# Smart pest management - integrated and innovative approaches for managing pumpkin beetle infestation in cucurbits

**Ramesh K. B., Gangaraj R., Viveka Nand Singh., Pushpendra Pratap Singh, Jai Prakash Gupta, Harihar Singh**

Cucurbitaceous vegetables are the major source of income for small holding farmers. However, production potential of this vegetable is hindered by many pests like red pumpkin beetle, fruit fly, cucurbit stink bug, cucumber thrips, cutworms etc. Red pumpkin beetle (RPB) has been a significant concern in cucurbit production, damaging from germination up to harvesting. This chapter analyses host preference shown by RPB among different cucurbits along with severity of damage. Moreover, this paper shows heavier application of insecticides to control RPB which has adverse effect on human health and agro-ecosystem. In order to reduce such haphazard application of insecticides, other control techniques need to be formulated and familiarize with farmers. Integrated pest management (IPM) is the best option that provides several measures, alternative to insecticide and facilitates sustainable environment management. Different kinds of eco-friendly techniques practiced by farmers are in need to refine scientifically. In addition, it elicits appropriate integration of such techniques in field research that are applicable to farmer's field.

***Keywords:*** *Cucurbitaceous, red pumpkin beetle, agro-ecosystem, integrated pest management, eco-friendly*

Ramesh K. B*., Gangaraj R., Viveka Nand Singh., Pushpendra Pratap Singh, Jai Prakash Gupta, Harihar Singh
ICAR-Indian Institute Vegetable Research, Regional Research Station, Sargatia, Kushinagar, Uttar Pradesh, India.

*Email: rameshjayaveera@gmail.com

Access: CC BY-NC
Publisher: Cornous Publications LLP., Puducherry, India.
Integrated Crop Pest Management Using Innovative Approaches
Editors: Dr. Srinivasa N, Dr. Ramesh K B, Mr. Varun Arya, Dr. Twinkle
ISBN: 978-81-993853-5-1
DOI: https://doi.org/10.37446/edibook252025/43-52

## Introduction

Cucurbits belongs to the family cucurbitaceae. It is the largest group of the summer season vegetable crop encompassing 130 genera and 800 species (Wang et al., 2022). Cucurbitaceous crops such as pumpkin, cucumber, bottle gourd, bitter gourd, muskmelon and watermelon are widely cultivated in tropical and subtropical regions. These crops are valued for their nutritional importance, economic value and contribution to food security. However, cucurbit cultivation is severely affected by a number of insect pests, among which the pumpkin beetle is one of the most destructive. The pumpkin beetle, primarily belonging to the genus *Aulacophora*, causes extensive damage to cucurbit crops, particularly during the seedling stage, often leading to severe yield losses. Two species are particularly notorious in South Asia: the red pumpkin beetle, *Aulacophora foveicollis* and the blue pumpkin beetle, *Aulacophora cincta* (Figure1). Among these, the red pumpkin beetle is the most widespread and economically damaging species in India and neighbouring countries. Both the species are closely related and share similar life cycles, where field studies in regions like India, Nepal and Bangladesh show they actually have completely different preferences when it comes to their host plants. Red pumpkin beetle (*A. foveicollis*) is the more widespread of the two and it highly prefers muskmelons, cucumbers and sweet gourds. Interestingly, it tends to avoid bitter-tasting plants. Blue pumpkin beetle (*A. cincta*) species steps in exactly where the red beetle leaves off. It heavily targets bitter gourds, ribbed gourds and sponge gourds. Recently, it has also been documented as a new pest of jasmine plants in some areas. Both adult and larval stages contribute to crop damage. Adults feed on foliage, flowers, and tender shoots, while larvae remain in the soil and feed on roots and underground plant parts.


**Figure 1. Two notorious species *viz.*, Red pumpkin beetle, *Aulacophora foveicollis* and the Blue pumpkin beetle, *Aulacophora cincta* in South Asia**

In many cucurbit-growing regions, yield losses caused by pumpkin beetle infestation can reach 35-75%, especially when infestations occur during the early crop growth stage. Conventional management practices have relied heavily on chemical insecticides however, indiscriminate pesticide use has led to problems such as pesticide resistance, environmental contamination, pest resurgence, and adverse effects on beneficial organisms. In recent years, there has been increasing emphasis on integrated pest management (IPM) and innovative sustainable approaches to control pumpkin beetle populations while minimizing ecological damage. Integrated management combines cultural, mechanical, biological, botanical, and chemical methods in a compatible and environmentally safe manner. Advances in microbial control agents, semiochemicals, nanotechnology, and digital agriculture are further contributing to innovative pest management strategies.

## Distribution and Host Range

Pumpkin beetles are widely distributed across Asia, Africa, and parts of Europe, with a particularly high prevalence in South and Southeast Asia. In India, the pest occurs throughout cucurbit-growing regions including the Indo-Gangetic plains, central India, and southern states. The pest primarily attacks members of the family Cucurbitaceae, including: Pumpkin (*Cucurbita moschata*), Cucumber (*Cucumis sativus*), Bitter gourd (*Momordica charantia*), Bottle gourd (*Lagenaria siceraria*), Ridge gourd (*Luffa acutangula*), Snake gourd (*Trichosanthes cucumerina*), Muskmelon (*Cucumis melo*), Watermelon (*Citrullus lanatus*) etc (Figure 2). Among these hosts, pumpkin, cucumber, and bottle gourd are highly susceptible.

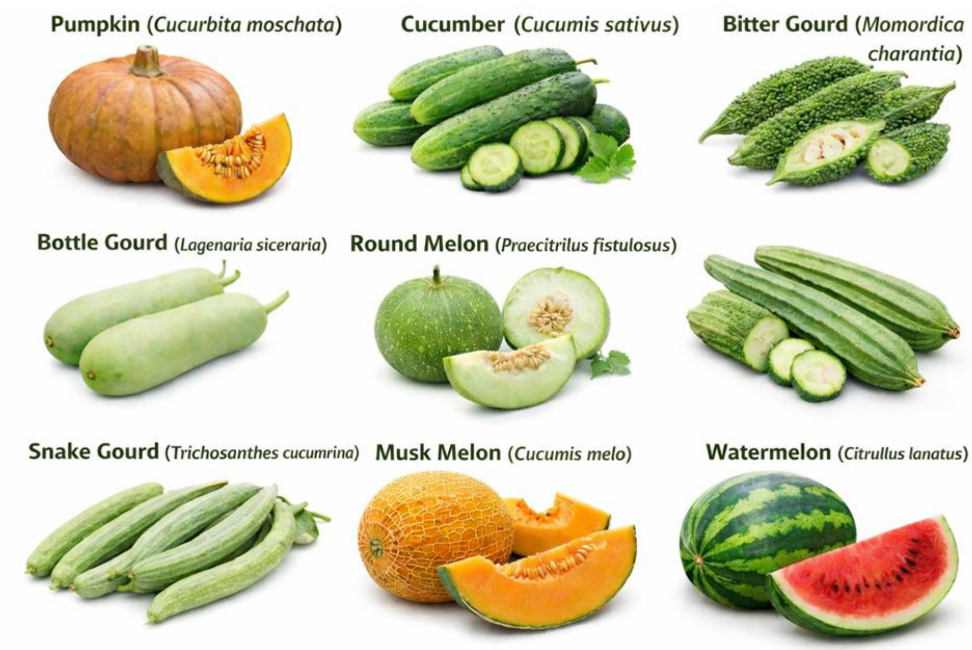


**Figure 2. Major cucurbitaceous host plants of Red Pumpkin Beetle**

**Biology and Life Cycle**

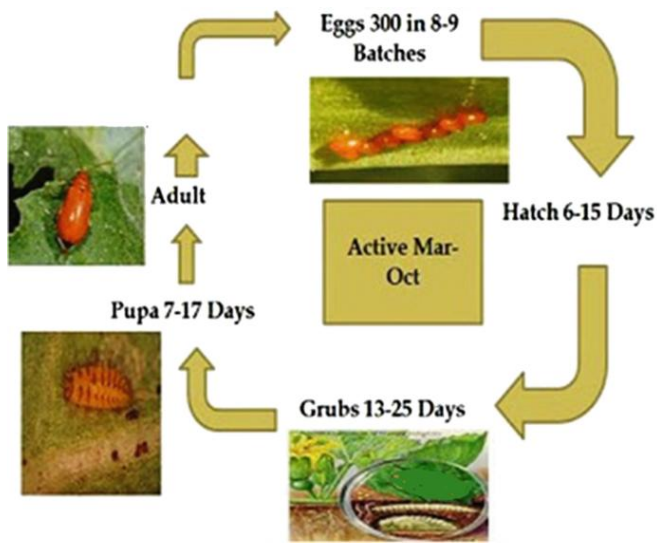


**Figure 3. Biology and Lifecycle of Red Pumpkin Beetle**

Understanding the life cycle of pumpkin beetle is crucial for designing effective pest management strategies. Females lay eggs in moist soil near the base of cucurbit plants at a depth of 2-5 cm. The eggs are oval and yellowish in colour. A single female may lay 150-300 eggs during her lifetime. The incubation period typically ranges from 6 to 15 days, depending on environmental conditions. The larvae are creamy white, slender, and cylindrical with a brown head capsule. They remain in the soil and feed on roots, root hairs, and underground stems of cucurbit plants. The larval stage consists of three to four instars and lasts approximately 13-25 days. Pupation occurs in the soil within an earthen cell. The pupal period lasts about 7-17 days. Adults are elongated beetles with a bright orange-red coloration in the red pumpkin beetle. Adult beetles feed on leaves, flowers, and fruits. Adults are highly active and capable of flying long distances. The adult lifespan ranges from 40 to 60 days (Figure 3). Under favourable conditions, the pest may complete 5-8 generations per year (Mondal et al., 2020).

**Nature of Damage**

Both larval and adult stages cause significant damage to cucurbit crops. Adults feed on leaves, flowers, tender stems and fruits (Figure 4). They scrape the green tissues of leaves, leaving behind a skeletonized appearance. Severe feeding results in defoliation and stunted plant growth. Young seedlings are particularly vulnerable and may be completely destroyed. Larvae feed on roots, root hairs, underground stems. This feeding disrupts water and nutrient uptake, leading to wilting, yellowing, and plant death.


**Figure 4. Nature of Damage and damage symptoms caused by Red Pumpkin Beetle**

**Economic Impact**

Heavy infestations during the seedling stage may lead to complete crop failure, making pumpkin beetle one of the most important pests of cucurbit crops.

**Conventional Management Practices**

Traditionally, pumpkin beetle management has relied on the use of chemical insecticides such as Carbaryl, Malathion, Chlorpyrifos, Imidacloprid etc. Although these chemicals can provide quick control, their overuse has resulted in several problems such as development of insecticide resistance, destruction of natural enemies, environmental pollution, residues in food products and health hazards for farmers and consumers. Therefore, modern pest management strategies emphasize integrated approaches that reduce dependence on chemical pesticides.

**Integrated Pest Management (IPM) Strategies**

Integrated Pest Management (IPM) is a sustainable approach that combines multiple compatible techniques to maintain pest populations below economic threshold levels.

- **Cultural Practices**

Cultural control methods are preventive measures that reduce pest establishment and reproduction. Early sowing of cucurbit crops helps avoid peak beetle activity. Rotating cucurbit crops with non-host crops reduces pest carryover in soil and deep ploughing exposes larvae and pupae to sunlight and predators. Removal of alternate hosts by eliminating wild cucurbit plants near cultivated fields reduces pest reservoirs. Planting highly attractive cucurbit species as trap crops can divert beetles away from the main crop.

- **Mechanical and Physical Control**

Adult beetles can be collected manually during early morning hours when they are less active. Fine mesh nets can protect young seedlings from beetle attack. Coloured sticky traps may help monitor beetle populations. Studies have demonstrated that polyethylene cages effectively protect cucumber seedlings from infestation by the red pumpkin beetle for up to one month after germination. Three cage heights *viz*., 30 cm, 45 cm, and 60 cm were evaluated as physical control measures. Among these, a 30 cm high polyethylene cage with a perimeter of 120 cm proved to be the most effective and economical method for managing this pest during the early growth stage of cucumber seedlings (Chaudhary, 1995). The response of pumpkin beetles to kairomones and parakairomones was investigated by Lewis and Metcalf in 1996. Their study indicated that sticky traps baited with single or multicomponent lures did not capture significantly more beetles than the unbaited control traps for two species of pumpkin beetles. However, visual and floral cues were found to influence beetle attraction, as yellow-colored traps and squash blossoms showed greater attractiveness to pumpkin beetles such as the Red pumpkin beetle.

- **Botanical Control**

Plant-based pesticides provide environmentally friendly alternatives to synthetic chemicals. Common botanicals include Neem oil, Neem seed kernel extract (NSKE), Azadirachtin, Neem leaf extract, Ardusi leaf extract, Garlic bulb extract, Ginger rhizome extract, Dashparni, Teekha sat (TS) formulations. Neem-based products act as feeding deterrents, growth regulators, repellents. Other plant extracts such as garlic, chilli, and tobacco extracts have also shown insecticidal properties against pumpkin beetles. According to recent literature, Among the botanicals evaluated, neem-based products demonstrated significant efficacy against the Red pumpkin beetle. Treatments with azadirachtin seed kernel extract (5%) and neem leaf extract (10%) effectively suppressed beetle populations while causing minimal adverse effects on pollinators. In field evaluations on cucumber, the lowest beetle population was recorded in plots treated with azadirachtin at 0.0006%, which was statistically at par with treatments of neem seed kernel extract (NSKE) 5% and neem oil at 0.5%.

- **Biological Control**

Biological control involves the use of natural enemies and microbial agents. Several natural predators feed on pumpkin beetles, including ground beetles, spiders and ants. Although parasitoids are less commonly reported for pumpkin beetles, some parasitic wasps may attack beetle eggs or larvae. Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* have shown promising results in controlling adult beetles. These fungi infect and kill the insects while posing minimal risk to humans and beneficial organisms. Several predators and parasitoids play an important role in the natural regulation of the Red pumpkin beetle, particularly when incorporated into an IPM strategy.

Parasitoids attack the larval, pupal, or adult stages of the beetle, often leading to host mortality during development. Among them, braconid parasitoids such as *Opius fletcheri*, *Opius compensatus*, and *Opius insisus* are known to parasitize the larval and pupal stages. Tachinid flies belonging to the family Tachinidae also parasitize adult beetles. In addition, species such as *Apanteles plusia* and *Apanteles taragamae* have been reported to exhibit parasitic activity against this pest. Predators also contribute significantly to the suppression of beetle populations by feeding on eggs, larvae, and sometimes adults. Predatory reduviid bugs such as *Rhynocoris fuscipes* are known to attack adult beetles.

Additionally, coccinellid beetles (ladybird beetles) prey on eggs and early larval stages, while ground beetles (Carabidae) and various spider species act as generalist predators inhabiting the soil and crop canopy, feeding primarily on larvae and other vulnerable stages. The conservation and augmentation of these natural enemies can significantly enhance the biological regulation of red pumpkin beetle populations in cucurbit ecosystems.

- **Chemical Control in IPM**

Chemical insecticides should be used judiciously and only when pest populations exceed economic threshold levels. Recommended insecticides include Imidacloprid, Thiamethoxam, Spinosad etc. Seed treatment with systemic insecticides can protect seedlings during early growth stages. However, pesticide applications should be rotated to prevent resistance development.

### Innovative Approaches for Pumpkin Beetle Management

#### a) Semiochemical-Based Pumpkin beetle management

Semiochemicals are chemical signals used by insects for communication. These include Pheromones and Kairomones. Pheromone traps can be used for monitoring, mass trapping and mating disruption. Although pheromone-based systems for pumpkin beetles are still under development, research is progressing toward identifying species-specific attractants (Shapiro & Mauck, 2018). The olfactory responses of antennal chemosensilla in male and female *A. foveicollis* to plant volatiles were examined using electroantennography (EAG).

Behavioural responses were further assessed through olfactometer bioassays under laboratory conditions. The studies indicated a stronger preference for certain compounds from the plant extract, including saturated straight-chain hydrocarbons/n-alkanes (C14, C17, C19, C20, C21, and C25), the aromatic compound 1,4-dimethoxybenzene, and the green leaf volatile (GLV) decanal. These compounds function as semiochemicals involved in host location (Bhowmik et al., 2022).

**Table 1. Literature research towards identifying volatile organic compounds**

| Chemical class | Compounds | Role |
|---|---|---|
| Aromatic compounds | 1,4-Dimethoxybenzene, phenols, benzaldehyde | Strong attractants |
| Terpenoids | D-limonene, α-pinene, phytol, geraniol | Host plant recognition |
| Green leaf volatiles | Nonanal, decanal | Damage-induced cues |
| Hydrocarbons | Heneicosane, pentacosane, tetradecane | Short-range feeding cues |
| HIPVs | Hydrocarbons & aldehydes | Aggregation on damaged plants |

### b) Microbial Bio-pesticides for Pumpkin beetle management

Microbial insecticides offer environmentally friendly pest control options. Examples include, *Bacillus thuringiensis*, *Beauveria bassiana* and *Metarhizium anisopliae*. These pathogens infect insects and cause mortality through toxin production or infection. Among these, *Beauveria bassiana* has demonstrated high efficacy when applied at concentrations of 3.0 g $L^{-1}$ (1.15% WP) or 1.0 ml $L^{-1}$ (1.5% liquid formulation), resulting in substantial suppression of beetle populations. Field studies have reported up to 70% reduction in crop damage, along with significant decreases in adult beetle populations, often performing better than or comparable to other biopesticides.

Another effective entomopathogenic fungus, *Metarhizium anisopliae*, typically available in 1.0-1.5% WP or liquid formulations, has also shown high mortality against both adult beetles and soil-dwelling grubs. Similarly, *Verticillium lecanii* applied at approximately 5 g $L^{-1}$ has demonstrated significant effectiveness in reducing red pumpkin beetle populations under field conditions. These microbial biocontrol agents provide environmentally safe alternatives to chemical insecticides and can be effectively integrated into sustainable pest management strategies for cucurbit crops.

### c) Nanotechnology for Pumpkin beetle management

Recent advances in nanotechnology have led to the development of nano-formulated pesticides and botanicals that exhibit enhanced efficacy against the Red pumpkin beetle. Neem-based nano-emulsions containing azadirachtin (e.g., nano-neem formulations) have been reported to provide significantly higher insecticidal activity compared to conventional neem oil formulations due to improved stability, penetration and controlled release properties. Similarly, Nano emulsions derived from the essential oil of *Acorus calamus*, with particle sizes around 10.93 nm, have demonstrated high effectiveness as nano-botanical agents for suppressing beetle populations in cucurbit crops. In addition to botanical nanoformulations, several nano-insecticide systems have also shown promising results.

Solid nanodispersions of Emamectin benzoate (approximately 69.69 nm) have been reported to significantly reduce larval and adult damage under both laboratory and field conditions. Green-synthesized Silver nanoparticles (around 33.38 nm), produced using plant extracts such as neem, have also exhibited strong larvicidal and adulticidal activity against the beetle. Furthermore, nanoemulsions of Malathion (approximately 69.25 nm) have demonstrated faster action and higher mortality rates compared with conventional malathion formulations. Another promising nanomaterial is Zinc oxide nanoparticles synthesized using plant sources such as *Pongamia pinnata*. Although these nanoparticles have primarily been evaluated against stored grain beetles, they have shown potential in reducing larval development, fecundity, and egg hatchability, indicating their possible application in broader pest management strategies.

**d) Molecular approaches for Pumpkin beetle management**

RNA interference is a gene-silencing technology that can target specific pest genes responsible for survival or reproduction. RNAi-based pest management has the potential to provide highly specific control, reduced environmental impact and minimal harm to beneficial organisms. Research on RNAi-based management of coleopteran pests is rapidly advancing (Jin et al., 2025; Sparks et al., 2020; Das et al., 2020; Dhillon & Sharma, 1987).

**Table 2. Molecular Approaches and Target Genes for Management of Red Pumpkin Beetle**

| Molecular Approach | Target Gene/Protein | Functional Role in Insect | Mode of Action in Pest Management | Expected Outcome |
|---|---|---|---|---|
| RNA interference (RNAi) | Chitin synthase (CHS) | Involved in chitin biosynthesis and cuticle formation | Silencing of CHS disrupts exoskeleton formation and molting | Larval mortality and developmental defects |
| RNA interference (RNAi) | V-ATPase subunits | Regulates ion transport and cellular homeostasis in midgut cells | Gene knockdown disrupts gut physiology and energy metabolism | Reduced survival and feeding |
| RNA interference (RNAi) | Acetylcholinesterase (AChE) | Essential enzyme for nerve impulse transmission | Silencing leads to accumulation of acetylcholine causing neural dysfunction | Paralysis and death |
| RNA interference (RNAi) | Juvenile hormone esterase (JHE) | Regulates insect growth and metamorphosis | Suppression disrupts hormonal balance and development | Abnormal molting and reduced reproduction |
| RNA interference (RNAi) | Odorant binding proteins (OBPs) | Involved in host plant recognition and olfaction | Gene silencing interferes with host location and feeding behavior | Reduced host attraction and feeding |
| CRISPR/Cas gene editing (future potential) | Doublesex (Dsx) gene | Controls sex differentiation | Gene disruption can alter reproductive development | Population suppression |
| CRISPR/Cas gene editing (future potential) | Vitellogenin (Vg) gene | Egg yolk protein precursor essential for reproduction | Gene knockout reduces egg production | Reduced fecundity |
| Transgenic plant-mediated RNAi | Digestive protease genes | Involved in protein digestion in insect gut | Expression of dsRNA in host plants targeting digestive enzymes | Reduced growth and survival |
| Symbiont-mediated RNAi (SMR) | Essential metabolic genes | Critical metabolic pathways | Engineered symbiotic microbes deliver dsRNA to insects | Long-term gene silencing and population control |

**Integration of Multiple Strategies**

Effective pumpkin beetle management requires combining different approaches in a well-coordinated IPM program. A typical integrated strategy may include:

1. Deep summer ploughing
2. Early sowing of cucurbit crops
3. Installation of monitoring traps
4. Application of neem-based botanicals
5. Use of microbial biopesticides
6. Conservation of natural enemies
7. Limited use of selective insecticides when necessary.

**Future Research Directions**

Despite significant progress in pumpkin beetle management, several challenges remain. Future research priorities include identification of effective pheromones for mass trapping, development of resistant cucurbit varieties, exploration of insect gut microbiomes for pest control, application of metagenomics for understanding pest-microbe interactions, development of RNAi-based pest management technologies, Integration of artificial intelligence for real-time pest monitoring. Advances in biotechnology, microbiology, and digital agriculture are expected to play a major role in developing next-generation pest management strategies.

**Conclusion**

Pumpkin beetle remains one of the most destructive pests of cucurbit crops worldwide, causing severe economic losses, particularly during the seedling stage. Conventional reliance on chemical insecticides has created ecological and resistance-related challenges. Therefore, sustainable management requires an integrated approach that combines cultural, mechanical, biological, botanical, and chemical control methods. Recent innovations such as microbial biopesticides, semiochemical-based strategies, nanotechnology, RNA interference, and digital agriculture are opening new avenues for environmentally safe pest control. Integrating these technologies within a comprehensive IPM framework can significantly reduce pumpkin beetle populations while minimizing environmental impact. The adoption of integrated and innovative pest management strategies will be crucial for ensuring sustainable cucurbit production, improving farmer livelihoods, and safeguarding agroecosystem health in the future.

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