

THE GREEN PEACH APHID, *MYZUS PERSICAE* (SULZER): A GLOBAL PEST AND ITS SUSTAINABLE MANAGEMENT APPROACHES

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ABSTRACT

The green peach aphid, *Myzus persicae* (Sulzer), is a globally distributed pest with a remarkably broad host range, infesting over 400 plant species, including several economically important crops. It is considered as a pest due to its high reproductive potential, adaptability to diverse agroclimatic zones, and ability to transmit numerous plant viruses. This review provides a comprehensive account of the global distribution and extensive host range of *M. persicae*, along with insights into its bio-ecology, including life cycle dynamics, feeding behaviour, and environmental adaptability. It explores various management strategies, including cultural practices, biological interventions, and chemical control measures. Special emphasis is given on the challenges posed by insecticide resistance, which significantly hampers effective chemical control. The review highlights the importance of integrated pest management (IPM) strategies that combine multiple sustainable approaches to reduce dependence on chemical inputs and mitigate resistance development. Understanding the biology and ecological interactions of *M. persicae* is key to designing effective, long-term management programs suited to both conventional and organic farming systems.

INTRODUCTION

Aphids rank among the most economically significant pests within the order Hemiptera, with approximately 100 species known to cause substantial agricultural losses worldwide (Van-Emden and Harrington, 2017). Unlike chewing insects, aphids are sap feeders that inflict minimal visible tissue damage. During feeding, they inject effector proteins through their saliva, which actively suppress the plant's natural defence mechanisms (Ali *et al.*, 2021). By extracting phloem sap, aphids weaken their host plants, leading to reduced vigour and fitness compared to healthy, uninfested plants (Rodriguez-Saona *et al.*, 2010). In addition to the physical damage, aphids play a critical role as vectors of plant viruses and excrete honeydew, a sticky substance that fosters the growth of sooty mould, further impairing the plant's photosynthetic ability (Ali *et al.*, 2021).

Among aphids, the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), stands out due to its extreme polyphagy and high efficiency in transmitting viruses. It feeds on the vascular tissues of plants and is capable of spreading over 100 different plant viruses, causing significant harm to crops (Goggin, 2007). *M. persicae* is globally distributed and especially prevalent in North America, Europe, and Asia, where it poses a persistent challenge to agricultural productivity (Ali *et al.*, 2021). Its ability to attack a wide variety of host plants, combined with its competence as a

virus vector, underscores its status as a major pest of global concern. This aphid species is highly adaptable, with a broad host plant range and a remarkable capacity to develop resistance to various insecticides (De-Little *et al.*, 2017).

Efforts to manage *M. persicae* populations have increasingly turned toward biological control strategies, leveraging natural enemies such as predators and parasitoids as sustainable alternatives to chemical pesticides. Adult winged forms of *M. persicae* are relatively small, measuring up to 2.1 mm, and they reproduce primarily through parthenogenesis, with a single sexual generation annually and a rapid life cycle of about 15 days (Vorburger *et al.*, 2003). The damage inflicted by *M. persicae* is both direct (through sap extraction) and indirect (through the transmission of plant pathogens), making its management critical across many crop systems (Vorburger *et al.*, 2003; Capinera, 2020).

DISTRIBUTIONAL PATTERN OF *M. PERSICAE*

In Himachal Pradesh, India, *M. persicae* is recognized as a major pest under polyhouse conditions, particularly affecting bell pepper crops. Infestation levels vary widely across districts, with rates reported between 19.25% and 88.54%, depending on crop stage and location (Gavkare *et al.*, 2014). Similarly, in Northeast Bihar, *M. persicae* has been observed on more than 26 species of food plants spanning eight families, with Brassicaceae being the most severely impacted. Natural enemies in the region play an

important role in regulating aphid populations (Kumar, 2013). Across India, the pest's broad host range allows it to establish itself in several states, including Gujarat, Uttar Pradesh, and West Bengal, highlighting its adaptability and widespread presence (Singh and Joshi, 2020).

Outside India, *M. persicae* continues to pose significant threats to agriculture. In Australia, it is a major vector of turnip yellows virus (TuYV) in crops such as pea (*Pisum sativum*), faba bean (*Vicia faba*), lupin (*Lupinus albus*), chickpea (*Cicer arietinum*), and lentil (*Lens orientalis*), contributing to substantial losses, including up to 46% yield reduction in canola (*Brassica napus*) fields (Nancarrow *et al.*, 2022). The aphid's ability to persist even in the absence of preferred crops further enhances its impact, as it can switch to alternative hosts like *Convolvulus arvensis*, *Chenopodium album*, and *Amaranthus retroflexus*, which act as reservoirs for future infestations (Nampeera *et al.*, 2022). In New Zealand, *M. persicae* is a key vector of potato virus Y (PVY) and leaflet curl virus (LCV), both of which are among the most damaging pathogens affecting potato crops (London *et al.*, 2020). Similarly, in China, it is considered a major pest on tobacco (*Nicotiana tabacum*), with significant economic implications (Li *et al.*, 2016). In Brazil, the peach-potato aphid is primarily responsible for the transmission of PVY and tomato yellow top virus (ToYTV), leading to tomato yield losses ranging from 20% to 70%, and reductions in fruit production of up to 85% (Pinheiro *et al.*, 2013). The economic impact of *M. persicae* is also evident in the United Kingdom, where aphid infestations are estimated to cause annual losses of up to GBP 70 million (Hemming *et al.*, 2022). One of the most critical concerns is its role in spreading turnip yellows virus (TuYV), which can slash oilseed rape yields by as much as 26% (Hemming *et al.*, 2022). Effective management of this virus alone could result in a yield profit increase of GBP 60-90 million per year for UK growers (Stevens *et al.*, 2008).

The pest's extensive host range, coupled with its ability to exploit both young and senescing plant tissues, underpins its global success and resilience (Kennedy *et al.*, 1950). Protected cultivation environments, such as polyhouses, create favourable conditions for rapid aphid population growth, leading to significant damage to crops like capsicum (Singh and Joshi, 2020). Moreover, the distribution and abundance of *M. persicae* are closely linked to the presence of natural enemies, such as parasitoids and entomopathogenic fungi, which are integral components of integrated pest management strategies aimed at reducing reliance on chemical control methods (Kumar, 2013; Singh and Joshi, 2020).

HOST RANGE OF *M. PERSICAE*

M. persicae is a highly adaptable pest that infests over 400 plant species, including vital crops such as potatoes, bell peppers, chili, citrus, beans, sugar beet, and tobacco (Emden *et al.*, 1969; Bass *et al.*, 1998). Several studies show that its ability to thrive on different plants, like sugar beet and potato, is due to both genetic diversity and its ability to adjust to various conditions. These traits are inherited separately and don't rely on the aphids' specific preferences for certain plants (Weber, 1985). In addition to causing direct feeding damage, it is a proficient vector for more than 100 plant viruses, posing a significant threat to global agriculture (Van-Emden *et al.*, 1969). This species exhibits both holocyclic (sexual) and anholocyclic (asexual) life cycles. In temperate zones, the aphid follows a holocyclic pattern, involving sexual reproduction and the overwintering of eggs on *Prunus* species. In contrast, in warmer regions, it reproduces asexually throughout the year. Despite these climatic influences, most populations retain the potential for sexual reproduction (Blackman, 1974). Photoperiod primarily triggers the production of sexual morphs, while temperature governs the global distribution of life cycle types, delineating six climatic zones.

Hong *et al.* (2019) reared *M. persicae* on five different plants (*Brassica campestris*, *Capsicum annuum*, *Nicotiana tabacum*, *Raphanus sativus*, and *Vicia faba*) and found that it developed fastest on *V. faba*, with a preadult period of 6.48 days and a pre-reproductive period of 6.67 days. *M. persicae* lived longer and had extended reproductive periods on *R. sativus* and *N. tabacum*. The highest fecundity was recorded on *R. sativus* (80.83 nymphs per female), followed by *N. tabacum* and *V. faba*. Overall, *V. faba*, *R. sativus*, and *N. tabacum* were identified as the most suitable

hosts, promoting faster development, higher reproduction, and greater population growth (Hong *et al.*, 2019).

BIO-ECOLOGY OF *M. PERSICAE*

The innate capacity for increase of *M. persicae* was determined through demographic analysis of parthenogenetic populations at constant temperatures ranging from 5°C to 30°C. *M. persicae* showed a capacity for population growth between 5°C and 25°C, with the intrinsic and finite rates of increase calculated at various temperatures. The upper temperature threshold for growth was estimated between 25°C and 30°C, and the lower threshold was below 5°C. The optimum temperature for growth was 25°C. Temperature influenced the capacity for increase by altering developmental time, survival rate, and fecundity, with the age at which maximum fecundity occurred being more important than total fecundity (Barlow, 1962).

Treatment of tomato plants with benzothiadiazole (BTH) or methyl jasmonate (MJ) significantly slowed *M. persicae* population growth compared to controls. BTH reduced aphid fecundity without affecting the timing of reproduction or mortality. MJ also reduced fecundity, though not significantly, suggesting other mechanisms contributed to slower aphid growth. A mixture of MJ and BTH reduced aphid populations nearly as much as MJ alone, indicating only mild antagonism between JA- and SA-dependent plant defence pathways (Boughton *et al.*, 2006).

M. persicae developed faster and showed higher fecundity under fluctuating temperatures than under constant conditions (Davis *et al.*, 2006). The optimal temperature for population growth was 26.7°C, with developmental thresholds at 6.5°C (lower) and 37.3°C (upper). At optimal conditions, its intrinsic rate of increase was 0.356, and population doubling time was 1.95 days. Under fluctuating conditions, a female produced 12.2 progeny per week, compared to 5.9 under constant temperatures. The aphid could survive brief daily exposure to 38.5°C. These findings suggest that a 2.5-3.5°C rise in summer temperatures would likely favour *M. persicae* population growth in midwestern North America (Davis *et al.*, 2006).

Under laboratory conditions (20 ± 1°C, 70% RH), developmental times varied across nine pepper cultivars, from 6.1 days on Yatasto to 11.4 days on Jaen, with survival rates nearing 100%. Bilano and Yatasto cultivars supported the highest reproductive potential, with intrinsic rates of increase (r_m) ranging from 0.281 to 0.174 females/female/day. Bird and Bilano also showed the highest net reproductive rates (R_0) of 63.8 and 62.89, respectively, while lower values were observed on Cabezo de la Sierra and Almuden, indicating possible host resistance (La Rossa *et al.*, 2013). Further research at 25 ± 1°C and 60% RH identified the Erciyes cultivar as the most favourable for aphid development, supporting the shortest life cycle (6.66 days) and highest fecundity (62.68 offspring). Erciyes also had the highest intrinsic rate of increase ($r = 0.332 \text{ d}^{-1}$), finite rate of increase ($\lambda = 1.394 \text{ d}^{-1}$), and net reproductive rate ($R_0 = 62.7$), along with the shortest generation time ($T = 12.45$ days). Conversely, Amiral, Mertcan, and Naz cultivars showed reduced aphid performance, highlighting their potential resistance (Özgökçe *et al.*, 2018).

Fadloli and Rahardjo (2024) observed that on chili plants, *M. persicae* completes its life cycle in about 8.85 days, progressing through four nymphal stages. Adults live an average of 11.93 days and produce approximately 21 offspring per female. The intrinsic rate of increase (r) was calculated at 0.38 individuals per female per day, with a net reproductive rate (R_0) of 14.41. Biometric data from Romanian potato fields (2005-2007) described wingless adults as green to pale yellow, measuring 1.9-2.3 mm in length. Winged forms featured black thoraxes and green abdomens with a characteristic dark dorsal patch. Measurements showed body lengths averaging 2.44 mm, with corresponding head, thorax, and abdomen widths of 0.41 mm, 0.89 mm, and 1.02 mm, respectively (Fericean *et al.*, 2011). These winged forms are highly mobile, dispersing easily to colonize a wide range of host plants.

MANAGEMENT STRATEGIES FOR *M. PERSICAE*

Cultural Control

Cultural methods are a fundamental component of integrated pest management (IPM), aimed at creating unfavourable conditions for pests (Abate *et al.*, 2000). Practices such as crop rotation, sanitation, intercropping, destruction of plant debris, and

strategic planting arrangements significantly reduce pest populations (Brader, 1979; Smit and Matengo, 1995). In fruit orchards, winter pruning is commonly employed to modify plant architecture, indirectly suppressing *M. persicae* by limiting oviposition sites on mature leaves (Grechi *et al.*, 2008). Complementary strategies, including intercropping with companion plants (Geiger *et al.*, 2010) and the application of neem-based products (Déla *et al.*, 2014), further enhance pest suppression. Additionally, elicitors such as benzothiadiazole (BTH), cis-Jasmone (CJ), and methyl jasmonate (MeJA) have been shown to induce systemic plant resistance against aphid infestation (Dardouri *et al.*, 2019; Boughton *et al.*, 2006). Despite their environmental advantages, these methods remain underutilized, underscoring the need for broader adoption to meet sustainable agriculture goals (Deguine *et al.*, 2021). Intercropping with species like *Tagetes patula* alongside *Capsicum annuum* effectively deters *M. persicae* through the emission of repellent volatiles (Dardouri *et al.*, 2017). However, the aphid's broad host range complicates cultural control efforts (Acheampong *et al.*, 2012). Physical barriers, such as insect-proof nets treated with repellents, have shown significant success in reducing *M. persicae* infestations in crops like *Brassica oleracea* (Däder *et al.*, 2015; Martin *et al.*, 2013). Similarly, the use of insect-free seedlings markedly lowers early aphid pressures, as demonstrated by Mpumi *et al.* (2020).

Biological Control

In response to the limitations of chemical control, interest in alternative management strategies has grown. Biological control methods, including the deployment of natural defence elicitors, biological control agents, and entomopathogens, offer promising avenues for sustainable management (Dardouri *et al.*, 2019; Barzman *et al.*, 2015). The use of natural enemies, such as parasitoids and predators, has been shown to significantly reduce *M. persicae* populations and mitigate crop damage (Andorno and López, 2014; Cabral *et al.*, 2009). Similarly, entomopathogenic fungi and other pathogens have demonstrated considerable potential in suppressing aphid infestations (Paschapur *et al.*, 2021; Bamisile *et al.*, 2021). These biological interventions, often integrated into pest management (IPM) programs, contribute to reducing reliance on chemical pesticides while promoting ecosystem health.

Around 200 biocontrol agents from families such as Coccinellidae, Cantharidae, Syrphidae, Anthocoridae, Pentatomidae, Aphelinidae, Braconidae, and Phytoseiidae have been identified as potential agents (Acheampong *et al.*, 2012; Mohammed and Hatcher, 2017). The success of these agents often depends on the host plant, as plants release volatile compounds that act as signals for pollinators and natural enemies (Clavijo McCormick *et al.*, 2014; Xu and Turlings, 2018). Infestation by *M. persicae* triggers the release of herbivore-induced plant volatiles (HIPVs), which enhance the recruitment of parasitoids and predators (Ahmed *et al.*, 2022). Field surveys have revealed a rich diversity of natural enemies, including *Aphidius ervi*, *Diaeretiella rapae*, *Aphidius colemani*, and *Coccinella septempunctata*, supporting earlier reports that identified approximately 150 predators, 50 parasitoids, and 40 entomopathogens associated with *M. persicae* (Acheampong *et al.*, 2012).

Among entomopathogens, fungi represent a particularly promising group. Although over 750 species of entomopathogenic fungi (EPF) are known, only a few are commercially utilized (Mora *et al.*, 2016; Torres-Quintero *et al.*, 2016). Species such as *Beauveria bassiana* and *Metarhizium anisopliae* exhibit broad-spectrum efficacy, affecting over 300 insect species including *M. persicae* (Torres-Quintero *et al.*, 2016). These fungi infect insects by penetrating the cuticle, leading to reduced feeding, impaired development, lower fecundity, and ultimately death (Mora *et al.*, 2016; Torres-Quintero *et al.*, 2016). In addition to direct mortality, applications of *B. bassiana*, *Isaria fumosorosea*, and *M. anisopliae* can disrupt aphid foraging behaviour, further limiting their impact on crops (Torres-Quintero *et al.*, 2016). EPFs have also been effective against other aphids such as *Sitobion avenae*, *Aphis glycines*, and *Aphis craccivora*, highlighting their broader applicability (Torres-Quintero *et al.*, 2016).

Plants also employ entomopathogenic viruses (EPVs) as a natural defence mechanism. For example, *M. persicae* can acquire and

transmit *M. persicae densovirus* (MpDNV) during feeding, aiding plant protection by spreading the virus among aphid populations (Torres-Quintero *et al.*, 2016). Some plant viruses, like potato virus Y (PVY), can indirectly weaken aphids by reducing their growth and increasing their susceptibility to natural enemies (Torres-Quintero *et al.*, 2016). However, not all plant-virus interactions are beneficial; certain viruses, such as Turnip mosaic virus, can enhance aphid performance by boosting their growth, feeding, and fecundity (Torres-Quintero *et al.*, 2016). Entomopathogenic nematodes (EPNs) contribute to pest suppression mainly through indirect mechanisms. Their presence in the soil can activate plant defence pathways, enhancing enzyme activity in the roots while dampening responses in aerial parts (Torres-Quintero *et al.*, 2016). Although entomopathogenic nematodes, such as *Steinernema carpocapsae*, exhibit low direct infectivity against *M. persicae*, their ability to modulate plant defences highlights their potential as a valuable component of integrated management strategies (Torres-Quintero *et al.*, 2016). Insecticide seed treatments, such as those containing imidacloprid and thiamethoxam, can affect the behaviour and effectiveness of natural enemies like *A. colemani* and *Mallada signatus*. These treatments may increase aphid mummification but can also reduce the searching and cleaning time of parasitoids, indicating a complex interaction between chemical and biological control methods (Ward *et al.*, 2024). Use of insectary plants like *Lobularia maritime*, which can enhance the abundance of natural enemies such as hoverflies and parasitoids in agricultural lands. These plants provide shelter and additional resources that can improve the fitness, and effectiveness of predators and parasitoids (Aparicio *et al.*, 2021; Aparicio *et al.*, 2018).

Conservation biological control involves using natural vegetation and field margins to support higher populations of natural enemies, thereby enhancing the biological control of *M. persicae*. (Ramadan *et al.*, 2022; Zumoffen *et al.*, 2021). Hence, biological control of this aphids with natural enemies like parasitoids and/or predators is a critical component of IPM programs. Yano (2006) stated that coccinellid predator release can reduce the aphid population and is considered an alternative to insecticide applications.

Chemical Control

To address the growing challenges posed by agricultural pests, innovative pest management strategies are continually being developed (Nauen *et al.*, 2015). These strategies are generally classified into chemical, biological, and cultural approaches (Barzman *et al.*, 2015). Among these, chemical control remains the predominant method, primarily due to the widespread availability, proven efficacy, and straightforward application of synthetic pesticides (Deguine *et al.*, 2021). Consequently, the management of *M. persicae* has largely relied on chemical pesticides (Wu and Song, 2007).

Active ingredients such as pyrethroids, carbamates, organophosphates, and neonicotinoids have exhibited substantial activity against *M. persicae* and other herbivorous insects (Rawat *et al.*, 2013; Gibson *et al.*, 1982; Foster *et al.*, 2002). Although resistance to many of these chemical classes has been documented in *M. persicae*, certain compounds continue to demonstrate effectiveness, particularly when integrated with complementary control measures (Faraone *et al.*, 2015; Ahmed *et al.*, 2022). However, increasing concerns regarding the ecological impact and risks to non-target organisms have prompted regulatory restrictions on their use (Geiger *et al.*, 2010).

M. persicae has developed resistance to multiple classes of insecticides, including neonicotinoids and sulfoxaflor. In Australia, resistance to neonicotinoids is attributed to metabolic resistance through the enhanced expression of the cytochrome P450 gene, CYP6CY3 (De Little *et al.*, 2017). Sulfoxaflor resistance has also been detected, indicating multiple independent evolutionary events leading to resistance (Ward *et al.*, 2024). Skouras *et al.* (2023) stated that deltamethrin and imidacloprid are commonly used insecticides for controlling sub-sucking insects in greenhouses. Due to indiscriminate use of pesticides, aphids have developed resistance to majority of the pesticides. Globally, *M. persicae* exhibits a diversity of resistance mutations, influenced by host-plant associations and environmental factors (Singh *et al.*, 2021; Bass *et al.*, 1998).

INSECTICIDE RESISTANCE IN *M. PERSICAE*

M. persicae exhibits a variety of resistance mechanisms, including gene amplification and mutations. The amplification of esterase genes, such as E4 and FE4, leads to increased esterase production, which detoxifies a wide range of insecticides (Field *et al.*, 1988; Field and Devonshire, 1992). Additionally, mutations such as L1014F (kdr) and MACE (modified acetylcholinesterase) contribute to resistance against pyrethroids and carbamates, respectively (Foster *et al.*, 2002; Voudouris *et al.*, 2016). The R81T mutation confers resistance to neonicotinoids and has been detected in some populations (Voudouris *et al.*, 2016). Resistance in *M. persicae* is dynamic, with fluctuations in resistance frequencies influenced by insecticide use and environmental factors. Long-term surveys in England and Greece have shown that resistance mechanisms can decline when insecticide pressure is reduced, suggesting fitness costs associated with resistance (Foster *et al.*, 2002; Voudouris *et al.*, 2016). Monitoring efforts in various regions, including China and Saudi Arabia, have identified varying levels of resistance to different insecticides, highlighting the need for region-specific management strategies (Tang *et al.*, 2017; Sabra *et al.*, 2023). Research has revealed that *M. persicae* can rapidly evolve resistance through both genetic and biochemical changes. The presence of multiple resistance mechanisms within single genotypes suggests a complex interplay of genetic factors (Bass *et al.*, 1998). Studies have also shown that resistance can be linked to specific multilocus genotypes (MLGs), which are selected for by certain insecticides (Mingeot *et al.*, 2021). Pirimicarb resistance in a *M. persicae* strain (Pc-R) exhibiting 131-fold resistance was attributed primarily to a saturated Ser431Phe mutation in the acetylcholinesterase (AChE) gene, resulting in AChE insensitivity (Kwon *et al.*, 2009). Minimal cross-resistance to other organophosphates and carbamates, but moderate cross-resistance to neonicotinoids, was observed by Kwon *et al.* (2009). Enhanced carboxylesterase (CbE) activity, mainly due to a pl 4.9 esterase identified as the E4 type, also contributed to resistance. Gene amplification (4.0-fold) and increased transcription (10.5-

fold) of the E4 CbE gene further supported the development of pirimicarb resistance (Kwon *et al.*, 2009).

M. persicae has developed resistance to multiple classes of insecticides, including neonicotinoids and pyrethroids, due to extensive use over the years (Bass *et al.*, 1998; De Little *et al.*, 2017; Hlaoui *et al.*, 2022). Resistance mechanisms include target site mutations and enhanced expression of detoxification genes like CYP6CY3, which are linked to metabolic resistance (De Little *et al.*, 2017; Hlaoui *et al.*, 2022; Troczka *et al.*, 2021). This resistance complicates pest management and necessitates integrated pest management strategies (Bass *et al.*, 1998; Hlaoui *et al.*, 2022).

Reducing insecticide resistance in *M. persicae* is critical for effective pest management, and several strategies have been identified to address this issue (Fig.1). Synergists like rifampicin enhance the toxicity of insecticides such as imidacloprid, clothianidin and cyantraniliprole by inhibiting detoxifying enzymes and downregulating resistance genes (Mezei *et al.*, 2020; Li *et al.*, 2024). Piperonyl butoxide further enhance the efficacy of imidacloprid when used alongside rifampicin (Mezei *et al.*, 2020). Alternative insecticides, including sulfoxaflor, provide effective control of neonicotinoid-resistant aphid populations due to their distinct mode of action and lower resistance (Mezei *et al.*, 2020; Pym *et al.*, 2022). Genetic insights, particularly the overexpression of CYP6CY3, suggest that targeting resistance genes through RNA interference could restore susceptibility to insecticides (Hu *et al.*, 2023). Monitoring resistance mechanisms, such as mutations in CYP6CY3, is crucial for guiding insecticide selection and management (Kirkland *et al.*, 2023; Tang *et al.*, 2017; Hu *et al.*, 2023). Integrated pest management (IPM) strategies, including biological control with entomopathogenic fungi and insecticide rotation, can reduce resistance pressure (Margaritopoulos *et al.*, 2020; Hu *et al.*, 2023). Combining synergists, alternative insecticides, genetic monitoring, and IPM offers a comprehensive approach to managing resistance in *M. persicae*.

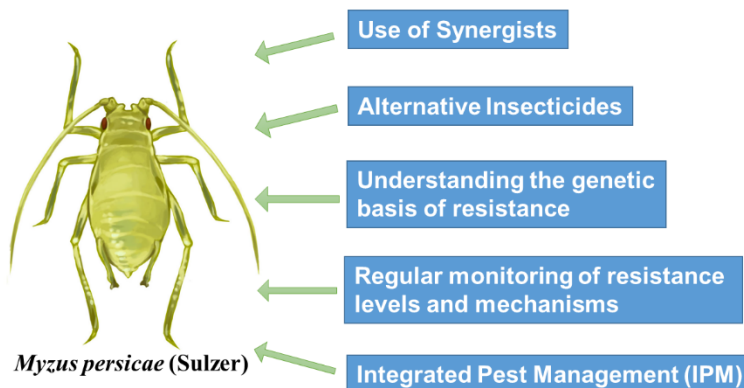


Fig.1 Approaches for Reducing Insecticide Resistance in *M. persicae*

CONCLUSION

In conclusion, the sustainable management of *M. persicae* is challenged by widespread pesticide resistance, less awareness among farmers, financial barriers, and the slow implementation of alternative control methods. Although many farmers are aware of the environmental risks, they often prefer chemical pesticides because they are affordable, readily available, and deliver quick results in short time period. The rapid development of resistant biotypes also makes breeding of resistant crops varieties more difficult. To tackle these issues, a more integrated management approach is urgently needed which combines entomopathogens, plant defence elicitors, biocontrol agents, biopesticides, and resistant crop varieties within an IPM framework. Strengthening farmer education and engagement through targeted training programs will be useful for incorporating sustainable pest management strategies against *M. persicae*.

REFERENCE

- Abate, T., van Huis, A., & Ampofo, J. K. O. (2000). Pest management strategies in traditional agriculture: an

African perspective. Annual review of entomology, 45(1), 631-659.

- Acheampong, S., Gillespie, D. R., & Quiring, D. (2012). Survey of parasitoids and hyperparasitoids (Hymenoptera) of the green peach aphid, *Myzus persicae* and the foxglove aphid, *Aulacorthum solani* (Hemiptera: Aphididae) in British Columbia. Journal of the Entomological Society of British Columbia, 109, 12-22.
- Ahmed, Q., Agarwal, M., Alobaidi, R., Zhang, H., & Ren, Y. (2022). Response of aphid parasitoids to volatile organic compounds from undamaged and infested Brassica oleracea with *Myzus persicae*. Molecules, 27(5), 1522.
- Ali, J., Covaci, A. D., Roberts, J. M., Sobhy, I. S., Kirk, W. D., & Bruce, T. J. (2021). Effects of cis-jasmone treatment of brassicas on interactions with *Myzus persicae* aphids and their parasitoid *Diaeretiella rapae*. Frontiers in Plant Science, 12, 711896.
- Andorno, A. V., & López, S. N. (2014). Biological control of *Myzus persicae* (Hemiptera: Aphididae) through

- banker plant system in protected crops. *Biological Control*, 78, 9-14.
- Aparicio, Y., Gabarra, R., and Arnó, J. (2018). Attraction of *Aphidius ervi* (Hymenoptera: Braconidae) and *Aphidoletes aphidimyza* (Diptera: Cecidomyiidae) to Sweet Alyssum and Assessment of Plant Resources Effects on their Fitness. *Journal of economic entomology*, 111(2), 533-541.
 - Aparicio, Y., Riudavets, J., Gabarra, R., Agustí, N., Rodríguez-Gasol, N., Alins, G., Blasco-Moreno, A., and Arnó, J. (2021). Can Insectary Plants Enhance the Presence of Natural Enemies of the Green Peach Aphid (Hemiptera: Aphididae) in Mediterranean Peach Orchards?. *Journal of Economic Entomology*, 114, 784 - 793.
 - Bamisile, B. S., Akutse, K. S., Siddiqui, J. A., & Xu, Y. (2021). Model application of entomopathogenic fungi as alternatives to chemical pesticides: Prospects, challenges, and insights for next-generation sustainable agriculture. *Frontiers in Plant Science*, 12, 741804.
 - Barlow, C. A. (1962). The influence of temperature on the growth of experimental populations of *Myzus persicae* (Sulzer) and *Macrosiphum euphorbiae* (Thomas) (Aphididae). *Canadian Journal of Zoology*, 40(2), 145-156.
 - Barzman, M., Bärberi, P., Birch, A. N. E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., ... & Sattin, M. (2015). Eight principles of integrated pest management. *Agronomy for sustainable development*, 35, 1199-1215.
 - Bass, C., Puinean, A., Zimmer, C., Denholm, I., Field, L., Foster, S., Gutbrod, O., Nauen, R., Slater, R., and Williamson, M. (1998). The evolution of insecticide resistance in the peach potato aphid, *Myzus persicae*. *Insect biochemistry and molecular biology*, 51, 41-51.
 - Blackman, R. L. (1974). Life-cycle variation of *Myzus persicae* (Sulz.) (Hom., Aphididae) in different parts of the world, in relation to genotype and environment. *Bulletin of Entomological Research*, 63(4), 595-607.
 - Boughton, A. J., Hoover, K., & Felton, G. W. (2006). Impact of chemical elicitor applications on greenhouse tomato plants and population growth of the green peach aphid, *Myzus persicae*. *Entomologia Experimentalis et Applicata*, 120(3), 175-188.
 - Brader, L. 1979. Integrated pest control in the developing world. *Annual review of entomology*, 24, 225-254.
 - Cabral, S., Soares, A. O., & Garcia, P. (2009). Predation by *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae) on *Myzus persicae* Sulzer (Homoptera: Aphididae): effect of prey density. *Biological Control*, 50(1), 25-29.
 - Capinera, J. 2020. *Handbook of Vegetable Pests*, Academic Press: Cambridge, MA, USA.
 - Clavijo McCormick, A. N. D. R. E. A., Gershenson, J., & Unsicker, S. B. (2014). Little peaks with big effects: establishing the role of minor plant volatiles in plant-insect interactions. *Plant, cell & environment*, 37(8), 1836-1844.
 - Däder, B., Legarrea, S., Moreno, A., Plaza, M., Carmo-Sousa, M., Amor, F., ... & Fereres, A. (2015). Control of insect vectors and plant viruses in protected crops by novel pyrethroid-treated nets. *Pest Management Science*, 71(10), 1397-1406.
 - Dardouri, T., Gautier, H., Ben Issa, R., Costagliola, G., & Gomez, L. (2019). Repellence of *Myzus persicae* (Sulzer): evidence of two modes of action of volatiles from selected living aromatic plants. *Pest management science*, 75(6), 1571-1584.
 - Davis, J. A., Radcliffe, E. B., & Ragsdale, D. W. (2006). Effects of high and fluctuating temperatures on *Myzus persicae* (Hemiptera: Aphididae). *Environmental Entomology*, 35(6), 1461-1468.
 - De Little, S., Edwards, O., Van Rooyen, A., Weeks, A., and Umina, P. (2017). Discovery of metabolic resistance to neonicotinoids in green peach aphids (*Myzus persicae*) in Australia. *Pest management science*, 73 8, 1611-1617.
 - Deguine, J. P., Aubertot, J. N., Flor, R. J., Lescourret, F., Wyckhuys, K. A., & Ratnadass, A. (2021). Integrated pest management: good intentions, hard realities. A review. *Agronomy for Sustainable Development*, 41(3), 38.
 - Déla, M. A., Koffivi, K. G., Komina, A., Arnaud, A., Philippe, G., & Adolé, G. I. (2014). Evaluation of neem leaves-based preparations as insecticidal agents against the green peach aphid, *Myzus persicae* (Sternorrhyncha: Aphididae). *African Journal of Agricultural Research*, 9, 1344-1352.
 - Fadloli, A. I. R., & Rahardjo, B. T. (2024). Biology and Demographic Statistic *Myzus persicae* on Chili Plant. *Journal of Tropical Plant Protection*, 5(1), 31-36.
 - Faraone, N., Hillier, N. K., & Cutler, G. C. (2015). Plant essential oils synergize and antagonize toxicity of different conventional insecticides against *Myzus persicae* (Hemiptera: Aphididae). *PloS one*, 10(5), e0127774.
 - Fericean, L. M., Palagesiu, I., Palicica, R., Prunar, S., and Vârteiu, A. M. (2011). The behaviour, life cycle and biometrical measurements of *Myzus persicae*. *Research Journal of Agricultural Science*, 43(2), 34-39.
 - Field, L. M., & Devonshire, A. L. (1992). Insecticide resistance by gene amplification in *Myzus persicae*. In *Resistance'91: Achievements and developments in combating pesticide resistance*. Dordrecht: Springer Netherlands, pp. 240-250.
 - Field, L. M., Devonshire, A. L., & Forde, B. G. (1988). Molecular evidence that insecticide resistance in peach-potato aphids (*Myzus persicae* Sulz.) results from amplification of an esterase gene. *Biochemical journal*, 251(1), 309-312.
 - Foster, S., Harrington, R., Dewar, A., Denholm, I., and Devonshire, A. (2002). Temporal and spatial dynamics of insecticide resistance in *Myzus persicae* (Hemiptera: Aphididae). *Pest management science*, 58 9, 895-907.
 - Gavkare, O. M. K. A. R., Surjeet, K., Yuvraj, S., & Bhopale, S. P. (2014). Abundance of the *Myzus persicae* (Sulzer) under protected environment in Himachal Pradesh, India. *J Ind Pollut Control*, 30(2), 285-287.
 - Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., ... & Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and applied ecology*, 11(2), 97-105.
 - Gibson, R. W., Rice, A. D., & Sawicki, R. M. (1982). Effects of the pyrethroid deltamethrin on the acquisition and inoculation of viruses by *Myzus persicae*. *Annals of Applied Biology*, 100(1), 49-54.
 - Goggin, F. L. (2007). Plant-aphid interactions: molecular and ecological perspectives. *Current opinion in plant biology*, 10(4), 399-408.
 - Grechi, I., Sauge, M. H., Sauphanor, B., Hilgert, N., Senoussi, R., & Lescourret, F. (2008). How does winter pruning affect peach tree-*Myzus persicae* interactions?. *Entomologia Experimentalis et Applicata*, 128(3), 369-379.
 - Hemming, D., Bell, J., Collier, R., Dunbar, T., Dunstone, N., Everatt, M., ... & Scaife, A. A. (2022). Likelihood of extreme early flight of *Myzus persicae* (Hemiptera: Aphididae) across the UK. *Journal of Economic Entomology*, 115(5), 1342-1349.
 - Hlaoui, A., Chiesa, O., Figueroa, C. C., Souissi, R., Mazzoni, E., & Boukhris-Bouhachem, S. (2022). Target site mutations underlying insecticide resistance in Tunisian populations of *Myzus persicae* (Sulzer) on peach orchards and potato crops. *Pest Management Science*, 78(4), 1594-1604.
 - Hong, F., Han, H. L., Pu, P., Wei, D., Wang, J., & Liu, Y. (2019). Effects of five host plant species on the life

- history and population growth parameters of *Myzus persicae* (Hemiptera: Aphididae). *Journal of Insect Science*, 19(5), 15.
- Hu, J., Chen, F., Wang, J., Rao, W., Lin, L., & Fan, G. (2023). Multiple insecticide resistance and associated metabolic-based mechanisms in a *Myzus persicae* (Sulzer) population. *Agronomy*, 13(9), 2276.
 - Kennedy, J. S., Ibbotson, A., & Booth, C. O. (1950). The distribution of aphid infestation in relation to leaf age: *Myzus persicae* (Sulz.) and *Aphis fabae* Scop. on spindle trees and sugar-beet plants. *Annals of Applied Biology*, 37(4), 651-679.
 - Kirkland, L. S., Chirgwin, E., Ward, S. E., Congdon, B. S., van Rooyen, A., & Umina, P. A. (2023). P450-mediated resistance in *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) reduces the efficacy of neonicotinoid seed treatments in *Brassica napus*. *Pest Management Science*, 79(5), 1851-1859.
 - Kumar, K. S. (2013). Seasonal abundance of *Myzus persicae* (Sulzer) and its association with food plants and natural enemies in Northeast Bihar. *Biolife*, 1(4), 195-199.
 - Kwon, D. H., Choi, B. R., Lee, S. W., Clark, J. M., & Lee, S. H. (2009). Characterization of carboxylesterase-mediated pirimicarb resistance in *Myzus persicae*. *Pesticide Biochemistry and Physiology*, 93(3), 120-126.
 - La Rossa, F. R., Vasicek, A., & López, M. C. (2013). Effects of pepper (*Capsicum annuum*) cultivars on the biology and life table parameters of *Myzus persicae* (Sulz.) (Hemiptera: Aphididae). *Neotropical Entomology*, 42, 634-641.
 - Li, Y., Xu, Z., Shi, L., Shen, G., & He, L. (2016). Insecticide resistance monitoring and metabolic mechanism study of the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), in Chongqing, China. *Pesticide Biochemistry and Physiology*, 132, 21-28.
 - Li, Z., Li, W., Mu, Q., Zhu, Y., Qin, W., Shi, X., & He, Y. (2024). Rifampicin synergizes the toxicity of insecticides against the green peach aphid, *Myzus persicae*. *Ecotoxicology and Environmental Safety*, 276, 116291.
 - London, H., Saville, D. J., Merfield, C. N., Olaniyan, O., & Wratten, S. D. (2020). The ability of the green peach aphid (*Myzus persicae*) to penetrate mesh crop covers used to protect potato crops against tomato potato psyllid (*Bactericera cockerelli*). *PeerJ*, 8, e9317.
 - López, G. I., Alvarez, A. E., Petroselli, G., Erra-Balsells, R., & Audisio, M. C. (2019). Aphicidal activity of *Bacillus amyloliquefaciens* strains in the peach-potato aphid (*Myzus persicae*). *Microbiological research*, 226, 41-47.
 - Margaritopoulos, J. T., Kati, A. N., Voudouris, C. C., Skouras, P. J., & Tsitsipis, J. A. (2021). Long-term studies on the evolution of resistance of *Myzus persicae* (Hemiptera: Aphididae) to insecticides in Greece. *Bulletin of Entomological Research*, 111(1), 1-16.
 - Martin, T., Palix, R., Kamal, A., Deletre, E., Bonafos, R., Simon, S., & Ngouajio, M. (2013). A repellent net as a new technology to protect cabbage crops. *Journal of Economic Entomology*, 106(4), 1699-1706.
 - Mezei, I., Bielza, P., Siebert, M. W., Torne, M., Gomez, L. E., Valverde-Garcia, P., ... & Sparks, T. C. (2020). Sulfoxaflor efficacy in the laboratory against imidacloprid-resistant and susceptible populations of the green peach aphid, *Myzus persicae*: Impact of the R81T mutation in the nicotinic acetylcholine receptor. *Pesticide Biochemistry and Physiology*, 166, 104582.
 - Mingot, D., Hautier, L., & Jansen, J. P. (2021). Structuration of multilocus genotypes associated with insecticide resistance of the peach potato aphid, *Myzus persicae* (Sulzer), in potato fields in southern Belgium. *Pest Management Science*, 77(1), 482-491.
 - Mohammed, A., and Hatcher, P. (2017). Combining entomopathogenic fungi and parasitoids to control the green peach aphid *Myzus persicae*. *Biological Control*, 110, 44-55.
 - Mora, M. A. E., Rouws, J. R. C., & Fraga, M. E. (2016). Occurrence of entomopathogenic fungi in Atlantic forest soils. *Microbiol. Discov*, 4(1).
 - Mpumi, N., Machunda, R. S., Mtei, K. M., & Ndakidemi, P. A. (2020). Selected insect pests of economic importance to *Brassica oleracea*, their control strategies and the potential threat to environmental pollution in Africa. *Sustainability*, 12(9), 3824.
 - Nampeera, E. L. (2022). Management of green peach aphid, *Myzus persicae* in amaranth using host plant resistance and seed treatment (Doctoral dissertation, JKUAT-CoANRE).
 - Nancarrow, N., Aftab, M., Hollaway, G., Rodoni, B., & Trębicki, P. (2022). Symptomless turnip yellows virus infection causes grain yield loss in lentil and field pea: A three-year field study in south-eastern Australia. *Frontiers in Plant Science*, 13, 1049905.
 - Nauen, R., Jeschke, P., Velten, R., Beck, M. E., Ebbinghaus-Kintscher, U., Thielert, W., ... & Raupach, G. (2015). Flupyradifurone: a brief profile of a new butenolide insecticide. *Pest management science*, 71(6), 850-862.
 - Özgökçe, M. S., Chi, H., Atlıhan, R., & Kara, H. (2018). Demography and population projection of *Myzus persicae* (Sulz.) (Hemiptera: Aphididae) on five pepper (*Capsicum annuum* L.) cultivars. *Phytoparasitica*, 46, 153-167.
 - Paschapur, A.; Subbanna, A.; Singh, A.K.; Jeevan, B.; Stanley, J.; Rajashekhar, H.; Mishra, K.K. Unraveling the Importance of Metabolites from Entomopathogenic Fungi in Insect Pest Management. In *Microbes for Sustainable Insect Pest Management*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 89-120.
 - Pinheiro, P. F., Queiroz, V. T. D., Rondelli, V. M., Costa, A. V., Marcelino, T. D. P., & Pratissoli, D. (2013). Insecticidal activity of citronella grass essential oil on *Frankliniella schultzei* and *Myzus persicae*. *Ciência e Agrotecnologia*, 37, 138-144.
 - Pym, A., Umina, P. A., Reidy-Crofts, J., Troczka, B. J., Matthews, A., Gardner, J., ... & Bass, C. (2022). Overexpression of UDP-glucuronosyltransferase and cytochrome P450 enzymes confers resistance to sulfoxaflor in field populations of the aphid, *Myzus persicae*. *Insect Biochemistry and Molecular Biology*, 143, 103743.
 - Ramadan, M. M., Bayoumy, M. H., & Afifi, M. (2022). Ecological studies on the Peach green aphid, *Myzus persicae* and its natural enemies. *Journal of Plant Protection and Pathology*, 13(1), 29-35.
 - Rawat, N., Singh, R., & Sharma, P. L. (2013). Evaluation of some insecticides against the green peach aphid, *Myzus persicae* (Sulzer) (hemiptera: Aphididae). *Indian Journal of Entomology*, 75(2), 113-117.
 - Rodriguez-Saona, C. R., Musser, R. O., Vogel, H., Hum-Musser, S. M., & Thaler, J. S. (2010). Molecular, biochemical, and organismal analyses of tomato plants simultaneously attacked by herbivores from two feeding guilds. *Journal of Chemical Ecology*, 36, 1043-1057.
 - Sabra, S. G., Abbas, N., & Hafez, A. M. (2023). First monitoring of resistance and corresponding mechanisms in the green peach aphid, *Myzus persicae* (Sulzer), to registered and unregistered insecticides in Saudi Arabia. *Pesticide Biochemistry and Physiology*, 194, 105504.
 - Singh, H., & Joshi, N. (2020). Management of the aphid, *Myzus persicae* (Sulzer) and the whitefly, *Bemisia tabaci* (Gennadius), using biorational on capsicum under protected cultivation in India. *Egyptian Journal of Biological Pest Control*, 30, 1-9.
 - Singh, K. S., Cordeiro, E. M., Troczka, B. J., Pym, A., Mackisack, J., Mathers, T. C., ... & Bass, C. (2021). Global patterns in genomic diversity underpinning the evolution of insecticide resistance in the aphid crop pest *Myzus persicae*. *Communications Biology*, 4(1), 847.

- Skouras, P. J., Karanastasi, E., Lycoskoufis, I., Demopoulos, V., Darras, A. I., Tsaferos, A., ... & Stathas, G. J. (2023). Toxicity and Lethal Effect of greenhouse insecticides on *Coccinella septempunctata* (Coleoptera: Coccinellidae) as biological control agent of *Myzus persicae* (Hemiptera: Aphididae). *Toxics*, 11(7), 584.
- Smit, N. E. J. M., & Matengo, L. O. (1995). Farmers' cultural practices and their effects on pest control in sweetpotato in South Nyanza, Kenya. *International Journal of Pest Management*, 41(1), 2-7.
- Stevens, M.; McGrann, G.; Clark, B.; Authority, H. 2008. Turnip Yellows Virus (Syn Beet Western Yellows Virus): An Emerging Threat to European Oilseed Rape Production; HGCA: Cape Town, South Africa.
- Tang, Q. L., Ma, K. S., Hou, Y. M., & Gao, X. W. (2017). Monitoring insecticide resistance and diagnostics of resistance mechanisms in the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) in China. *Pesticide Biochemistry and Physiology*, 143, 39-47.
- Torres-Quintero, M. C., Arenas-Sosa, I., Hernández-Velázquez, V. M., Suárez-Rodríguez, R., & Peña-Chora, G. (2016). Characterization of *Bacillus thuringiensis* (Bacillaceae) strains pathogenic to *Myzus persicae* (Hemiptera: Aphididae). *Florida Entomologist*, 99(4), 639-643.
- Troczka, B. J., Singh, K. S., Zimmer, C. T., Vontas, J., Nauen, R., Hayward, A., & Bass, C. (2021). Molecular innovations underlying resistance to nicotine and neonicotinoids in the aphid *Myzus persicae*. *Pest Management Science*, 77(12), 5311-5320.
- Van-Emden, H. F., Eastop, V. F., Hughes, R. D., & Way, M. J. (1969). The ecology of *Myzus persicae*. *Annual review of entomology*, 14(1), 197-270.
- Van-Emden, H.F., Harrington, R. 2017. Aphids as Crop Pests, Cabi: New York, NY, USA.
- Vorburger, C., Lancaster, M., & Sunnucks, P. (2003). Environmentally related patterns of reproductive modes in the aphid *Myzus persicae* and the predominance of two 'superclones' in Victoria, Australia. *Molecular ecology*, 12(12), 3493-3504.
- Voudouris, C. C., Kati, A. N., Sadikoglou, E., Williamson, M., Skouras, P. J., Dimotsiou, O., ... & Margaritopoulos, J. T. (2016). Insecticide resistance status of *Myzus persicae* in Greece: long-term surveys and new diagnostics for resistance mechanisms. *Pest Management Science*, 72(4), 671-683.
- Ward, S. E., Hoffmann, A. A., Van Helden, M., Slavenko, A., & Umina, P. A. (2024). The effects of insecticide seed treatments on the parasitism and predation of *Myzus persicae* (Homoptera: Aphididae) in canola. *Journal of Economic Entomology*, 117(1), 102-117.
- Weber, G. (1985). Genetic variability in host plant adaptation of the green peach aphid, *Myzus persicae*. *Entomologia experimentalis et applicata*, 38(1), 49-56.
- Wu, X. F., & Song, C. M. (2007). The resistance of *Myzus persicae* (Sulzer) against Omethoate in Tobacco fields of Yunnan. *Journal of Gansu Agricultural University*, 6, 102-105.
- Xu, H., & Turlings, T. C. (2018). Plant volatiles as mate-finding cues for insects. *Trends in Plant Science*, 23(2), 100-111.
- Yano, E. (2006). Ecological considerations for biological control of aphids in protected culture. *Population Ecology*, 48, 333-339.
- Zumoffen, L., Carla, G., Signorini, M., and Salvo, A. (2021). Use of plants by *Myzus persicae* in agroecosystems: Potential applications in conservation biological control. *Journal of Applied Entomology*, 145, 767 - 776.