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Navigating the Threat: Invasive Insect Pests and Their Impact on Indian Agriculture

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Authors' contributions

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

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Review Article

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ABSTRACT

Globalization has accelerated the movement of goods and planting materials, increasing the risk of invasive alien pests entering India. These pests, which include species like the Fall armyworm, spiraling white fly and Tomato Pinworm, are serious risks to agriculture, human health, and ecosystems. The introduction of these pests frequently causes significant economic damage through crop loss and demands the overuse of chemical insecticides, which harms humans and reduces natural predators and pollinators. India's diverse environment encourages the spread of

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these alien insects, with 23 invasive species identified to yet. This review focusses on the characteristics that make these insects invasive, their common entry points, and the establishing process. Effective management practices are critical for mitigating their impact. Strict adherence to import laws, international cooperation, and early detection and identification at entrance points are critical methods for preventing the spread of these pests.

Conclusion: The growing threat of invasive pests to Indian agriculture underscores the urgent need for proactive and comprehensive management strategies. Effective management requires a multifaceted approach, including strict enforcement of import regulations, early detection and rapid response at entry points, and the adoption of sustainable control measures like biological management.

Keywords: Invasive pests; globalization; biological control; quarantine; economic impact; risk assessment; interdisciplinary collaboration.

ABBREVIATIONS

DPPQ&S : Directorate of Plant Protection, Quarantine, and Storage.
PQ Order : Plant Quarantine (Regulation of Import into India) Order.
IUCN : International Union for Conservation of Nature.
NBAIR : National Bureau of Agricultural Insect Resources.

1. INTRODUCTION

Anthropogenic activities like grain and wood movement, trucking, air travel, and marine trips all contribute significantly to the spread of invasive insect pests to new areas. These non-native or exotic pests can establish populations outside of their normal ranges through a variety of trade-related paths, including both legal and illicit plant material smuggling [1]. In India, the introduction of at least 33 invasive insect pests *via* various channels underlines the vital need for robust plant quarantine legislation to avoid future pest incursions. Invasive species, including insect pests, are often regarded as one of the most serious dangers to agricultural biodiversity, human and animal health, forestry, and general ecological stability. These species, by definition, disrupt established ecosystems, which can have serious environmental and economic effects. They frequently cause significant crop losses, jeopardize food security, and contribute to biodiversity loss by displacing native species and modifying habitat structures [2]. Invasive species normally colonize in four stages: introduction, establishment, spread, and naturalization. Each level poses unique issues that necessitate particular management solutions to mitigate potential consequences [3]. India's large and diversified geography, which covers around 3.2 million square kilometers, makes it vulnerable to invading species. The country's diverse climatic conditions and great biodiversity make it an appealing target for invasive organisms [4]. This risk is exacerbated by India's large trade activities, which amount $330.07 billion in exports and $462.9 billion in imports [5-7]. This high volume of foreign trade increases the risk of invasive pests entering the country. The International Union for Conservation of Nature (IUCN) defines invasive species as those that establish themselves in new settings and disrupt natural or semi-natural ecosystems, jeopardizing native biodiversity [8]. India has identified a total of 173 invasive species, including 47 that damage agricultural systems and 23 particular insect species [9]. For addressing these issues, India has established a robust plant quarantine system. This framework was established by the Destructive Insects and Pests Act of 1914 and is handled by the Directorate of Plant Protection, Quarantine, and Storage (DPPQ&S) [4]. Plant Quarantine (Regulation of Import into India) Order, 2003, replaces previous regulations and oversees the import of plant materials. This order establishes six regional plant quarantine stations for the import of seeds and propagative materials, along with detailed schedules describing regulated, forbidden, and restricted goods (PQ Order, 2003). Stringent inspections and certifications are required to assure compliance with phytosanitary requirements, which are critical in limiting the introduction and spread of exotic pests [1,2].

Invasive species, notably insect pests, are a serious and growing threat to India's agricultural economy and biodiversity. These pests, because of their propensity to establish and spread in novel habitats, represent severe threats to crop

harvests and natural ecosystems. Strict import laws, international coordination, and early detection technologies are all required for effective threat management. Implementing these measures requires interdisciplinary collaboration among scientists and policymakers to detect pests, assess their ecological and economic implications, and establish long-term control strategies. Such techniques include preventive, eradication, and control measures that are adapted to the unique dangers posed by invasive species. [7,8].

2. PATHWAYS OF INVASION

Invasive species frequently travel to new settings *via* diverse paths, which are projected routes that facilitate their movement. These routes encompass maritone, land, and air transportation. The globalization of trade and travel has increased the frequency and severity of these invasions. Some species are actively imported for commercial or agricultural reasons, while others are accidentally introduced. Here are the primary pathways through which invasive insect pests enters new regions:

2.1 Introduced as Contaminants

The global trade in logs contributes an important source of foreign exchange in India. However, this trade also provides as a pathway for the spread of exotic species. Long-term storage of logs without treatment can contain a variety of insects and pathogens. When these logs are imported, they carry the resident alien species. Similarly, historically, the importation of food goods and seeds led in the unintended introduction of pests due to EPA's lax regulatory limits on pollutants [1].

2.2 Living Industry Pathway

The life industry pathway includes the trading of horticultural crops, aquaculture organisms, pets, and live seafood. These biological organisms frequently carry their respective pests. For example, the introduction of apple woolly aphids to India is linked to the importation of apple rootstock from England [10]. Such trade may accidentally introduce exotic pests in new locations.

2.3 Transportation-Related Pathways

Increased tourism and international transport have heightened the risk of pest invasions.

2.4 Pathways of Introduction include

Accidental Introduction: Insects or other organisms can be unintentionally introduced by travellers.

Unintentional Transit: Alien species can be moved from one location to another without deliberate intent.

Cargo Shipments: Air, land, and sea transport of goods can carry invasive species.

Food Trade: Infested food products can contribute to pest introduction.

Accidental Introduction by Tourist: Fruits or vegetables carried by tourists can harbor pests [2].

2.4.1 Steps in invasion

The invasion process of an alien species generally involves four sequential steps: Introduction, establishment, spread and naturalization.

Introduction is the transfer of an insect to a new region outside of its natural range. This is frequently achieved by passive movement helped by vectors, usually human activities. Despite extensive quarantine checks, early detection of invading insects is difficult. For example, timber beetles (Cerambycidae) were transferred to Antarctica via logs, demonstrating passive transport [3]. Some insects, such as the autumn armyworm (*Spodoptera frugiperda*), can migrate over great distances, challenging invasion control efforts. They are said to have journeyed from Africa to the Indian subcontinent, while the specific method of arrival is unknown. Similarly, the Monarch butterfly (*Danaus plexippus*) moved from North America to Australia in the nineteenth century [1].

2.4.2 Establishment

Establishment happens when an introduced species overcomes environmental constraints and begins to thrive in its new environment. The number of propagules injected and the level of environmental disturbance both have an impact on successful establishment. Invasive species frequently capitalise on disturbances that native species are not equipped to deal with. Global warming exacerbates this by changing resource availability and habitat suitability, promoting the spread of exotic insects while harming native species [2].

2.4.3 Spread

Once established, invasive species can spread to other areas. This spread is influenced by environmental factors such as weather conditions, microclimate, and habitat quality. Behavioural responses (e.g., aggressiveness) and morphological traits (e.g., wing development) of insects also affect their spread. Human-mediated transport can facilitate rapid spread, although the success of this spread depends on the habitat's permeability to the invasive species [10].

2.4.4 Naturalization

Naturalization begins when an invasive species overcomes abiotic and biotic barriers to survival and reproduction. This stage signifies the species' integration into the new ecosystem, where it becomes part of the regular ecological and reproductive processes [1].

2.5 Common Traits of Invasive Species

Invasive species, including insects, typically possess several traits that enhance their ability to thrive in new environments:

Fast Growth: They exhibit rapid growth rates, enabling them to quickly dominate new areas.

High Reproduction Rates: They reproduce prolifically, even under unfavorable conditions.

Adaptability: They show high compatibility with the new ecosystem and can survive a wide range of environmental conditions.

Long-Distance Mobility: They can move long distances, either naturally or through human transport.

Phenotypic Plasticity: They can adapt their physical traits to varying environmental conditions.

Generalist Diets: They are able to consume a wide range of food types, increasing their chances of survival.

Competitive Ability: They are often highly competitive with native species and can exploit resources more efficiently.

2.6 Impact of Invasive Pest Species on Agro-Ecosystems

Invasive pest species provide one of the most serious dangers to agricultural ecosystems. In absence of natural enemies or control measures these pests can dominate and outcompete local species in the new environment, thus disturbing the ecological balance. Invasive pests can significantly alter the structure and species composition of ecosystems, affecting native species by competing for resources, altering nutrient cycles, and indirectly influencing various aspects of ecosystem health, biodiversity, and agricultural productivity [2]. The global economic cost of invasive species has been calculated at $1.288 trillion over the last 50 years, demonstrating their significant economic impact [3].

2.7 Direct Threats of Invasive Species

1. **Predation on Native Species:** Invasive pests may prey on native species, disrupting local food webs and ecological balance.
2. **Resource Competition:** They out-compete native species for food and other essential resources, leading to a decline in native populations.
3. **Disease Transmission:** Some invasive species carry or cause diseases that can impact native flora and fauna, affecting their health and reproduction [1].

2.8 Indirect Threats of Invasive Species

1. **Changes in Food Webs:** Invasive species can alter the food web by destroying or replacing native food sources. This can lead to a reduction in food availability for native wildlife, impacting their survival and reproduction [2].
2. **Decreased Biodiversity:** The dominance of invasive species can reduce the abundance and diversity of native species, leading to habitat loss and the decline of native wildlife. This is particularly concerning for ecosystems that rely on specific native species for ecological stability [3].
3. **Altered Ecosystem Conditions:** Invasive species can change environmental conditions, such as soil chemistry or wildfire intensity, further impacting native species and ecosystem health [2].

3. Recent Invasive Insect Pests in India (Table.1)

3.1 Fall Armyworm (*Spodoptera frugiperda*)

First reported in India in May 2018 in Karnataka. The fall armyworm has rapidly spread, with infestations ranging from 2% to 35% in maize

Table 1. List of invasive insect pests introduced in India

Sl. No	Common name	Scientific Name	Entry to India (Place)	From/Native
1.	San Jose scale	*Quadraspidiotus perniciosus* (Comstock) (Hemiptera: Diaspididae)	1879/(1921-Kashmir)	China
2.	Woolly apple aphid	*Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae)	1889-Coonoor, Tamil Nadu/ 1909 Uttar Pradesh	China/America
3.	Potato tuber moth	*Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae)	1906- (East Bengal, Now in Bangladesh)	Italy
4.	Cottony cushion scale	*Ivory pyralin* Maskell (Hemiptera: Margarodidae)	1920-Tamil Nadu	Australia
5.	Pine woolly aphid	*Pineus pini* (Macquart) (Hemiptera; Adelgidae)	1970-Nilgiris, Tamil Nadu	Western & Central Europe
6.	Subabul psyllid	*Heteropsylla cubana* Crawford (Hemiptera: Psyllidae)	1988 Tamil Nadu & Bangalore	Central America
7.	Coffee berry borer	*Hypothenemus hampei* Ferrari (Coleoptera: Curculionidae)	1990-Gudalur, Tamil Nadu	Northeast Africa
8.	Serpentine leaf miner	*Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae)	1991-Hyderabad, Telangana	Florida (U.S.A.)
9.	Spiraling white fly	*Aleurodicus disperses* Russell (Hemiptera: Aleyrodidae)	1993-Kerala	Central America
10.	Coconut Eriophyid mite	*Aceria guerreronis* Keifer (Arachnida: Eriophyidae)	1997-Enakulam, Kerala	Mexico
11.	Eucalyptus gall wasp /Blue gum chalcid	*Leptocybe invasa* Fisher & La Salle (Hymenoptera: Eulophidae)	2001-Karnataka/Tamil Nadu	Australia
12.	Erythrina gall wasp	*Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae)	2006-Kerala	Tanzania, East Africa
13.	Cotton mealy bug	*Phenacoccus solenopsis,* (Hemiptera: Pseudococcidae)	2006-Gujarat	Central america
14.	Papaya mealy bug	*Paracoccus marginatus* Williams and Granara de	2007-Coimbatore, Tamil Nadu	Mexico

Sl. No	Common name	Scientific Name	Entry to India (Place)	From/Native
		Willink (Hemiptera: Pseudococcidae)		
15.	Jack Beardsley mealybug (Banana)	*Pseudococcus jackbeardsleyi* Gimpel and Miller. (Hemiptera: Pseudococcidae)	2012-Karnataka	America
16.	Madeira mealybug (Hibiscus)	*Phenacoccus madeirensis* Green (Hemiptera: Pseudococcidae)	2012-Karnataka	Neotropical
17.	South American tomato pinworm/ Tomato leaf minor	*Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)	2014-Pune, Maharashtra	South America
18.	Coconut Spindle infesting leaf beetle	*Wallacea* sp. (Coleoptera: Chrysomelidae)	2014/2015- Andaman Islands	Oriental region-Australia
19.	Chilli black thrips	*Thrips parvispinus*	2015- Bengaluru	Indonesia
20.	Rugose spiraling whitefly (Coconut)	*Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae)	2016-Tamil Nadu	Central America
21.	Fall armyworm (Maize)	*Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae)	2018-Karnataka	America
22.	Nesting whitefly (Coconut)	*Paraleyrodes minei Iaccarino* (Hemiptera: Aleyrodidae)	2018-Kerala	Syria
23.	Bondar's Nesting Whitefly (Coconut)	*Paraleyrodes bondari* Peracchi (Hemiptera: Aleyrodidae)	2018-Kerala	Central America
24.	Cassava mealy bug	Phenacoccus manihoti	2020	Africa

crops. This polyphagous pest attacks over 353 species including 73 families, including major crops like rice, sorghum, and sugarcane, causing significant damage and threatening food security [10].

3.2 Rugose Spiralling Whitefly (*Aleurodicus rugioperculatus*)

Native to Central America, this pest was first recorded in India in 2016. It infests a variety of crops, including coconut, banana, and mango. The whitefly causes stress to plants by depleting nutrients and excreting honeydew, which supports the growth of sooty mould [1]. These pests have spread across southern India and continues to expand its host range.

3.3 South American Tomato Pinworm (*Tuta absoluta*)

Known for its destructive impact on tomato crops, *Tuta absoluta* was first observed in Maharashtra in 2014. This pest can cause up to 90% yield loss and severely affected fruit quality. Its ability to attack various solanaceous plants, combined with its resistance to insecticides, poses a significant threat to tomato production [3].

3.4 Neo-Tropical Whitefly (*Aleurotrachelus atratus*)

Dentified in India in February 2019, this whitefly infests coconut and ornamental palms. It has been observed to cause 10-60% damage to

leaflets per palm and is associated with other invasive whiteflies and pests. The Neo-Tropical whitefly is known for its extensive host range and significant impact on palm crops [10].

In 2023, two invasive insect pests, Apple leaf blotch miner, Leucoptera malifoliella, (Lyonetiidae: Lepidoptera) in Union territory of Jammu & Kashmir and Mango soft scale, Fistulococcus pokfulamensis, (Coccidae: Hemiptera) in and around Bengaluru have been detected. Both have firmly established and continue to spread further without much scope for their containments [11].

4. Management of Invasive Insects (Fig.1)

4.1 Pre-Introduction

Effective invasive insect control begins with preventive efforts to keep them from spreading to new areas. This phase entails numerous essential techniques, including pest risk assessment (PRA), strict quarantine protocols, and continual monitoring [1]. PRA is critical for analyzing a pest's potential threat before it arrives, allowing for the development of tailored preventative tactics. These procedures are specified in India's Plant Quarantine Order 2003, which sets forth extensive regulations for the importation of plants and plant products. The National Bureau of Plant Genetic Resources (NBPGR) and the Directorate of Plant Protection, Quarantine, and Storage (DPPQS) play crucial roles in managing invasive pests. NBPGR focuses on conserving plant genetic resources and developing pest-resistant varieties. Meanwhile, DPPQS implements phytosanitary measures, monitors pest outbreaks, and regulates plant imports to prevent the spread of invasive species. Together, they enhance plant protection through research, surveillance, and policy, ensuring effective management of pest threats to agriculture and biodiversity.

4.2 Post-Introduction or Pre-Spread

When a pest is detected but has not yet spread extensively, immediate actions are necessary to prevent further dissemination. This typically involves rejecting infested consignments and applying fumigation treatments to affected lots. Such measures are essential to eliminate the pest and prevent its establishment in new areas [10]. Post-introduction management requires swift and effective responses to mitigate the risk of spread, which can otherwise lead to larger infestations and more significant economic and ecological impacts.

4.3 Established Pests

For pests that have already established populations, a multifaceted approach is needed to manage and control their impact. This includes a combination of cultural, biological, and chemical control methods.

- **Biological Control**

To assist restrict the pest's proliferation, this technique involves introducing natural enemies from its original environment. Biological management can be extremely effective if introduced predators or parasitoids establish themselves and significantly reduce pest populations. However, in order to minimize unforeseen outcomes, substantial research must be conducted prior to the introduction of biological control agents. For example, the introduction of *Zygogramma bicolorata* in India to control *Parthenium hysterophorus* resulted in the agent becoming a pest of sunflowers, underscoring the significance of thorough testing before release [3].

- **Chemical Control**

Pesticides are used as a reactive measure to manage established pest populations. The selection and application of pesticides must be based on a thorough understanding of their mode of action, selectivity, and residual effects. Effective chemical control relies on using pesticides judiciously to minimize potential environmental and health impacts [1].

- **Cultural Control**

Cultural practices involve modifying agricultural practices to reduce pest populations, such as crop rotation, altering planting times, or using pest-resistant plant varieties. Monitoring and early detection play a critical role in managing invasive pests. In India, 71 plant quarantine stations, equipped with molecular diagnostics, pheromones, and traps, are utilized to detect invasive pests early and manage their spread [12]. These facilities ensure that invasive species are identified and addressed promptly to prevent larger infestations (Fig.1).

Fig.1. Management of invasive insects

5. MANAGEMENT OF NEW INVASIVE INSECT PESTS

Effective management of new invasive insect pests involves several essential steps:

5.1 Monitoring

Successful eradication requires monitoring over extended periods, typically for at least two years or two pest generations. This prolonged monitoring helps ensure that the pest is fully controlled and prevents resurgence [13-15].

5.2 Identification

Accurate identification of the pest by experts is critical for determining the appropriate management strategy [16-18]. Correct identification ensures that the pest is accurately diagnosed and that the management approach is tailored to its specific characteristics.

5.3 Risk Assessments

Assessing the risk posed by the pest involves studying its biology, distribution, and current status. This assessment helps in evaluating the available mitigation options and determining the optimal window for intervention [19-21]. Risk assessments are crucial for prioritizing management actions and allocating resources effectively.

5.4 Eradication Programs

For high-risk pests, broad-scale eradication efforts should be implemented. These efforts are complemented by educational outreach to inform the public about the pest and effective control measures. Public awareness and cooperation are essential for the success of eradication programs.

5.5 Risk Assessment Review

Risk assessments should be regularly updated based on new information about the pest's biology, distribution, and management options [22-24]. Ongoing review ensures that management strategies remain relevant and effective in light of new data.

5.6 Management Strategies

- Study the pest's biology, ecology, and natural enemies to develop effective management strategies.
- Analyse the ecological and genetic characteristics of the pest.
- Track the geographical distribution of the pest and develop resistant cultivars.
- Use insecticides judiciously to prevent the development of resistance.
- Conserve and augment natural enemies to enhance biological control.
- Modify crop management practices and develop integrated pest management programs.
- Implement phytosanitary regulations to prevent the introduction of new pests (Van Barratt & Kuhlmann, 2005).

6. CONCLUSION

Invasive insect species are a major danger to biodiversity, agricultural systems, and ecosystems globally. Their introduction and spread, exacerbated by globalization and climate change, have resulted in significant economic

and environmental losses, notably in nations such as India. Addressing these difficulties demands a comprehensive international management strategy. This includes stricter regulation, increased worldwide collaboration for information sharing, and the construction of a hierarchical system with specialized professionals to analyze, monitor, and eradicate risks. Public awareness initiatives are also vital for reducing unintentional incursions. Natural enemies can be used to effectively manage and control invasive insect pests, acting as a vital counterbalance to these pests. By integrating these strategies, we can mitigate the impacts of invasive insects and safeguard both natural ecosystems and agricultural productivity.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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