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Insect Pests of Cabbage (*Brassica oleracea* var. *capitata*) and Their Natural Enemies: A Review

Rajashekarappa K [a++], Vinayak Madarakhandi [b#], Kaveri Aramani [c], Kishore S.M [d#*], Ulfat Jan [e#], Shashikala B [f#] and Manikanta M. R [d†]

[a] ZAHRS, Department of Entomology, College of Agriculture, Navile, KSNUAHS, Shivamogga-577204, India.
[b] Department of Entomology, College of Agriculture, UAS, Dharwad-580005, Karnataka, India.
[c] Department of Sericulture, College of Agriculture, UAS, Bangalore, Karnataka-560065, India.
[d] Department of Entomology, College of Agriculture, Navile, KSNUAHS, Shivamogga-577204, India.
[e] Department of Entomology, Shere Kashmir University of Agricultural Sciences and Technology, Kashmir, India.
[f] Division of Entomology, ICAR-IARI, New Delhi, 110012, India.

Authors' contributions

This work was carried out in collaboration among all authors. Authors RK, VM and KA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors KSM, UJ and SB managed the analyses of the study. Author MMR managed the literature searches. All authors read and approved the final manuscript.

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[++] *Associate Professor;*
[#] *Ph.D Scholar;*
[†] *MS.c Scholar;*
**Corresponding author: Email: kishoresm@uahs.edu.in;*

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ABSTRACT

Cabbage (*Brassica oleracea* var. *capitata*) is one of the most important cruciferous vegetables globally, valued for its nutritional richness and economic significance. However, production suffers heavy losses due to a diverse complex of insect pests, notably diamondback moth (*Plutella xylostella*), cabbage aphid (*Brevicoryne brassicae*), tobacco caterpillar (*Spodoptera litura*) and cabbage butterfly (*Pieris brassicae*), which can cause yield reductions of 30-80%. Natural enemies-including predators, parasitoids and entomopathogens-play a central role in regulating these pests and form the backbone of sustainable integrated pest management (IPM). Despite their potential, several challenges limit their effectiveness, including pesticide disruption, poor synchronization with pest populations and habitat simplification. Climate change adds further complexity by altering pest and natural-enemy interactions, often leading to phenological mismatches. Recent advances in molecular diagnostics, RNA interference (RNAi) and microbial biocontrol formulations offer promising alternatives for strengthening eco-friendly pest suppression. Yet, successful adoption requires greater farmer awareness, reliable extension support and enabling policy measures such as biopesticide regulation and IPM incentives. This review synthesizes current knowledge on cabbage pests and their natural enemies, highlighting ecological interactions, limitations, advances and future perspectives to guide sustainable pest management strategies.

Keywords: Cabbage; natural enemies; biological control; integrated pest management; climate change*; microbial formulations.*

1. INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata*) is most widely grown cruciferous vegetables worldwide, cultivated across temperate and tropical regions. They are integral components of the human diet, used in fresh, cooked, fermented and processed forms. Globally, countries like China, India, Japan, Germany and South Korea are leading producers (Faruq *et al*., 2022; Khan & Talukder, 2017). In India, cabbage and cauliflower together account for a significant share of the *rabi* vegetable area, with states such as West Bengal, Bihar, Odisha, Maharashtra and Karnataka being major producers (Pallavi *et al*., 2023; Bana *et al*., 2012). Their adaptability to varied climatic conditions and relatively short duration make them important for both commercial and subsistence farming (Samec *et al*., 2017).

Cabbage was valued not only for their culinary versatility but also for their rich nutritional profile. They are excellent sources of dietary fiber, vitamins (notably vitamin C, A and K), minerals (calcium, potassium, phosphorus) and bioactive compounds such as glucosinolates and carotenoids (Pallavi *et al*., 2023; Stefan & Ona, 2020). These compounds are known to contribute to antioxidant activity, cancer risk reduction and cardiovascular health. Economically, they are high-value cash crops, generating income for smallholder farmers as well as commercial growers. India alone contributes nearly 10% of global cabbage production, with a productivity of around 20 t/ha in some states (Faruq *et al*., 2022; Khan & Talukder, 2017). Export potential also enhances their importance, especially in processed and fresh forms for regional markets.

Despite their significance, cabbage and cauliflower face substantial yield losses due to insect pests. Among the most destructive are the diamondback moth (*Plutella xylostella*), tobacco caterpillar (*Spodoptera litura*), cabbage butterfly (*Pieris brassicae*), semilooper (*Trichoplusia ni*), cabbage aphid (*Brevicoryne brassicae*), mustard aphid (*Lipaphis erysimi*), leaf webber (*Crocidolomia binotalis*) and painted bug (*Bagrada hilaris*) (Raja *et al*., 2014; Venkateswarlu *et al*., 2011). Infestations can reduce marketable yield by 30-80%, with diamondback moth alone causing up to 90% yield loss in severe outbreaks (Sultana *et al*., 2019; Bana *et al*., 2012). Insect pests attack at all growth stages-nursery, vegetative and head/curd formation-leading to deformed heads, reduced market quality and increased susceptibility to secondary infections (Faruq *et al*., 2022; Kishore *et al*., 2024a; Kishore *et al*., 2024b). Additionally, reliance on indiscriminate pesticide use has led to issues of resistance (especially in *P. xylostella* and *S. litura*), resurgence and negative environmental impacts (Sultana *et al*., 2019; Faruq *et al*., 2022). So, integrated pest management (IPM) is the alternative sustainable approach for controlling insect pests. This IPM is a holistic, eco-friendly approach that combines biological, cultural, mechanical, and chemical methods to manage pests in a sustainable way.

2. MAJOR INSECT PESTS OF CABBAGE

2.1 Diamondback Moth (*Plutella xylostella* L.)

- **Distribution:** Cosmopolitan pest, occurring in tropical and temperate regions wherever crucifers are cultivated (Bana *et al*., 2012; Kumar *et al*., 2024).
- **Biology:** Adults are small, greyish-brown moths. Females lay 150-300 eggs, and larvae are slender, green and highly mobile. The life cycle completes in 18-25 days, enabling multiple generations per season (Kumar *et al*., 2021).
- **Nature of damage:** Larvae feed on undersides of leaves, producing small “window panes.” Severe infestation skeletonizes leaves and reduces photosynthetic activity (Jat *et al*., 2017).
- **Seasonal incidence:** Infestation usually begins from January and persists till harvest in northern India. Peaks occur in February-March in Rajasthan and Bihar (Lal *et al*., 2020; Bana *et al*., 2012). Higher temperature and sunshine favour its abundance, whereas humidity reduces incidence (Choudhary *et al*., 2024).
- **Economic impact:** Considered the most destructive pest of cabbage, causing yield losses up to 52% in India (Mpumi *et al*., 2020).

2.2 Cabbage Aphid *(***Brevicoryne brassicae** *L.)*

Aphids play a main role in transmitting viral diseases to cabbage and other crucifers. These aphids are the primary vectors for several important viruses such as Turnip Mosaic Virus (TuMV), Cauliflower Mosaic Virus (CaMV) and Beet Western Yellow Virus (BWYV).

- **Distribution:** Widespread in Asia, Europe and Africa; major pest in temperate cabbage-growing regions (Kumar *et al*., 2021).
- **Biology:** Reproduces parthenogenetically, forming dense colonies. Each aphid lives 20-25 days under favourable conditions (Ramireddy & Dwivedi, 2021; Gill *et al*., 2013).
- **Nature of damage:** Sap sucking causes curling, yellowing, stunting and honeydew deposition that leads to sooty mould (Sarma *et al*., 2021).
- **Seasonal incidence:** Infestation begins in November-December and peaks in January-February in northern India (Bana *et al*., 2012; Sarukh *et al*., 2023). Populations are favoured by low temperature and high humidity.
- **Economic impact:** Yield losses may reach 50-80% in severe infestations (Ramireddy & Dwivedi, 2021).

2.3 Cabbage Butterfly (*Pieris brassicae* L.)

- **Distribution:** Found across Asia, Africa and Europe, particularly in temperate climates (Pungyambam *et al*., 2023).
- **Biology:** Females lay clusters of yellow eggs on leaf undersides. Gregarious larvae are green with black markings and feed heavily in early stages (Ramireddy & Dwivedi, 2021; Kumar *et al*., 2018).
- **Nature of damage:** Larvae defoliate plants, leaving veins intact, reducing head formation (Pungyambam *et al*., 2023).
- **Seasonal incidence:** Appears from December, peaking in February-March. Population increases with temperature but decreases with humidity (Ramireddy & Dwivedi, 2021).
- **Economic impact:** Can cause 30-40% yield loss through heavy defoliation (Patra *et al*., 2013).

2.4 Cabbage Looper (*Trichoplusia ni* Hubner)

- **Distribution:** Common in subtropical and temperate zones of India, North America, and East Asia (Jat *et al*., 2017; Franklin *et al*, 2011).
- **Biology:** Eggs are laid singly; larvae move in a looping fashion. Each female lays 300-600 eggs and the cycle completes in 3-4 weeks (Sarma *et al*., 2021).
- **Nature of damage:** Feeds on leaf margins and inner leaves, leaving irregular holes. Severe attack delays head formation. The eggs and adult stage is harmless, but the larval stage (caterpillars) is harmful. The caterpillars feeds on cabbage leaves, it chews the cabbage leaves and causes larger holes and sometimes skeletonizing the foliage. Heavy infestations may reduce yield and quality.

- **Seasonal incidence:** Most active in December-February in cabbage fields (Mamay *et al*., 2023).
- **Economic impact:** Sporadic but severe infestations may reduce yield by 20-30% (Mpumi *et al*., 2020).

2.5 Cutworms (*Agrotis* spp.)

- **Distribution:** Distributed across India and globally, infesting nurseries and transplanted crops (Lal *et al*., 2020).
- **Biology:** Eggs are laid on weeds or debris. Larvae are nocturnal, feeding at night and hiding in soil during the day. Pupation occurs in soil (Sarma *et al*., 2021).
- **Nature of damage:** Young larvae cut seedlings at ground level; older larvae attack foliage (Hasan *et al*., 2021).
- **Seasonal incidence:** Highest damage reported in November-December in nurseries (Lal *et al*., 2020).
- **Economic impact:** Stand loss in nurseries and young crops reduces yield by 15-25% (Mpumi *et al*., 2020).

2.6 Flea Beetles (*Phyllotreta* spp.)

- **Distribution:** Common in crucifer crops across tropical and subtropical regions (Lal *et al*., 2020).
- **Biology:** Small, black beetles with enlarged hind legs. Eggs are laid near roots; larvae feed on roots and adults on foliage (Patel *et al*., 2017).
- **Nature of damage:** Adults create numerous "shot holes" on leaves, reducing photosynthetic activity (Jat *et al*., 2017).
- **Seasonal incidence:** Appear in January, peaking February-March (Lal *et al*., 2020).
- **Economic impact:** Severe infestation can wipe out seedlings, causing 20-30% crop loss (Mpumi *et al*., 2020).

2.7 Leaf Miners (*Liriomyza* spp.)

- **Distribution:** Found worldwide, severe in warmer zones. In India, *Liriomyza brassicae* is the common crucifer pest (Kumar *et al*., 2021).
- **Biology:** Adults are small flies; larvae mine inside leaves, pupating in soil (Sarma *et al*., 2021).
- **Nature of damage:** Mines reduce photosynthetic area, because premature leaf drops and favour pathogen entry (Monica *et al*., 2021).
- **Seasonal incidence:** Peak infestations occur in December-February in eastern India (Kumar *et al*., 2021).
- **Economic impact:** Generally minor, but heavy outbreaks may reduce yield by 10-15%.

2.8 Other Minor Pests (thrips, mites, etc.)

- **Thrips (*Thrips tabaci*):** Cause silvering, curling and vector viral diseases (Sarma *et al*., 2021).
- **Mites (*Tetranychus urticae*):** Infest during dry periods, leading to bronzing and leaf drop (Karuna *et al*., 2023).
- **Economic impact:** Usually minor, but can cause 5-10% localized losses under favourable conditions (Jat *et al*., 2017).

3. NATURAL ENEMIES OF CABBAGE PESTS

Cabbage production suffers heavy losses from insect pests such as diamondback moth (*Plutella xylostella*), cabbage webworm (*Hellula undalis*), leaf webber (*Crocidolomia binotalis*), aphids (*Brevicoryne brassicae*, *Lipaphis erysimi*) and cutworm (*Spodoptera litura*). Natural enemies play a crucial role in regulating these pests in the cabbage ecosystem (Aiswarya *et al*., 2018).

3.1 Predators

Predatory insects provide an essential check on pest outbreaks. Ladybird beetles (*Coccinella septempunctata*, *Chilomenes sexmaculata*, *Coccinella transversalis*) are important aphid predators, significantly reducing populations of *B. brassicae* and *L. erysimi* (Ravi *et al*., 2014; Sarma *et al*., 2021). Syrphid flies such as *Ischiodon scutellaris* and lacewings (*Chrysoperla carnea*) also exert strong predatory pressure on aphid colonies. Other generalist predators including spiders and predatory bugs (*Orius* spp.) supplement control by feeding on caterpillars and soft-bodied insects (Ballal & Verghese, 2015). Field observations revealed that the population peaks of ladybird beetles coincided with aphid outbreaks, indicating their effectiveness as biological control agents (Kumar *et al*., 2024). The other predators that feed on cabbage other than aphids are ground beetles, rove beetles, predatory stink bugs, spiders, wasps, and birds (Ahmed & Kumari, 2024).

3.2 Parasitoids

Parasitoids play a specialized role in suppressing cabbage lepidopteran pests. The braconid *Cotesia plutellae* and ichneumonid *Diadegma semiclausum* are among the most effective parasitoids of *P. xylostella* (Labou *et al*., 2017). In West Africa, *Oomyzus sokolowskii* has also been identified as an important parasitoid of *P. xylostella* (Labou *et al*., 2016). Egg parasitoids like *Trichogramma* spp. parasitize eggs of *S. litura* and *H. undalis*, reducing larval establishment. In Kerala, a braconid parasitoid (*Protapanteles* sp.) was reported from larvae of *Plusia signata* (Ravi *et al*., 2014). The parasitoids of aphids are tiny wasps in the family Braconidae (subfamily Aphidiinae). Key examples are *Aphidius colemani*, *Aphidius ervi*, *Diaeretiella rapae* and *Lysiphlebus testaceipes* (Parween et al., 2023).

3.3 Entomopathogens

Entomopathogens provide microbial regulation of key cabbage pests. The bacterium *Bacillus thuringiensis* (Bt) is widely effective against *P. xylostella*, *C. binotalis*, and semiloopers (Kumar *et al*., 2024; Irsad *et al*., 2023). Fungal pathogens such as *Beauveria bassiana* and *Metarhizium anisopliae* cause natural epizootics in *P. xylostella* and *S. litura* populations, especially under humid field conditions (Kumar *et al*., 2024). Viruses, particularly nucleopolyhedroviruses (NPVs), have been used against *S. litura*, while entomopathogenic nematodes attack soil-dwelling cutworms and armyworms (Rana *et al*., 2021).

4. INTERACTION BETWEEN PESTS AND NATURAL ENEMIES

4.1 Trophic Interactions and Ecological Dynamics

Cabbage ecosystems support complex trophic interactions between insect pests and their natural enemies. Major phytophagous pests include *Plutella xylostella* (diamondback moth), *Spodoptera litura* (tobacco caterpillar), *Hellula undalis* (cabbage head borer), *Crocidolomia binotalis* (cabbage leaf webber), and aphids such as *Brevicoryne brassicae* and *Lipaphis erysimi* (Labou *et al*., 2017; Kumar *et al*., 2024). These herbivores are suppressed by a variety of parasitoids and predators. Key parasitoids include *Diadegma semiclausum* and *Oomyzus sokolowskii*, which specifically attack *P. xylostella*, while *Protapanteles* sp. parasitizes semilooper larvae (Prabaningrum & Moekasan, 2020; Ravi *et al*., 2014).

Predatory guilds are equally important, with coccinellid beetles (*Coccinella septempunctata*, *Chilomenes sexmaculata*), syrphid flies (*Ischiodon scutellaris*), and lacewings feeding on aphid colonies (Sahu *et al*., 2019; Ravi *et al*., 2014). Seasonal field observations demonstrate that natural enemy populations often increase following pest outbreaks, indicating a density-dependent regulation. For example, cabbage aphid (*B. brassicae*) infestations were followed by surges in coccinellid beetles and syrphids, leading to significant reductions in aphid densities (Yadav & Pervez, 2025). Similarly, parasitoid-mediated mortality of *P. xylostella* can suppress larval populations below economic thresholds when their abundance is conserved (Labou *et al*., 2017).

4.2 Role of Biodiversity in Pest Suppression

Biodiversity plays a crucial role in maintaining ecological balance in cabbage fields. Prabaningrum & Moekasan (2020) reported that the cabbage ecosystem harboured insect communities from Lepidoptera, Homoptera, Hymenoptera and Coleoptera, with parasitoids and predators constituting 2.5% of total insect abundance. Although seemingly low in proportion, their regulatory impact was significant in reducing pest outbreaks.

In diversified systems, such as natural or ecological farming practices, the abundance and activity of beneficial insects are higher compared to conventional monocultures. These systems sustain moderate to high species diversity, which enhances ecological resilience. For instance, mixed cropping and reduced pesticide reliance allow complementary action of multiple enemies, ensuring that no single pest species dominates. The conservation of biodiversity thus acts as a natural buffer, minimizing crop damage and reducing chemical dependency (Schleich *et al*., 2019).

4.3 Factors Influencing Effectiveness of Natural Enemies

The effectiveness of natural enemies in suppressing pest populations is strongly influenced by ecological, agronomic and anthropogenic factors.

Climate: Temperature and humidity are key regulators of pest-enemy dynamics. Studies in West Bengal showed that *P. xylostella* peaked during cooler months, coinciding with reduced parasitoid efficiency, while higher humidity favoured aphid multiplication. Similarly, in Karnataka, aphid abundance was negatively correlated with minimum temperature and evening relative humidity, affecting the timing of predator build-up (Isaq *et al*., 2023; Ris *et al*., 2022).

Cropping system: Continuous availability of crucifers promotes year-round survival of both pests and their natural enemies (Kumar *et al*., 2024). However, monocropping often supports faster pest multiplication compared to polycropping or intercropping systems. Crop phenology also influences pest succession, with leaf feeders dominating in vegetative stages and head borers and aphids becoming prominent in reproductive stages (Sahu *et al*., 2019).

Pesticide use: Indiscriminate use of broad-spectrum insecticides has been repeatedly shown to reduce the abundance of natural enemies, disrupting biological control. Labou *et al*. (2017) observed that higher insecticide sprays increased *P. xylostella* incidence due to destruction of parasitoids like *O. sokolowskii*. Similarly, Prabaningrum & Moekasan (2020) reported that threshold-based pest management reduced insecticide applications by 33-82%, thereby conserving beneficial insects and stabilizing the ecosystem. Long-term pesticide use also promotes resistance in pest populations, undermining chemical control while natural enemies remain highly vulnerable (Washim *et al*., 2024).

5. INTEGRATED PEST MANAGEMENT (IPM) IN CABBAGE

5.1 Role of Natural Enemies in IPM

Natural enemies play a central role in regulating insect pest populations in cabbage. Key parasitoids such as *Cotesia plutellae* and *Diadegma semiclausum* have been reported to effectively parasitize *Plutella xylostella* (diamondback moth), significantly reducing larval populations (Prabaningrum and Moekasan, 2020). Predators including ladybird beetles (*Coccinella septempunctata*), syrphid flies (*Toxomerus geminatus*), and spiders have been observed to suppress populations of aphids such as *Brevicoryne brassicae* and *Lipaphis erysimi* (Kumar *et al*., 2021). Seasonal field studies further confirm that natural enemies track pest outbreaks and help in maintaining populations below economic threshold levels (Bana *et al*., 2012; Venkateswarlu *et al*., 2011; Ibrahim *et al*., 2020).

5.2 Cultural Practices

Cultural techniques form the foundation of IPM in cabbage. Crop rotation with non-cruciferous crops has been shown to reduce carry-over of key pests such as diamondback moth and aphids (Patra *et al*., 2013). Trap cropping with mustard is highly effective in diverting pests like flea beetles and DBM away from cabbage fields. Use of resistant or tolerant varieties such as Golden Acre and Barkha F1 has been reported to reduce aphid colonization (Ramireddy & Dwivedi, 2021; Lal *et al*., 2020). Moreover, adjustment of sowing dates has proven useful; early planting reduced cabbage aphid incidence compared to late sowing in North-Eastern India (Patra *et al*., 2012).

5.3 Biological Control Strategies

Biological control is the most widely adopted eco-friendly approach in cabbage IPM. Release of parasitoids such as *Cotesia plutellae* and *Diadegma semiclausum* has consistently lowered DBM populations (Prabaningrum & Moekasan, 2020). Microbial biocontrol agents including *Bacillus thuringiensis* (Bt), *Beauveria bassiana*, and *Metarhizium anisopliae* have shown promising results against lepidopteran pests without adverse impacts on natural enemies (Kumar *et al*., 2024). Additionally, predators like syrphid flies and coccinellid beetles enhance aphid suppression when combined with parasitoid releases (Ramireddy & Dwivedi, 2021).

5.4 Compatibility of Biocontrol with Chemical Methods

For successful IPM, chemical control must be compatible with biological agents. Studies have shown that selective insecticides such as emamectin benzoate and neem-based formulations are less harmful to parasitoids and predators (Prabaningrum & Moekasan, 2020). Threshold-based insecticide applications reduced spray frequency by 33-82% compared to calendar spraying, without compromising yield. In contrast, indiscriminate use of broad-spectrum insecticides has led to resistance in DBM populations, pest resurgence and disruption of natural enemy complexes (Hasan *et al*., 2021; Baker *et al*., 2020). Other selective insecticides in integrated pest management includes Diflubenzuron, methoxy-fenozide, spinosad and flonicamid that can disrupt insect pests without harming non-target organisms.

5.5 Success Stories and Case Studies

Several case studies highlight the success of IPM in cabbage. In Indonesia, threshold-based IPM using sex pheromone traps combined with selective sprays reduced pesticide use by one-third while maintaining yields (Prabaningrum & Moekasan, 2020). In West Bengal, India, mustard trap cropping with releases of *Cotesia plutellae* significantly suppressed DBM and leaf webber infestations. In Bihar, natural enemy complexes consisting of *Cotesia plutellae*, syrphid flies and coccinellids effectively suppressed DBM and aphids without chemical intervention (Kumar *et al*., 2021). Similarly, farmers in South Africa reported a 40% reduction in insecticide applications with improved crop quality after adopting trap cropping, pheromone traps and parasitoid releases (Bhardwaj *et al*., 2017).

6. CHALLENGES AND FUTURE PERSPECTIVES

6.1 Limitations in Natural Enemy Effectiveness

Although predators, parasitoids, and entomopathogens play a vital role in suppressing cabbage insect pests, their effectiveness under field conditions is often constrained. Key limitations include low abundance or diversity of natural enemies in simplified cropping systems, poor synchronization with pest life cycles, intraguild predation and adverse effects of broad-spectrum insecticides. Habitat degradation and limited refuge availability further reduce their persistence. While augmentative releases and habitat manipulation strategies have shown promise, inconsistent outcomes highlight the context-dependent nature of natural enemy performance (Jeffris, 2023).

6.2 Impact of Climate Change on Pest-Natural Enemy Interactions

Climate change introduces new complexities into pest–natural enemy dynamics. Rising temperatures, altered rainfall and increased frequency of extreme events affect the biology and ecology of both pests and their natural enemies. Phenological mismatches-where pests emerge earlier than natural enemies-can undermine biological control. Additionally, heat stress and drought conditions often reduce parasitoid survival and host-finding efficiency, while changes in host plant physiology under elevated CO_2 levels may indirectly alter pest-enemy interactions. These factors together make the outcomes of natural biological control less predictable in changing agro-ecosystems (Nayak *et al*., 2020).

6.3 Advances in Biocontrol (Molecular Tools and Microbial Formulations)

Recent innovations are transforming the scope of biocontrol in cabbage ecosystems. Molecular tools such as DNA barcoding, metabarcoding and next-generation sequencing enable precise identification of cryptic pests and natural enemies, as well as monitoring of trophic interactions. RNA interference (RNAi) and other molecular approaches are being explored for pest suppression with high specificity. On the microbial side, significant progress has been achieved in the development of improved formulations of entomopathogenic fungi, bacteria and viruses, using encapsulation and fermentation technologies to enhance persistence, shelf-life and field efficacy. Despite these advances, regulatory hurdles, cost of production and field variability continue to challenge large-scale application (Karmakar *et al*., 2025; Hu *et al*., 2025).

6.4 Need for Farmer Awareness and Policy Support

The success of biological control strategies for cabbage pests depends heavily on farmer awareness and supportive policy frameworks. Many farmers still rely on chemical pesticides due to lack of knowledge, limited access to quality biocontrol agents, and inadequate extension support. Strengthening farmer training through field schools, demonstration plots and ICT-based advisory services can improve adoption of ecologically sustainable practices. Policy measures such as streamlined registration of biopesticides, subsidies or incentives for IPM adoption, and strict regulation of pesticide misuse are essential to scale up the use of natural enemies (Jaiswal *et al*., 2022). Effective coordination among researchers, policymakers and extension agencies will ensure that biological control becomes an integral part of sustainable cabbage production systems (Mishra *et al*., 2020; Muley & Chavan, 2023).

7. CONCLUSION

Cabbage production worldwide faces serious challenges from insect pests that significantly reduce yield and quality. Natural enemies remain the most ecologically sound means of regulating pest populations, yet their field-level effectiveness is often constrained by indiscriminate pesticide use, habitat degradation and lack of synchronization with pest phenology. Climate change further complicates biological control by disrupting pest-enemy dynamics and increasing unpredictability of outcomes. Nevertheless, recent advances in molecular tools, entomopathogen formulations and improved delivery technologies hold promise for more effective and sustainable pest management. For these innovations to succeed, farmer participation, awareness and accessibility to quality biocontrol products are crucial. Strengthened extension services, supportive policies and incentive frameworks can accelerate adoption of IPM approaches, reducing pesticide dependence and enhancing ecological resilience. Integrating natural enemies with cultural, biological and selective chemical methods will ensure more reliable and environmentally sustainable cabbage production systems in the future.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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