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Integrated Pest Management Approaches for Invasive Pests: Challenges and Opportunities

Mahesh Pathak[1], Kennedy N[1], Mukesh Sehgal[2], Meenakshi Malik[2], Pranab Dutta[1], RK Patidar[1], Bimal Sahoo[1], Sikha Harita[1], Hia Kalita[1]

[1]School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umaim, Meghalaya, India.
[2]ICAR-NCIPM, LBS Building, Pusa, New Delhi, India.

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Corresponding Author:
Mahesh Pathak, School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umaim, Meghalaya, India.
E-mail Id:
pathakmahesh@gmail.com

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I N T R O D U C T I O N

Biological invasion is regarded as a biological pollution because it causes losses to the biodiversity. Invasive species are threats to agricultural biodiversity as well as humanhealth. These species are non-native or exotic species having great affinity of dispersal and adaptation. They are introduced unintentionally into a new area where they get a favorable climate increase in number and establish. Furthermore, the new area will be devoid of its natural enemy which unleashes the invasive species' growth without any limitation. According to the International Union for Conservation of Nature (IUCN), an Invasive Alien Species (IAS) is an exotic species which becomes established in natural or seminatural ecosystems or habitats, is an agent of change and threatens native biological diversity. India has harbored a total of 173 invasive species including 47 invasive species of agricultural ecosystem, out of which 23 are insects.

A species that has established and spread or has the potential to do so outside of its natural distribution range, and which then threatens ecosystems, habitats or other species, potentially causing economic or environmental damage, or harm to human health is called Invasive species [Invasive Species Specialist Group (ISSG) module, IUCN, 2012]. The current study is principally supported and framed based on the publication by Neha Gupta et al., (2019) and Naveena et al (2020) wherein, invasive pests of India were listed. The current study focused on the invasive pests of India and their natural enemies and also has updated the already existing list. In India, the Directorate of Plant Protection, Quarantine and Storage are responsible for the 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. Such kind of biological invasion can be well regarded as biological pollution that causes maximum losses to biodiversity. Invasive species are threats to agricultural biodiversity as well as human and animal health. Since these species are non-native and exotic, they have great power of dispersal and adaptation. Owing to the inadequate documentation of all the invasive species of India, the present review was undertaken

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.

Common Characters of Invasive Pests Species

- Very resilient
- Short life cycle
- Broad host range
- High dispersal ability
- Ability to withstand many environmental conditions
- High fecundity
- Voracious feeders
- Benefits from mutualist interaction

Steps of Invasion

Invasion of alien species can be occurred by four steps:

- Introduction
- Establishment
- Spread
- Naturalization

Introduction: Invasion of alien species may be intentional or unintentional. Introduction of invasive pests may be intentionally or unintentionally depending up of its economic values., infesting fruits carried by tourists, or hidden in soil of imported plants.

It may be occurred due to long distance migration (BPH in rice), or dur to transportation (parthenium along with wheat in India), human activities and aquatic plants (water lettuce).

Establishment: If the invaded species will be able to overcome the environmental barriers in the place of introduction, 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 newly introduced species has to overcome the barrier to dispersal within the new region from the original place of introduction which cancope with the abiotic environment and biota in the area.

Naturalization: Overcoming of barriers to regular reproduction with surmounting of abiotic & biotic barriers to survival rate results naturalization of invasive pests.

Impact of Invasive pests

- Competition
- Predation
- Parasitism
- Hybridization
- Poisoning
- Disease
- Flammability
- Heavy feeder

Outcomes of Impact

Environmental Impact

- Native species declines
- Primary production alteration
- Plant health
- Habitat degradation

Socio-economic Impact

- Agricultural damage
- Infrastructure damage
- Human health
- Reduction in tourism

Table 1.Invasive Insect Pests in India

Common Name	Scientific Name	Year of Introduction	Reference
Woolly apple aphid	Eriosoma lanigerum (Hausmann)	1889	Mishra, 1920
San Jose scale	Quadraspidiotus perniciousus (Comstock)	1911	Singh, 2004
Diamond back moth	Plutella xylostella (Linn.)	1914	Fletcher, 1914
Lantana bug	Orthezia insignis Browne	1915	Muniappan et al., 1986
Cottony cushion scale	Icerya purchasi Maskell	1921	Singh, 2004
Potato tuber moth	Phthorimaea operculella (Zeller)	1937	Singh, 2004
Pine woolly aphid	Pineus pini (Macquart)	1970	Singh, 2004
Subabul psyllid	Heteropsylla cubana Crawford	1988	Jalali & Singh, 1989
Serpentine leaf miner	Liriomyza trifolii (Burgess)	1990	Singh, 2004
Coffee berry borer	Hypothenemus hampei (Ferrari)	1990	Vega et al., 1999

Spiraling whitefly	Aleurodicus disperses Russell	1993	Palaniswami et al., 1995
Coconut eriophidmite	Aceria gurreronis Keifer	1997	Singh, 2004
Silver leaf whitefly	Bemisia argentifolii Bellows	1999	Singh, 2004
Papaya mealy bug	Paracoccus marginatus Williams & Granara de Willink	2005	Jhala et al., 2008
Erythrina gall wasp	Quadrastichus erythrinae Kim	2005	Faizal et al., 2006
Blue gum chalcid	Leptocybe invasa Fisher & La Salle	2006	Singh, 2004
Cotton mealy bug	Phenococcus solenopsis Tinsley	2006	Nagrare, 2009
South American tomato leaf miner	Tuta absoluta Meyrick	2014	Sridhar et al., 2014
Fall armyworm	Spodoperda frugiperda (J.E. Smith)	2018	Shylesha et al., 2018

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.

- **Identification:** The invasive insect pests should be correctly identified by theexpert
- **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 foraction
- **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
- **Risk Assessment Review:** The knowledge about the invasive species is necessary, rate of the level of risk for that organism in newenvironment.The information on biology, its distribution, economic importance and management option
- **Monitoring:** For successful eradication of the programme, the survey data for most organisms two years or two generations isconsidered

Management Strategies against Invasive Insect Pests

- There is need to study the biology and ecology of known insect pests and their naturalenemies
- Study the ecology and genetic makeup of the Invasive insectpest
- Tracking of geographical distribution ofpest
- Developing cultivars resistant to insectpests
- Judicious use of insecticides to prevent resistance and resurgencedevelopment
- To identify, conserve and augment natural enemies of invaded insectpests
- Modify crop managementpractices
- Develop suitable integrated pest management programmes
- Phytosanitary regulations to prevent or limit the introduction of risky insectpests

IPM Approaches in Different Invasive Pests

Wooly Apple Aphid: *Eriosoma lanigerum* (Hausmann) F: Aphididae, O: Hemiptera.

Hosts: Feeds on the Rosaceae family. *Malus domestica* is the preferred host for woolly aphid.

Economic Importance: Eriosoma lanigerum affects all stages of apples. It occurs in both aerial and subterranean parts of the apple tree. On feeding twigs, branches result in galls and deformation of tissues whereas feeding on roots results in the formation of root galls. Severe infestation may also result in the harbouring of basidiomycetes fungi.

- **Native of:** China
- **Entry in India:** Tamil Nadu in the year 1889
- **Reported by:** Thakur and Dogra (1980)

IPM Approaches

Resistant Root Stock

Malling rootstock series (MM106, MM111) as well as G41 and G202.

Cultural Control

- Monitor suckers and pruning cuts between petal fall and 1st cover
- Remove water sprouts on major scaffold limbs early in the season (June)
- Paint large pruning cuts to discourage colonies
- Remove larger colonies during summer pruning
- Marigold plant can be established around the orchard to provide alternate food source for wooly aphid

Biological Control

- *Aphelinus mali* is the potential parasitoid of apple woolly aphid. In 1930 it has suppressed the insect population up to 98 % in Kullu valley

- Other effective predators are Coccinella septumpunctata, Ballia ancharis, Chilomenes bijugus

Chemical Control

- Flonicamid (Mainman) is specially recommended for managing this pest
- Spray Dimethoate 30 EC @ 0.06%
- Spray Methyl demeton 25 EC @ 0.025%

Apple San Jose Scale

Hosts: The San José scale has been collected from nearly 250 plant species around the world, mostly rosaceous fruit trees.

Economic Importance: San Jose scale is a major pest of rosaceous fruit trees. It infests mainly the bark and branches, occurring also on the fruit, which it discolors. A red halo-like spot (due to secreted toxins) appears on tender peach twigs within 24 hours of crawler settlement, the spot growing along with the pest. Infested tissues may crack and exude gum, followed by desiccation and die-back. Wounded, weakened branches may be attacked by wood-boring insects. Heavy infestations cause the death of branches and even that of entire trees within a few years.

The scale raises very large populations on the wooden parts of the trees (especially on the trunk), and as the dead insects do not drop off, this results in thick shield layers on the trunks and main branches.

Entry in India: In the year 1879 (Kashmir in the year 1921).

Native of: China

Reported by: Fotedar (1941)

IPM Approaches

Monitoring

Monitoring should be done during the dormant period for ensuring the scale development in tree crops.

Cultural Control

- Monitor crawlers by using double sided sticky traps in the month of April and May
- Monitor male San Jose scale flights by using pheromone traps in the month of March

Biological Control

Several parasites and predators attack San Jose scale. In Washington, the parasitoids recorded from San Jose scale include *Encarsia perniciosi* and *Aphytis sp*.

- **Field release of Predator Coccinellid:** *Chilocorus circumdatus*
- **Field Release of Parasitoids:** *Aspidiotophagus sp.* and *Prospaltella perniciosi*

Chemical Control

- Fumigation should be done in nursery stock with HCN gas or methyl bromide. Spray with Phosalone 50 EC @ 0.05% or Fenitrothion 50 EC @ 0.05%in summer months
- Spray with diesel oil emulsion at 8-12 l/ tree (diesel oil 4.5 l, soap 1 kg, water 54 -72 lt.) in winter months
- Oil sprays work the best on the black cap stage, so apply them in early January

Potato Tuber Moth

Entry in India: Uttar Pradesh 1906 (East BengalNow in Bangladesh); Tamil Nadu 1920.

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

Economic Importance: Caterpillars initially mine into leaves and later make a way in veins into petioles, then to stem and some time to the tubers in the soil. It can complete 12 generations in one year (Hill, 1993). After harvesting of potato these insects may infest the tubers in the field as well as other volunteer crops like solanaceous crops like tomato & brinjal (Gilboa and Podoler et al., 1995 and Coll et al., 2000).

Native of: Italy

Reported by: Lefroy (1907)

Challenges in IPM

Pesticide Pressure or Integrated Pesticide Management

Worldwide, about 4 million tons of pesticides per year are used although their distribution is uneven in different countries (FAOSTAT, 2010). Despite the fact that the consumption of pesticides in India is still very low, about 0.5 kg/ ha of pesticides against 6.60 and 12.0 kg/ha in Korea and Japan, respectively, there has been a widespread contamination of food commodities with pesticide residues, basically due to non-judicious use of pesticides. In India, 51% of food commodities are contaminated with pesticide residues and out of these, 20% have pesticides residues above the maximum residue level values on a worldwide basis (Gupta, 2004). Among the various pesticides used in India, 40% of all the pesticides used belong to organochlroine class of chemical pesticides (FAO, 2005; Gupta, 2004). The other major category is organophosphate pesticides. Regarding the usage of technical pesticides, insecticides account for 80% of total pesticide used in the country, followed by herbicides and fungicides. Globally herbicides are the leading category followed by insecticides and fungicides. In India, the share of herbicides is insignificant (MAFF, 1999-2000).

Lack of training in pesticide use, ignorance about potential dangers to health and environment, poor literacy, inappropriate mixing and application methods, repeated and excessive dosage of pesticides application are some related factors relevant to pesticide usage and safety measures in India (Abhilash and Singh, 2009).

Although pesticides are generally profitable in agriculture, their use does not always decrease crop losses. For example, despite the more than 10-fold increase in insecticide (Organochlorines, Organophosphates and Carbamates) use in the United States from 1945 to 2000, total crop losses from insect damage have nearly doubled from 7 to 13% (Pimentel et al., 1991). Still farming community is using the excessive and indiscriminate use of pesticides. Pesticides continue to play the key role in arthropod pest management. However, some key species (*Heliothis armigera Hubner, Plutella xylostella L.*) are developing high levels of insecticide resistance and with the human and environmental health concerns related to pesticide use, cultural techniques are increasingly being used. The combination of genetic resistance, hygiene, and monitoring of crops for threshold levels of infestation, allows the most economic and effective use of chemical controls with the result that economic yields can be maximized.

Environmental Degradation/ Losses

Extensive and indiscriminate usage of chemical pesticides has resulted in environmental degradation, adverse effects on human health and other organisms, eradication of beneficial insects and the development of resurgence and resistant to pesticides in insects pests. Reliance on single control tactics have resulted in environmental degradation, contamination of food products, problems of residues and resistance in target species, thereby seriously impairing the sustainability (Vega et al., 2009; Miller et al., 2010). It is therefore essential to devise a sound management system that is based on ecological principles resulting in sustainable agricultural production without disturbing the balance of nature (Overton, 1996; Lewis et al., 1997; Kennedy and Sutton, 2000).

Lack of Proper Taxonomy of Pests and Biocontrol Agents

Identification or proper diagnosis is the pre-requisite in the IPM programme. We often talk of biodiversity loss, but unless we have a detailed account of the existing species, the loss cannot be pinpointed. Numerous examples can be cited where wrong classification has led to misinterpretations. Taxonomy plays an important role in the management of pests and weeds. To illustrate this point, Salvinia molesta (kariba weed), native of Brazil, is an aquatic fern and one of the world's worst weeds. The environmental damage caused by it has been enormous. It chokes lakes, reservoirs, slow-moving rivers, irrigation systems, rice paddies, fishponds, etc. with continuous metre-thick mats of dense vegetation. In addition to rendering the water useless for normal use, its presence can lead to the breeding of mosquitoes. Initially, the weed was identified as *Salvinia auriculata*. A weevil, *Cyrtobagouss ingularis*, from Trinidad was used in Africa to control it, but the effort failed. Later, this weed was identified as *S. molesta*, whose growth in Queensland was controlled by *Cyrtobagous* from Brazil. It is evident from these examples as to how effective control or mitigation measures could be implemented. Similarly, identification of an effective biological control agent for Azolla depended on expert taxonomic work. Floating water fern/fairy fern (*Azolla filiculoides*) has for years been a highly effective invasive species in South Africa, creating problems in inland waterways. The weevil, Stenopel musrufinasus was found effective in cleaning up sites heavily infested with Azollawithin months. Proactive taxonomy of biotypes of whiteflies, *Siphonius phillyreae* and *Bemisia tabaci* causing viral epidemic in crops in Argentina allowed effective implementation of biological control programmes via natural enemies such as *Encarsia hispidia, E. protransvena* and *E. transvena* (Viscarret et al., 2003).

Problems in Pest Management in Context of Climate Change

Climate change no longer is a matter of opinion or speculation. Of concern now is the assessment of the extent of the changes and their potential impacts. Climate change, food insecurity, and energy demand are major concerns for modern agriculture and their impact is increasing rapidly. The last decade has seen new developments in food production: the genetic engineering of organisms and the organic chemical-free agriculture. Biotechnology and release of Genetically Modifiedorganisms (GMOs), such as engineered soybean, colza, maize and tomatoes, didpromise a solution to food security needs and nutritional problems (Khush, 2002). According to the main private biotechnology companies (Aventis, Monsanto, Novartis, Zeneca, etc.), these GMOs may be resistant to insect pests, molds, frost, dry conditions, etc. and could revolutionize agriculture (Pingali and Traxler, 2002). For example, soybean and other plants were modified to be tolerant to glyphosate, a common herbicide used to fight weeds allowing for much higher crop yields. However, because the weeds become increasingly resistant to this herbicide, the use of these Genetically Modified (GM) plants renders the farmers dependent on the use of more and more glyphosate.

Lack of Information and Communication Technology (ICT) in IPM

Practically, IPM is concerned with most constitutional levels of agroecosystems, from populations and communities down to individual viruses or genotypes, genomes and genes, as well as up to the levels of landscape and global ecosystems. In fact, IPM practices are involved in a complex course responding to climatic change, soil dynamics, vegetation evolution and human activities. ICT is any technology that enables communication and the electronic capture, processing and transmission of information. Radio, television and print media are vital in many developing countries. Over the last decade, 'new' ICTs, such as mobile phones and Internet-associated applications such as Voice over Internet Protocol (VoIP), have become available to growing numbers worldwide. Developing countries face challenges when harnessing the potential of ICT for economic development (Michelle and Fong, 2009). The potential of ICT for the speedy dissemination of information to farmers needs to be realized (Meera et al., 2004). Integrated Pest Management (IPM) practices have to solve many problems of sensitivity and intractability in the sustainable development of agriculture. CT has proved to be a powerful tool in pest forecasting as a prop to giving priority to prevention, as pest forecasting involves data acquisition, processing and information dissemination. ICT can also be very helpful in terms of enforcing IPM (Shen et al., 2012).

Ecological Pest Management Programme

The aim of this new approach is to shift management strategies so that they have less reliance on chemicals and more on the biology of pestsand their interactions with crops. Thus, ecologically-based IPM combining all approaches - physical, cultural, chemical and biological is the only option for sustaining productivity and maintaining the health of ecosystems (Kennedy and Sutton, 2000). Most of the IPM inventories like cultural, mechanical, biological, plant resistance and biotechnological approaches are basically compatible and supportive tactics in the IPM strategy.

Hence, strengthening of IPM infrastructure, especially for surveillance and forecasting the outbreak of localized insect pests and diseases and mass multiplication of bio-control agents for filed use, should be given adequate attention and priority. IPM programmes need to be designed in a way to manage pests on the one hand and ensure the build-up of beneficial organisms on the other (Kennedy and Sutton, 2000).

Ensuring the Availability of Biological Control Agents and IPM Devices

Efforts shall also be made to ensure the timely availability of biological control agents on demand to farmers to help them adopt IPM in the true spirit by encouraging the private sector, Government organizations, central and state agricultural universities in providing such support services. Government must have to strengthen the programme through some new policy to establish more number of regional biocontrol laboratories, encourage the use of bio-pesticides and bio-control agents and safer and efficacious.

Habitat Manipulation or Ecological Engineering

It is evident that the crop diversification tends to increase natural enemy abundance and diversity, providing a system more resilient to pest population increase. Overall farming diversity within the agroecosystem may also affect biological control by natural enemies, due in part to a wider range of flowering plants that provide nectar (carbohydrate) and pollen (protein) resources to insects during more times of the growing season. Thus, pest outbreaks tend to be less common in polycultures than in monocultures (Andow, 1991). The response of beneficial insect populations to habitat manipulation depends upon their ability to use or exploit one or more of the plant components of the agroecosystem (Altieri and Nicholls, 2004). Flowering plant strips adjacent to fields help support beneficial insect biodiversity in agricultural landscapes (Baggen and Gurr, 1998; Carreck and Williams, 2002; Fiedler and Landis, 2007a, 2007b; Tuell et al., 2008). Much of the testing of flowering plants has been done with non-native annual or biennial flowering species, although these often blooming one growing season requiring annual sowing. A welldesigned flowering border adjacent to a crop field will provide necessary resources and alternative food source for natural enemies during periods when crop pest and crop flower numbers are low, thus maintaining high populations of natural enemies supported by the provision of nutrients throughout the season (Landis et al., 2000).

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, 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. These invasive insect pests can be minimized with formulation and implementation of IPM modules comprising of 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.

Integrated Pest Management (IPM) is a viable option to overcome these pest problems. IPM strategies are based mainly on conservation and augmentation of natural enemies, need based minimum use of pesticides and backed by continuous monitoring of pests proved much superior to farmers own control practices, which mainly comprised of intensive chemical pesticidal applications. IPM technology has increased the natural enemies' population and empowered the farmers for decision making for various interventions. It also empowered them for identification of beneficial and harmful insect pests and use of pesticides on the basis of economic threshold level. If this approach which is mainly based on pest surveillance and monitoring, conservation and augmentation of natural enemies, and application of pesticides as last resort, is propagated by proper motivation and involvement of the farmers, may lead to substantial reduction in pesticide consumption, help overcome residue problem and keep the environment safe. It will further help in sustaining the productivity of cropping systems.

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