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RECENT EVENTS OF INVASIVE AND MIGRATORY PESTS AND LESSONS LEARNT

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ABSTRACT

In the increasing globalisation era, movement of goods and planting materials between countries being carried out at ease, are potential factors of introduction of invasive alien insects, diseases, and weeds in India. Infested fruits carried by international travellers, cargo / sea shipments of wood logs, food trade, and accidental introduction through air travels were the potential ways of entry of invasive alien insects into any country. The entry of alien invasive pest causes huge economic damage by way of direct crop loss. In addition, the panic situation to save the crops results in indiscriminate use of chemical insecticides that is harmful to applicator, farmer and consumer. Frequent application of insecticides leads to reduction in natural enemies and pollinators there by having an adverse impact on the ecosystem. The present paper critically reviewes the existing plant quarantine regulations in India, recent invasive and migratory insect pest problems and way forwards to safeguard Indian Agriculture.

Key words: Destructive Insect Pest Act, Plant Quarantine Order, invasives pest, locust, bio-security

Anthropogenic activities such as grain and wood shipments, long-distance trucking, aeroplanes and ship voyages can introduce insect pests into new areas. As a result, many species have been able to establish new populations outside of their native range. Most pathways for introductions are trade related. Unauthorized (illegal) smuggling of plants, stem cuttings, seeds or any other plant parts also leads to introduction of pests into new place. The risk of introductions through this pathway is high and it is important to have measures in place to regulate this pathway (Singh et al., 2020). At least 33 invasive insect pests have gained entry into India through various means (Daniel et al., 2020), thereby warranting robust plant quarantine regulations to prevent off the possible pest incursions. Invasive species threaten the ecological and economic well-being of any country (Pimental et al., 2001).

The common characteristics of introduced alien pests include rapid reproduction and growth, high dispersal ability, phenotypic plasticity (ability to adapt physiologically to new conditions) and ability to survive on various food types and in a wide range of environmental conditions. The biological process of colonization or invasion by alien organisms can be divided into four steps

- Introduction of the species
- Establishment and reproduction of the introduced species
- Spread
- Naturalization

With the increase in international trade, there has been an enhanced risk of introduction of exotic pests into our country. Plant quarantine is the first line of defense in plant protection which keeps these injurious pests away from our territory. When considering the present pest status in India, we can infer that a vast majority of them are mere introductions. Pathways of introduction of exotic pests may be either natural or human mediated. The consequences of these introductions are manifold including imbalance of native ecosystem, loss of biodiversity, transmission of dreadful diseases, creating genetic changes and threatening the existence of endangered species (Singh et al., 2020). No criteria have yet been agreed for the minimum damage, spread or size of population needed for an alien species to be considered invasive. However, it is clear that a very small number of individuals, representing a small fraction of the species' genetic variation in its native range, can be enough to generate, through its reproduction and spread, massive

environmental damage in a new environment (Mack, 2000). India had implemented its regulations about a century back to deal with such issues. All these adverse effects will lead to socioeconomic instability. Thus, the plant quarantine system in India is to be strengthened by various means like exotic pest surveillance, building up more infrastructural facilities, creating public awareness and formulating pest incursion management plans.

Plant Quarantine regulatory measures in India are operative through the 'Destructive Insects & Pests Act, 1914 (Act 2 of 1914)' (Govt. of India, 1914). The purpose and intent of this Act is to prevent the introduction of any insect, disease, or other pests from abroad or from one place to another in India which is or may be destructive to the crops in the country. Directorate of Plant Protection, Quarantine & Storage (DPPQ&S) established in 1946 under Ministry of Agriculture & Farmers Welfare (Department of Agriculture, Cooperation & Farmers Welfare) implements Plant Quarantine Regulations issued under the Act to prevent introduction of invasive pests. The import of plants and plant materials are covered under the Plant Quarantine (Regulation of Import into India) Order, 2003 (PQ Order, 2003) issued under the Section 3 (1) of DIP Act, 1914 and amendments issued there under from time to time.

Inspection of agricultural commodities for export as per the requirements of importing countries is governed under IPPC and Phytosanitary Certificates are issued. PQ Order, 2003 effective from 1.1.2004 replaces the PFS Order, 1989 and Cotton Regulations, 1972 and other previous orders. Seeds and Propagative plant material can only be imported through six regional plant quarantine stations *viz*., Amritsar, Bengaluru, Chennai, Kolkata and Mumbai & New Delhi, while regional PQ station, Kandla is notified for import of consumption materials only. Commodities for consumption can be imported through all the notified ports. In PQ order, 2003, points of entries are notified vide Schedules - I, II & III; commodities prohibited are notified in Schedule-IV (15 Nos.), and commodities restricted to enter are notified in Schedule-V (17 Nos.). The commodities regulated to import with additional declarations and special conditions are covered in Schedule-VI (700 Nos). Commodities of least risk category for consumption purpose are specified in Schedule-VII (519 Nos). Phytosanitary certificate (PSC) is must for the commodities covered in Schedule-VI & Schedule-VII. The Quarantine weeds (57 nos.) are notified in Schedule-VIII. Import Inspection fee and treatment fee are stipulated in Schedule-IX. Exim committee clearance is required for import of agricultural commodities for propagation purpose such as seeds of coarse cereals, pulses, oil seeds, fodder crops and seeds/stock material of fruit plant species except the trial material of the above as specified in PQ Order schedule – XII, in which certain quantities of seeds are permitted for trial purpose/ accession to gene bank of ICAR-NBPGR. A list of different entry points including different airports, seaports, land frontier etc. are mentioned hereunder in Table 1.

Table 1. List of points of entry for import of plants and plant products in India

Sl. No.	Points of Entry	No.
1.	Seaports	46
2.	Airports	24
3.	Land Frontier Stations	24
4.	Inland Container Depots and Container Freight Stations	78
5.	Foreign Post Offices	11
Total		183

INDIAN PLANT BIOSECURITY UMBRELLA

Directorate of Plant Protection, Quarantine & Storage (DPPQ&S) is the apex body for implementation of Destructive Insect Pest Act 1914 (DIP Act 1914) and Plant Quarantine Order (Regulation of Import into India) Order 2003 and also carries duties and responsibilities of National Plant Protection Organization (NPPO) as per article IV of IPPC. The objective of protecting Indian Biosecurity is achieved through robust networking of Govt. Departments, Institutes, State Governments and Private agencies. There are 60 Plant Quarantine Stations and its camp offices of DPPQS spread across the country and headquarters at Faridabad. In addition, 28 State Agricultural Universities, 24 Indian Council

of Agriculture Research Institutes, One institute each of Indian Council of Forest Research and Education, Ministry of Commerce and Industry and ICRISAT, etc are notified by the Central Government to carry out different aspects of Plant Quarantine activities and are the part of plant quarantine system in India. Above all, the Customs is in forefront in implementing ISPM 15 (International Standards for Phytosanitary Measures No. 15 - Regulation of wood packaging material in international trade) as per Chapter II Clause 20 (A) of PQ Order 2003. Section 4 of the DIP Act 1914 empowers the Customs to operate the notification issued under DIP Act, as it has the same power issued under Section 11 of Customs Act 1962. The National Institute of Plant Health Management (NIPHM), Hyderabad is the nodal agency for capacity building in agricultural biosecurity.

Under seeds Division, Department of Agriculture & Farmers Welfare, Govt of India, an interdisciplinary EXIM Committee is constituted to deal with application for exports/imports of seeds and planting materials. The committee deals in accordance with the New Policy on Seed Development and EXIM regulation. The committee always acts in consonance with the Plant Quarantine Regulations prior to according permission for import of any planting materials into India.

Import of live insects and other arthropods/ nematodes/microbial cultures including algae/bio-control agents covered under Sixth Amendment of 2016, vide S.O.2453 (E), dated 5th July, 2016 of Plant Quarantine Order 2003. The consignments shall be imported only with the valid Import Permit issued by the competent authority as specified under Schedule-X. Further, only through points of entry specified under Clause 3(14). The consignment of beneficial insects shall be accompanied by a certificate issued by National Plant Protection Organisation at the country of origin with additional declarations for freedom from specified parasites and parasitoids and the bio-control agents free from hyper-parasites. The consignment of beneficial insects/ bio-control agents shall be subjected to post-entry quarantine as may be prescribed by the Plant Protection Adviser, Govt. of India.

PEST INCURSIONS IN INDIA

Incursions of alien invasive insect pests have been a regular phenomenon in India, even though a robust regulatory mechanism is in place. A tentative list of major introduced and established pests is mentioned in Table 2. Many pests have invaded into India, and it is quite difficult to pin-point the pathways of entry since India shares porous borders with many neighbouring countries. Incursions of pests such as Fall armyworm, Rugose Spiralling Whitefly, South American Tomato Pinworm, Papaya Mealybug, Coconut Eriophyid Mite, Eucalyptus Gall Wasp, Erythrina Gall Wasp, Coffee Berry Borer, Spiralling Whitefly, Serpentine Leaf Miner, Sunflower Downy Mildew, Anthurium Blight, Crown Gall, Parthenium, Phalaris, etc., are causing severe economic losses to various crops in India (Sushil, 2015, 2016, 2018 & 2021; Shashank et al., 2015, Chakravarthy et al., 2017; Sharanabasappa et al., 2018; Sundararaj & Selvaraj 2017; Shylesha et al., 2018; Josephrajkumar et al., 2019; Chandrikamohan et al., 2019; Joshi et al. 2020; Sampathkumar et al., 2021).

Plant pathogens such as Groundnut Bud Necrosis Virus (GBNV), Soybean Bud Blight, Mung bean/ Urd Bean Leaf Curl, Tomato Bud Blight, Potato Stem Necrosis, Bunchy Top of Banana, and Tobacco Streak Virus (TSV) in sunflower and other crops, are emerging as serious problems and continuing to spread over large areas. India faced huge losses due to Late Blight Disease of Potato caused by *Phytophthora infestans* affecting potato field grown in a significant area in the country. Foliar blight in wheat, Bract Mosaic in Banana, Sheath Blight in Maize and Paddy are few other serious pathogens causing considerable losses (Sathyanarayana & Satyagopal, 2013). There are 173 invasive alien species documented in India belonging to 117 genera and 44 families, which represent about 1% of the Indian flora (Reddy, 2008). Among these species Tropical America region contribute the maximum number/per cent (with 128 species or 74%) followed by tropical Africa (11%). The other regions, which contribute marginally, are Australia, Afghanistan, Brazil, East Indies, Europe, Madagascar,

Mascarene Islands, Mediterranean, Mexico, Peru, Temperate South America, Tropical West Asia, West Indies and Western Europe (Raj et al*.,* 2018).

STRATEGIES FOR PREVENTION OF INVASIVE SPECIES

Despite having stringent quarantine regulation, the invasive alien species often get established in a small or larger part of the country.Extensive surveys in the areas where the invasive were first reported are needed to identify the extent and nature of damage, biology, native natural enemies, and host range of the pest. This will aid in forewarning the farmers regarding the outbreak of the invasive and adopt appropriate control measures. In India, the research scientists work in hand with line departments like Department of Agriculture/ Horticulture/KVKs to create awareness among farmers during times of outbreak of invasive insects. Pest surveillance at the borders of the country and other high risk entry points should be a regular feature for early detection of the invasive pests. Techniques used for eradication, containment or control should be cost-effective, safe to the environment, humans and agriculture, as well as socially, culturally and ethically acceptable. Mitigation measures should take place in the earliest possible stage of invasion. Hence, early detection of new introductions of invasive species is important, and needs to be combined with the capacity to take rapid follow-up action. Where it is feasible and cost-effective, eradication should be given priority over other measures to deal with established invasive alien species.

Table 2. List of major introduced and established insects/ mites in India

Sl. No.	Common name	Scientific name and Taxonomic Position	Year of first report
1	Apple woolly aphid	*Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae)	1889
2	San Jose scale	*Quadraspidiotus perniciosus* Comstock (Hemiptera: Diaspididae)	1911
3	Lantana bug	*Insignorthezia insignis* (Browne) Syn. *Orthezia insignis* (Browne) (Hemiptera: Ortheziidae)	1915
4	Cottony cushion scale	*Icerya purchasi* (Maskell) (Hemiptera: Monophlebidae)	1921
5	Potato tuber moth	*Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae)	1937
6	Diamond-back moth	*Plutella xylostella* (Linnaeus) (Lepidoptera: Plutellidae)	1941
7	Pine woolly aphid	*Pineus pini* (Macquart) (Hemiptera: Adelgidae)	1970
8	Subabul psyllid	*Heteropsylla cubana* Crawford (Hemiptera: Psyllidae)	1988
9	Serpentine leaf miner	*Liriomyza trifolii* Burgess (Diptera: Agromyzidae)	1990
10	Coffee berry borer	*Hypothenemus hampei* Ferrari (Coleoptera: Curculionidae)	1990
11	Spiralling whitefly	*Aleurodicus disperses* Russell (Hemiptera: Aleyrodidae)	1994
12	The coconut eriophyid mite	*Aceria gurrreronis*Keifer (Arachnida: Eriophyidae)	1995
13	Silver leaf whitefly	*Bemisia argentifolii* Bellows and Perring (Hemiptera: Aleyrodidae)	1999
14	Erythrina gall wasp	*Quadrastichus erythrinae* Kim (Hymenotptera: Eulophidae)	2005
15	Eucalyptus gall wasp or Blue gum chalcid	*Leptocybe invasa* (Fisher and LaSalle) (Hymenotptera: Eulophidae)	2006
16	Cotton mealybug	*Phenacoccus solenopsis*Tinsley (Hemiptera: Pseudococcidae)	2006
17	Papaya mealybug	*Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae)	2009
18	Tomato leaf miner	*Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)	2014
19	Rugose spiraling whitefly	*Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae)	2017
20	Solanum whitefly	*Aleurothrixustrachoides* (Back*)* (Hemiptera: Aleyrodidae)	2018
21	Fall army worm	*Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae)	2018
22	The woolly whitefly	*Aleurothrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae)	2019
23	Neotropical whitefly	*Aleurotrachelus atratus* Hempel (Hemiptera: Aleyrodidae)	2019
24	Bondar's nesting whitefly	*Paraleyrodes bondari* Peracchi(Hemiptera: Aleyrodidae)	2019
25	Neotropical nesting whitefly	*Paraleyrodes minei Iaccarino* (Hemiptera: Aleyrodidae)	2019
26	Cassava mealybug	*Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae)	2020

CLASSICAL BIOLOGICAL CONTROL

Classical biological control for addressing alien invasive insect pests with international cooperation appears to be an important approach in the management of these invasive species. International collaboration for the management of invasive species is of utmost importance as exchange of resources can help in timely control of the pest. In the recent years several invasive insects are managed through Classical biological control by introduction of natural enemies from home range. ICAR-NBAIR located at Bengaluru has played an import role in import of several biocontrol agents in timely management of notorious insect pests and weeds. The details of the recent imported natural enemies/weed bioagents by ICAR-NBAIR are mentioned below in Table 3.

Table 3. Recent importation of biocontrol agents by ICAR-NBAIR, Bengaluru

Name of the insect agent	Country of Import	Introduced year	Purpose of introduction	Impact
1. *Quadrastichus mendeli* Kim & La Salle 2. *Selitrichodes kryceri* Kim & LaSalle (Hymenoptera: Eulophidae)	Israel (Permit No. 39/208 dated 10.10.08)	2008	Management of Eucalyptus Gall Wasp	An estimated 8000 ha damage of eucalyptus gall wasp was checked, saving the paper industry
1. *Acerophagus papayae* Noyes & Schauff 2. *Anagyrus loecki* Noyes & Menezes 3. *Pseudleptomastix mexicana* Noyes & Schauff (Hymenoptera: Encyrtidae)	Puerto Rico	2010	Management of papaya mealybug infesting papaya, cassava, mulberry, teak and other plant species	An annual saving of 1,623 crores has accrued to the farmers in Tamil Nadu, Karnataka and Maharashtra
1. The solitary parasitoid, *Anagyrus lopezi* (De Santis) (Hymenoptera: Encyrtidae)	Republic of Benin (Permit No. 17/2020-21 dated 29.10.2020)	August 2021	Management of alien invasive cassava mealybug in cassava	Envisage another classical biological control for the management of cassava mealybug in near future.

The plant quarantine system with tough regulations is a prerequisite for any country, and it is first line of defence against introduction of alien invasive pests. The plant quarantine organization in India has a very robust set-up and been intercepting large number of pests in imported consignments from different countries. ICAR-NBPGR since 1976 to 2019 has intercepted 78 pests which are not known to occur in India in the imported germplasm consignments. The interceptions of three years (2017-2019) by the DPPQS are given in Table 4. A total of 422 species of pests of plants and its products including insects, fungi, weeds, bacteria, viruses, nematodes and weeds have been intercepted from about 200 commodities imported from more than 50 countries (Table 4).

During 1986 to 1989, Muthaiyan et al., (1990) has intercepted 47 species of insects on the imported logs through major ports in India. During 1997 and 1998, nineteen exotic weeds have been intercepted and identified in wheat grain consignments imported through 10 major ports of India. Out of 19 exotic weeds intercepted, seven were considered noxious in nature and entry of these weed are prohibited along with agricultural commodities in most of the developed countries. To avoid entry of exotic weeds into wheat growing areas, the entire consignment of 2.5 million tons was diverted to non-wheat growing areas for consumption purposes.

Table 4. Pests intercepted in imported commodities during 2017-2019

Organism	Number of species	Number of Commodities	Country of origin
Bacteria	15	13	USA, France, Netherland, Spain, Italy, Israel, Kenya, Germany, Ireland, Singapore (10)
Fungi	158	154	USA, UK, Australia, New Zealand, Japan, South Korea, Canada, China, France, Germany, Denmark, Taiwan, Bhutan, Netherland, Singapore, Sri Lanka, Thailand,, Sudan, Costa Rica, Cuba, Fiji, Malaysia, Papua New Guinea, Solomon Island, Tahiti, Russia, Israel, Kenya, Pakistan, Zimbabwe, Poland, S. Africa, Mexico, Peru, Hong Kong, Philippines, Turkey, Spain, Italy, Bhutan, Egypt, Venezuela, Burkina Faso, Kuwait, Indonesia, Hungary, Ivory Coast, French Polynesia, Scotland (49)
Viruses	7	12	USA, France, Netherland, Germany, Israel, Australia, Malaysia, Singapore, Thailand, Costa Rica (10)
Nematodes	32	45	USA, UK, Turkey, Singapore, Thailand, Netherland, France, Germany, Malaysia, Sri Lanka, Ireland, Scotland (12)
Insects	98	32	USA, UK, China, Japan, Vietnam, Kenya, Malaysia, Singapore, Australia, Austria, Colombia, Indonesia, Ivory Coast, Myanmar, Nigeria, Panama, Togo, Netherland, Fiji, Costa Rica, Lagos, Zimbabwe, Turkey, Russia (24)
Weeds	112	7	USA, Australia, Canada, France, Turkey, Myanmar (6)

(Source: http://plantquarantineindia.nic.in/PQISPub/html/pestIntercept-con.htm, Nagaraju et. al., 2020, 2021 & 2022; Raju et al., 2019 & 2022)

DOMESTIC QUARANTINE

Destructive Insects & Pests Act 1914 under Section 4 (a) empowers Central Government to regulate or prohibit transport of any commodity within country that is likely to spread insect or disease and cause damage to the crop. Till date, nine pests of different host plants are regulated for their movement along with host plants from their area of occurrence to other part of the country. Such provisions have helped in restricting the pest proliferation from one region of the country to other region. There is a dire need to revisit the pests of regional importance and such pests may find a suitable place under domestic quarantine regulation. List of the pests along with host plants and restricted area under domestic quarantine are detailed in Table 5.

Table 5. List of pests with details under domestic quarantine in India

Sl. No.	Pest/Disease	Host Plant	From	To
1	Fluted Scale (*Icerya purchasi*)	Citrus and woody plants	Mysore, Chennai (T N) & Kerala	Any other part of India
2	San Jose Scale (*Aspidiotus perniciosus*)	Apple and Pome fruits	Punjab, UP, Madras (TN), WB, Assam, Orissa, HP, Jammu & Kashmir	Any other part of India
3	Banana Bunchy top (virus)	Banana planting material	Assam, Kerala, Orissa, T N, & West Bengal	Any other State & UT
4	Banana mosaic (virus)	Banana plants& plant material	Maharashtra & Gujarat	Any other State &UT
5	Potato Wart (*Synchytrium endobioticum*)	Potato	Darjeeling (WB)	Any other State or place in India
6	Apple Scab (*Venturia inaequalis*)	Apple planting material	Jammu & Kashmir, Himachal Pradesh	Any other State
7	Codling Moth (*Carpocapsa pomonella*)	Apple & walnut plants including fruits	Ladakh District (J&K)	Any other area in J&K
8	Potato Cyst Nematodes (*Globodera rostochiensis &G. pallida*)	Potato	Tamil Nadu, H.P., Uttarakhand, J&K	Any other State & UT
9	Coffee Berry Borer (*Hypothenemus hampei*)	Coffee seeds/plants/ powder	Nilagiri Dt (T.N), Kodagu Dt (Karnataka) & Wayanad Dt (Kerala)	Any other parts of the Indian Union

INTERNATIONAL OBLIGATIONS

The International Plant Protection Convention (IPPC), Secretariat, housed at FAO, facilitates the development of internationally agreed standards for the application of phytosanitary measures in international trade to prevent and control the spread of plant pests. The standards developed under IPPC are recognized by the WTO under WTO-SPS agreement. Thus, the scope of the IPPC covers any invasive alien species that may be a plant pest. India is signatory in IPPC, Asia Pacific Plant Protection Convention (APPPC) and WTO-Sanitary and Phytosanitary Agreement (WTO-SPS) since its inceptions from 1952. This clearly indicates, India's assurance towards pest free global trade of plants and plant products.

At regional level, APPPC helps member countries, analyse the risks to their national plant resources and use science-based approaches to safeguard their wild and cultivated plants. The Commission helps the member countries to improve their capacity for pest surveillance, pest risk analysis, pest risk management through systems approaches, and implementation of regional and international standards for phytosanitary measures. It helps, with the measures to enact during outbreaks of invasive species to promote safe agricultural trade. The APPPC actively facilitates information exchange networks among member countries, which allows countries to share import and export requirements, pest reports, updated pest control programmes, and early warning of risks. The Commission also helps countries, to develop plant health policy and regulations, and systems and practices to minimize the potential risk of the introduction and spread of regulated pests (FAO, 2021). International trade in goods, services, and intellectual property between the member countries of the WTO is disciplined by the 1994 Uruguay Round Agreements. This regime provides a binding rule, enforced by a compulsory dispute settlement mechanism, designed to ensure that governments extend free market access to each other's products and services. Particularly relevant to alien species that are characterised as pests or diseases in the 1995 WTO Agreement on the application of SPS Agreement, which allows member countries to adopt national measures or standards to: (1) protect human, animal and plant life from the risks arising from the entry, establishment or spread of pests, diseases, or disease-carrying organisms or disease- causing organisms; and (2) prevent or limit other damage within the territory of the Member from the entry, establishment or spread of pests (McNeely, 2000).

MIGRATORY PESTS - LOCUST PLAGUES AND UPSURGES IN INDIA

The desert locust, *Schistocerca gregaria*, is one of the most notorious insect pests of the world which inhabits the entire Northern Africa and Western Asia (Fig. 1). It affects 64 countries between Moracco and India during the outbreak period. A single swarm of locust made up of several million individuals can eat away every kind of plant on its way in no time. There are two distinct subspecies namely *Schistocerca gregaria gregaria* (Forskal) and *Schistocerca gregaria flaviventris* (Burmeister). The current outbreak began with heavy rains in 2018 in the Arabian Peninsula. During Spring 2019, swarms spread from these areas, and by June 2019, the locusts spread north to Iran, Pakistan, and India and south to East Africa. By the end of 2019, heavy swarms occurred in Iran, Pakistan and India. The current locust invasion is the worst in India since 1993. The outbreak originated from two cyclones (May and Oct 2018) that allowed three generations of breeding - from June 2018 to March 2019 - in the Arabian Peninsula, Iran and Pakistan that caused an 8,000-fold increase in locust numbers. The locusts currently attacking crops in India, bread and matured in Iran and Balochistan in Pakistan. Still the swarms of locusts breeding in Horn of Africa are likely to reach India and Pakistan next month. In India, the desert areas of Rajasthan, Gujarat and Haryana in North West India were severely affected. Millions of locusts have now affected around 100 districts in five states of Rajasthan, Madhya Pradesh, Uttar Pradesh, Gujarat and Maharashtra and predicted to invade many other states in the next few weeks.

The desert locust occurs in a phases of plague cycles, a period of more than two consecutive years of wide-spread breeding and swarm production followed by a period of 1-8 years of very little locust activity called as the recession period. India witnessed several locust plague and locust upsurges and incursions during last two centuries as indicated below (Table 6.) (http://ppqs.gov.in/divisions/locust-control-research/locust-plagues-and-upsurges)

Table 6. Locust plagues and upsurges in India (www. http://ppqs.gov.in/)

Locust plagues	Locust Upsurges	
	Year	Swarm incursion
1812-1821	1964	4
1843-1844	1968	167
1863-1867	1973	6
1869-1873	1974	6
1876-1881	1975	19
1889-1891	1976	2
1900-1907	1978	20
1912-1920	1983	26
1926-1930	1986	3
1940-1946	1989	15
1949-1955	1993	172
1959-1962	1997	4
	1998, 2002, 2005, 2007, 2010	Small scale breeding
	2019	276
	2020	103

International cooperation on locust management

India is a member of FAO Commission for Controlling the Desert Locust in South-West Asia (SWAC) since 1964. In SWAC, other participating countries are Afghanistan, Iran and Pakistan. India is regular member of DLCC since 1959. India is regularly participating in the meetings/ sessions of the FAO's SWAC & DLCC, Joint Survey Programmes with Pakistan and Iran organized by FAO; Indo-Pak joint border meeting during summer months. India is also participating in Inter Regional workshop like Desert Locust Information Officers' workshop, Contingency Planning and Financing System for locust control etc.

History and establishment of Locust Warning Organization (LWO) in India

In the nineteenth century, India experienced a serious of locust outbreaks during 1812, 1821, 1843-44, 1863, 1869, 1878, 1889-92, and 1896-97. Several efforts were made by British Government to combat the swarms. The first of these measures was to systematically collect and record data on locust occurrences. Only after the result of series of locust outbreaks between 1926-32, that ravaged the central and western part of the undivided British India was the need felt for establishment of a centralised organization. This resulted in the formation of the Standing Locust Committee in 1929 and the Central Locust Bureau in 1930. Research on the desert locust began in 1931 and established a permanent Locust Warning organization (LWO) in March 1939, with headquarters at New Delhi and a substation at Karachi in 1942. Later, this organization was merged with the Directorate of Plant Protection Quarantine and Storage, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India in 1946.

LWO is responsible for monitoring, survey and control of Desert Locust in Scheduled Desert Area (SDA) mainly in the States of Rajasthan and Gujarat. LWO has its field head quarters at Jodhpur. Besides, Locust Circle Offices (10 nos.) located in Rajasthan and Gujarat. One Field Station Investigation Laboratory (FSIL) is located at Bikaner (Fig. 1).

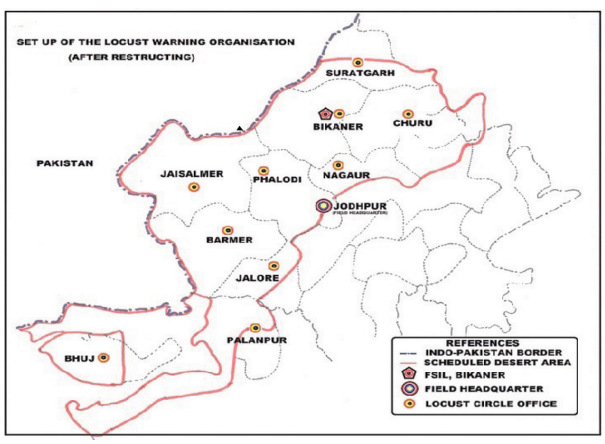

Fig. 1. Locust Warning Organisation (LWO) – Stations in India

The area of scheduled desert is about 2.00 lakh square Kilometer. LWO has its central head quarters

at Faridabad, while field head quarters at Jodhpur. Besides, Locust Circle Offices (10 nos.) located in Rajasthan and Gujarat, one Field Station Investigation Laboratory (FSIL) is located at Bikaner. Incursion of exotic locust swarms into India is prevented by LWO through organization of suitable control operation in coordination with state agriculture and other departments.

LWO keeps itself abreast with the prevailing locust situation at National and International level through monthly Desert Locust Bulletins of FAO issued by the Desert Locust Information Service (DLIS), AGP Division Rome, Italy. Survey data are collected by the field functionaries from the fields which are transmitted to LWO circle offices, field HQ Jodhpur and Central HQ Faridabad, where these are compiled and analyzed to forewarn the probability of locust outbreak and upsurges. The locust situation is appraised to the State Governments of Rajasthan and Gujarat with the advice to gear up their field functionaries to keep a constant vigil on locust situation in their areas and intimate the same to nearest LWO offices for taking necessary action at their end.

The main objective of Locust Warning Organisation (LWO) is protection of standing crops and other green vegetation from the ravages of Desert locust which is one of the most dangerous pests occurring in desert areas throughout the world. Lot of innovations have been made in the field of locust survey and surveillance for quick transmission of locust survey data, their analysis, decision making, mapping of survey areas through computerization, adoption of new software like eLocust3 and RAMSES by the LWO (Fig. 2). eLocust3g, is a GPS satellite communicator that can send basic data in real time on a standard form.

Desert locust management

On seeing the Locust swarm invasion, farmers may up take following preventive and management measures. Information to the nearest ICAR Institute / State Agrl. University / State department agriculture or Central Integrated Pest Management Centre (CIPMC) or any of the locust warning organizations or its nearest field station is a must for correct identification of the desert locust and to take up appropriate control measures. The locust should not be misidentified with other commonly occurring grasshoppers.

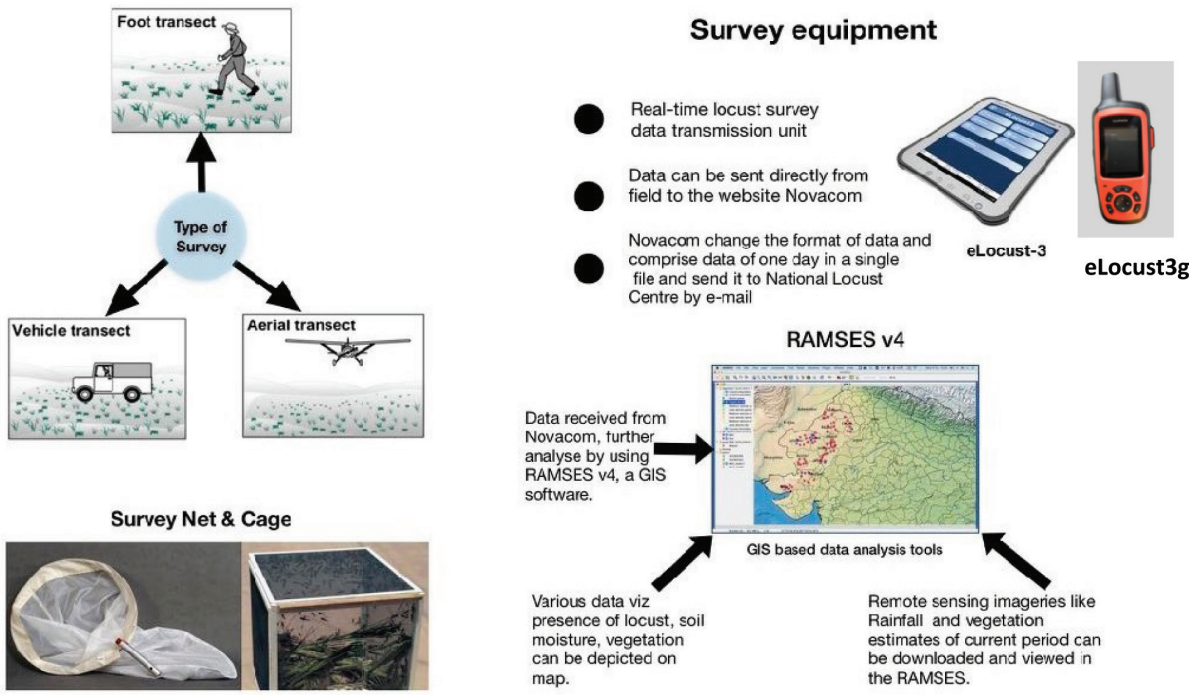

Fig. 2. Locust surveillance system by LWO

Cultural and mechanical methods

1. Make loud sound in the cropped field by beating empty tins/metal plates, drum or radio or through any other electronic sound system to prevent locust swarm landing on the crop.
2. If hopper band is formed and observed marching, ignite dry grass or any trash in front of the marching hopper band to kill the nymphs.
3. Dig a trench 2 feet deep and 2 feet wide in front of marching hopper band for trapping and killing by the application of any one of the insecticides mentioned herewith
4. Movement of vehicles from the infested area to the fresh area to be checked for the roosting locust swarms on the vehicle roof top and treated with chemicals accordingly.
5. The desert locust adults and mature swarms use downwind air for their flight and in this manner the movement of the swarms could be predicted for issuing alert warning and management.

Chemical methods

1. Spray 5% Neem seed kernel extract on standing crop as feeding deterrent.
2. If hatching of eggs started and nymphs observed, spray bio-pesticide – *Metarrhizium anisopliae var. acridum* @ 75 gram/15 lit water (Not available in India) or any recommended insecticide (Table 7).
3. If a locust swarm is spotted invading a cropped area, the State Agriculture Department should arrange Aerial spraying of ULV formulation of insecticide with the help of ULV nozzles on a Helicopter or drone.

Table 7. Recommended insecticides against the locust

S. No.	Insecticides	Dose (gram active ingredient per ha)	
		Hopper nymphs	Adults
Recommended on standing crops			
1.	Chlorpyriphos 20% & 50% EC	240	240
2.	Deltamethrin 2.8% EC & 1.25% ULV	12.5	12.5
3.	Diflubenzuron 25% WP	60	NA
4.	Fipronil 5% SC & 2.92% EC	6.25	6.25
5.	Lambdacyhalothrin 5% EC & 10% WP	20	20
6.	Malathion 50% EC & 25% WP & 96% ULV	925	925
Recommended for the control of Locust, only in the scheduled Desert Area and not on the standing crops			
1.	Fenitrothion 96% ULV	1.0 lit/ha desert area	
2.	Fenvalerate 0.4% DP	25kg/ha	
3.	Malathion 5% DP	25kg/ha	
4.	Quinalphos 1.5% DP	25kg/ha	

WAY FORWARD

India being a farming country cannot afford to have frequent invasion of exotic / migratory pests. Different agro-climatic conditions and diversity of crops grown in the country favours the establishment of pests across groups. Modern fancies like kitchen garden, terrace garden, etc also result in establishment and occurrence of alien invasive pests and goes unnoticed by the regulators, till they migrate to farmers' fields and major havocs are caused on economic crop. These modern fancies coupled with small land holding and socio-economic conditions of the farming communities are inhibition in the implementation of major eradication programmes.

India has a very robust interdisciplinary Plant Quarantine system in place with required regulatory backup. The personnel involved in the phytosanitary inspection and clearance of imported agricultural commodities are highly qualified, which is witnessed in the interceptions in the past. However, the resources

must be motivated and channelized towards achieving the plant biosecurity of India, with necessary training and laboratory backup with state-of-the-art laboratory facilities. All the stakeholders including researchers, extension functionaries, farmers, general public, etc should be sensitized towards implementing plant quarantine regulations. Interception and salvaging one consignment, is a prevention of one potential invasion of a quarantine pest. Therefore, private accredited treatment providers in the country should also be sensitized about importance of salvaging an infested consignment.

A very high risk of pest invasion lies in import of growing materials. Such consignments after import are being kept under Post Entry Quarantine Facilities (PEQ) for reasonably long time under the supervision of Designated Inspection Authorities (DIA/IA). Such facilities need to be strictly monitored by the DIA at regular intervals for insect pests, diseases, nematodes, viruses, weeds, etc. More than 60% of exotic pests established in India in the past are associated with the plant propagules, fresh fruits, and vegetables. Therefore, it is high time to notify/designate multidisciplinary inspection authorities for inspection and clearance of plants in PEQ.

Weeds are intercepted in the imported bulk shipments of cereals, pulses, germplasm material, etc. Quarantine weeds like *Thlaspi arvense, Polygonum lapathifolium, Raphanus raphanistrum* are being regularly intercepted in imported consignments from different countries. There are no phytosanitary treatments available for disinfestation of such bulk consignments. Even if available, are time consuming and expensive. Therefore, reasonable time must be given for proper inspection of these commodities by the well-trained phytosanitary inspectors.

A separate unit in the National Plant Protection Organization can be established to deal with already introduced pests. The unit can have representatives from different stakeholders like ICAR Institutes, Central Integrated Pest Management Centres (CIPMCs), State Agriculture Universities (SAUs), State Governments, Krishi Vigyan Kendras (KVKs), Non-Government Organizations (NGOs), local bodies and communities to carry out emergency mitigation measures including eradication programme.

India being a diverse country having varied climatic zones, domestic quarantine imposed under Section 4 (a) of DIP Act 1914 on area specific economically important pests of different crops need to be strictly monitored by the respective state governments. All the state borders should have a functional check-post with technically sound manpower for strict compliance of the domestic quarantine.

Chapter II Clause 2 (21) of PQ Order 2003 permits the import of cut flowers, garlands, bouquets, dry fruits/nuts etc., weighing not more than two kilograms for personal consumption without a Phytosanitary Certificate or an import permit. The citizen centric provision in the PQ Order 2003 should not be misinterpreted and misused for unlawful activities. Such consignments either received at foreign post offices, airports, seaports, etc. as an accompanied baggage shall always be subjected for phytosanitary inspection either by Custom officer or Plant Quarantine officer. The Customs works round the clock at ports and Section 4 of the DIP Act 1914 empowers the Customs to operate the notification issued under DIP Act, as it has the same power issued under Section 11 of Customs Act 1962. Officers on duty can refer the plant and plant materials intercepted from passengers to Plant Quarantine officers. Periodical awareness programs to the Customs officials on regular intervals on powers enshrined to them in DIP Act is need of the hour.

REFERENCES

CABI. 2021. https://www.cabi.org/isc/abstract/20013122305, Interception of weeds in imported wheat grain consignments.

Chakravarthy A K, Kumar K P, Sridhar V, Prasannakumar N R, et al. 2017. Incidence, hosts and potential areas for invasion by Rugose Spiralling Whitefly, *Aleurodicus rugiopersculatus* Martin (Hemiptera: Aleyrodidae) in India. Pest Management in Horticultural Ecosystems 23: 41-49.

Chandrika M, Josephrajkumar A, Merin B, Arya K, et al. 2019. First record of the non-native neotropical nesting whitefly, *Paraleyrodes minei* Iaccarino on coconut palms in India and its co-existence with Bondar's nesting whitefly *Paraleyrodes bondari* Peracchi. Current Science 117: 515-519.

Daniel A J, Ashok K, Pavithran S, Ranjith M. 2020. Review on invasive insect pests in India and their predators and parasitoids. Journal of Experimental Zoology India 23: 987-1006.

FAO. 2021. http://www.ippc.int/en/ and http://www.fao.org/asiapacific/apppc/en/.

Govt. of India. 1914. The Destructive Insects and Pests Act (Act No. II of 1914) passed by Governor General of India in Council on 3rd Feb 1914 and subsequent modifications. 4 pp.

Govt. of India. 2003. Plant Quarantine Order (Regulation of import into India). Gazette notification S.O. 1322 (E), dated 18th Nov., 2003 and subsequent modifications. 331 pp.

Josephrajkumar A, Chandrika M, Merin Babu, Arya Krishna, et al. 2019. First record of the invasive Bondar's Nesting Whitefly, *Paraleyrodes bondari* Peracchi on coconut from India. Phytoparasitica, 47: 333–339. DOI 10.1007/s12600-019- 00741-2.

Joshi S, Pai S G, Deepthy K B, Ballal C R, Watson, G W. 2020. The cassava mealybug, *Phenococcus manihoti* Matile-Ferrero (Hemiptera: Coccomorpha: Pseudococcidae) arrives in India. Zoo Taxa, 4772: 191-194.

Mack R N. 2000. Assessing the extent, status and dynamism of plant invasions: current and emerging approaches. Mooney H A, Hobbs R J (eds.). Invasive species in changing world. Island Press, Washington D.C. 384 pp.

McNeely J A. 2000. Global strategy for addressing the problem of invasive alien species. Global Invasive Species Programme (GISP). *https://www.cbd.int/doc/principles/ais-strategy-gisp.pdf.*

Muthaiyan M C, Vijaya Kumar C S K, Krishnasamy N, Murali R, et al. 1990. Plant Quarantine Problem in import of logs and timbers, Quarterly Newsletter, Asia and Pacific Plant Protection Commission, FAO, 33 (4): 13-19.

Nagaraju D K, Kalleshwaraswamy C M, Maharaj Singh, Jain R K, et al. 2020. First interception of two wood feeding potential invasive *Coptotermes* termite species in India. International Journal of Tropical Insect Science 41: 1043-1052. https://doi.org/10.1007/s42690-020-00287-5.

Nagaraju D K. 2021. Rugose Spiralling Whitefly (RSW), *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae): an urban nuisance. Insect Environment 24: 156-157.

Nagaraju D K, Iyyanar D, Maharaj Singh, Esakkirani B, et al. 2021, Interception of non-indigenous weed seeds in lentil and lentil husk shipments imported from Australia, Canada, U.S.A., and Sri Lanka to India. Indian Journal of Weed Science 53(4): 417–420.

Nagaraju D K, Ravichandaran S, Prakasam V, Ramesh H P, et al. 2021. Interception of *Venturia inaequalis*, a pathogen of quarantine significance in apple shipments imported into India. Pest Management in Horticultural Ecosystems 27(2): 157-161.

Nagaraju D K, Prema Ranjitham T, Esakkirani B, Kapoor K S, et al. 2021. Interception of Saproxylic Hemiptera, *Fulvius anthocoroides* (Reuter, 1875) on wooden logs imported from Cameroon to India, a new report for Cameroon. Insect Environment 24(3): 423-426.

Nagaraju D K, Kasturi N, Maharaj Singh, Iyyanar D, et al. 2022. Interception of *Hololepta plana* (Sulzer) (Coleoptera, Histeridae) a rare beetle on poplar logs imported from Belgium. Insect Environment 25(1): 18-20. DOI: 10.55278/CBMZ7758.

Nagaraju D K, Iyyanar D, Maharaj Singh, Prema Ranjitham T, et al. 2022. Exotic storage pests intercepted in raw cashew nuts shipments imported into India and cost of salvaging the intercepted material. Insect Environment, 25(2): 189-196. DOI: 10.55278/URCL8831.

Nagaraju D K, Jain R K, Iyyanar D, Maharaj Singh, et al. 2022. Interception of live *Phratora laticollis* (Suffrian) (Coleoptera: Chrysomelidae) on poplar logs imported from Belgium and Germany. Indian Journal of Entomology 84: 1-3. https://doi.org/10.55446/IJE.2022.441.

Pimentel D, McNair S, Janecka J, Wightman J, et al. 2001. Economic and environmental threats of alien plant, animal and microbe invasions. Agriculture, Ecosystems & Environment 84: 1-20.

Raj R, Das T K, Kaur R, Singh R, Shekhawat K. 2018. Invasive noxious weed management research in India with special reference to *Cyperus rotundus*, *Eichhornia crassipes* and *Lantana camara*. Indian Journal of Agricultural Sciences 88: 181-196.

Raju J, Gokulraam M, Mohan S M, Keshavamurthy G M, et al. 2019. Interception of live exotic species *Cordylomera spinicornis* (Fabricius) (Coleoptera: Cerambycidae) in Tali wood imported from African countries. Journal of Entomology and Zoology Studies 7: 432-435.

Raju J, Nagaraju D K, Priti S, Kalleshwaraswamy C M, Sundararaj R. 2022. Invasion of wood degraders through wood import and need to strengthen the plant quarantine measures in India. Science of Wood Degradation and its Protection, Springer, 709-744 pp.

Reddy C S. 2008. Catalogue of invasive alien flora of India. Life Science Journal 5: 84-89.

Sampathkumar M, Mohan M, Shylesha A N, Joshi S, et al. 2021. Occurrence of cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Pseudococcidae: Hemiptera), a new invasive pest on cassava in India and prospects for its classical biological control opportunities in India. Current Science 120: 432-435.

Sathyanarayana N, Satyagopal K. 2013. Invasive alien species: problems and the way forward. Pest Management in Horticultural Ecosystems 19: 85-91.

Sharanabasappa, Kalleshwarswamy C M, Ashokan R, Mahadevaswamy H M, et al. 2018. First report of fall army worm, *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera: Noctuidae): an alien invasive pest on maize in India. Pest Management in Horticultural Ecosystems 24: 23-29.

Shashank P R, Chandrashekhar K, Meshram N M, Sreedevi K. 2015. Occurrence of *Tuta absoluta* (Lepidoptera: Gelechiidae) an invasive pest from India. Indian Journal of Entomology 74: 323-329.

Shylesha A N, Jalali S K, Gupta A, Varshney R, et al. 2018. Studies on new invasive pest *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and its natural enemies. Journal of Biological Control 32: 1-7.

Singh S, Sharma J H, Udikeri A, Ansari H. 2020. Invasive insects in India. El-Shafie H (ed.). Invasive Species - Introduction Pathways, Economic Impact and Possible Management Options. DOI: 10.5772/intechopen. 91986.

Sundararaj R, Selvaraj K. 2017. Invasion of rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae): a potential threat to coconut in India. Phytoparasitica 45: DOI: 10.1007/s12600-017-0567-0.

Sushil S N, Verghese A, Viraktamath C A, Ballal C R, Nagaraju D K. 2015. South American Tomato Pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Directorate of Plant Protection Quarantine and Storage, Ministry of Agriculture and Farmers Welfare, Government of India 6 pp.

Sushil S N. 2016. National Agricultural Bio-security System in India – Strengths and Challenges. International Conference on *"Plant, Pathogen and People: Challenges in Plant Pathology to Benefit Humankind"* on February 23-27, 2016 at NASC, New Delhi.

Sushil S N. 2018. Plant Protection Regulations in India - Strengths & Challenges. XVI AZRA International conference on Applied Zoological Research for Sustainable Agriculture and Food Security, February 9-11, 2018 at Banaras Hindu University, Varanasi.

Sushil S N, Nagaraju D K, Srivastava R P. 2021. Safeguarding Indian agriculture through plant quarantine regulations: emerging issues and way forward. Journal of Ecofriendly Agriculture 16(2): 97-105.

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