

# Recent Invasive Insects of India and Strategies for their Management

Mogili Ramaiah, S. Routray, K.C. Sahoo, P.V.Raghuteja

Invasive alien insect species have emerged as a major challenge to agricultural sustainability, biodiversity, and ecosystem services in India. In recent decades, the rate of invasion has increased dramatically due to globalization, increased international trade, climate change, and anthropogenic activities. India has witnessed a sharp rise in invasive insect incursions, with more than 15 new pest species reported between 2013 and 2023 alone. These invasive pests are characterized by high reproductive potential, polyphagy, rapid dispersal, and absence of natural enemies, resulting in severe crop losses and ecological imbalance. Major invasive pests such as *Spodoptera frugiperda* (J.E. Smith), *Phthorimaea absoluta* (Meyrick), *Aleurodicus rugioperculatus* Martin, and *Thrips parvispinus* (Karny) have caused widespread economic damage to multiple crops. This chapter synthesizes the status, pathways, impacts, and management strategies of invasive insects in India, with emphasis on biosecurity, biological control, and integrated pest management (IPM).

**Keywords:** *Thrips parvispinus*, globalization, invasive insects, ecological imbalance, management strategies

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## Introduction

Agroecosystems are human-managed, simplified ecological systems characterized by low biodiversity and high levels of disturbance (e.g., tillage and pesticide use), within which insects perform multiple functional roles, including herbivory, pollination, biological control, and decomposition (Price et al., 2011, Sahoo et al., 2024). Invasive alien species (IAS) are organisms that are intentionally or unintentionally introduced beyond their native geographical range, where they establish, spread, and cause ecological, economic, or environmental harm. Among IAS, invasive insects represent one of the most problematic groups due to their high reproductive potential, short life cycles, and remarkable ecological adaptability. Their ability to exploit

diverse ecological niches, coupled with efficient dispersal mechanisms, enables them to colonize new habitats rapidly and outcompete native fauna. In agricultural ecosystems, invasive insects are particularly important as they directly threaten crop productivity, food security, and farmer livelihoods (Sakai et al., 2001; Pimentel et al., 2001).

In India, the incidence of invasive insect pests has increased dramatically in recent decades. The intensification of global trade, liberalization of agricultural markets, and increased movement of plant materials such as seeds, saplings, fruits, and ornamentals have significantly enhanced the risk of pest introductions. International transport systems, including cargo shipments and passenger movement, serve as major pathways for accidental introductions of invasive species (Kolar and Lodge, 2002; Hulme, 2009). Historically, only a limited number of invasive insect species were recorded in India; however, recent years have witnessed a rapid increase in their occurrence, with several economically important pests being reported across diverse agro-climatic regions (Sushil et al., 2024; Selvaraj et al., 2016; Sharanabasappa et al., 2018).

The successful establishment and spread of invasive insects in new environments are governed by a combination of ecological and evolutionary factors. Favorable climatic conditions, particularly in tropical and subtropical regions like India, provide an ideal environment for rapid population growth and multiple generations per year. The availability of abundant and continuous host plants, often in the form of monoculture cropping systems, further facilitates their establishment and spread (Desneux et al., 2010; Montezano et al., 2018). One of the most widely accepted explanations for invasion success is the “enemy release hypothesis,” which posits that invasive species escape their co-evolved natural enemies (predators, parasitoids) and pathogens in their native range, allowing their populations to expand unchecked in the introduced regions (Sakai et al., 2001). In addition, invasive insects often exhibit high phenotypic plasticity and genetic variability, enabling them to adapt rapidly to new environmental conditions, host plants, and management practices (Lee, 2002; Whitney and Gabler, 2008). Recent invasions in India, such as fall armyworm (*Spodoptera frugiperda*), tomato pinworm (*Phthorimaea absoluta*), and rugose spiralling whitefly (*Aleurodicus rugioperculatus*), exemplify the rapid establishment and widespread impact of invasive pests (Sharanabasappa et al., 2018; Shashank et al., 2015; Selvaraj et al., 2016). These pests are characterized by high dispersal ability, polyphagy, and resistance to conventional control measures, making their management particularly challenging. The fall armyworm, for instance, is capable of long-distance migration and feeds on a wide range of host plants, contributing to its rapid spread across continents (Abbas et al., 2022; Montezano et al., 2018). Invasive insects also exert profound indirect effects on ecosystems. They can alter species interactions, disrupt food webs, and modify ecosystem processes such as nutrient cycling and energy flow. In agricultural systems, their presence often leads to increased reliance on chemical pesticides, which negatively affects non-target organisms, including pollinators and natural enemies, thereby exacerbating ecological imbalance (Deshmukh et al., 2020). Furthermore, some invasive insects act as vectors of plant pathogens, amplifying their impact on crop health and productivity.

At the global scale, invasive species are recognized as one of the leading drivers of biodiversity loss, second only to habitat destruction (Sala et al., 2000; Kolar and Lodge, 2002). They contribute to the decline and extinction of native species through competition, predation, and habitat modification. Economically, invasive species impose enormous costs on agriculture, forestry, and natural ecosystems. It has been estimated that invasive species cause global economic losses exceeding US\$ 1.4 trillion annually, highlighting their significance as a major biosecurity concern (Pimentel et al., 2001).

Given the increasing frequency, scale, and impact of biological invasions, there is an urgent need to strengthen our understanding of invasive insect ecology and management. In India, where agriculture forms

the backbone of the economy and supports a large proportion of the population, the threat posed by invasive insects is particularly severe. Effective management requires a multidisciplinary approach integrating biosecurity measures, early detection systems, ecological understanding, and sustainable pest management strategies. Strengthening institutional frameworks, enhancing research capacity, and promoting international collaboration are essential to mitigate the risks associated with invasive insects and to safeguard agricultural productivity and ecological stability.

### Status and trends of invasive insects in India

India has a long history of invasive insect introductions, beginning with early records such as the apple woolly aphid (*Eriosoma lanigerum*) in 1889 and San Jose scale (*Quadraspidiotus perniciosus*) in the early twentieth century (Thakur and Dogra, 1980; Fotedar, 1941). Over time, several pests such as diamondback moth (*Plutella xylostella*), serpentine leaf miner (*Liriomyza trifolii*), and coffee berry borer (*Hypothenemus hampei*) became established in Indian agroecosystems (Fletcher, 1914; Viraktamath et al., 1993; Kumar et al., 1990).

In recent years, the rate of invasion has accelerated significantly. The fall armyworm (*Spodoptera frugiperda*) was first reported in India in 2018 and rapidly spread across the country, causing severe damage to maize and other crops (Sharanabasappa et al., 2018). Similarly, the tomato pinworm (*Phthorimaea absoluta*) has become a major pest in vegetable production systems (Shashank et al., 2015). Other invasive pests such as rugose spiralling whitefly (*Aleurodicus rugioperculatus*) (Selvaraj et al., 2016), cassava mealybug (*Phenacoccus manihoti*) (Joshi et al., 2020), and nesting whiteflies (*Paraleyrodes* spp.) (Josephraj Kumar et al., 2019) have further intensified the invasion scenario. Recent additions such as apple leaf blotch miner (*Leucoptera malifoliella*) and mango soft scale (*Fistulococcus pokfulamensis*) indicate that invasions are continuing at an alarming rate (Joshi et al., 2023) (Figure 1). The increasing frequency of invasions reflects the vulnerability of Indian agroecosystems to exotic pests.

**An updated checklist of Invasive Alien Insect species (IAS)**

SI	Year	Common name	Scientific name	Family: Order	Origin	Reference
1	1889	Woolly aphid of apple	<i>Eriosoma lanigerum</i>	Aphididae: Hemiptera	China/America	Thakur and Dogra (1980)
2	1911	San Jose Scale	<i>Quadraspidiotus perniciosus</i>	Diaspididae: Hemiptera	China	Fotedar (1941)
3	1915	Lantana bug	<i>Orthezia insignis</i>	Ortheziidae: Hemiptera	Sri Lanka/ West Indies	Muniappan and Viraktamath (1986)
4	1921	Cottony cushion scale	<i>Icerya purchase</i>	Monophlebidae: Hemiptera	Australia	Rao and Cherian (1944)
5	1937	Potato tuber moth	<i>Phthorimaea operculella</i>	Gelechiidae: Lepidoptera	Italy	Lefroy (1907)
6	1941	Diamond back moth	<i>Plutella xylostella</i>	Plutellidae: Lepidoptera	Europe and East Asia	Fletcher (1914)
7	1958	Sugarcane woolly aphid	<i>Ceratovacuna lanigera</i>	Aphididae: Hemiptera	Mexico	Basu and Banerjee (1958);

						Mote and Puri (2003)
8	1970	Pine wooly aphid	<i>Pineus pini</i>	Adelgidae: Hemiptera	Western and Central Europe	Mc Avoy et al (2007)
9	1970	Brown Peach Aphid	<i>Pterochloroides persicae</i>	Aphididae: Hemiptera	Central Asia	Mann et al. (1979); Mahendran et al. (2018)
10	1987	Banana Skipper	<i>Erionota torus</i>	Hesperiidae: Lepidoptera	South East Asia	Prasad and Singh (1987); Deka et al. (1996)
11	1988	Subabul psyllid	<i>Heteropsylla cubana</i>	Psylliidae: Hemiptera	Central America	Veeresh (1990)
12	1990	Serpentine leaf miner	<i>Liriomyza trifolii</i>	Agromyzidae: Diptera	Florida (USA)	Viraktamath et al (1993)
13	1990	Coffee berry borer	<i>Hypothenemus hampei</i>	Curculionidae: Coleoptera	Africa	Kumar et al (1990)
14	1994	Spiraling white fly	<i>Aleurodicus disperses</i>	Aleyrodidae: Hemiptera	Central America	Palaniswami et al (1995)
15	1997	Coconut eriophid mite	<i>Aceria guerreronis</i>	Eriophyidae: Acarina	Mexico	Singh (2004)
16	1997	Stem borer on Guava	<i>Aristobia reticulator</i>	Cerambycidae: Coleoptera	China	Shylesha et al. (2000)
17	1999	Silver leaf whitefly	<i>Bemisia argentifolli</i>	Aleyrodidae: Hemiptera	United States	Singh (2004)
18	2003	Arecanut Whitefly	<i>Aleurocanthus arecae</i>	Aleyrodidae: Hemiptera	Asia	David and Manjunath 92003)
19	2004	Cotton mealy bug	<i>Phenacoccus solenopsis</i>	Pseudococcidae: Hemiptera	Central America	Tanwar et al. (2007)
20	2005	Lotus lily midge	<i>Stenochironomus nelumbus</i>	Chironomidae: Diptera	China	Deepu and Habeeburrahman (2008)
21	2006	Eucalyptus gall wasp (Blue gum chalcid)	<i>Leptocybe invasa</i>	Eulophidae: Hymenoptera	Australia	Jacob et al (2007)
22	2006	Erythrina gall wasp	<i>Quadrastichus erythrinae</i>	Eulophidae: Hymenoptera	Tanzania/East Africa	Faizal et al. (2006)
23	2008	Papaya mealy bug	<i>Paracoccus marginatus</i>	Pseudococcidae: Hemiptera	Mexico	Muniappan et al. (2008)
24	2012	Banana mealy bug	<i>Pseudococcus elisae</i>	Pseudococcidae: Hemiptera	Central America	Tanwar et al. (2007)

25	2012	Jack Beardsley mealybug	<i>Pseudococcus jackbeardsleyi</i>	Pseudococcidae: Hemiptera	America	Shylesha (2013)
26	2012	Madeira mealy bug	<i>Phenacoccus madeirensis</i>	Pseudococcidae: Hemiptera	Neotropical region	Shylesha and Joshi (2012)
27	2014	Tomato pinworm	<i>Phthorimaea absoluta</i>	Gelechiidae: Lepidoptera	South America	Shashank et al. (2015)
28	2014	Solanum Whitefly	<i>Aleurothrixus trachoides</i>	Aleyrodidae: Hemiptera	Neotropical Region	Dubey and Sundararaj(2015)
29	2015	Coconut Spindle infesting leaf beetle	<i>Wallacea</i> sp.	Chrysomellidae: Coleoptera	Oriental region/Java/ Australia	Prathapan and Shameem (2015)
30	2015	Western flower thrips	<i>Frankliniella occidentalis</i>	Thripidae: Thysanoptera	Southwestern US	Tyagi and Kumar (2015)
31	2015	Black Thrips	<i>Thrips parvispinus</i>	Thripidae: Thysanoptera	South East Asia	Tyagi et al. (2015)
32	2016	Rugose whitefly	<i>Aleurodicus rugioperculatus</i>	Aleyrodidae: Hemiptera	Florida (USA)	Selvaraj et al. (2016)
33	2017	Arecanut Aphid	<i>Tuberaphis xinglongensis</i>	Aphididae: Hemiptera	East and South-east Asia and Africa	Joshi et al. (2022)
34	2018	Fall armyworm	<i>Spodoptera frugiperda</i>	Noctuidae: Lepidoptera	America	Sharanabasappa et al. (2018)
35	2019	Bondar's nesting whitefly	<i>Paraleyrodes bondari</i>	Aleyrodidae: Hemiptera	Central America	Josephraj Kumar et al. (2019)
36	2019	Neotropical whitefly	<i>Aleurotrachelus atratus</i>	Aleyrodidae: Hemiptera	Brazil	Selvaraj et al. (2019)
37	2019	Nesting whitefly	<i>Paraleyrodes meini</i>	Aleyrodidae: Hemiptera	Syria	Chandrika Mohan et al. (2019)
38	2020	Wooly whitefly	<i>Aleurothrixus floccosus</i>	Aleyrodidae: Hemiptera	Neotropical region	Sundararaj et al. (2020)
39	2020	Cassava mealy bug	<i>Phenacoccus manihoti</i>	Pseudococcidae: Hemiptera	South America	Joshi et al. (2020)
40	2020	Leek moth	<i>Acrolepiopsis assectella</i>	Acrolepiidae: Lepidoptera	Europe	Dewangan and Deol (2021)
41	2023	Apple leaf blotch miner	<i>Leucoptera malifoliella</i>	Lyonetiidae: Lepidoptera	Central Asia / Europe (temperate regions)	Joshi et al. (2023)
42	2023	Mango soft scale	<i>Fistulococcus pokfulamensis</i>	Coccidae: Hemiptera	Hong Kong / Southeast Asia	Joshi et al. (2023)

43	2023	Coffee moth of Kerala (Bag worm)	<i>Capulopsyche keralensis</i>	Psychidae: Lepidoptera	India (endemic – Kerala)	Unnikrishnan et al., 2023
44	2024	New Scale of <i>Cycas circinalis</i> (Queen sago)	<i>Aulacaspis madiunensis</i>	Coccidae: Hemiptera	Indonesia (Madiun, Java)	Joshi et al. (2024)
45	2024	New Scale on Cardamom	<i>Aulacaspis elettaria</i>	Coccidae: Hemiptera	India	Joshi et al. (2024)
46	2024	Cassava Green mite	<i>Mononychellus mcgregori</i>	Tetranychidae	South America	(Dyamanagoud, 2024)
47	2024	Invasive Annona Whitefly	<i>Aleurotrachelus anonae</i>	Aleyrodidae: Hemiptera	Neotropical region	Selvaraj & Sushil, 2024
48	2025	Nesting whitefly	<i>Paraleyrodes pseudonaranjae</i>	Aleyrodidae: Hemiptera	Central America	Selvaraj & Sushil, 2025

(Modified from Mogili Ramaiah et al, 2025)

### Pathways of introduction and spread

The introduction and spread of invasive insects are strongly linked to anthropogenic activities, particularly globalization and trade liberalization. International trade in agricultural commodities, live plants, and nursery stock has been identified as the primary pathway for the introduction of invasive pests worldwide (Hulme, 2009; Liebhold et al., 2012). Among these, the trade of ornamental plants is considered especially high-risk due to the frequent movement of live plant material harboring cryptic pest stages such as eggs and larvae. In addition, wood packaging materials, including pallets and crates, have facilitated the global spread of several wood-boring insects, highlighting the role of non-living trade components in pest dissemination (Haack et al., 2014). In countries like India, where biosecurity infrastructure is still evolving, informal and illegal pathways such as passenger baggage further complicate pest exclusion efforts (Work et al., 2005). Beyond introduction, the rapid spread of invasive insects is driven by both biological traits and environmental factors. Highly migratory species such as *Spodoptera frugiperda* demonstrate exceptional dispersal capacity, with the ability to migrate over hundreds of kilometers aided by wind currents, thereby enabling rapid colonization of new areas (Westbrook et al., 2016; Abbas et al., 2022).

Such dispersal capabilities significantly reduce the effectiveness of localized management strategies and necessitate regional or continental-level coordination. Climate change further amplifies invasion dynamics by altering species distribution patterns and enhancing habitat suitability. Warmer temperatures and changing precipitation regimes have been shown to facilitate the poleward expansion of many insect pests and increase their voltinism (Bebber et al., 2013; Early et al., 2016). Importantly, the interaction between climate change and trade creates a synergistic effect, accelerating both the introduction and establishment of invasive species. Therefore, understanding invasion pathways requires an integrated perspective that combines trade dynamics, climate projections, and species-specific biological traits.

Figure 1. A few invasive insect species have been reported recently in India



Chilli black thrips, *Thrips parvispinus*



Greenhouse Orthezia, *Orthezia insignis*



Rugose Spiraling Whitefly (RSW),  
*Aleurodicus rugioperculatus*



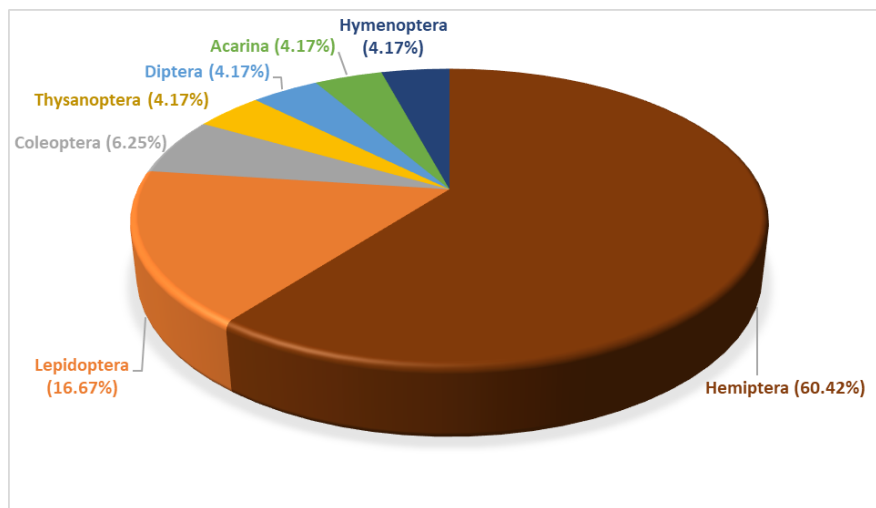
Bondar's Nesting Whitefly (BNW),  
*Paraleyrodes bondari*



Fall armyworm, *Spodoptera frugiperda*

### Biological and ecological traits of invasive insects

The success of invasive insects is underpinned by a suite of life-history and ecological traits that confer competitive advantages in novel environments. High fecundity, short generation time, and rapid population growth enable invasive species to establish viable populations even from small founder populations (Sakai et al., 2001). Polyphagy is another key trait, allowing invasive insects to exploit a wide range of host plants and persist across diverse agroecosystems. For example, *Spodoptera frugiperda* exhibits extreme host plasticity, feeding on over 300 plant species, which enhances its resilience to changes in cropping patterns (Montezano et al., 2018). A critical concept explaining invasion success is the enemy release hypothesis, which suggests that invasive species experience reduced pressure from natural enemies in their introduced range, allowing them to allocate more resources to growth and reproduction (Keane and Crawley, 2002). However, recent studies indicate that this hypothesis may not universally apply, as some invasive species rapidly acquire native natural enemies, leading to partial ecological regulation (Colautti et al., 2004). This highlights the dynamic nature of invasion ecology and the need for context-specific understanding. Phenotypic plasticity and rapid evolutionary adaptation further enhance the invasiveness of insect pests. Invasive populations often exhibit genetic changes that improve their tolerance to environmental stress, host plant defenses, and chemical control measures (Lee, 2002). The development of insecticide resistance in invasive species such as *Phthorimaea absoluta* exemplifies the evolutionary potential of these organisms under strong selection pressure (Desneux et al., 2010). These adaptive traits not only facilitate establishment but also complicate management efforts.

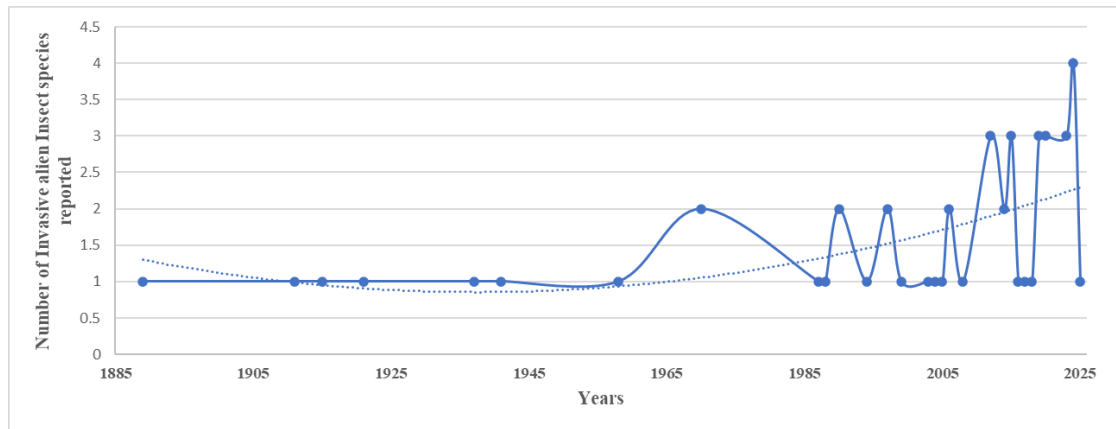


**Figure 2. Contribution of Major Insect Orders to Invasive Alien Insect and Acarid Assemblages in India (1889–2025)**

The distribution of invasive insect pests in India is strongly dominated by the order Hemiptera, which accounts for the majority share (60.42%) of recorded species. This is followed by Lepidoptera (16.67%), indicating their significant contribution to the invasive pest complex, particularly in agricultural ecosystems. Coleoptera represent a smaller proportion (6.25%), while other orders such as Thysanoptera, Diptera, Hymenoptera, and Acari each contribute equally (4.17%). The predominance of Hemipteran pests highlights their adaptability, high reproductive potential, and efficient dispersal mechanisms, making them a major concern for crop protection. Overall, the order-wise distribution reflects the uneven taxonomic representation of invasive pests in India and underscores the need for targeted monitoring and management strategies focusing on the most dominant groups.

### Possible reasons for the dominance of order Hemiptera

The dominance of invasive species belonging to the order Hemiptera (e.g., aphids, whiteflies, scale insects, and mealybugs) in India can be attributed to a combination of ecological, biological, and anthropogenic factors. One of the primary drivers is increased propagule pressure associated with globalization and the expansion of international trade. Hemipterans are frequently introduced unintentionally through the import of horticultural plants, ornamental species, and fresh agricultural produce, resulting in repeated introduction events that enhance establishment success (Lockwood et al., 2005; Hulme, 2009). Their small size and cryptic behavior further facilitate their entry and spread, as many species remain undetected during quarantine inspections due to their concealed feeding habits and minute morphology (Paini et al., 2016).



**Figure 3. Temporal trend in the annual reporting of invasive alien insect species in India (1886–2025). The dotted line represents a polynomial trendline fitted to the data**

In addition, Hemiptera exhibit high invasive potential due to their reproductive strategies, particularly parthenogenesis, which allows a single individual to establish a viable population without mating, thereby overcoming Allee effects and accelerating population growth (Simon et al., 2002). Their polyphagous feeding behavior is another crucial factor, enabling them to exploit a wide range of host plants in novel environments, which increases their adaptability and establishment success in diverse agroecosystems across India (Sax et al., 2007).

Furthermore, the enemy release hypothesis suggests that invasive hemipterans often experience reduced pressure from natural enemies such as predators and parasitoids in introduced regions, allowing rapid population expansion (Keane & Crawley, 2002). Finally, climate change and rising temperatures have created favorable conditions for the survival, reproduction, and geographic expansion of many tropical and subtropical hemipteran species, thereby enhancing their invasive potential and distribution range in India (Bebber et al., 2013; Deutsch et al., 2018).

### Impacts of invasive insects

The impacts of invasive insects extend beyond direct crop damage and encompass broader ecological and economic consequences. In agricultural systems, invasive pests significantly reduce crop yields and quality, leading to increased production costs and reduced profitability. For instance, *Spodoptera frugiperda* has caused widespread damage to maize crops in India, with reported yield losses varying across regions depending on infestation intensity and management practices (Sharanabasappa et al., 2018). Similarly,

*Phthorimaea absoluta* has emerged as a major constraint in tomato production, with the potential to cause complete crop failure under unmanaged conditions (Desneux et al., 2010).

Ecologically, invasive insects disrupt native biodiversity through mechanisms such as competition, predation, and habitat modification (Simberloff et al., 2013). These disruptions can cascade through trophic levels, altering food web dynamics and ecosystem functioning. Moreover, the increased reliance on chemical pesticides for managing invasive pests can negatively impact non-target organisms, including pollinators and natural enemies, thereby exacerbating ecological imbalance (Geiger et al., 2010).

From an economic perspective, invasive species impose substantial costs on agriculture, forestry, and natural ecosystems. Pimentel et al. (2001) estimated that invasive species cause global economic losses exceeding US\$ 1.4 trillion annually. However, these estimates are often conservative, as they do not fully account for indirect costs such as ecosystem service degradation and long-term environmental impacts. In developing countries like India, where agricultural livelihoods are highly vulnerable, the socio-economic consequences of invasive pests are particularly severe.

### **Management strategies for invasive insects**

The management of invasive insects has progressively shifted from conventional, reactive control measures toward proactive, integrated, and technology-driven strategies that emphasize prevention, sustainability, and ecological balance. Prevention through stringent quarantine regulations and biosecurity frameworks remains the most cost-effective approach, as post-establishment eradication is often impractical and resource-intensive (Liebhold et al., 2016). In India, regulatory instruments such as the Plant Quarantine Order (2003) provide a foundation for pest exclusion, although their success depends on effective enforcement, infrastructure, and institutional capacity (Sushil et al., 2024). Early detection and rapid response are central to modern management frameworks, supported by advanced surveillance systems integrating pheromone traps, remote sensing, geographic information systems (GIS), and artificial intelligence (AI)-based predictive modeling, which enable real-time monitoring and forecasting of pest outbreaks (Early et al., 2016).

Recent advances in molecular diagnostics, including DNA barcoding, environmental DNA (eDNA), and genomic tools, have significantly enhanced the accuracy and speed of species identification, facilitating timely and targeted interventions (Hebert et al., 2003). Biological control continues to serve as a cornerstone of sustainable management, with classical biological control programs successfully managing invasive pests such as papaya mealybug and cassava mealybug, while conservation biological control enhances native natural enemy populations through habitat manipulation (Muniappan et al., 2008; Shylesha et al., 2018; Joshi et al., 2020). These approaches are complemented by Integrated Pest Management (IPM) frameworks that combine biological, cultural, mechanical, and need-based chemical methods to minimize environmental impacts and delay resistance development (Deshmukh et al., 2020).

Innovative biotechnological tools, including RNA interference (RNAi), CRISPR/Cas9-based gene editing, and the sterile insect technique (SIT), are emerging as highly selective and environmentally safe strategies for pest suppression, although their large-scale application requires further validation and regulatory approval (Zotti et al., 2018). In addition, semiochemical-based approaches such as pheromone-mediated mass trapping and mating disruption provide species-specific alternatives to chemical pesticides and are increasingly incorporated into IPM programs. Agroecological practices, including crop diversification, resistant varieties, and habitat management, further enhance ecosystem resilience and support natural biological control (Altieri et al., 2015).

Despite these advancements, the successful implementation of integrated and innovative pest management strategies depends on strong institutional frameworks, policy support, stakeholder participation, and capacity building. National agencies, research institutions, and international agreements such as the International Plant Protection Convention (IPPC) play a crucial role in facilitating coordinated responses to transboundary pest threats (FAO, 2021). Thus, an integrated approach combining policy, ecology, and technology is essential for the effective and sustainable management of invasive insect species.

### **Challenges and future perspectives**

Invasive insect species continue to pose a serious and expanding threat to agriculture, biodiversity, and ecosystem stability worldwide, particularly in countries like India where diverse agro-climatic conditions and intensive cropping systems favor pest establishment and spread. Despite considerable progress in research, surveillance, and management strategies, several challenges still hinder the effective control of invasive insects. Rapid globalization and increasing international trade have significantly enhanced the movement of pests across geographical boundaries, while climate change is altering species distribution patterns and facilitating their establishment in new regions. In addition, the rapid evolution of pest resistance to conventional control measures further complicates management efforts (Early et al., 2016). Limitations in diagnostic infrastructure, lack of real-time surveillance data, and inadequate coordination among stakeholders also reduce the efficiency of current pest management programs. Addressing these challenges requires a forward-looking and multidisciplinary approach. Future research should prioritize the development of predictive models for invasion risk assessment, incorporating climate change projections and ecological variables to identify potential hotspots for pest establishment and spread. The integration of emerging technologies such as artificial intelligence, remote sensing, geographic information systems, and big data analytics can greatly enhance pest surveillance, early warning systems, and decision-making processes. In addition, strengthening diagnostic capabilities through molecular tools and improving information-sharing networks among research institutions, quarantine agencies, and farmers will be critical for rapid response to new invasions. Integrated invasive insect pest management using innovative approaches represents a significant shift toward sustainable and resilient agricultural systems. The combination of traditional ecological knowledge with modern technologies such as advanced monitoring systems, molecular diagnostics, biological control innovations, and precision agriculture offers promising opportunities for improving pest management outcomes while minimizing environmental impacts. Furthermore, increased public awareness, farmer participation, and stakeholder collaboration are essential components of successful invasion management strategies.

Overall, the effective management of invasive insects will depend on the integration of science, policy, and practice. Strengthening institutional frameworks, enhancing international collaboration, and promoting interdisciplinary research will be vital to address the growing challenges posed by invasive insect species. A coordinated global and national effort is therefore necessary to safeguard agricultural productivity, protect biodiversity, and ensure long-term ecological sustainability.

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