracea* var. *gemmifera*; cabbage, *Brassica oleracea* var. *capitata* (L.); cauliflower, *Brassica oleracea* var. *botrytis* (L.); kale, *Brassica oleracea* var. *acephala* (L.); mustard, *Brassica juncea* (L.); radish, *Raphanus raphanistrum* (L.); and turnip, *Brassica rapa* (L.)); Cucurbitaceae (cucumber, *Cucmis sativus* (L.); squash, *Cucurbita pepo* L.)); Fabaceae (bean, *Phaseolus vulgaris* (L.); pea, *Pisum sativum* (L.)); Poaceae (maize, *Zea mays* (L.); wheat, *Triticum aestivum* (L.); barley, *Hordeum vulgare* (L.); and rice, *Oryza sativa* (L.)); and Solanaceae (potato, *Solanum tuberosum* (L.); pepper, *Capsicum annuum* (L.); and tomato, *Solanum lycopersicum* (L.) [9][10][11][12][13][14]. Additionally, the peach–potato aphid acts as an important vector and transmits over hundreds of plant viruses, including potato leafroll virus (PLV), potato virus Y (PVY), beet western yellows viruses, beet yellows viruses, lettuce mosaic virus, cauliflower mosaic virus, turnip mosaic virus, cucumber mosaic, and watermelon mosaic viruses, which indirectly affect the growth and development of the host plant [3][9][15][16][17][18].

2. Pest Traits Influence Control Strategies

The ecological success of *M. persicae* as a polyphagous pest could be attributed to its short generation time, high fecundity, the presence of sexual and asexual populations, polyphenism (biotype), the ability to shift to new host plants, the transmission of viruses, and the development of resistance [6][11]. The transmission of plant viruses (persistent and non-persistent) by *M. persicae* is mostly facilitated by the winged forms due to their ability to fly, enabling the spreading of viruses between hosts [18][19]. This allows for both short-distance and long-distance transmission, with the latter playing a significant role in the spread of viral diseases across extensive geographic areas. The ability of aphids to transmit viruses over long distances is of great concern in an agricultural context, as it contributes to the rapid dissemination and establishment of viral infections in susceptible plant populations.

M. persicae also excretes honeydew (a sugary liquid), which affects the physiology of host plants and their interaction with other herbivores [20]. A list of challenges associated with *M. persicae* is presented in the chart given below in **Figure 1**.

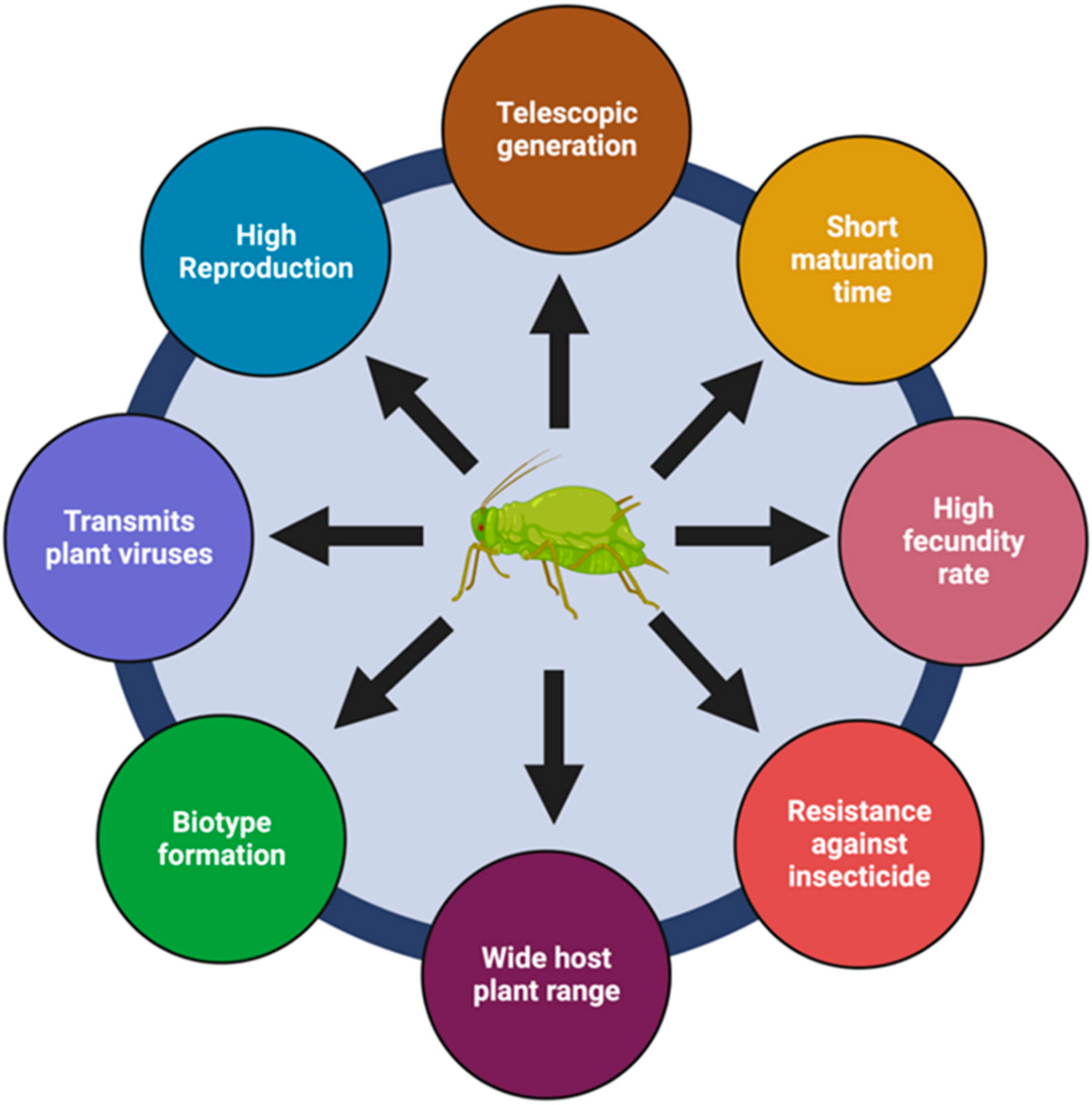

Figure 1. Factors that ensure the ecological success of *Myzus persicae* as a polyphagous and cosmopolitan pest of economic importance.

3. Suppression of Plant Defence

M. persicae is known for its ability to subvert plant defences and disrupt defence-related pathways [21]. Unlike herbivores with chewing-type mouth parts, *M. persicae* is a silent feeder that causes less physical damage [22][23]. Previous studies have shown that plants can recognize the salivary proteins of *M. persicae* and modulate their defence strategies by producing deterrent compounds, including indole glucosinolates that covert indol-3-ylmethoxyglucosinolates (I3M) to 4-methoxyindol-3-ylmethoxygluosinolates (4MI3M)), callose formation, the plugging of sieve tubes, and the accumulation of reactive oxygen species (particularly hydrogen peroxide) [24][25][26][27]. However, *M. persicae* releases specific effector proteins, including Mp1, Mp55, MpC002, Mp59, Mp60, Mp61, Mp62, and Mp63, to counteract or reduce plant-induced defence responses, such as the synthesis of antifeedants and antibiotic compounds [28][29].

The expression of *M. persicae* salivary proteins in the host plant makes the plant more susceptible to it by increasing fecundity and reducing the synthesis of defensive compounds [27]. For example, the overexpression of the salivary proteins Mp55 and MpC003 is responsible for high aphid fecundity, reduced production of deterrent compounds, and making host plants more susceptible to *M. persicae* [30][31]. When *Arabidopsis thaliana* (L.) overexpressed Mp55 proteins, it resulted in high aphid fecundity; reduced levels of deterrent compounds, such as indole glucosinolates and 4MI3M; decreased callose deposition; and a lower abundance of defence signalling molecules, like hydrogen peroxide [27]. The expression of *M. persicae*-induced salivary proteins (Mp55) presumably avoids the activation of plant defence systems and promotes aphid feeding [32].

4. Economic Importance of Peach–Potato Aphid

Myzus persicae is responsible for both qualitative and quantitative losses in agricultural production by causing chlorosis, necrosis, wilting, defoliation, and fruit abortion. It directly affects plant nutritional status via feeding on plant sap [33]. According to previous studies, *M. persicae* is responsible for a considerable loss in crop yield, causing billions of dollars of losses globally [11][34]. Specifically, in the UK, aphid infestation causes up to a GBP 70 million loss per year [35]. *M. persicae* is considered one of the most common and devastating brassica (*B. oleracea*) pests in the UK, causing direct and indirect damage by spreading one of the most deleterious plant viruses, turnip yellow virus (TuYV), which can reduce final yield up to 26% [35]. Controlling this virus could result in an increase in total yield profit equivalent to GBP 60–90 million per year for oilseed rape growers in the UK [36]. In India, the peach–potato aphid is a key pest of sweet pepper that causes a 38 to 42% yield loss under a controlled environment [37]. In Brazil, the peach–potato aphid primarily serves as a vector for PYV and tomato yellow top virus (ToYTV), which causes a 20–70% loss of tomato (*S. lycopersicum*) yield and reduces fruit production by up to 85% [38]. In Australia, this pest is responsible for the transmission of TuYV in pea (*P. sativum)*, faba bean (*Vicia faba* (L.)), lupin (*Lupinus albus* (L.)), chickpea (*Cicer arietinum* (L.)), and lentil (*Lens orientalis* (L.)) crop fields, and a loss of 46% in canola (*Brassica napus* (L.)) yield has been reported [39]. In New Zealand, *M. persicae* transmits potato virus Y (PVY) and leaflet curl virus (LCV), which are among the most damaging potato viruses and cause significant yield loss [40]. In China, *M. persicae* is also considered a primary pest for *N. tabacum* [41].

5. Current Management Practices

New pest management and control strategies are being developed in order to meet current and future challenges [42]. These pest management practices fall under the following categories “chemical, biological, and cultural” [43]. However, the use of chemical pesticides is one that is common due to their availability, efficacy, and ease of use [44]. Therefore, the majority of current management practices for *M. persicae* are based on chemical pesticides [45]. Synthetic pesticides containing active ingredients, such as pyrethroids, carbamate, organophosphates, and neonicotinoids, have a strong negative effect on a number of herbivores, including *M. persicae* [46][47][48].

Besides chemical methods, there are several other management approaches that show high potential in managing this pest, such as the use of natural defence elicitors and biocontrol agents, the application of entomopathogens, and cultural methods [3][49]. An accumulating body of evidence shows that the use of biocontrol agents, i.e., parasitoids and predators, can be an excellent managing tool to protect crop plants from direct damage caused by this pest [50][51]. Similarly, the use of entomopathogens against *M. persicae* have revealed a hidden potential for its management [52][53]. Cultural methods, such as intercropping companion plants [54], the application of neem leaf extract [55], and winter pruning, have also been found to be effective against the peach–potato aphid [56]. Altering plant defence mechanisms using natural compounds is another preventive measure, which presents some potential as a future pest management tool [3][57].

6. Challenges with Current Management Practices

6.1. Development of Insecticidal Resistance

The majority of current pest management approaches rely on the use of chemical insecticides, either solely or in combination [58]. However, the excessive use of these synthetic chemicals has led to an increased burden on insects to develop resistance against insecticides [45]; similarly, the control of *M. persicae* through chemical means remains difficult, owing to its ability to develop resistance [59]. The peach–potato aphid has developed resistance to various insecticides, with a total of 483 cases of insecticide resistance documented for this species on the APRD (Arthropod Pesticide Resistance Database) involving 84 active ingredients [60], making *M. persicae* the single most resistant aphid pest species and placing it in the overall top ten of the most resistant arthropod pests [61]. The exceptional ability of *M. persicae* to evolve a remarkable diversity of distinct mechanisms of resistance has made this species an emerging model of molecular evolution in insects.

6.2. Adverse Effect on Non-Target Organisms

The literature on the insecticidal side effects on arthropods reports that more than 400 agricultural chemicals have adverse effects on natural enemies, ranging from sublethal to lethal [62]. The excessive use of synthetic pesticides is responsible for deleterious effects on non-target organisms, such as pollinators (fields treated with spinosad residues showed the low survival of *Apis mellifera* (L.)), predators (spinosad derivatives caused the mortality of *Hibana futilis* (Banks) and *Araneus prantensis* (Emerton) upon treatment), and parasitoids (severe adverse effects of the dried residue of spinosad have been found on several parasitoids, including *A. colemani*, *Aphytis melinus* (DeBach), *Leptomastix dactylopii* (Howard), and *Encarsia formosa* (Gahan)) [63][64][65]. Parasitoids, which are of great economic significance in pest management and play a vital role in controlling pest populations, are badly affected by the excessive use of these synthetic chemicals [66].

6.3. Elicitation of Plant Defence: An Underutilized Tool

Despite excellent results, the use of natural defence compounds as plant defence elicitors under field conditions is still in its early stage [3][67]. The majority of these studies are limited to the laboratory and are still waiting for application in the field. For instance, CJ is a natural plant-derived compound that has been tested on several economically important crops (*S. tuberosum*, *B. oleracea*, *T. aestivum*, and *S. lycopersicum*) against various sucking pests, including *M. persicae* [3][68][69][70]. Many laboratory studies have investigated the role of CJ in inducing resistance in plants against pests, and almost all have validated that CJ induces resistance to pests [3][68][69][70][71].

6.4. Underutilisation of Cultural Practices

Cultural methods are commonly used to create unfavourable conditions for pests, which is one of the main goals of pest management approaches [72]. Cultural practices, such as crop rotation and sanitation, intercropping, the destruction of plant debris, and the avoidance of adjacent planting of crops, and trap crops, play a critical role in pest management [73][74]. For instance, winter peach pruning is practised, particularly in fruit orchards, to adjust plant load, which indirectly affects the performance of pests, i.e., *M. persicae* [75]. Reportedly, *M. persicae* is primarily found on mature leaves; therefore, winter pruning has been found to be an effective way to reduce pest infestations [56][75]. By removing some buds, a potential habitat for egg-laying is reduced, leading to a decrease in the overall population of *M. persicae*.

6.5. Lack of Resistant Cultivars

The use of aphid-resistant cultivars in combination with integrated pest management approaches represents an excellent option for managing *M. persicae* [76]. One of the significant differences between aphid-resistant and aphid-susceptible lines of the same crop is the length of time required by the aphid to reach the phloem during probing [77]. Aphids take a longer time to reach the phloem on resistant lines (*Medicago truncatula* (Gaertn.) cv. Jester) and cannot feed successively on it [78][79]. However, it has been observed that plant resistance is often overcome after a few years due to the emergence of new biotypes [80][81]. *M. persicae* has the ability to form biotypes, which differ in behaviour or physiology and allow this pest to expand its host range and rapidly occupy a new ecological niche [82].

7. Potential Biological Control Agents

7.1. Predators and Parasitoids

Extensive research has been conducted to evaluate the efficacy of certain biological control agents against *M. persicae* in laboratory and field settings [50]; a diverse range of 200 biocontrol agents from various families, including Coccinellidae, Cantharidae, Syrphidae, Anthocoridae, Pentatomidae, Aphelinidae, Braconidae, and Phytoseiidae, have been identified as potential insect agents for managing *M. persicae* populations [83][84]. The host plant plays a crucial role in implementing the biocontrol approach of naturally occurring biological control agents, and the effectiveness of these agents depends on the species and physiological status of the host plants. Plants release volatile compounds that serve as a cue for pollinators and other natural enemies of pests to locate the host plants [85][86]. Infestation with *M. persicae* has been observed to increase the release of volatile compounds known as herbivore-induced plant volatiles (HIPVs), which recruit parasitoids and predators [87].

7.2. Entomopathogenic Bacteria

Previous studies have shown that environmental microbes have the potential to kill herbivorous pests, including aphids, when applied in pest management programmes [88][89][90]. Several bacterial species (*Pseudomonas fluorescens* (Flügge) PpR24; *Bacillus amyloliquefaciens* [91] strains, CBMDDrag3, PGPBacCA2, and CBMDLO3; *Saccharopolyspora spinosa* [92]; and *Bacillus thuringiensis* (Berliner) [93]) and bacterial-derived insecticides (Bosal 10EC and Spinosad 240SC) have been tested on several important crops, including *B. oleracea*, *A. thaliana*, *B. vulgaris*, and *C. annuum*. On application of bacterial insecticides, a high reduction in the population of *M. persicae* has been recorded; for instance, a diet containing bacterial suspension showed 100% mortality of adults and nymphs [88] and a 57% population reduction in *M. persicae* on cauliflower [90]. *C. annum*, *A. thaliana*, and *B. vulgaris* showed a population reduction of 68%, 57%, and 69%, respectively, after application of *P. fluorescens* PpR24 [89].

7.3. Entomopathogenic Fungi

More than 750 species of entomopathogenic fungi (EPF) belonging to 85 genera are functionally known for their ability to infect arthropods [52][53][94][95][96]. However, most of them have not been used commercially to manage plant pests yet. These fungi are naturally present in agricultural soil, but their efficacy in nature is not high because of the low spore numbers. Their effectiveness can be improved through the inundative release of EPF. The most studied species of EPF belong to the genera *Metarhizium, Beauveria, Hirsutella, Isaria*, *and Lecancillium* [53].

7.4. Entomopathogenic Viruses (EPVs)

Plants come in contact with numerous viruses due to their interactions with herbivores. This plant–virus interaction serves as a reservoir for viruses and affects the performance of the associated herbivorous community. Plants take advantage of entomopathogenic viruses and utilise them as a defence tool against a number of plant pests [97]. For example, *M. persicae* spread Parvovirus (*M. persicae* densovirus MpDNV) during feeding on plants. The infected host plants use this EPV as a part of their defence strategies by spreading the infection to non-infected subsequent future visiting aphids [98].

7.5. Entomopathogenic Nematodes

Below-ground plant and root–herbivore interactions can affect above-ground plant–herbivore interactions [99][100]. Some nematodes are important entomopathogens that can impact the performance of attacking herbivores (below- and above-ground) on host plants by inducing plant defence mechanisms [101].

8. Sustainable Strategies

8.1. Augmentative Release of Biocontrol Agents

The biological control of insect pests is one of the most efficient and eco-friendly ways to manage them. It involves three basic approaches: the conservation, importation, and augmentation of natural enemies [102]. In Yunnan province, China, the augmentative release of the parasitoid, *Aphidius gifuensis* (Ashmead), significantly reduced the pest population in tobacco fields [103]. Similarly, in Himachal Pradesh, India, three species of parasitoids (*Aphelinus asychis* (Walker), *Aphidius matricariae* (Haliday), and *A. ervi*) showed high parasitism rates when tested against *M. persicae* in greenhouse experiments [104].

8.2. Resistant Plant Varieties

Previous studies have shown that breeding programmes with a primary goal of achieving high yield can have a negative impact on host plant resistance, making crops more susceptible to pests due to the manipulation of their genetics to produce high yields [105][106][107][108]. This hypothesis was investigated in an earlier study, where the performance of *M. persicae* on three wild potato, *Solanum stoloniferum* (Schltdl.) (23072, 22718 and 18333) and one cultivated potato, *S. tubersoum* (L.) cv., Desiree lines was observed [98]. All wild potato lines were highly resistant against *M. persicae* and caused high adult mortality in cage bioassays.

8.3. Natural Compounds as Plant Defence Elicitor

Extensive literature is available wherein natural compounds have been found effective in inducing plant defence [109]. Compounds, such as *cis*-Jasmone (CJ), β-ocimene, benzothiadiazole, and methyl jasmonate chitosan, have shown an elevated level of defence in plants, like *B. napus*, *S. tuberosum*, and *L. esculentum*, respectively [3][110]. In particular, the exogenous application of MeJA induces the formation of defence enzymes and reduces pupal/larval weights, performance, population densities, and feeding behaviour [109][111][112][113][114]. CJ is another well-known example of a plant defence elicitor, which has been tested on several important crops, including brassica, tomato, wheat, maize, sweet paper, and cotton, against sucking pests [3][71][115][116][117][118][119].

8.4. Intercropping Companion Plants

Another important aspect of management strategies for *M. persicae* is intercropping. There are various studies against different herbivores (*Thrips tabaci* (Lindeman), *Aphis gossypii* (Glover), and *M. persicae*) that support the idea of planting different crops in the same field [120][121]. A study that was conducted to investigate the effect of companion plants on *M. persicae* showed that *T. patula and Basil* release VOCs that directly and indirectly affect the performance and behaviour of *M. persicae* when used as companion plants with *C. annuum* in the field [49]. Similarly, intercropping garlic with tobacco, and celery, maize, and sunflower with potato reduces *M. persicae* populations significantly [122][123]. A volatile analysis of the blend released by companion plants showed the presence of several compounds, such as (*E*)-β-farnesene, β -linalool, caryophyllene, and pinene, that have a repellent effect on several herbivores, including *M. persicae* [49][117][124].

9. Proposed Integrated Pest Management for *Myzus persicae*

An accumulating body of evidence has reported the economic loss caused by *M. persicae* across a wide range of crop plants, and several studies have been performed to develop control strategies to manage this pest. However, the majority of these studies have focused on a single control measure, either a biological or chemical control, such as the effect of host plants [108][125]; predators [126][127]; EPFs [128][129][130]; EPNs (157); EPVs [131][132]; and push–pull strategies (intercropping and trap crops) [133]. A few pioneering studies used combined biocontrol agents, such as three species of EPF along with 1% azadirachtin [129][130], or biocontrol recruitment via host-plant-induced defence [3].

An IPM pyramid provides detailed information about the actions required to control pests, starting from the bottom (prevention) and progressing towards the top (chemical control), if the prevention and biocontrol strategies fail to suppress the population below the economic threshold [134][135]. Agronomic practices have been extensively reviewed [136], and incorporating these practices would be helpful in reducing the use of chemical pesticides and biological controls [137][138][139]. To synergise biological controls, the use of conventional aphicides in IPM is also valid while adhering to IPM guidelines regarding chemical pesticides [44]. To boost IPM strategies, the use of biocontrol agents in combination with priming agents benefits overall management strategies [43][134].

10. Conclusions

In conclusion, there are several obstacles that hinder the utilization of non-chemical pest control methods, including a lack of awareness, financial instability, a shortage of trained staff, and poor technical advancements [140]. In developing countries, people are either unaware of integrated pest management approaches or there is a lack of trained staff for the successful implementation of control strategies [140]. For example, a survey conducted in Chitwan, Nepal, revealed that only 17% of farmers received one short-term training session on integrated pest management. Financial instability and poor technical advancements are also significant factors that impede the adoption of such potential approaches [141]. In contrast, farmers show a high preference for chemical pesticides due to factors such as falling prices of generic pesticides, their easy availability and readiness for application, and quick response (less time consuming) [142][143][144].

The formation of biotypes means that developing insect-resistant crop varieties is a more complex and challenging process for this species, as it can easily adapt to new resistant varieties as well [145]. Therefore, resistant-cultivar-based agriculture should be investigated further to make crops more resistant and less palatable to *M. persicae* [11]. The application of natural plant defence elicitors on crops needs to be explored in the field [3][146].

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