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Status of invasive insect pests of India and their natural enemies

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Abstract

Invasive insect pest are one of the major and most rapidly growing threats to agricultural biodiversity, forestry, human and animal health, etc. resulting in huge economic losses. Incidence of invasive insect pests such as Woolly apple aphid; *Eriosoma lanigerum* (Hausmann), San Jose scale; *Quadraspidiotus perniciosus* (Comstock), Lantana bug; *Orthezia insignis* Browne, Cottony cushion scale; *Icerya purchasi* Maskell, Potato tuber moth; *Phthorimaea operculella* (Zeller), Diamond back moth; *Plutella xylostella* (Linn.), Pine woolly aphid; *Pineus pini* (Macquart), Subabul psyllid; *Heteropsylla cubana* Crawford, Serpentine leaf miner; *Liriomyza trifolii* (Burgess), Coffee berry borer; *Hypothenemus hampei* (Ferrari), Spiraling whitefly; *Aleurodicus disperses* Russell, Silver leaf whitefly; *Bemisia argentifolii* Bellows, Blue gum chalcid; *Leptocybe invasa* Fisher & La Salle, Coconut eriophid mite; *Aceria gurreronis* Keifer, Papaya mealy bug; *Paracoccus marginatus* Williams & Granara de Willink, Cotton mealy bug; *Phenacoccus solenopsis* Tinsley, Erythrina gall wasp; *Quadrastichus erythrinae* Kim, South American tomato leaf miner; *Tuta absoluta* Meyrick, Fall armyworm; *Spodopерda frugiperda* (J.E. Smith) has been noticed. The invasion of the pests in new areas sometimes lead to the outbreak of the pest due to lack of natural enemies. Therefore, exploration should be made in the areas of origin of the pests or efforts should be made to search some effective natural enemies in the invaded area so that the pest population could be curtailed with in Economic Threshold Level. These invasive insect pests can be minimized with the use of biological control agents or their natural enemies and quarantine set up need to be upgraded as this could result in the globalization of pests.

Keywords: invasive insect pest, natural enemies

1. Introduction

Invasive species are one of the major and most rapidly growing threats to agricultural biodiversity, livelihoods, human and animal health, forestry and biodiversity and result in huge economic losses [1-2]. Invasive insect pests are non-native or exotic organisms that occur outside their natural adapted habitat and dispersal potential. However, some of the invasive insect pests become invasive when they are introduced deliberately or unintentionally outside their natural habitats into new areas where they express the capability to establish, invade and outcompete native species [3]. According to the International Union for Conservation of Nature and Natural Resources (IUCN) invasive insect pest is one which becomes established in natural or seminatural ecosystems or habitat, and threatens native biological diversity. The invasives are widely distributed in all kinds of ecosystems throughout the world.

The globalization has increased international agricultural trade, and movement of seeds and planting materials has enhanced the risk of introduction of invasive insect pests into India. These insect pests can multiply in large proportion and cause damage to economically important plant species and crop plants.

The invasive insect pests become invasive in introduced area due to the absence of natural enemies and congenial environment parameters. National Plant Protection Organizations (NPPO) has curtailed the accidental or intentional introduction of plant pests into newer areas through legal mechanisms.

In India, the Directorate of Plant Protection, Quarantine and Storage is responsible for implementation of Destructive Insect and Pest Act, 1914 through Plant Quarantine (Regulation of Import into India) Order, 2003 to prevent entry, establishment and spread of exotic plant pests into India to safeguard agriculture, horticulture and forest tree plants. Plant Quarantine stations are established at various points of entry such as seaports, airports and land frontiers to

implement the provisions of PQ Order, 2003.

Invasive species

Invasive alien species occur in all major taxonomic groups, including viruses, fungi, algae mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals. Invasive species tend to be, hardy, long lived, voracious, aggressively pervasive, very resilient, rapid growth, generalized diet, ability to move long distances and prolific breeding^[4].

Steps of Invasion

Invasion by alien organisms can be divided into four steps, i. Introduction, ii. Establishment, iii. Spread, iv. Naturalization.

Introduction: Some non-native species are imported intentionally for economic purposes, but many others arrive unintentionally in shipping containers, infesting fruits carried by tourists, or hidden in soil of imported ornamental plants. The introduction of invasives can occur through: Long

distance migrations or movements (e.g. the brown planthopper, *Nilaparvata lugens* in rice), Transportation e.g. Parthenium along with wheat grains in India, Human activities and Aquarium plants e.g. water fern, water lettuce.

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

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

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

Table 1: Some of the invasive insect pests in India are listed below:

Common Name	Scientific Name	Year of Introduction	Reference
Woolly apple aphid	<i>Eriosoma lanigerum</i> (Hausmann)	1889	Mishra (1920) ^[5]
San Jose scale	<i>Quadraspidiotus perniciosus</i> (Comstock)	1911	Singh (2004) ^[6]
Lantana bug	<i>Orthezia insignis</i> Browne	1915	Muniappan <i>et al.</i> , 1986 ^[7]
Cottony cushion scale	<i>Icerya purchasi</i> Maskell	1921	Singh (2004) ^[6]
Potato tuber moth	<i>Phthorimaea operculella</i> (Zeller)	1937	Singh (2004) ^[6]
Diamond back moth	<i>Plutella xylostella</i> (Linn.)	1914	Fletcher (1914) ^[8]
Pine woolly aphid	<i>Pineus pini</i> (Macquart)	1970	Singh (2004) ^[6]
Subabul psyllid	<i>Heteropsylla cubana</i> Crawford	1988	Jalali & Singh (1989) ^[9]
Serpentine leaf miner	<i>Liriomyza trifolii</i> (Burgess)	1990	Singh (2004) ^[6]
Coffee berry borer	<i>Hypothenemus hampei</i> (Ferrari)	1990	Vega <i>et al.</i> , (1999) ^[10]
Spiraling whitefly	<i>Aleurodicus disperses</i> Russell	1993	Palaniswami <i>et al.</i> , (1995) ^[11]
Silver leaf whitefly	<i>Bemisia argentifolii</i> Bellows	1999	Singh (2004) ^[6]
Blue gum chalcid	<i>Leptocybe invasa</i> Fisher & La Salle	2006	Singh (2004) ^[6]
The coconut eriophid mite	<i>Aceria gurreronis</i> Keifer	1997	Singh (2004) ^[6]
Papaya mealy bug	<i>Paracoccus marginatus</i> Williams & Granara de Willink	2005	Jhala <i>et al.</i> , 2008 ^[12]
Cotton mealy bug	<i>Phenacoccus solenopsis</i> Tinsley	2006	Nagrare (2009) ^[13]
Erythrina gall wasp	<i>Quadraspidiotus erythrinae</i> Kim	2005	Faizal <i>et al.</i> , 2006 ^[14]
South American tomato leaf miner	<i>Tuta absoluta</i> Meyrick	2014	Sridhar <i>et al.</i> , 2014 ^[15]
Fall armyworm	<i>Spodoperda frugiperda</i> (J.E. Smith)	2018	Shylesha <i>et al.</i> , 2018 ^[16]

Some of the invasive pests in India are listed below

1. Woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Aphididae: Homoptera)

This pest was introduced in India during the 18th century with imported apple rootstock from China. It was first recorded in Conoor during 1889 and in 1909 reported from Kumaun in Hills of Uttar Pradesh (now in Uttarakhand) and in 1910 from Shimla. During 1920, it reached a pest status in India^[5].

Hosts: Primarily apple and pear etc.

Damage: Adults and nymphs suck the sap from the plants. They also attack the roots which develop swellings, the whole plant look sickly appearance and it may even die.

Natural enemies: Release of *Aphelinus mali* during 1930 in Kullu valley resulted 98% suppression of the pest. The same parasitoid when released in Shimla, Coimbatore, Shillong failed to establish. The effective predators are *Coccinella septempunctata*, *Coccinella transversoguttata*, *Balli aancharis*, *Chrysopa nigricornis*, *Exochomus uropygialis*,

Coleophora sunzetti etc.

2. San Jose scale, *Quadraspidiotus perniciosus* (Comstock) (Diaspididae: Homoptera)

The San Jose scale was a native of China and it reached India in 1911 and by 1933 had attained pest status in fruit orchards and plantations of poplars and willows.

Host: *Populus spp.*; *Salix spp.*; *Aesculus spp.*; *Alnus spp.*; *Betula spp.*; *Celtis spp.*; *Fagus spp.*; *Morus spp.* It also damage spp. of *Aesculus*, *Alnus*, *Celtis*, *Fraxinus* and *Morus*.

Damage: Nymphs and adults suck sap from twigs, branches and fruits. All above ground parts of the plants are infested. Attacks are generally on stems, branches but, in severe infestations, leaves and fruits may also be penetrated, bark often gets cracked and exudes gum, resulting in a surrounding dark brown gelatinous area. Heavy infestation causes cessation of growth and loss of yield. The infested region on bark turns into pink colour.

Natural enemies: The local natural enemies from Himachal Pradesh as reported by Rawat and Pawar ^[17] which included the *Aphytis sp.*, *Novaproclia* (Walker), *Encarsia perniciosi* (Towers) and the *Teleterbratus perversus* Compere and Zinna. The Predator, *Chilocorus infernalis* was reported by Rawat *et al.*, ^[18].

3. Lantana bug, *Orthezia insignis* Browne (Orthezidae: Homoptera)

In 1915 it was introduced into India, Nilgiri region from Sri Lanka or West Indies.

Hosts: Lantana, Coffee, Jacaranda, Citrus, Sweet potato, Gumwood, Brinjal, Rose etc.

Damage: *Orthezia insignis* is a mobile scale insects, Adult female has a large wax ovisac and species is parthenogenic. Eggs hatch inside the ovisac and the 1st instar nymphs then move out to feed.

Natural enemies: *Hyperaspis pantherina* Fursch (Coleoptera: Coccinellidae)

4. Cottony cushion scale, *Icerya purchase* Maskell (Margarodidae: Homoptera)

It was accidentally introduced into India in 1921.

Hosts: *Acacia decurrens*; *A. deabata* in addition to numerous other forestry and agricultural plant species.

Damage: The cotton cushion scale has done serious damage to plants in Nilgiri and Annamalai hills in South India and has become established throughout the country.

Natural enemies: *Rodolia cardinalis* was introduced for the control of this scale, and it has proven to be a very effective predator. Over the winter of 1888–1889 a lady beetle called vedalia beetle was introduced into California from Australia to combat cottony cushion scale, *Icerya purchase*.

5. Potato Tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae)

It was introduced with imported potato from Italy to India in 1937 and has spread through out India. It is distributed in almost all parts of the world.

Hosts: Tobacco, tomato, brinjal, beet and it is a serious pest of stored potato.

Damage: Caterpillars initially mine into leaves and later make way in veins into petioles, then to stem and some time to the tubers in soil. It can complete 12 generations in one year ^[19]. After the potato is harvested, the insect may continue to develop on tubers or volunteer plants remaining in the field including other solanaceous plants such as tomatoes ^[20–21].

Natural enemies: Insecticides commonly use to keep the pest below ETL with bio agents *Chelonis blackburni* and *Copidosoma kochleti* ^[22], *Chrysoperla zastrowi sillemi*, *Orius albidipennis* and *Labidura riparia* ^[23].

6. Diamond back moth, *Plutella xylostella* (Linn.) (Plutellidae: Lepidoptera)

In India, Diamond Back Moth was first recorded in 1914 ^[8] on cruciferous vegetables now it is distributed all over India wherever crucifers are grown.

Hosts: Cabbage, cauliflower, radish, knoll khol (rabi), turnip, beetroot, mustard.

Damage: Early instars mine undersurface of leaves and later instars make holes and feed. It was highly resistant to cypermethrin and fenvalerate and lower level to deltamethrin ^[24].

Natural enemies

Parasitoids: In Coimbatore, Tamil Nadu, Cherian and Basheer ^[25] observed 59.9% parasitization by *Brachymeria excarinata* Gahan and 18.2% parasitization due to *Tetrastichus sokolowskii* Kurdj. In Bangalore, ^[26] *A. plutellae* and *T. sokolowskii* causing 16 to 52% mortality and 28 to 96% parasitization of 2nd instar DBM larvae. The hyperparasites, appeared from August to October with a low (3.13%) parasitism in October and a high parasitism (39.13%) in September, the latter coinciding with peak parasitism by *A. plutellae* on the primary host.

Predators: Yellow wagtails (*Motacilla flava* Linnaeus) were found to feed on DBM larvae in Bangalore during cold season ^[26]. Jayarathnam further observed that the ants, *Tapinoma melanocephalum*, *Pheidole spp* and *Camponotus sericeus* were carrying away DBM larvae in the field.

7. Pine woolly aphid, *Pineus pini* (Macquart) (Adelgidae: Homoptera)

In India it was introduced in 1970, *P. pini* has caused severe damage to *Pineus patula* plantations in the Nilgiri hills of South India. This aphid has moved into new areas mostly by movement of infested planting stock.

Hosts: *Pineus spp.*; *Pineus patula*

Damage: The pine woolly aphid feeds on the shoots of *Pinus spp.*, at times causing tip dieback. Control of this pest by biological control is variable. In some areas control by biological control method has been successful and whereas in other areas it was not successful.

8. Subabul psyllid, *Heteropsylla cubana* Crawford (Psyllidae: Homoptera)

It is a native of Central America and was introduced into India during 19th century, The *Leucaena* psyllid was described from Cuba by Crawford in 1914 and it started its journey in 1983 when outbreaks occurred in Florida and it was also intercepted in Hawaii in 1984. Within a short span of two years it reached Sri Lanka in 1986 crossing the Pacific Ocean and was noticed in Chengalpattu district of Tamil Nadu, India during 1988 and Bangalore during May 1988 ^[27].

Damage: It sucks the sap from the young shoots, leaves and inflorescences which results in complete deformation of young shoots, plants of *Leucaena* species. In severe cases plant could not recover ^[28]. In Karnataka, plantation of *Leucaena* was abandoned due to the psyllid attack ^[29].

Natural enemies: In 1988, the lady beetle, *Curinus coeruleus* Mulsant from Mexico was introduced into India for the biological suppression of *H. cubana*. For ecological and

economic reasons, classical biological control has been deemed the most appropriate management strategy to control the psyllid [30].

9. Serpentine leaf miner, *Liriomyza trifolii* (Burgess) (Agromyzidae: Diptera)

The Serpentine leaf miner, *Liriomyza trifolii* (Burgess) entered India accidentally, during 1990-1991. The native country of this pest is USA (Florida). It was introduced probably along with cut chrysanthemum flowers during the early 1970s to California, USA [31]. The first report of its occurrence in India appeared in the proceedings of the annual castor research workers' group meeting held at Hyderabad [32].

Hosts: It is a polyphagous species affecting more than 78 annual plant species being especially serious on pea, cucurbits, tomato, castor and ornamental plants [33].

Damage: The adult female makes punctures in the leaf tissue with its ovipositor for both feeding and oviposition. The ratio of oviposition punctures to feeding punctures varies from 1:6 to 1:14. The larvae that hatch out from the eggs mine the leaf feeding on the mesophyll region leaving a serpentine structure. *Liriomyza* leaf miner may act as a vector of disease, kill seedlings, cause reduction in crop yields, accelerate leaf drop thus exposing the fruits like tomato for sunburn and reduce the aesthetic value of ornamental plants [31].

Natural enemies: A number of parasitoids attack larval and pupal stages of *L. trifolii* in its native country. Forty-five species of Chalcidoidea and Braconidae have been reported on larval and pupal stages of *L. trifolii* from different parts of the world. The parasitism in some areas may be as high as 51-98 per cent [34]. In India, parasitism by the indigenous parasitoids ranges from 0-39 per cent in Bangalore on tomato and cucumber and 49 per cent in Gujarat on castor [35] *Hemiptarsenus varicornis* (Girault) is the most pre dominant one. *D. begini* was introduced into India from California, USA and field released in the vegetable gardens around Bangalore during 1997 where it has not established in the field.

10. Coffee berry borer, *Hypothenemus hampei* (Ferrari) (Scolytidae: Coleoptera)

Coffee berry borer is believed to be native of Northeast Africa. In India it was for the first time reported from Gudalur in the Nilgiris during 1990. It has now spread into many coffee growing areas of Tamil Nadu (Gudalur and Kilkotagiri), Kerala (Wyanad) and Karnataka (Kodagu).

Hosts: It attacks both Arabica and Robusta types of coffee.

Damage: The adult beetle measures 1.0-1.9mm, brownish-black. The population is usually female dominated. The fertilized female bores an entrance hole at the terminal pore or in the calyx ridge of the differential tissue that surrounds the pore and lays bean shaped eggs.

Natural enemies: Parasitoids like, *Prorops nasuta* Waterston, *Cephalonomia stephanoderis* Betrem were introduced from Mexico into India and *Phymastichus coffea* Lasalle (Hymenoptera: Eulophidae) from Colombia (NBAII, Bangalore and the Coffee Board). *Cephalonomia*

stephanoderis Betrem (Homoptera: Bethyilidae) was the most abundant coffee berry borer parasitoid followed by *Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae) [11].

11. Spiraling whitefly, *Aleurodicus disperses* Russell (Aleyrodidae: Homoptera)

This is a native of the Caribbean region and Central America. It was first reported from India in 1993 from Kerala [12] and later from other parts of peninsular India [36].

Hosts: It is highly polyphagous affecting a wide range of host plants- 481 plants.

Damage: Nymphs and adults suck sap from host plants and can cause premature leaf drop. Copious white, waxy flocculent material secreted by the nymphs. Furthermore, sticky honeydew is produced which serves as a substrate for dense growth of sooty mould interfering with photosynthesis.

Natural enemies: Srinivasa *et al.* [37] reported the occurrence of *Encarsia haitiensis* Dozier in Bangalore, Karnataka. The per cent parasitization ranged from 0.00-38.88 on different host plants being highest on *Cassia siamea* Lamk. (Fabaceae). Ramani [38] reported both *E. haitiensis* and *Encarsia guaeloupe* viggiani from Lakshadweep Islands (India). The two native predators, *Axinoscymnus puttarudiahii* Kapur (Coleoptera: Coccinellidae) are able to discriminate between the parasitized and healthy larvae and pupae [38]. Predators *Oecophylla smaragdina* (F.) and *Solenopsis geminata* (F.) was also effective [39].

12. Silver leaf white fly, *Bemisia argentifolia* Bellows (Aleyrodidae: Homoptera)

Introduced in India in 1999.

Hosts: This was associated with an outbreak of tomato leaf curl virus disease (ToLCVD) which resulted in failure of the tomato crop.

Damage: There are four kinds of damages: The first is the disorder symptoms, e.g. irregular ripening of tomato fruits. The second is the sooty mould which is black fungi grown on honeydew excreted by the larvae of the silver leaf whitefly. The third is the viral disease (tomato yellow leaf curl virus) transmitted by the adults of this whitefly. The fourth is a cosmetic damage by the only existence of the adults and larvae on the leaves of ornamental plants.

Natural enemies: *Encarsia formosa*, *Eretmocerus eremicus*, *Lecanicillium lecani*, *Beauveria bassiana* and *Paecilomyces fumosoroseus*.

13. Blue gum chalcid, *Leptocybe invasa* Fisher & La Salle (Eulophidae: Hymenoptera)

It is a gall-inducing wasp native to Australia. It has been reported from India in planted forests and nurseries of *Eucalyptus camaldulensis* and a *E. tereticornis*.

Hosts: *Eucalyptus camaldulensis*; *E. tereticornis*; *E. grandis*; *E. deanei*; *E. nitens*; *E. botryoides*; *E. saligna*; *E. gunii*; *E. robusta*; *E. bridgesiana*; *E. viminalis*.

Damage: *L. invasa* lay eggs in the bark of shoots or the midribs of leaves. The eggs develop into minute, white,

legless larvae within the host plant. Damage is caused when the developing larvae produces galls on the leaf midribs, petioles and twigs. Repeated attack leads to loss of growth and vigour in susceptible trees. Severely attacked trees show gnarled appearance, stunted growth, lodging, dieback and eventually death of tree.

14. The Coconut eriophid mite, *Aceria gurreronis* Keifer (Eriophyidae; Arachnida):

It was first noticed in 1997 in Ernakulam District of Kerala and has spread to major coconut growing areas. In a survey conducted in 1999 at Kerala, nearly 42 per cent of plants were affected and estimated yield loss was around 22 per cent. The percentage of reduction in nut weight due to mite infestation was estimated as 2.12 per cent^[40].

Damage: Discolouration on nuts and the market value of nuts is affected.

Natural enemies: *Neoseiulus baraki* and *Hirsutella thompsonii*.

15. Papaya Mealy bug, *Paracoccus marginatus* (Pseudococcidae; Hemiptera)

The infestation was first noticed in 2007 on Papaya, at Coimbatore Tamil Nadu. By 2009, the pest assumed the major pest status across the country and caused huge damage to mulberry, tapioca, Jatropha, cotton and several fruits, flowers and plantation crops in Tamil Nadu causing 90 per cent damage. Fortunately the pest could be successfully managed through the intervention of classical biological control wherein *Acerophagus papayae* was imported from USA.

16. Cotton mealy bug, *Phenacoccus solenopsis* Tinsley (Pseudococcidae; Hemiptera)

This mealy bugs belong to one of the more common groups of small sap sucking insects. They are considered a major agricultural pest on multiple continents causing serious problems into geographic areas^[41]. Recent infestations of exotic cotton mealy bug *Phenacoccus solenopsis* (Tinsley) in nine cotton growing states of India and several states in Pakistan have resulted in loss of cotton crops which caused increased need for insecticides and other preventive measures^[42-43]. The importance of cotton to India cannot be over looked; as it is a major crop in India and million of citizens depend on this crop for livelihood^[44-45].

The earliest *P. solenopsis* infestations in India were recorded in 2005 in Gujarat state. It spread rapidly after it was first introduced. *P. solenopsis* is a polyphagous insect pest with a wide range of host plants. There are several natural enemies of mealy bugs that control their populations including the parasitoid *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae)^[46].

17. Erythrina gall wasp, *Quadrastichus erythrinae* Kim (Eulophidae; Hymenoptera)

It is a major invasive pest on *Erythrina spp.* in black pepper plantations of Kerala and Karnataka. The Erythrina gall wasp was first noticed in 2005 and 2006 and spread to all districts of Kerala and Karnataka and also recorded from Maharashtra. Nearly 60 per cent damage of Erythrina plants were observed in Wayanad District of Kerala during 2006. The damage in Erythrina plants directly affects production of black pepper in

these areas as Erythrina plants are used for trailing Black Pepper and Vanilla.

Host: The erythrina gall wasp forms galls on the leaves, stems, petioles, and young shoots of *Erythrina spp.* ("coral tree"), with atleast five species known to be affected. As galls are formed on the newly emerging leaves, there is a severe reduction in the number and size of leaves besides complete cessation of growth. Inside the leaf galls there is usually only one wasp per cell, whereas in the swollen tissues of shoots, twigs and petioles, more than five individuals are present^[47]. Affected trees appear to be scrawny with malformed and crinkled shoots, suffer severe defoliation and ultimately die^[48].

Biological Control: A long term and environmentally friendly solution is to import efficient living natural enemies capable of significantly reducing gall wasp infestations.

18. Solenopsis mealy bug

Solenopsis Mealy bug, *Phenacoccus solenopsis* Tinsley (Pseudococcidae: Homoptera), previously known as a pest of cotton but now possess a new threat to most of the cultivated crop plants. A total record of 84 host plants under 28 families were recorded at Central cotton growing zone of India up to 2009 out of which 60 plant species under 22 families belonged to weeds^[49]. Solenopsis mealy bug attack on malvaceae (lady finger), solanaceae (tomato, brinjal, potato, chilly), leguminosae (field bean), cucurbitaceae (pointed gourd, cucumber, melons and gourds)^[50]. Besides sucking the sap, they also secrete honey dew which deposited on the plants and create black sooty mould which reduced the photosynthetic activity of the plants.

Management: Remove of alternate hosts and weeds like Parthenium, Vernonia from the field will help to reduce the pest incidence. Spraying of fish oil resin soap @ 20g/lit of water or entomopathogenic fungi *Verticillium lecanii* @ 5g/lit of water give better control^[50].

19. South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)

Tomato leaf miner, *Tuta absoluta* was recorded for the first time on tomato at the Indian Institute of Horticultural Research (IIHR), Hessaraghatta, Bengaluru, Karnataka, India during the rabi season of 2014^[16]. In 1960s, this moth has become one of the key pests of tomato in South America^[51]. In Himachal Pradesh, It was noticed for the first time at Naini Solan during 2015^[52].

Nature of damage: After hatching, young larvae of *T. absoluta* immediately mined into tomato leaves, apical buds, stalks or fruits. Feeding resulted inconspicuous mines (blotches) and galleries on leaves and pin hole sized holes on fruits from the stalk end generally covered with the frass. Larvae mainly attacked leaves, creating blotch/leaf mines visible from both sides of the leaf. The mines have dark frass (excrement) visible inside and the mined areas turned brown and dried over time.

Host range: *T. absoluta* was recorded on two hosts viz., tomato as well as potato and the incidence was higher on tomato than potato. The main host plant of *T. absoluta* as tomato although the insect has also been reported on

solanaceous weeds, including *Solanum nigrum* and *Datura stramonium*. Damage has also been reported on egg plant, pepper and potato [53]. Tomato leaf miner may multiply during summer months in outdoors but it is not expected to survive winter conditions because its development stops between 6 and 9°C [54]. Alternative host plants, especially *S. nigrum* may play important role in continuous spread of this pest.

Natural enemies: *Nesidiocoris tenuis* (Reuter) (Hemiptera: Miridae) was found predated on eggs and early instars of *T. absoluta* under field conditions. Presence of this natural enemy feeding on whitefly in tomato ecosystem in India was earlier reported [55-56]. *Trichogramma achae* was also found to attack eggs of *Tuta absoluta*.

20. Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae)

Spodoptera frugiperda was recorded from many locations in Karnataka on maize crop. Occurrence of *S. frugiperda* in southern India is reported along with associated natural enemies. Severe damage was noticed in Chikkaballapur, Hassan, Shivamogga, Davanagere and Chitradurga during July–August 2018 [16].

Nature of damage: It lay eggs on the inner side of the whorl and also on the under surface of the leaf in a mass and is deposited in layers. The eggs are dome shaped brownish yellow coloured. After the eggs hatch the young larvae feed on the opened leaves by scraping and skeletonizing the upper epidermis leaving a silvery transparent membrane.

Later on the larvae enters into the whorl and start feeding between the leaves. Usually within a whorl, one or two larvae are present as a result a lot of faecal matter gets accumulated within the whorl leading to the characteristic symptom of damage. The older larvae feed on the developing primordial shoot, thus resulting in dead heart symptoms. Tassel feeding was also noticed.

Host range: A serious polyphagous pest of voracious nature with a wide host range of approximately more than 100 recorded plant species under 27 families [57]. This pest prefer plants from Gramineae family including many economically important plants such as maize, millet, sorghum, sugarcane, rice, wheat, etc. There are reports on its infestation on other field crops like cowpea, groundnut, potato, soybean, cotton, etc.

Natural enemies: *Telenomus sp.*, *Trichogramma sp.*

2. Prevention of Invasive Species

The first step of prevention is to identify the invasive insect pests that may become invasive and therefore require special attention. These may be put on a “blacklist” and prohibited entry under national legislation. Species cleared for introduction through passing a risk assessment analysis can reasonably be declared as safe (put on a “white list”), though monitoring is still required to ensure that the prediction remains accurate over time. The potential invasiveness of the majority of the world’s species is unknown and they should be placed on a “grey list”.

3. Management of New Invasive insect pests

The basic steps in this process will vary depending on the

Type of organism, Population size, Biology, Pest status, Available mitigation options.

1. **Identification:** The invasive insect pests should be correctly identified by the expert.
2. **Risk assessments:** First determine the level of risk, the invasive insect pests possess for the area. Study the biology of the organism, its distribution locally and worldwide?, status of the Pest, Mitigation options, Window of opportunity for action.
3. **Eradication programme:** If the risk possessed by the pest is high then eradication of the invasive species should be done widely. The other extension activities should be carried out to educate the people about this pest.
4. **Risk assessment review:** The knowledge about the invasive species is necessary, rate of the level of risk for that organism in new environment. The information on biology, its distribution, economic importance and management option.
5. **Monitoring:** For successful eradication of the programme, the survey data for most organisms two years or two generations is considered.

4. Management Strategies against Invasive insect pests

- There is need to study the biology and ecology of known insect pests and their natural enemies.
- Study the ecology and genetic make up of the Invasive insect pest.
- Tracking of geographical distribution of pest.
- Developing cultivars resistant to insect pests.
- Judicious use of insecticides to prevent resistance and resurgence development.
- To identify, conserve and augment natural enemies of invaded insect pests.
- Modify crop management practices.
- Develop suitable integrated pest management programmes.
- Phytosanitary regulations to prevent or limit the introduction of risky insect pests.

5. Conclusion

Invasion of insects was the result of globalization and the invasive insect pest caused substantial damage to the native flora and fauna, and also resulted in the extinction of species. The globalization has increased international agricultural trade, and movement of seeds and planting material has enhanced the risk of introduction of invasive pests into India. These species, if not accompanied by the natural enemies which keep them in check in their native range, can multiply in large proportion and cause damage to economically important plant species and crop plants. This paper culminates that the natural enemies provide appropriate control measures for invasive insect pests.

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