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Green solutions for mango insect pest management: A bio-rational perspective

Mango crops are affected by numerous insect pests, primarily hoppers, fruit flies, mealy bugs, borers, and thrips. Extensive use of chemical pesticides has led to pest resistance, resurgence, residue accumulation, and environmental pollution. This necessitates the adoption of environmentally friendly, bio-rational pest management practices. Bio-rational pest management relies on biodegradable, target-specific, and residue-free options, such as cultural, botanical, microbial, mechanical, and ICT-based approaches. Successful pest management in mango orchards depends on the correct application of multiple strategies, including orchard sanitation, pruning, neem formulations, microbial bio-pesticides, pheromone traps, and bio-agent applications. Digital and online tools, combined with "smart traps," IoT, and remote monitoring, enhance early warning systems, precision, and decision-making, supporting ecologically sound, economically viable, and sustainable protection strategies for mango orchards.

Keywords: Bio-rational pest management, Botanical and microbial pesticides, ICT and smart traps, Mango insect pests

INSECTS such as hoppers, fruit flies, mealy bugs, borers, leaf webbers, psylla, thrips, and semiloopers cause significant damage to mango crops, leading to yield losses and reduced export-quality fruit due to pesticide residues and quarantine restrictions. Historically, insect control relied on chemical pesticides; however, their use has led to resistance development, pest resurgence, environmental contamination, and concerns over biodiversity and human health. Consequently, there has been a shift toward sustainable, bio-rational, and eco-friendly pest management. Bio-rationals—bio-pesticides and non-chemical agents—are safer, more targeted, and biodegradable alternatives for suppressing pest populations. These include cultural methods, botanicals, insecticidal soaps, microbials, bio-agents (e.g., parasites/predators), as well as mechanical or physical methods (e.g., traps and pheromones). Their use promotes an environmentally sound pest management program for mango. The green solutions for mango insect pest management practices are discussed in the paper here.

Cultural or agro-practices

Cultural practices are conventional pest management techniques that involve farm activities such as ploughing, sanitation, pruning, intercropping, irrigation, and nutrient management. Cultural control is among the oldest, simplest, and most sustainable methods for controlling insect pests in mango orchards. These practices reduce the likelihood of environments supporting pest build-up while promoting tree health. Key practices include:

***Manual collection and orchard sanitation*:** In mid-sized orchards, cultural techniques can significantly reduce pest populations. Egg masses of mealy bugs near tree bases can be destroyed through ploughing and flooding. Shoots affected by shoot gall psylla or shoot borers can be pruned. Fruits infested by fruit flies can be collected from the ground. Removing alternate host plants, such as weeds that serve as breeding sites for pests like thrips and mealy bugs, greatly reduces re-infestation rates.

***Irrigation and water management*:** Flood irrigation directly influences insect pest populations in mango orchards. Mango trees that receive properly regulated irrigation often exhibit healthy tissues, a favorable canopy microclimate, and lower abundance of sap-sucking pests, particularly mango hoppers and mealy bugs. In contrast, excessive irrigation, prolonged flood irrigation, or waterlogging creates a microclimate conducive to pest outbreaks and disease development. High humidity around the canopy promotes infestations by pests such as thrips and hoppers, while water-saturated soils can weaken roots and increase susceptibility to fungal infections.

***Nutrition for tree health*:** The nutrition of mango trees plays a key role in determining pest infestation levels. Trees with excess nitrogen produce soft, succulent leaves that are highly attractive to sap-sucking pests such as hoppers, thrips, and mealy bugs, and also increase susceptibility to diseases like powdery mildew. Phosphorus promotes root development and flowering, while strengthening plant tissues, which reduces the likelihood of inflorescences being damaged by hoppers. Potassium enhances the tree's resilience against insect pests and

diseases by strengthening cell walls, improving water-use efficiency, and increasing fruit tolerance to fruit flies. Calcium strengthens cell walls, improving tissue hardness and enhancing resistance to pests and physiological disorders. Zinc increases leaf toughness, which lowers susceptibility to hopper infestations. Boron improves fruit set, and copper provides fungicidal protection. Additionally, organic manures and bio-fertilizers enhance soil structure, soil health, microbial activity, and support naturally occurring antagonists of pests.

***Tree height reduction*:** Reducing tree height and managing the canopy significantly improves pest and disease management in mango orchards. Tall trees with dense canopies can hinder effective spray coverage and penetration of pesticides while providing favorable habitats for serious pests. They may also increase disease incidence, as limited sunlight and poor airflow create conditions conducive to pathogen development. By lowering tree height and opening the canopy, sprays–both chemical and biological–can reach all parts of the tree more effectively. An open canopy reduces shaded, humid areas, exposing pests to sunlight and facilitating movement of natural enemies throughout the orchard. Improved air circulation and light penetration also decrease fungal disease, indirectly reducing pest pressure. The tree height reduction technology developed by ICAR-CISH supports better integrated pest management (IPM) through enhanced efficacy of sticky traps, pheromone traps, and biocontrol sprays, while also promoting pollinator activity.

***Annual pruning for pest reduction*:** Pruning is one of the simplest and most effective cultural management practices for keeping mango orchards healthy. When trees are too thick and crowded, pests such as hoppers, caterpillars, midges, mealy bugs, and fruit flies can find suitable locations to reside and reproduce. Pruning away dead, diseased, and unnecessary branches allows sunlight and fresh air to reach the canopy. This makes it less suitable for pests to lay eggs and access food, while also enabling natural enemies such as ladybird beetles, spiders, and wasps to help control pests. Hoppers, for example, prefer shady and wet areas, which are reduced through regular pruning. Moths rely on dead and crowded branches for shelter, which pruning removes.

***Conservation bio-control and habitat management*:** Conservation bio-control practices within mango orchards rely on retaining and enhancing the natural enemies of pests while establishing a self-regulating ecosystem that reduces the need for chemical pesticides. Natural enemies such as ladybird beetles, lacewings, spiders, predatory bugs, and parasitic wasps provide effective pest suppression. Maintaining appropriate habitats for these natural enemies is beneficial. Practices such as providing flowering plants, cover crops, hedgerows, and refuge areas with nectar and pollen support predators and parasitoids and also improve pollinator abundance. Retaining dead wood, leaf litter, and mulch benefits soil-based organisms, allowing natural enemies to survive. Intercropping (e.g., marigold, sunflower, cowpea), maintaining hedgerows, and refraining from spraying during flowering replicate naturally occurring pest control mechanisms in mango orchards.

***Fruit bagging*:** Bagging mango fruits is an environmentally sustainable pest management practice that reduces fruit fly infestation and pesticide residues. In this system, each fruit is individually covered with non-woven fabric, paper, or plastic bags approximately 2–3 weeks after fruit set. The bag acts as a physical barrier, preventing adult fruit flies from ovipositing while also protecting the fruit from other pests, diseases, and sunburn. Mango bagging can be integrated with other IPM strategies to maximize effectiveness.

Bio rational pesticides

Neem is the most widely used botanical insecticide in mango orchards due to its broad-spectrum activity against chewing, sucking, and boring pests. Its active ingredient, azadirachtin, functions as an insect growth regulator and a deterrent to feeding and oviposition. Research indicates that neem oil (2–3%) applied regularly from flowering to fruiting stages effectively suppresses mango hoppers and scale insects. Neem oil also reduces sooty mold risk by limiting honeydew produced by sucking pests. Neem seed kernel extract (NSKE) 5% is a traditional preparation widely used by mango growers. NSKE inhibits insect molting and reduces survival rates, while exhibiting anti-feeding activity on tender shoot tips, inflorescences, and juvenile fruits.

Insecticidal soaps

The ICAR-Indian Institute of Horticultural Research (IIHR), Bengaluru, has developed two eco-friendly insecticidal formulations: neem soap and pongamia soap. These soaps effectively manage sucking pests in mango and other horticultural crops. Neem soap targets mango hoppers, mealy bugs, aphids, thrips, and whiteflies, while pongamia soap is effective against hoppers, thrips, scales, and mealy bugs. Both formulations are

biodegradable, residue-free, and safe for natural enemies. IIHR recommends applying 10 ml per litre of water (1% solution) when pests first appear, with sprays repeated every 10–15 days as needed.

Microbial bio-pesticides

Fungi are among the most important microbial agents against sucking insects and soil-dwelling pests in orchards. For example, *Beauveria bassiana* has been used to control mango mealy bugs, hoppers, and scale insects. Field sprays of *B. bassiana* applied at the early stages of mealy bug infestation reduce the survival of crawlers in mango orchards. Another important fungus, *Metarhizium anisopliae*, is highly effective against many soft-bodied insects. In addition to managing pest populations, these fungi contribute to nutrient recycling by breaking down insect bodies, thereby promoting soil health and supporting sustainable orchard practices that maintain orchard ecology.

Bacillus thuringiensis (Bt), when ingested by lepidopteran larvae, produces Cry toxins that disrupt the gut, causing paralysis and ultimately killing the insect. Bt sprays in mango orchards reduce damage from caterpillar pests feeding on tender young flushes and inflorescences, particularly controlling leaf webber (*Orthaga euadrusalis*) infestations, and also show efficacy against other caterpillars. The relative safety of Bt on beneficial insects, including pollinators and predators, makes it ideal for integration into sustainable pest management programs. Moreover, Bt can be applied repeatedly over a crop cycle without posing a risk of resistance development.

Bioagents – parasite and predators

Bioagents, including parasites and predators, are reliable, ecologically sound, and self-sustaining components of pest management. They help maintain pest populations below economic threshold levels, thereby reducing the need for chemical interventions.

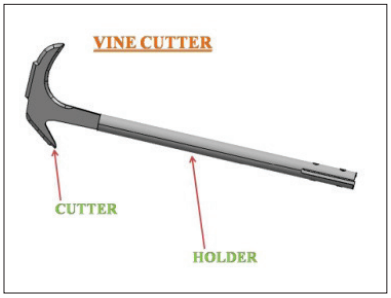
One of the key predators in mango orchards is *Chrysoperla*, commonly known as the "farmer's friend." Its larvae are voracious predators of a variety of soft-bodied insects, including mango hoppers, mealy bugs, and thrips. A single larva can consume 200–300 hopper nymphs or 150–200 mealy bug crawlers during its development, providing significant biological control. *Chrysoperla* is now mass-produced in insectaries and released at rates of 5,000–10,000 eggs per hectare.

Coccinellids, or predatory beetles, are effective biological control agents of mealy bugs and scale insects in mango orchards. Each adult can consume 200–300 mealy bug eggs or crawlers over its lifetime, substantially reducing mealy bug populations. Predatory ants (*Camponotus compressus*) are also crucial in controlling mango mealy bugs. When managed properly, these ants act as natural bio-guards, reducing scale and mealy bug populations and helping prevent pest outbreaks.

Spiders and other generalist predators, such as praying mantids and predatory bugs, further support the control of hoppers and many other pests. To enhance the biological control of Lepidopteran pests in mango, ICAR-CISH has developed the "Self Perpetuating Field Parasite Cage (SPFPC)," which allows indigenous natural enemies to be reared along with their hosts under field conditions.

Mechanical and physical methods – traps and pheromones

Mechanical and physical controls form the first line of defense in bio-rational pest management. These methods are simple, low-cost, and farmer-friendly, physically reducing pest populations without harming natural enemies or leaving residues. They are particularly useful in organic mango orchards and are highly accessible to smallholder farmers.



***CISH-PEST Hammer*:** The vine cutter and bark remover, also known as the CISH-PEST Hammer, is a unique tool designed to assist farmers in managing parasitic growths and infestations in fruit trees. It is commonly used to cut parasitic coils (strangling vines) growing in narrow spaces along branches, allowing them to be safely cut and pulled down even from tall trees without risk of injury. Besides removing vines, the CISH-PEST Hammer can also be used to remove bark infested with trunk borers. Farmers can sit and hold a guide corner of the infested bark, then deliberately strip off the borer-affected bark to expose and kill the larvae, thereby preventing further damage. This method simplifies the removal of parasitic plants and trunk borer pests, provides a sustainable approach to pest management, enhances tree health, and ultimately improves tree productivity.

***Tree banding technology for mealy bug control*:** ICAR-CISH has developed modified tree banding for the control of mango mealy bug which is placed on tree trunk in the month of December. It prevents crawlers emerging from the soil to crawl up to the tops of trees. The banding is done over a slurry of wet soil pasted on the tree trunk and provided with glue. The technology is simple to employ, inexpensive, and may be strongly advocated for mango farmers in North India.

Light traps:

CISH Trap-1: Automated colour-changing solar light insect trap with CFL having a restrictor for regulated crop

area illumination which contains violet and purple-black CFL tubes as a light source, and an electrified insect-killing mesh, to attract, trap, and kill insects. This trap can be used on a wide range of crops including vegetable crops, cereal crops, pulses, greenhouse crops, and fruit crops. The suggested application rate is 1 trap per ha.

CISH Trap-2: Solar-based insect trap with double attraction mechanism to attract and kill the flying insects which consists of a primary light source (blue and violet LED bulbs), then a water tub with an extra bulb underneath the trap assembly to attract the insects. The suggested application rate is 1 trap per acre. This trap fits in many crops: vegetable crops, cereal crops, pulses, crops in greenhouses, fruit crops, etc.

CISH Trap-3: Automatic electrical UV light source trap with restrictor having regulated crop area illumination which consists of a blue and violet LED bulb as the main light source and there is a water tub distanced under the trap assembly that has another bulb for insect attraction. One trap per acre is recommended for use. The trap can be used with numerous crops.

Auto-rotatory sticky light trap (day-night catch): The auto-rotatory (wind based) light sticky trap has a switchable light source composed of three colored light-emitting diodes (LEDs), with three yellow sheets that attract insects during the daylight period. It is recommended that 2–3 traps may be deployed per hectare.

***Pheromone trap*:** The Male Annihilation Technique (MAT) is one of the most effective methods for managing *Bactrocera dorsalis* and related fruit fly species. In mango orchards, male flies are attracted to methyl eugenol (ME)–baited traps containing small amounts of insecticide, where they are killed. This significantly reduces the mating population and subsequent fruit infestation.

The CISH-OMAT, a rain-resistant and durable fruit fly trap, provides an advanced solution that can be used across multiple fruit crops, including mango, guava, sapota, citrus, and papaya. Each trap uses modular attractant blocks, such as methyl eugenol, which are weatherproof and remain effective in the field for 4–6 weeks. It is recommended to install 10 traps per hectare at a height of approximately 1.5 m above ground level, positioned within the flight range of adult flies to ensure maximum capture.

***Food baits*:** Also known as Bait Annihilation Technique (BAT) consist of protein or jaggery + insecticide act as good attractants for managing the reproductive populations of fruit flies. These baits can be applied directly on the orchard foliage using bait spray techniques, or they can be put in rain-proof bait stations. The bait is most useful when it is used in conjunction with MAT as it attracts and kills both males and females.

Use of ICT in bio-rational pest management

The utilization of ICT in bio-rational pest management has enabled mango farmers and researchers to adopt more participatory and precise approaches for improved mango protection. Digital surveillance tools, such as mobile applications, GPS mapping, and remote sensing, are used to monitor and manage several key pests, including hoppers, mealy bugs, and fruit flies. Smart pheromone traps and light traps equipped with built-in sensors record pest catches and share real-time information with farmers and researchers.

Mobile applications and decision-support systems provide location-specific advisories on the use of neem products, entomopathogenic fungi, and pheromone traps. Remote sensing tools, drones, and Internet of Things (IoT)–based sensors that measure temperature, humidity, and soil moisture are increasingly used to anticipate pest outbreaks and enable need-based application of biocontrol agents. E-extension platforms (e.g., WhatsApp and YouTube) and linked farmer portals facilitate the dissemination of knowledge related to fruit bagging, tree banding, and other eco-friendly practices. The integration of artificial intelligence (AI) into pest prediction models, along with weather-based advisories, can further improve pest forecasting, minimize unnecessary pesticide applications, and promote sustainable pest management in mango production.

CONCLUSION

Bio-rational pest management has emerged as a sustainable and environmentally sound approach that balances effective pest control with environmental and human safety. Bio-rational strategies encompass a wide range of pest management techniques, including cultural and mechanical practices, botanicals, microbial bio-pesticides, natural enemies, pheromone traps, and ICT-based pest monitoring systems that are effective, residue-free, and economically viable. These approaches contribute to orchard health maintenance and help mitigate the impact of damaging organisms and other stress factors affecting ecosystem resilience. When bio-rational practices are integrated with smart technologies such as smart traps, drones, IoT sensors, and AI-based decision tools, pest management becomes more precise, timely, and efficient, thereby supporting sustainable mango production.

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