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Invasive pest and diseases in Indian agriculture: Management and case studies

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ABSTRACT

Alien invasive insect pests threaten global food security, ecosystems, human health, and economies, with their introduction becoming inevitable amid globalization and liberalized trade. India has experienced a sharp rise in such invasions, from 10 recorded pests over a century (1889–1989) to over 15 in the last decade (2013–2023), exacerbated by the absence of natural enemies and delayed management. This paper critically reviews the status, entry pathways, and impacts of invasive pests in India, evaluates regulatory frameworks, and proposes strategic management measures. The study synthesizes documented evidence of recent invasions, including the Cassava Mealybug, Fall Armyworm, and South American Tomato Pinworm, alongside new alerts like the Apple Leaf Blotch Miner and Mango Soft Scale. Findings reveal that India's porous borders, diverse agro-climates, and crop vulnerabilities facilitate pest establishment, leading to severe agricultural losses. Despite existing regulations, enforcement gaps, and rapid trade increases hinder effective containment. The paper highlights the urgent need for enhanced surveillance, early detection systems, and integrated pest management (IPM) strategies. Practical implications include strengthening phytosanitary measures, fostering international collaboration, and promoting research on biological control agents. By addressing regulatory weaknesses and adopting proactive mitigation approaches, India can reduce the ecological and economic risks posed by invasive pests, safeguarding its agrarian economy and global trade interests.

Contribution/Originality: This study provides a comprehensive overview of serious invasive pests and diseases in India. This mini-review, based on existing literature, highlights various alien species, their potential management strategies, case studies, and threats to Indian agriculture.

1. INTRODUCTION

An alien species is one that humans have purposefully or unintentionally introduced from one geographic area to another, or by human agency, for societal or personal gain. It is also referred to as exotic, imported, non-indigenous, or non-native. When alien species become regionally dominant, they overrun natural communities and pose a severe threat to native biodiversity. These species are known as invasive alien species. (Management of alien species in India). According to Pimentel et al. [1] invasive alien species, which include introduced plants, animals, and other creatures, pose the second greatest threat to biodiversity and habitat degradation. Their establishment and spread endanger ecosystems, habitats, and other species [2]. According to Lowe et al. [3] the top 100 worst IAS in the world are made up of fish, birds, reptiles, plants, microbes, macrofungi, amphibians, and fish. It seems that certain characteristics, or certain combinations of characteristics, enable invasive species to outcompete native species. In India, systematic recording of invasive insect species is starting to take place [4]. The Zoological Survey of India (ZSI) has listed 157

alien invasive animal species for the first time. Of the 157 identified species by ZSI, 58 are found on land and in freshwater habitats, and 99 are found in marine ecosystems. This number does not include invading microbe species [5]. India contributes over 8% of the world's species diversity while making up only 2.4% of the planet's land area [6]. Viruses, infections, plants, and animal pests are examples of exotic invasive species that pose a major danger to the ecological and economic health of every habitat and region on Earth [7]. It is possible for alien creatures to accidentally or intentionally find their way into new areas. Travel across nations and continents, as well as the importation of various goods such as wood, cereals, fodder, etc., all contribute to accidental introductions [8]. Every invasive species possesses certain biological characteristics that contribute to their success in establishing new habitats. Compared to native plants, invasive alien plants have greater capacities for competitive resource capture and utilization, produce a high number of easily dispersible, lightweight seeds, and develop rapidly [9]. Typically, invasive species are robust, long-lived, ravenous, fiercely widespread, incredibly durable, have a broad diet, can travel great distances, and spawn copiously [10].

1.1. Steps of Invasion

The biological steps of colonization or invasion by alien organisms can be divided into four steps: introduction, establishment, spread, and naturalization.

Figure 1 illustrates the steps for the invasion of alien species

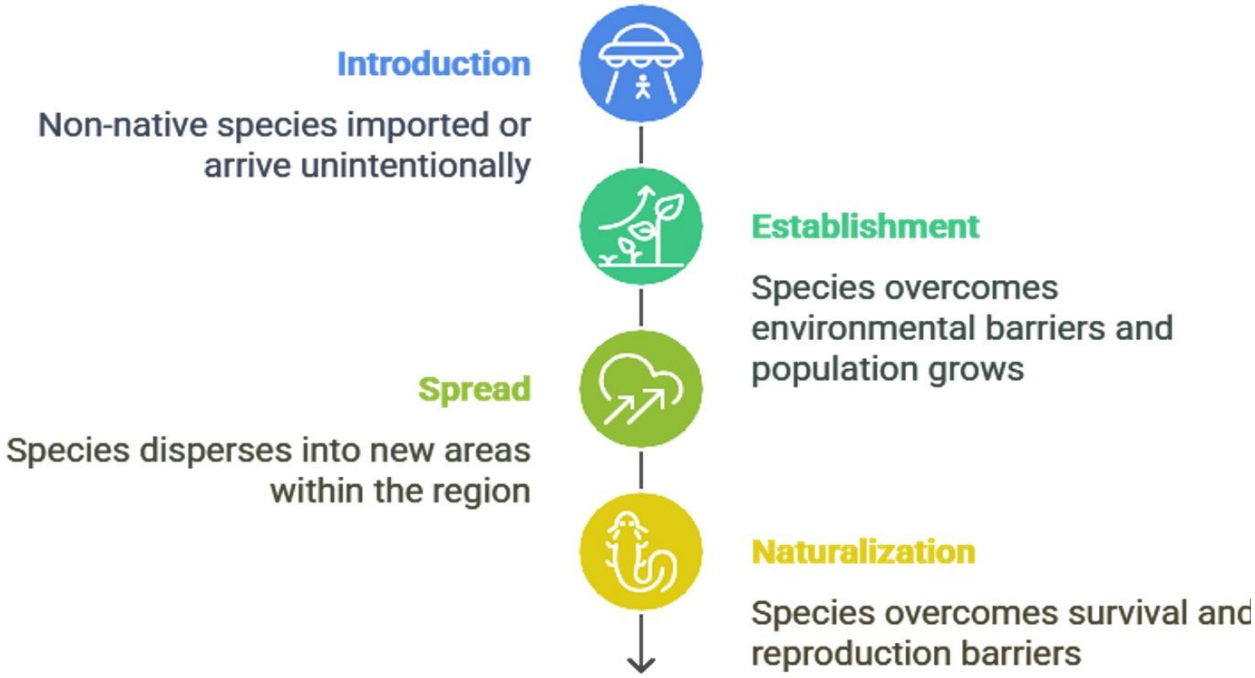

Figure 1. Presents the steps for the invasion of alien species.

Introduction: Some non-native species are imported intentionally for economic purposes, but many others arrive unintentionally in shipping containers, lurking under the bark of log imports, infesting fruits carried by tourists, swimming in ballast water exchanged in harbors, quietly reproducing in the intestines or bloodstream of unsuspecting travelers, or hidden in the soil of imported ornamental plants. Most are harmless or fail to become established, but some proliferate and spread in ways that endanger native species in the invaded ecosystem, undermine agriculture, threaten public health, or create other unwanted and often irreversible disruptions. Six broad mechanisms by which alien species might be introduced to a region have been described [11]: deliberate release (e.g., game animals, sport fishes, pets); escape from captivity (e.g., ornamental garden plants, pets); contaminants of commodities (e.g., weed seeds, pest insects, microbial pathogens); stowaways on transport vectors (e.g., marine organisms fouling ship hulls

or in ballast water, latent endophytic pathogens in plants); anthropogenic corridors (such as through the Suez and Panama Canals); or unaided spread from other invaded regions. The initiation of the process through the introduction of invasives can occur through: (i) long-distance migrations or movements (e.g., the brown planthopper, *Nilaparvata lugens* in rice); (ii) transportation (e.g., Parthenium along with wheat grains in India); (iii) human activities; (iv) aquarium plants (e.g., water fern, water lettuce).

Establishment: Once the invasive species has overcome the environmental barriers in the introduced area, it then establishes itself, and at this stage, populations are sufficiently large, making the probability of local extinction due to environmental factors negligible.

Spreading: The spreading of a species into areas away from initial sites of introduction requires that the introduced species also overcome barriers to dispersal within the new region, which can cope with the abiotic environment and biota in the area.

Naturalization: Naturalization begins when abiotic and biotic barriers to survival rates are surmounted and when various barriers to regular reproduction are overcome.

1.2. Growth of Invasive Pest Numbers in India

The invasive pest species pose a substantial threat to biodiversity, due to various factors:

a. Expansion of geographic range, climate change, and its impact on insects and pests: Insect pests are expected to extend their geographic range from the tropics and subtropics to temperate regions, which will lead to increased abundance of tropical insect species and sudden outbreaks of pests. Climate change also influences the ecology and biology of insect pests and diseases. Increased temperatures cause migration of insect species towards higher latitudes, while in the tropics, higher temperatures might adversely affect specific pest species. The likely impacts of any change in climate on pest populations are manifold [12]. Temperature is probably the single most important environmental factor influencing insect behavior, distribution, survival, and reproduction. It has been estimated that with a 2°C temperature increase, insects might experience one to five additional life cycles per season. *Helicoverpa armigera* is continuously expanding in northern India on cotton, pulses, and vegetables [13].

b. Physiological and ecological impacts: Some species that are able to adapt to warmer climates may become major pests. Differential responses to various environmental factors could disrupt synchronization in phenology between insects and host plants or natural enemies [14].

c. Changes in pest herbivory: More sap-feeding insects are expected to emerge as major pests when plants are grown in elevated levels of carbon dioxide [15]. Lower foliar nitrogen content due to increased CO2 causes an increase in food consumption by herbivores, up to 40%, and increased overwintering survival. The temperature in India is expected to rise by 1-5°C within the next 100 years. Accelerated metabolic rates at higher temperatures may shorten the duration of insect diapause due to faster depletion of stored nutrient resources [16].

d. Increase in the number of generations: With every 2°C rise in temperature, multivoltine insects may have 1-5 additional generations.

e. Breakdown of host plant resistance: Severe yield loss in sorghum may occur in India due to the breakdown of resistance against midge *Stenodiplosis sorghicola* and spotted stem borer *Chilo partellus* [17].

1.3. Invasive Pests in India

India has experienced the introduction of several invasive insect pests that have caused significant damage to agriculture and horticulture. One such pest is the Woolly Apple Aphid (*Eriosoma lanigerum*), introduced in the 18th century from China via imported apple rootstock. It was first recorded in Conoor (1889) and became a major pest by 1920 [18]. This pest attacks apples and pears, sucking sap and damaging roots. Biological control through the parasitoid *Aphelinus mali* successfully reduced its population by 98% in Kullu Valley, though attempts in other regions failed. Another serious pest, San Jose Scale (*Quadraspidiotus perniciosus*), native to China, reached India in 1911 and

became a major pest by 1933. It affects a variety of temperate trees, including *Populus* and *Morus* species. Infestation leads to bark cracking and yield loss. Natural enemies like *Encarsia perniciosi* and *Chilocorus bijugus* were found effective [19]. The Cottony Cushion Scale (*Icerya purchasi*), introduced from Australia in 1921, caused damage to Acacia species and was effectively controlled by the predator *Rodolia cardinalis*. The Potato Tuber Moth (*Phthorimaea operculella*), introduced with Italian potato imports in 1937, affects stored potatoes and solanaceous crops. It mines leaves and tubers, completing up to 12 generations per year [20]. Parasitoids like *Chelonus blackburni* and *Copidosoma koehleri* help in management. The Diamond-Back Moth (*Plutella xylostella*), first recorded in India by Fletcher [21]. It is a serious pest of crucifers. Early instars mine the underside of leaves, and later instars create holes. It shows resistance to cypermethrin and fenvalerate. In Tamil Nadu, *Brachymeria excarinata* and *Tetrastichus sokolowskii* showed 59.9% and 18.2% parasitism, respectively [22], while in Bangalore, *A. plutellae* was effective [23]. The Silverleaf Whitefly (*Bemisia tabaci*), introduced in 1999 in Karnataka, is polyphagous and transmits Tomato Yellow Leaf Curl Virus (ToLCV). It causes damage by sap removal and the development of sooty mould. Effective natural enemies include *Encarsia formosa*, *Chrysoperla carnea*, and *Delphastus pusillus*. The Papaya Mealybug (*Paracoccus marginatus*), noticed in Coimbatore in 2007, became a major pest by 2009, affecting crops like papaya, cotton, and guava. It produces honeydew leading to sooty mould, and was successfully managed by importing *Acerophagus papayae* from the USA.

The Fall Armyworm (*Spodoptera frugiperda*), a polyphagous pest affecting maize and over 100 plant species, was reported from Karnataka in 2018 [24]. It causes whorl feeding, leaf damage, and dead heart symptoms. Natural enemies such as *Telenomus sp.* and *Trichogramma sp.* are helpful in its control. The Erythrina Gall Wasp (*Quadrastichus erythrinae*), noticed in Kerala and Karnataka around 2005-06, caused major damage to *Erythrina* trees used in black pepper plantations, with *Aprostocetus exertus* identified as an effective biocontrol agent [25]. Finally, the Tomato Leaf Miner (*Tuta absoluta*), native to Peru, was recorded in Pune in 2014 [26]. It damages tomato by mining in leaves and fruits, with *Nesidiocoris tenuis* and *Neochrysocharis formosa* providing control [27]. These examples highlight the threat posed by invasive insect pests and the importance of classical biological control in India's integrated pest management strategies. Table 1 lists the most important invasive pests of India.

Table 1. Is list of Important invasive pests of India..

S. No.	Pest Name	Origin	Host(s)	Damage	Biological Management
1	Woolly apple aphid (*Eriosoma lanigerum*)	China (via rootstock)	Apple, pear	Suck sap, root swellings, plant decline	Parasitoid: *Aphelinus mali*; Predators: *Coccinella septempunctata*, *Exochomus uropygialis*, etc.
2	San Jose scale (*Quadraspidiotus perniciosus*)	China	Poplar, willow, mulberry, others	Sapsucking on stems/fruits, bark cracks, and growth cessation	Parasitoids: *Aphytis sp.*, *Encarsia perniciosi*; Predator: *Chilocorus bijugus*
3	Cottony cushion scale (*Icerya purchasi*)	Australia	Acacia spp., ornamentals	Sap feeding, major damage in the Nilgiri hills	Predator: *Rodolia cardinalis*
4	Potato tuber moth (*Phthorimaea operculella*)	Italy	Potato, tobacco, tomato, brinjal	Leaf mines, tuber entry, multiple generations	Parasitoids: *Chelonus blackburni*, *Copidosoma koehleri*
7	Papaya mealybug (*Paracoccus marginatus*)	Noted in Coimbatore (2007)	Papaya, cotton, guava, and many crops	Honeydew & sooty mould on leaves/fruits	Parasitoid: *Acerophagus papayae* (from USA)
8	Fall armyworm (*Spodoptera frugiperda*)	India (Karnataka, 2018)	>100 spp., mainly maize, sorghum	Whorl feeding, dead heart, tassel damage	Parasitoids: *Telenomus sp.*, *Trichogramma sp.*
9	Erythrina gall wasp (*Quadrastichus erythrinae*)	Noted in Kerala (2005)	Coral tree (*Erythrina spp.*)	Gall formation in petioles, leaves	Parasitoid: *Aprostocetus exertus*
10	Tomato leaf miner (*Tuta absoluta*)	Peru (Pune, India in 2014)	Tomato, solanaceous crops	Mines in leaves, buds, fruits	Predator: *Nesidiocoris tenuis*; Parasitoid: *Neochrysocharis formosa*

1.4. Invasive Diseases in India

Several plant diseases have historically impacted Indian agriculture, causing significant crop losses and affecting livelihoods. One of the earliest recorded is coffee rust (*Hemileia vastatrix*), first observed in Ceylon in 1868 and in India by 1879 in Karnataka. It remains prevalent in Karnataka, Kerala, and parts of Madhya Pradesh, severely affecting leaves and leading to reduced yields. Management involves the destruction of infected foliage and the use of resistant varieties like S 238 and S 395, along with Bordeaux mixture sprays. Potato late blight (*Phytophthora infestans*), historically infamous for the Irish Famine, was reported in India in 1883 in the Nilgiris and Darjeeling. It damages leaves, stems, and tubers, leading to up to 70% yield losses in epidemic years. Recommended control includes fungicide sprays (mancozeb/zineb), tuber handling precautions, and cultivation of resistant varieties like Kufri Naveen and Kufri Moti. Paddy blast (*Pyricularia oryzae*) has been known since ancient rice cultivation and was first noted in India in 1913. It affects all aboveground parts, causing typical spindle-shaped lesions. Use of resistant varieties (IR-64, CO 47) and systemic fungicides like tricyclazole is effective. Flag smut of wheat (*Urocystis tritici*) was first seen in Australia and later reported in India in 1918. It affects wheat leaves and stems, causing sori filled with dark spores. Control includes seed treatment with carboxin and the use of resistant varieties such as Pusa 44.

Table 2 presents the list of important invasive diseases of India

Table 2. Shows the important invasive diseases of India.

S. no.	Disease (Pathogen)	Origin	Host & damage	Management
1	Coffee Rust (*Hemileia vastatrix*)	First reported in India (1879), Karnataka. Common in Karnataka, Kerala, and MP.	Host: Coffee. Affects leaves and tender shoots; yellow to brown spots, defoliation, and stunted plants with reduced yield.	Destroy diseased leaves, grow resistant varieties (S 238, S 395), and spray Bordeaux mixture (0.5%) seasonally.
2	Potato Late Blight (*Phytophthora infestans*)	Reported in India (1883) in Nilgiris and Darjeeling.	Host: Potato, Tomato. Leaf and tuber blight, purple-brown lesions, white fungal growth, and yield loss up to 70%.	Spray Mancozeb/Zineb (0.2%), use resistant varieties (Kufri Naveen, Kufri Moti), and avoid tuber injuries.
3	Paddy Blast (*Pyricularia oryzae*)	Reported in India (1913); major outbreak in 1919 (Tanjore Delta, TN).	Host: Rice. Attacks all aboveground parts. Spindle-shaped lesions, neck and panicle rot, and grain loss.	Use tolerant varieties (IR-64, CO 47), seed treatment, and apply tricyclazole.
4	Flag Smut of Wheat (*Urocystis tritici*)	Reported in India (1918), Layallpur (Punjab).	Host: Wheat. Causes grey-black sori on leaves, leaf twisting, wilting, and spore balls.	Seed treatment with carboxin (2g/kg), resistant varieties (Pusa 44, WG 377).
5	Potato Wart (*Synchytrium endobioticum*)	Reported in India (1952), Darjeeling.	Host: Potato. Causes granular swellings on the eyes, turns black, and reduces marketability.	Resistant varieties (Kufri Jyoti), soil sterilization (formalin, mercuric chloride).
6	Rice Bacterial Leaf Blight (*Xanthomonas oryzae pv. oryzae*)	Reported in India (1951), an epidemic in 1963 (Bihar).	Host: Rice. Yellow lesions, leaf drying, Kresek symptom in seedlings.	Burn stubbles, grow resistant varieties (IR 20, TKM), apply streptomycin + copper oxychloride.
7	Banana Bunchy Top (BBTV)	Observed in India around 1940 (Kerala).	Host: Banana. Causes leaf streaks, bunching, no fruit, twisted bananas.	Use virus-free suckers, remove infected plants, and apply Fernoxone.
8	Potato Cyst Nematode (*Heterodera rostochiensis*)	Detected in India (1961), Ooty (Tamil Nadu).	Host: Potato. Symptoms include stunted growth, yellowing, root galls, and female cysts on roots.	Crop rotation (3-7 years), resistant varieties (Kufri Swarna), apply carbofuran.

Potato wart (*Synchytrium endobioticum*), reported in 1952 in Darjeeling, is a severe tuber disease causing wart-like outgrowths. Although movement restrictions were implemented, the disease remains a concern. Resistant cultivars (e.g., Kufri Jyoti) and soil disinfection methods are employed. Bacterial leaf blight of rice (*Xanthomonas oryzae* pv. *oryzae*) was first observed in India in 1951 and became widespread with the introduction of susceptible varieties. Symptoms include leaf lesions and the "Kresek" symptom in seedlings. Management includes sanitation, resistant

cultivars (IR 20, TKM), and streptomycin-based sprays. Banana bunchy top virus (BBTV), introduced from Sri Lanka around 1940, causes a bunched appearance of leaves and often prevents fruiting. Aphids and infected suckers spread the virus. Control involves removing infected plants and using virus-free suckers. Lastly, potato cyst nematode (*Heterodera rostochiensis*), detected in India in 1961, causes stunted plants and early senescence. Long crop rotations, resistant varieties (Kufri Swarna), and carbofuran application are effective control measures. These historical outbreaks underline the importance of plant pathology, quarantine, and integrated disease management to sustain agriculture in India.

1.5. Management

What tools we have?

A. International agreements, legislation, and voluntary self-regulation:

Efficient responses to biological invasions require prioritizing measures to prevent the arrival of potentially invasive alien species, the timely management of incursions, and effective management of those already established [2]. Achieving these goals requires implementing mechanisms to regulate the intentional introduction of alien species and identifying pathways and mitigation methods for unintentional arrivals. It also demands enforcing preventive measures and ensuring the timely deployment of protocols for detection and rapid response to deal with new incursions. Protocols are needed to assess the feasibility of eradicating newly established Invasive Alien Species (IAS) and to design cost-effective management of widespread IAS that cause the most severe impacts [28].

B. National biosecurity programs:

The term 'biosecurity' refers to measures to prevent and manage biological invasions [29]. A close correspondence exists between the various stages of the invasion process and different biosecurity activities. For example, border biosecurity refers to measures such as inspection, quarantines (bans on imports), and sanitary treatments (e.g., fumigation) of imported goods at or near the border. Every country implements biosecurity measures to protect natural resources and citizens from invasion-related impacts.

International trade creates important pathways for the accidental movement of alien species, and the trend of increasingly globalized economies has contributed to increased invasion rates. To address this problem, the World Trade Organization designated the International Plant Protection Convention of the UN Food and Agriculture Organization as the international standard-setting body for border biosecurity [30].

The IPPC provides rules by which national plant protection organizations can implement biosecurity practices. The IPPC also sets standards that are harmonized among countries to limit the spread of invasive alien species while promoting free trade. Under IPPC guidelines, each country is able to select a level of predetermined risk when implementing biosecurity practices.

C. Technological advances in management:

Established populations of IAS have long been managed to low densities or even eradicated, primarily through three methods: mechanical or physical control, chemical control, and biological control. Each method has recorded substantial successes as well as failures, but incremental technological advances have improved all three methods and reduced non-target impacts [31]. Significant advances have occasionally enabled the successful management or eradication of a much broader range of invasions [32].

Invasive insects, especially lepidopterans, have long been managed with pheromones, particularly through attract-and-kill or mating disruption methods [33]. Similarly, the male-sterilization technique has been widely used to manage or eradicate invasive insect populations [34].

D. Surveillance and monitoring:

The importance of early-warning and rapid-response initiatives, and concurrently the need for surveillance to inform such approaches, is widely recognized. Most countries do not implement integrated national invasive alien species surveillance programs.

Figure 2 illustrates diverse strategies for the management of invasive pests

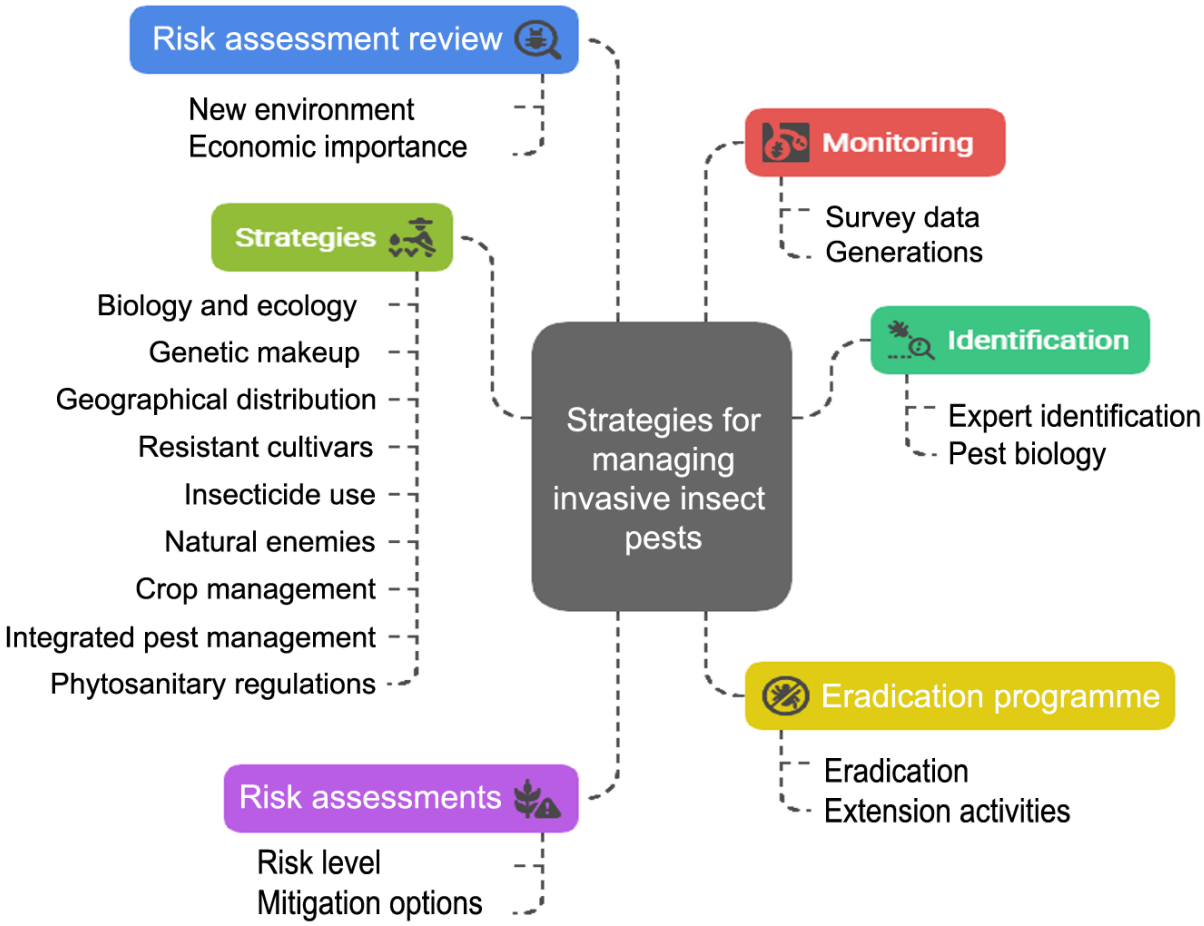

Figure 2. Depicts Strategies for the management of invasive pests..

1.6. Case Studies

The Papaya Mealybug (*Paracoccus marginatus*), first reported in Coimbatore, Tamil Nadu in 2007, rapidly became a serious invasive pest across India by 2009, damaging over 60 plant species, including papaya, mulberry, tapioca, and cotton, with incidence reported in Karnataka by 2010. It causes damage by sucking plant sap, leading to crinkled leaves, sooty mould formation, and a reduction in photosynthesis. Effective control was achieved through classical biological control using parasitoids such as *Acerophagus papayae*, *Anagyrus loecki*, and *Pseudleptomastix mexicana*, and predators like *Cryptolaemus montrouzieri* [35, 36]. The invasive weed Lantana camara, introduced in India in 1807 as an ornamental plant, has since spread across 13.2 million hectares, affecting forests, pastures, and croplands, particularly in the Himalayan foothills where it shelters crop-damaging wild boars. It is considered one of the most aggressive invasive plants due to its prolific growth [17, 37, 38]. The Potato Wart disease, caused by *Synchytrium endobioticum*, was introduced into Darjeeling from Denmark in 1953, and despite control measures including soil sterilization and domestic quarantine under the DIP Act (1959), it still persists in parts of West Bengal, causing significant losses by forming soft, warty galls on potato tubers [39-42].

2. CONCLUSION

The management of invasive pests in India presents a significant challenge to sustainable agriculture due to their destructive impact on a wide range of crops and the rapidity with which they spread. Effective strategies should focus on early detection, strict quarantine measures, the use of biological control agents, and integrated pest management (IPM) practices. Strengthening farmer awareness, enforcing regulatory frameworks, and promoting research on pest

biology and eco-friendly control methods are crucial to mitigate the threats posed by these invasive species. Collaborative efforts among government agencies, research institutions, and farming communities are essential to protect crop yields, biodiversity, and national food security.

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