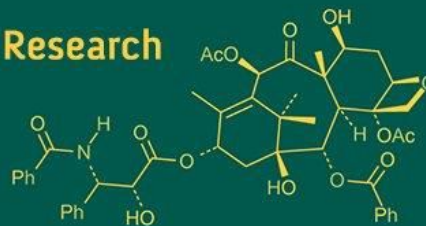


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
 ISSN Online: 2617-4707
 NAAS Rating (2025): 5.29
 IJABR 2025; 9(12): 1040-1046
www.biochemjournal.com
 Received: 11-09-2025
 Accepted: 17-10-2025

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Biological suppression of major insect pests in mango ecosystems

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DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i12m.6709>

Abstract

Mango (*Mangifera indica* L.) is a commercially important fruit crop grown extensively in tropical and subtropical countries; yet, its productivity is severely limited by a variety of insect pests. Major pests such as mango hopper, fruit fly, stem borer, mealybug, thrips and scale insects reduce productivity and quality. Excessive dependence on chemical insecticides for pest control has resulted in pesticide resistance, pest resurgence, environmental contamination and health hazards. In this context, biological suppression offers a sustainable and eco-friendly alternative for managing insect pests in mango ecosystems. This review synthesizes available literature on the role of natural enemies predators, parasitoids and entomopathogenic microorganisms in regulating major insect pests of mango. The review emphasizes the potential of biological suppression to reduce chemical pesticide dependence, enhance ecosystem services and promote sustainable mango production. Future research directions focusing on mass rearing of bioagents and field efficacy of biological control are also outlined.

Keywords: Mango (*Mangifera indica* L.); insect pests, biological control, natural enemies, predators, parasitoids, entomopathogens, Integrated Pest Management (IPM), sustainable mango production, eco-friendly pest management

Introduction

Mango (*Mangifera indica* L.) belongs to the Anacardiaceae family and originated in Indo-Burma. It has since spread to the tropics and subtropics. India boasts the most diverse mango collection, with over 1000 identified types (Mukherjee, 1997) [27]. Mango farming in India dates back 4,000-6000 years. Hsüan-tsang is believed to be the first to popularize mango outside of India. Historical records and palaeobotanical evidence support its origin in the Indo-Burma-Malay region. It spread to China in the 7th century, East Africa about the 10th century and the Philippines in the early 15th century. Since the end of the 15th century, it has expanded from South and Southeast Asia to tropical and subtropical regions worldwide. It spread to Africa in the 16th century, Brazil in the 1700s, Mexico in the early 19th century, Jamaica in 1782, Hawaii in 1809 and America in the late 19th century. It then spread worldwide (Yadav and Singh, 2017) [61].

Mango is India's most important fruit crop and is regarded as the "king of fruits". Delicious taste, good flavor and a lovely scent. It is rich in vitamins A and C. The tree is resilient and low-maintenance. India's main export destinations for fresh mangoes and mango pulp are the UAE, Kuwait and other Middle Eastern countries, with a minor number exported to the European market. India is the largest mango producing country. India has a 15% share of the global mango market and exports 40% of the fruit. There is potential to increase mango output in the country (Verma *et al.* 2021) [56].

According to Tandon and Verghese (1985) [52] and Pena *et al.* (1998) [32], around 400 pest species infest mango trees globally. Several authors, including de Laroussilhe (1980) [10], Tandon and Verghese (1985) [52], Veeresh (1989) [53], have published global pest lists for mango. Mango pests have been identified in India (Srivastava, 1998) [48], Australia (Anonymous, 1989) [3], Israel (Wysoki *et al.* 1993; Swirski *et al.* 2002) [60, 50], the USA (Peña, 1993) [33].

Mango trees are attacked by a wide variety of insect pests, including thrips, leafhoppers, mealybugs, white mango scale, shoot gall psylla, midges, mango stem borers, mango shoot borers, fruit flies, stone weevil and leaf webber. These pests affect different parts of the tree

at various stages of growth and development, contributing to significant yield and quality losses in mango production.

Key pest distribution varies by area in India. Insect pests, including Diptera, Hemiptera and Lepidoptera as well as secondary and occasional pests, pose a significant danger to mango production (Verghese, 1998) [55].

In this context, biological control has become a viable and environmentally responsible substitute for chemical pest control. Utilizing living natural enemies like parasitoids, entomopathogenic fungi, bacteria, viruses and predators to reduce pest populations to levels that may be economically controlled is known as biological control. In order to sustain long-term pest management with the least possible negative impact on the environment, it is a key component of Integrated Pest Management (IPM) techniques. The use of biological control in mango ecosystems has regained attention because to recent developments in biocontrol technology and growing awareness of sustainable agricultural methods. The objective of this review paper is to present a thorough analysis of the biological control agents utilized in mango farming, including their mechanisms of action, efficacy and possibilities for incorporation into commercial production systems.

Mango major insect pest and their biological control

1. Thrips

- Conservation of natural enemies that include predatory thrips, predatory mites (e.g. *Amblyseius* spp.), anthocorid bugs or minute pirate bugs (*Orius* spp.), ground beetles, lacewings, hoverflies and spiders (Venkata *et al.* 2018) [54].
- Apply neem soap (10 g/l) or pesticides containing neem to stop thrips from establishing (Venkata *et al.* 2018) [54].
- *Aleurodothrips fasciapennis* (Franklin) and *Haplothrips bedfordi* Jacot-Guillarmod were the only predatory thrips recorded (Grove *et al.* 2001) [16].
- Two percent neem oil has been found to be effective against adult thrips. When pollinators are at their least active, midday is the ideal time to spray (Aliakbarpour *et al.* 2011) [2].

2. Leafhoppers

- Conservation of natural enemies, particularly predators such as coccinellids (e.g., *Coccinella septempunctata*, *C. transversalis*, and *Menochilus sexmaculatus*) and spiders, to suppress leafhoppers (Venkata *et al.* 2018) [54].
- The *M. anisopliae* strain (MaIIHR) offers a sustainable and eco-friendly alternative to chemical insecticides for control of mango hoppers (Radha *et al.* 2025) [34].
- Entomopathogenic fungi such as *Verticillium lecanii*, *Metarhizium anisopliae* (1x10⁸ cfu/ml) and *Beauveria bassiana* (10⁸ cfu/ml) on tree trunks twice during flowering and once during off-season help manage hopper population (Munj *et al.* 2025) [28].
- Spray botanical pesticides such as azadirachtin (1% at 3 ml/l), neem oil and pungam oil (1% at 10 ml/l) on low hopper populations (4/panicle) (Chaudhari *et al.* 2017) [5].
- Two botanicals, Neem extract and Mahogoni extract, were tested at three concentrations (0.5%, 1.0%, and 1.5%) to control *Amritodus atkinsoni* L. However, Neem extract (1.5%) outperformed Mahogoni extract (1.5%) (Shawan *et al.* 2018) [43].

- The biopesticide azadirachtin-based Neem oil (0.3%) was efficient against mango hoppers (Adnan *et al.* 2014) [1].
- Spray Neem Azal (10000 ppm @ 3 ml/lit. of water) during panicle emergence, followed by Nimbicidene (1500 ppm @ 3 ml/l of water) 15 days later. After 15 days, apply a third spray of Neem Azal (10000 ppm @ 3 ml/lit. of water), followed by a fourth spray of Nimbicidene (1500 ppm @ 3 ml/l of water). This module is used to control mango hoppers (Kumari *et al.* 2014) [22].
- Egg parasitoids such as *Gonatocerus* sp., *Aprostocetus* sp. and *Polynema* sp., have been employed to control mango hoppers (Fasih and Srivastava, 1990) [13].
- Mango hoppers have been controlled with predators such as *Chrysoperla carnea* (Kimmings), *Mallada boninensis* (Okomote) and *Bochartia* sp. Mantidae and Lygaeidae have been observed feeding on mango hopper nymphs (Fasih and Srivastava, 1990) [13].
- For the first time in India, an entomopathogenic fungus from the *Hirsutella* genus was utilized against mango hoppers (Choudhary *et al.* 2012) [6].
- *Beauveria bassiana* also effective to control leafhoppers (Hossain *et al.* 2019) [19].
- *Beauveria bassiana*, neem oil, mahogany oil, and karanja oil were the four insecticides (one microbe and three botanicals) that were tested against the mango hopper (Rahman *et al.* 2018) [36].
- Mango hopper counts were lower when *Verticillium lecanii* 1.15% WP (2x10⁸ cfu/g) was present on tree trunks during the off-season and during the flowering period. This was comparable to *Metathizium anisopliae*, which also had 1.15% WP (2x10⁸ cfu/g) on tree trunks during both periods (Raghunandan *et al.* 2020) [35].
- Neem seed kernel extract (NSKE) at 5% was shown to be the most efficient biopesticide that were studied in lowering the incidence of *A. atkinsoni*. This was followed by *Lecanicillium lecanii* at 1.15% WP, neem oil at 1%, and Neem Leaf Extract (NLE) at 10% (Mohapatra *et al.* 2019) [25].

3. Mealybugs

- Preservation of biocontrol agents (predators) such as *Sumnius renardi*, *Rodolia fumida* and *Menochilus sexmaculatus*.
- Ladybird beetles (*Cryptolaemus montrouzieri*) were shown to be effective predators at a rate of ten per plant (Munj *et al.* 2025) [28].
- It has also been discovered that applying a *Beauveria bassiana* product (2 g/l) or 5% NSKE around tree trunks during the second week of December works well (Rai *et al.* 2019) [38].
- The Australian ladybird beetle's larvae and adults, *Cryptolaemus montrouzieri*, Scymnus sp., *Diadiplosis coccidarum* (cockel), lacewing larvae and adults and Syrphid (hover fly) larvae are significant predators. The carnivorous butterfly (*Spalgis epius*) effectively consumes mealy bug adults, nymphs, and ovisacs (Das *et al.* 2018; Mani *et al.* 2011) [8, 24].

4. White mango scale

- In South Africa, it was noticed that *Chilocorus nigrita* (Fabricius) and *Rhyzobius lophanthae* Blaisdell

(Coleoptera: Coccinellidae) were consuming WMS (Coll and Abd-Rabou, 1998) [7].

- Four natural enemies, including *Cryptolaemus montrouzieri*, *Chilocorus stigma*, *Chilocorus bipustulatus* larvae, *Chrysoperla carnea*, and an unknown lady beetle larvae, were discovered to prey on white mango scale (Wale & Melis, 2024) [57].
- In South Africa, *Encarsia* sp. (Hymenoptera: Aphelinidae) parasitoids feed on *A. tubercularis*, with a parasitism rate of 17.7% on mango crops (Schoeman, 1987) [42].
- Ladybird beetle *Chilocorus* sp. (Coleoptera: Coccinellidae) larvae feed on white mango scale at all stages. The studies concluded that the scale on white mango scale does not interfere with the feeding of *Chilocorus* sp. Larvae were able to reach the body of the scale and chew it (Djirata *et al.* 2016) [11].
- Conserve natural enemies; *Promascidia unfascitiventris* and *Anagrus pseudococci* are the two main parasitoids found on scales. Predators such as *Cryptolaemus montrouzieri*, *Chilocorus nigritus*, and *Scymnus* sp., as well as the larvae of the midge predator *Coccodiplosis* sp., were observed to consume this coccid in large quantities. (Tandon and Lal, 1978) [51].

5. Shoot gall psylla

- Black ladybird beetle, purple pirate insect and brown lace all contribute significantly to pest population suppression (Kadam *et al.* 2017) [20].
- Nimbicidine, neem seed kernel extract, *Baeauveria bassiana* also used to control shoot gall psylla (Rahman *et al.* 2016) [37].

6. Midges

- Conservation of parasitoids of cecidomyiid pests, like *Platygaster* sp., *Systasis* sp. and *Euplemus* sp. associated with *Dasineura* sp. and *Tetrastichus* sp. associated with *Erysomyia indica*. An external parasitoid, the pteromalid, *Pirens* sp., was found attacking *Procytiphora mangiferae* (Felt.). Predators of the cecidomyiid included *Formica* sp., *Oecophila* spp. and *Camponotus* spp. (Grover 1986) [17].
- Predators of the cecidomyiid included *Formica* sp., *Oecophila* spp., and *Camponotus* spp. (Pena *et al.* 1998) [32].
- A number of parasitoids have been introduced to India; species such as *Chrysonotomyia pulcherrima* and *Chrysonotomyia* spp. Have been released in Oman so far (Sankaran & Mjeni, 1988) [41].

7. Mango stem borers

- In the laboratory, Sundra Babu (1974-75) noticed a type of mite called *Proctolaclans bickleyi* on the bodies of grubs. Additionally, he noticed that the grub had a parasitic *Brevibucca* sp. Rhabditid nematode.
- Other studies revealed the presence of fungi *Aspergillus niger* and *A. flavus* on the gut microbiota of healthy grubs. A laboratory test of a mite species, *Proctolaclans bickleyi*, revealed that the Rhabdidae nematode was

parasitic on the grubs, particularly *Brevibucca* sp. (Baradevanal *et al.* 2021) [4].

- Sweet flag stolen extract, Nimex and *Lantana camera* is botanical insecticide also used to control mango stem borer (Magar *et al.* 2022) [23].

8. Mango shoot borers

- Conservation of indigenous ant species, such as *O. smaragdina*, should help reduce shoot borer attacks (Khoo 2001; Sands & Murphy 2001) [21, 40].
- *Nagyruss P.*, Barcon Greeni Ashmead, *Meteorus* sp., *Araneus sinhagadensis*, *Stagodyphus sarasinorum*, and *Serratia marcescens* were discovered in Malihabad (Singh, 1993) [46].
- In this study, azadirachtin 1500 ppm @ 33 ml was found to be more efficient than other bio pesticides against mango shoot borer. The effectiveness of bio pesticides in this study is as follows: azadirachtin 1500 ppm at 33 ml, azadirachtin 1500 ppm at 40 ml, azadirachtin 1500 ppm at 27 ml, azadirachtin 1500 ppm at 20 ml and NSKE 500 gm. *Beauveria bassiana* has 2x10⁸ CFU/gm, followed by *Metarrhizium anisopliae* and *Verticillium lacani*, both with 2x10⁸ CFU/gm. (Patel & Pandya, 2022) [31].

9. Fruit flies

- Augmentative Releases of *Diachasmimorpha longicaudata* (Ashmead) parasitoids for control fruit fly (Montoya *et al.* 2000) [26].
- *Diachasmimorpha* species have been introduced to various parts of the world for the traditional biological control of these pests (Wharton, 1989) [58].
- The female *Diachasmimorpha longicaudata* (Ashmead), a solitary tephritid fruit fly endoparasitoid, responded favorably (Eben *et al.* 2000) [12].

10. Stone weevil

- Nuclear polyhedrosis virus was detected in Bangalore (Shukla *et al.* 1984) [44]. In Tripura, ants (*Oecophylla smaragdina*, *Camponotus* sp., and *Monomorium* sp.), fungi (*Aspergillus* sp.) and mites (*Rhizoglyphus* sp.) preyed on larvae, pupae and hibernating adults (De and Pande, 1988) [9].

11. Leaf webber

- An important larval parasitoid in Kerala was identified as *Goniozus* sp. (George and Abdurahman, 1985) [14].
- The parasite *Hormius*, *Tetrastichus* and *Pediobius bruchicida* (Rondani) are the natural enemies to control leaf webber (Singh, 1993) [46].
- The antagonist *Aspergillus flavus* used against pest (Gupta & Gopal, 2002; Srivastava & Tandon, 1980) [18, 47].
- The Parasitoid *Hormius* and *Goniozus* natural enemies effective against pest (NAIP, 2022; George & Abdurahman, 1985) [29, 15].
- *Brachymeria lasus* natural enemies for control of mango leaf Webber (Rajkumar & Shukla, 2019; Singh, 1993) [39, 46].
- Nimbicidine 0.2% and Nemactine 0.4% are botanical pesticide used against mango leaf Webber (Singh, 1993) [46].

Table 1: Pest of mango and their damaging stage

S.N.	Common name	Scientific name	Family	Order	Damaging stage
1	Thrips	<i>Rhipiphorothrips cruentatus</i> (Hood)	Thripidae	Thysanoptera	Nymph and Adult
2	Leafhoppers	<i>Idioscopus clypealis</i> (Lethierry), <i>I. nitidulus</i> (Walker), <i>I. nagpurensis</i> (Pruthi) and <i>Amritodus atkinsoni</i> (Lethierry)	Cicadellidae	Hemiptera	Nymph and Adult
3	Mealybugs	<i>Drosicha mangiferae</i> (Green), <i>Drosicha stebbingi</i> (Green)	Monophlebidae	Hemiptera	Nymph and Adult
4	White mango scale	<i>Aulacaspis tubercularis</i>	Diaspididae	Hemiptera	Nymph and Adult
5	Shoot Gall Psylla	<i>Apsylla cistellata</i> Buckton	Psyllidae	Hemiptera	Nymph and Adult
6	Midges	<i>Erosomya indica</i> Grover,	Cecidomyiidae	Diptera	Maggot
7	Mango Stem Borers	<i>Batocera rufomaculata</i>	Cerambycidae	Coleoptera	Grub
8	Mango Shoot Borers	<i>Chlumetia transversa</i>	Noctuidae	Lepidoptera	Caterpillar
9	Fruit fly	<i>Bactrocera dorsalis</i> , <i>Anastrepha</i> spp	Tephritidae	Diptera	Maggot
10	Stone Weevil	<i>Sternonchetus mangiferae</i>	Curculionidae	coleptera	Grub and Adult
11	Leaf webber	<i>Orthaga euadrusalis</i>	Pyalidae	Lepidoptera	Caterpillar

Table 2: Major insect pest of mango and their biocontrol agents

S.N.	Insect pest species	Type of biocontrol agent	Name of biocontrol agent	Order / Family of Bioagents	Mode of action / Target stage	References
1	Mango hopper	Predator	<i>Coccinella septempunctata</i> , <i>C. transversalis</i> and <i>Menochilus sexmaculatus</i> and spider.	Coleoptera: Coccinellidae	The adult and larval stages of the ladybug actively search for, capture and ingest pest.	Venkata <i>et al.</i> 2018 [54]
		Predator	<i>Chrysoperla carnea</i> (Kimmins), <i>Mallada boninensis</i> (Okomote)	Neuroptera: Chrysopidae	Mangooppers are controlled through predation by their larval stage. The larvae aggressively hunt for food, particularly mango hopper nymphs with soft bodies.	Fasih and Srivastava, 1990 [13]
		Egg parasitoid	<i>Aprostocetus</i> sp.,	Hymenoptera: Eulophidae	The female wasp deposits her eggs within the mango hopper's eggs and the parasitic larva develops internally, eating and destroying the host egg in the process.	Fasih and Srivastava, 1990 [13]
		Egg parasitoid	<i>Gonatocerus</i> sp. And <i>Polynema</i> sp	Hymenoptera: Mymaridae	These wasps put their eggs within the hoppers' eggs, preventing them from hatching and controlling their numbers.	Fasih and Srivastava 1990 [13]
2	Mealybug	Predator	<i>C. montrouzieri</i>	Coleoptera: Coccinellidae	Both the adult and larval stages engage in direct predation.	Mani <i>et al.</i> 2011 [24]
		Parasitoid	<i>1043nagyruss</i> p.	Hymenoptera :Encyrtidae	Parasitism, in which the female wasp lays an egg inside the mealybug's body; and secondarily, host feeding.	Narasimham and Chacko, 1988 [30]
		Parasitoid	<i>Coccophagus</i> sp.	Hymenoptera: Aphelinidae	Larvae develop internally within the mealybug host. The major form of action is parasitism, which ultimately kills the host insect.	Narasimham and Chacko, 1988 [30]
3	Midges	Parasitoids	<i>Eupelmus</i> sp	Hymenoptera: Eupelmidae	The female deposit eggs inside or on the victim's body, and the developing wasp larvae feed on and finally kill the host.	Grover, 1986 [17]
		Endoparasitoids	<i>Platygaster</i> sp.	Hymenoptera: Platygasteridae	The female wasp deposits her eggs within the midge larvae, and the growing parasitoid larvae feed and mature internally, eventually killing the host midge before it can finish its life cycle.	Grover, 1986 [17]
		Parasitoid	Pteromalid	Hymenoptera: Pteromalidae	Pteromalid wasps are parasitoids that lay their eggs within or on mango midge larvae or pupae.	Grover, 1986 [17]

					Before developing into adult wasps, the larvae feed on the midge and kill it.	
		Predators	<i>Oecophila</i> spp and <i>Camponotus</i> spp	Hymenoptera: Formicidae	Ants attack and kill midge adults/larvae	Pena <i>et al.</i> 1998 [32]
4	Shoot gall psylla	Predator	Black ladybird beetles	Coleoptera : Coccinellidae	Mango shoot gall psylla by predation. Both adult beetles and their larvae are natural enemies of the psyllid, feeding on its eggs and nymphs, which are often found on fresh leaves and inside forming galls.	Kadam <i>et al.</i> 2017 [20]
		Predator	Brown lace	Neuroptera: Hemerobiidae	Both the larvae and adults of the brown lacewing are natural predators that actively seek for, capture, and consume psylla in the mango orchard.	Kadam <i>et al.</i> 2017 [20]
5	Fruit Flies	Parasitoid	<i>Diachasmimorpha longicaudata</i> Ashmead	Hymenoptera: Braconidae	It is a larval-prepupal endoparasitoid that kills its host by laying its eggs inside fruit fly larvae.	Montoya <i>et al.</i> 2000 [26]; Wharton, 1989 [59]; Eben <i>et al.</i> 2000 [12]
6	Leaf webber	Parasitoid	<i>Goniozus</i> spp	Hymenoptera: Bethyridae	As a larval ectoparasitoid, <i>Goniozus</i> sp. paralyzes the leaf webber caterpillar and deposits its eggs on its body. The growing wasp larvae feed externally on the host until it dies.	George and Abdurahman, 1985 [14]
		Larval parasitoids	<i>Hormius</i> spp.	Hymenoptera: Braconidae	Parasitism <i>Goniozus</i> sp. lays eggs on or in leaf webber larvae, and the growing parasitoids kill the host.	Singh, 1993 [46]; George & Abdurahman, 1985 [15]
		Parasitoids	<i>Tetrastichus</i> spp.	Hymenoptera: Eulophidae	Parasitism <i>Tetrastichus</i> sp. lays eggs inside leaf webber larvae or pupae, and the resulting parasitoids develop within and kill the host.	Singh, 1993 [46]
		Parasitoids	<i>Pediobius bruchicida</i>	Hymenoptera: Eulophidae	Parasitism <i>Pediobius bruchicida</i> lays eggs inside leaf webber larvae or pupae, where the developing parasitoids feed internally and kill the host.	Singh, 1993 [46]

Conclusion

Biological suppression plays a vital role in the sustainable management of major insect pests in mango ecosystems. Natural enemies such as predators, parasitoids and entomopathogens effectively reduce pest populations while minimizing environmental and health risks associated with chemical pesticides. The conservation and integration of these biological control agents within integrated pest management strategies can enhance long-term pest regulation. Strengthening research, farmer awareness and field-level implementation will further improve the effectiveness and adoption of biological control approaches in mango cultivation.

Acknowledgments

The authors express their sincere gratitude to Dr. Sajad Mohi-ud-din and Dr. Mudasir Gani for their insightful guidance, encouragement and valuable inputs during the preparation of this review. We also acknowledge the

contributions of researchers whose studies on biological control in mango ecosystems made this work possible.

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