Crop Pests in India: Current Status and Future Strategies

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Technological Innovations in Agriculture: Seeds of Progress

This book "Technological Innovations in Agriculture: Seeds of Progress" is a testament to this enduring journey of transformation. The interdisciplinary nature of this book reflects the diverse challenges facing modern agriculture, encompassing topics such as climate change resilience, soil health management, biotechnology applications, and agro-ecological practices. By integrating cutting-edge research with real-world applications, this book strives to bridge the gap between theory and practice, empowering stakeholders across the agricultural value chain to make informed decisions and drive positive change.

The idea for this book was born from a growing recognition of the critical role technology plays in addressing the myriad challenges facing agriculture today. Climate change, population growth, and diminishing natural resources present formidable obstacles that necessitate a rethinking of traditional farming methods. The convergence of cutting-edge technologies such as artificial intelligence, biotechnology, precision farming, and sustainable practices offers a beacon of hope in navigating these challenges.

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Preface

In the grand tapestry of human civilization, agriculture has always held a central and indispensable role. From the dawn of settled life, when our ancestors first tilled the soil and domesticated wild plants, to the sprawling, technologically advanced farms of today, agriculture has been the bedrock upon which societies have flourished. The book you are about to delve into, "Technological Innovations in Agriculture: Seeds of Progress" is a testament to this enduring journey of transformation. The interdisciplinary nature of this book reflects the diverse challenges facing modern agriculture, encompassing topics such as climate change resilience, soil health management, biotechnology applications, and agro-ecological practices. By integrating cutting-edge research with real-world applications, this book strives to bridge the gap between theory and practice, empowering stakeholders across the agricultural value chain to make informed decisions and drive positive change.

The idea for this book was born from a growing recognition of the critical role technology plays in addressing the myriad challenges facing agriculture today. Climate change, population growth, and diminishing natural resources present formidable obstacles that necessitate a rethinking of traditional farming methods. The convergence of cutting-edge technologies such as artificial intelligence, biotechnology, precision farming, and sustainable practices offers a beacon of hope in navigating these challenges.

As editors, we are immensely grateful to the contributing authors for their expertise and dedication in producing insightful chapters that provide a deep dive into the latest technologies, offering insights into how these advancements are being harnessed to improve crop yields, enhance food security, and promote environmental stewardship. This book is not merely a chronicle of technological progress; it is a call to action for researchers, policymakers, farmers, and stakeholders across the agricultural spectrum. It underscores the urgency of embracing innovation to secure a sustainable future for agriculture, where food systems are resilient, equitable, and capable of meeting the demands of a growing global population.

We are thankful to Deepika Book Agency, | e resources | publishers | distributors, New Delhi for their interest and effort related to the publication of the book.

We hope that this book may inspire you to think critically about the role of innovation in shaping a more sustainable and prosperous world. The seeds of progress are sown within these chapters, waiting to take root and flourish in the fertile ground of your imagination and action. May this exploration of cutting-edge agricultural technologies ignite your curiosity and inspire you to contribute to the ongoing journey of agricultural transformation.

Editors

Contents

11

Crop Pests in India: Current Status and Future Strategies

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Abstract

Crop pests are a major problem for agricultural productivity in India, affecting both the country's food security and the livelihoods of farmers. A vast range of pests, including weeds, illnesses, and insects, thrive in the nation's varied agroclimatic conditions. Currently, pests such as the Fall Armyworm, locust swarms, and the Whitefly have emerged as major threats to crops like maize, rice, and cotton, respectively. Climate change exacerbates this issue, as warmer temperatures and erratic rainfall patterns favour the proliferation of pests, disrupting traditional farming practices. Additionally, the overuse of chemical pesticides has led to the development of resistance among pest populations, further complicating pest management efforts. Looking ahead, the future trends in crop pest management in India necessitate a multifaceted approach. Integrated Pest Management (IPM), emphasizing biological controls, cultural practices, and judicious pesticide use, holds promise in mitigating pest damage sustainably. Furthermore, advancements in biotechnology offer potential solutions, with genetically modified crops engineered for pest resistance. However, the adoption of such technologies requires careful regulation and consideration of socio-economic implications. Strengthening agricultural extension services, promoting crop diversification, and investing in research and development are crucial steps in building resilience against crop pests and ensuring the sustainability of India's agricultural sector in the face of evolving pest pressures.

Keywords: Crop, Insect, Pest, Productivity

11.1 Introduction

Since the beginnings of agriculture about 10,000 years ago, farmers had to face difficulties from several organisms mainly animal pests (insects, mites, nematodes, rodents, slugs and snails, birds), plant pathogens (viruses, bacteria, fungi) and weeds (i.e. competitive plants) which are collectively being called as pests. Mainly two factors that hinder smooth crop production include abiotic and biotic factors. Abiotic factors are especially the lack or excess of water in the growth season, extreme temperatures, high or low irradiance and imbalance in nutrient supply. These abiotic factors can only be managed within certain limits. Whereas biotic factors (Pests) have the potential to reduce crop production substantially. These organisms may be controlled by applying physical (cultivation, mechanical weeding, etc.), biological (suitable cultivar, crop rotation, antagonists, predators, etc.) and chemical measures (pesticides). Crop protection has been developed for the prevention and control of crop losses due to pests in the field (pre-harvest losses) and during storage (post-harvest losses). Crop losses could be either qualitative or quantitative. Reduced productivity causes quantitative losses, which lowers the yield per unit area. Pests can cause qualitative losses through reducing the amount of valuable ingredients in the product, decreasing its market quality (for example, because of pigmentation), reducing its storage qualities, or contaminating the harvested product with pests, pest parts, or toxic pest products (like mycotoxins).

11.2 Major pests of crop plants

Weeds: Insects, diseases and weeds are the three main biological factors for losing crop yield and causing huge economic loss to farmers, amongst these three, Weeds are the most notorious yield reducers leading to India losing an average of $11 billion each year in 10 major crops. In many cases, Weeds are found to be economically more harmful than insects, fungi or other crop pests. In India, weeds, generally, reduce crop yields by 36.5% during rainy-season and 22.7% during winter, and in some cases, cause complete crop failure. They decrease quality of farm produce (food, fibre, oil, fodder), animal products (meat and milk) and cause health hazards for humans and animals. Besides, they, on an average, remove 30–40 kg N, 10–15 kg P_2O_5 and 20–40 kg K_2O per hectare (Das *et al*., 2012)

Plant diseases: India is regarded as a global agricultural powerhouse. It is the world's second-biggest producer of tea, cotton, fruits, vegetables, rice, wheat, and sugarcane. Approximately 60% of Indians work in the agriculture sector, which also accounts for 17% of the country's GDP. The low yield of Indian agriculture, which is 30-5% less than that of developing nations, is one of the main problems it faces. Climate change, insufficient water availability, pest and disease outbreaks, and poor soil fertility are the issues causing India's agricultural productivity to stagnate. Plant pathogens, particularly fungal pathogens, are the most concerning of all the factors and a major source of yield limitation in agriculture. In 2007, Punjab Agricultural University reported that plant diseases caused 26% of yield losses. In India, pests and illnesses cost the country's crops approximately INR 290 billion annually. Approximately 5,000 of the 30,000 plant diseases reported from various nations exist in India. An estimated 5 million tons of crop production are lost annually in India as a result of fungal diseases. At least 125 million tons of crops, including potatoes, maize, soybeans, wheat, and rice, were destroyed in 2012 by fungal infections. Fungi cause $60 billion worth of harm to rice, wheat, and maize worldwide each year. This has significant economic ramifications, including decreased market share, decreased production, and more unemployment in the food and agriculture industries (Shukla *et al*., 2022).

Nematode: Nematodes that parasitize plants are a significant biotic element that reduces crop productivity and, eventually, crop production. Besides inflicting direct losses in crop yields, plant-parasitic nematodes also play an important role in disease complexes involving other pathogens. The expression of damage in crop plants due to nematodes often goes unnoticed for want of diagnostic symptoms. Based on the data generated through the programme AICRP on Nematodes over the years, a critical analysis was made on losses in different crops. Plant-parasitic nematodes caused 21.3% crop losses amounting to Rs. 102,039.79 million (1.58 billion USD) annually; the losses in 19 horticultural crops were assessed at Rs. 50,224.98 million, while for 11 field crops it was estimated at Rs. 51,814.81 million. Rice root-knot nematode, *Meloidogyne graminicola*, was economically most important causing yield loss of Rs. 23,272.32 million in rice. Citrus (Rs. 9828.22 million), banana (Rs. 9710.46 million) among fruit crops; and tomato (Rs. 6035.2 million), brinjal (Rs. 3499.12 million) and okra (2480.86 million) among the vegetable crops suffered comparatively more losses (Kumar *et al*., 2020).

Mites: Mites pose one of the most important pests that deteriorate the quality of produce which affects the international quality standards. These miniature creatures of the class arachnid with their very unique physical structure and feeding habits make a close resemblance to spiders and ticks. Mites attack a wide array of crops and many other organisms like honey bees, which are critical to the pollination of many crops. Family Tetranychidae (Actinedida or Prostigmata) also known as "Spider mites", comprise the most important phytophagous mite pests of agriculture around the world, attacking food crops, trees, and ornamentals (Whiting and Van Den Heuvel, 1995). An epidemic of spider mites can cause significant yield losses and may even lead to death of the crop plant. About 1250 species of mites are reported to feed on 3877 plants of different species, however only 100 species are considered to be economically important. Eriophyoidea mites also called as "gall mites, blister mites, and rust mites" are considered to be second most important agricultural mite pests after the Tetranychidae. These mites have a unique relationship with host plants creating visible galls and other morphological abnormalities. Tenuipalpidae mites are also known as "false spider mites" as they closely resemble spider mites (family Tetranychidae) or as "flat mites" because of their flattened body in comparison to other mites. They are most common in tropical or subtropical climate and all Tenuipalpus feed on plants. (Baker and Tuttle, 1987). Approximately 30 genera with 900 described species were reported by Gerson and Collyer, 1984 but many may remain undiscovered on tropical and subtropical plants. Similarly Childers *et al*. (2003) reported that 3 species (*Brevipalpus californicus*, *B. obovatus*, and *B. phoenicis*) attack a total of 928 plant species in 513 genera in 139 families. Brevipalpus and Tenuipalpus are the two genera that cause damage to most of the plant species.

Insects: Food plants of the world are damaged by more than 10,000 species of insects (Dhaliwal *et al.*, 2010). The changing scenario of insect pest problems in agriculture as a consequence of green revolution technology has been well documented (Singh *et al*., 2002; Puri and Mote, 2003, Dhaliwal and Koul, 2010). There has been further shift in the status of several insect pests after the introduction of transgenic crops and the current scenario of climate change.

Puri and Ramamurthy (2009) documented a List of insect pests likely to become serious due to changes in ecosystems and habitats. The list is presented below:

Table 11.1: List of insect pests likely to be become serious

Insect Pests	**Crop**
Gram pod borer, Helicoverpa armigera (Hubner)	Cotton, pigeon pea, sunflower, tomato
Whitefly *Bemisia tabaci* (Gennadius)	Cotton, tobacco
Brown planthopper *Nilaparvata lugens* (Stal)	Rice
Green leafhopper *Nephotettix* spp.	Rice
Serpentine leaf miner *Liriomyza trifolii* (Burgess)	Cotton, tomato, cucurbits,
Fruit fly *Bactrocera* spp.	Fruits and vegetables
Wheat aphid *Macrosiphum miscanthi* (Takahashi)	Wheat, Barley, oats
Pink stem borer *Sesamia inferens* (Walker)	Wheat
Gall midge *Orseolia oryzae* (Wood-Mason)	Rice
Diamondback moth *Plutella xylostella* (Linnaeus)	Cabbage, cauliflower
Pyrilla *Pyrilla perpusilla* (Walker)	Rice, Sugarcane
Mealy bugs Paracoccus marginatus (Williams and Granara de Willink) and Phenacoccus solenopsis Tinsley	Field and horticultural crops

Insect Pests	Crop
Thrips Scirtothrips dorsalis Hood, Frankliniella schultzei Trybom, Thrips tabaci L., Scirtothrips citri (Moulton)	Groundnut, cotton, citrus

Losses due to insect pests in Indian agriculture have been estimated from time to time (Dhaliwal *et al*., 2003, 2004). Dhaliwal *et al*. 2010 reported that the overall crop losses increased from 7.2 per cent in early 1960s to 23.3 per cent in early 2000s. The maximum increase in loss occurred in cotton (18.0 to 50.0 %), followed by other crops like sorghum and millets (3.5 to 30.0 %), maize (5.0 to 25.0 %) and oilseeds (other than groundnut) (5.0 to 25.0 %).

Dhaliwal *et al*. (2007) reported the crop losses in different crops due to insect pests in pre and post green revolution era which is given below:

Table 11.2: Crop losses in different crops in pre and post green revolution era

Crop	Pre- green revolution era (1)	Post-green revolution era (2)	Changes in loss (2-1)
Cotton	18.0	50.0	+ 32.0
Groundnut	5.0	15.0	+ 10.0
Pulses	5.0	15.0	+ 10.0
Rice	10.0	25.0	+ 15.0
Maize	5.0	25.0	+ 20.0
Sorghum and millet	3.5	30.0	+ 26.5
Wheat	3.0	5.0	+ 2.0
Sugarcane	10.0	20.0	+ 10.0
Other oilseeds	5.0	25.0	+ 20.0
Average	7.2	23.30	+16.1

Table 11.3: List of recent pest infestations in India (Rathee and Dalal, 2018)

Common Name	Scientific Name	Crops	Reference
Tomato leaf miner	*Tuta absoluta* (Meyrick)	Tomato	Sridhar *et al*., 2014
Western flower thrips	*Frankliniella occidentalis* (Pergande)	Fruits and Vegetables	Tyagi and Kumar, 2015
Coffee berry borer	*Hypothenemus hampei* (Ferrari)	Coffee	Singh and Ballal, 1991
Coconut eriopyhid mite	*Aceria guerreronis*	Coconut	Sathiamma *et al*. 1998
Coconut leaf beetle	*Brontispa longissima* (Gestro)	Coconut	CPCRI, 2015
Eucalyptus gall wasp	*Leptocybe invasa* Fisher and La Salle	Eucalyptus	Jacob *et al*. 2007
Papaya mealybug	*Paracoccus marginatus* (William Granara de Willink)	Papaya, cotton and mulberry	Muniappan *et al*., 2008

As per the report from Directorate of Plant Protection, quarantine and storage, Faridabad major pest incidence occurred across the country during the period 2015-16 to 2023-24 is listed below:

Table 11.4: Major pest incidence during 2015-16 to 2023-24

Sl. No.	Pest	Crop	State
2015-16			
1	White fly (*Bemisia tabaci*)	Cotton	Gujarat, Madhya Pradesh, Punjab, Haryana and Rajasthan
2	Blast disease (*Pyricularia oryzae*)	Rice	Madhya Pradesh and Rajasthan
3	Red rot (*Colletotrichum falcatum*)	Sugarcane	Tamil Nadu
4	Brown plant hopper (*Nilaparvata lugens*)	Rice	Chhatisgarh
5	Pink boll worm (*Pectinophora gossypiella*)	Cotton	Gujarat, Maharashtra, Andhra Pradesh, Telangana and Karnataka
6	Yellow rust (*Puccinia striiformis*)	Wheat	J&K, Punjab, Haryana, Rajasthan, Uttarakhand, Uttar Pradesh and Gujarat
2016-17			
7	Rugose spiraling whitefly (*Aleurodicus rugioperculatus*)	Coconut Palm	Tamil Nadu, Karnataka & Kerala
8`	Swarming caterpillar (*Spodoptera mauritia*)	Rice	Odisha, Assam
9	Pink boll worm (*Pectinophora gossypiella*)	Cotton	Gujarat, Maharashtra, Andhra Pradesh, Telangana and Karnataka
10	Rhinoceros beetle (*Oryctes rhinoceros*)	Coconut	Andaman & Nicobar
11	Grey leaf spot	Coconut	Andaman & Nicobar
12	White fly (*Bemisia tabaci*)	Cotton	Gujarat, Punjab, Haryana, Rajasthan and Tamil Nadu
13	Brown Plant Hopper (*Nilaparvata lugens*)	Rice	Odisha and Telangana
14	Slug caterpillar	Coconut	Andaman & Nicobar
15	Banana skipper (*Erionotathrax*)	Banana	Tamil Nadu & Kerala
16	Mango nut weevil (*Sternochetus mangiferae*)	Mango	Tamil Nadu
17	Wheat Blast like disease (*Magnaporthe oryzae* sub *sp.triticum*	Wheat	West Bengal & Assam
2017-18			
18	Rugose spiraling white fly (*Aleurodicus rugioperculatus*)	Coconut Palm	Tamil Nadu, Karnataka, Telangana & Andhra Pradesh

19	Army worm (*Mythimna separata)*	Maize	Karnataka
20	Hairy caterpillar (*Spilosoma obliqua*)	Soybean	Madhaya Pradesh
21	Pink boll worm (*Pectinophora gossypiella*)	Cotton	Gujarat, Maharashtra, Andhra Pradesh, Telangana and Karnataka
22	Panama wilt	Banana	Tamil Nadu, Uttar Pradesh and Bihar
23	Brown Plant Hopper (*Nilaparvata lugens*)	Rice	Odisha
24	Wheat Blast like disease (*Magnaporthe oryzae sub sp.triticum*)	Wheat	West Bengal and Assam
2018-19			
25	Pink boll worm (*Pectinophora gossypiella*)	Cotton	Gujarat, Maharashtra, Andhra Pradesh, Telangana and Karnataka
26	Brown Plant Hopper (*Nilaparvata lugens*)	Rice	Odisha
27	Rugose SpirallingWhitefly (*Aleurodicus rugioperculatus*)	Coconut	Tamil Nadu, Karnataka, Telangana & Andhra Pradesh
28	Panama wilt	Banana	Tamil Nadu, Uttar Pradesh and Bihar
29	Fall Army Worm (FAW) *Spodoptera frugiperda*	Maize	Gujarat, Maharashtra, Karnataka, Telangana, Nadu, Odisha and Chhattisgarh States
2019-20			
30	Fall Army Worm (FAW) *Spodoptera frugiperda*	Maize	Gujarat, Maharashtra, Karnataka, Telangana, Chhattisgarh, West Bengal, Lucknow region of Uttar Pradesh, Madhya Pradesh, Jharkhand, Andaman & Nicobar islands, Bihar, North East States
31	Rugose Spiralling Whitefly	Coconut and Oil Palm	Karnataka, Kerala, Tamil Nadu, Telangana and Andhra Pradesh
32	Apple scab	Apple	Himachal Pradesh
33	Tobacco Leaf eating caterpillar	Soybean	Maharashtra
2020-21			
34	Fusarium wilt	Gram	Karnataka
35	Fall Army Worm	Maize	Karnataka, Rajasthan
36	Rugose Spiralling white fly	Coconut	Tamil Nadu, Karnataka
37	Neotropical whitefly	Coconut	Karnataka
2021-22			
38	Yellow rust (*Puccinia stiirformis*)	Wheat	Haryana, Maharashtra, Rajasthan, Punjab, Chhattisgarh, Uttarakhand, J & K

39	Fall Army Worm (FAW) *Spodoptera frugiperda*	Maize	Maharashtra, Uttar Pradesh, Haryana, Karnataka, Madhya Pradesh, Telangana, Punjab, Bihar, Jharkhand, Tamil Nadu, Sikkim, Rajasthan, Nagaland, Meghalaya
40	Invasive chilli thrips (*Thrips parvispinus*)	Chilli	Telangana, Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu
41	Pink boll worm (*Pectinophora gossypiella*)	Cotton	Punjab, Maharashtra, Karnataka, Gujarat, Haryana
42	White fly (*Bemisia tabaci*)	Cotton	Punjab, Haryana
43	Cassava mealy bug	Cassava	Tamil Nadu
44	Gundhi bug	Rice	Karnataka, Meghalaya, Kerala
45	White fly, leaf curl, fruit rot	Chilli	Andhra Pradesh
46	Bacterial streak	Rice	Tamil Nadu
2022-23			
47	Yellow rust (*Puccinia stiirformis*)	Wheat	Haryana , Himachal Pradesh , Punjab
48	Fall Army Worm (FAW) *Spodoptera frugiperda*	Maize	Maharashtra, Uttar Pradesh, Haryana, Karnataka, Punjab, Tamil Nadu, Rajasthan
49	Invasive chilli thrips (*Thrips parvispinus)*	Chilli	Andhra Pradesh, Maharashtra, Telangana
50	Pink boll worm (*Pectinophora gossypiella*)	Cotton	Punjab, Maharashtra
51	White fly (*Bemisia tabaci*)	Cotton	Tamil Nadu, Punjab, Haryana, Rajasthan
52	Thrips & Jassids	Cotton	Haryana, Maharashtra, Punjab
53	Rugose Spiraling Whitefly (RSW)	Coconut, Arecanut	Andhra Pradesh, Kerala, Andaman & Nicobar Islands
54	White grub	Sugarcane	Maharashtra
55	Sigatoka Disease	Banana	Tamil Nadu, Kerala
56	Cucumber Mosaic Virus (CMV)	Banana	Maharashtra
57	Southern Rice Black Streaked Dwarf Virus (SRBSDV)	Rice	Haryana, Punjab, Uttarakhand
58	Brown Plant Hopper	Rice	Punjab, Haryana, Maharashtra
59	White Backed Plant Hopper	Rice	Punjab, Haryana, Maharashtra, Bihar
60	Yellow stem Borer	Rice	Punjab, Odisha, Maharashtra
61	Leaf Folder	Rice	Punjab, Maharashtra
62	Wilt & Pod borer	Pigeon pea, chick pea	Maharashtra

2023-24			
63	Yellow Stem borer (*Scirpophaga incertulas*)	Rice	Maharashtra, Haryana, Madhya Pradesh
64	Leaf Folder (*Cnaphalocrocis medinalis (*Guenee*)*	Rice	Punjab, Odisha, Haryana, Uttarakhand
65	Jassids, Bacterial leaf blight, Swarming caterpillar, Blast	Rice	Maharashtra
66	Earhead caterpillar (*Leptocorisa acuta)*	Rice	Assam
67	Yellow Sigatoka (*Mycosphaerella musicola)*	Banana	Tamil Nadu
68	Sugarcane pyrilla	Sugarcane	Uttar Pradesh, Haryana
69	Rhinoceros beetle, Red palm weevil	Coconut	Kerala
70	Apple leaf blotch miner	Apple	Jammu and Kashmir

11.3 Future Forecasts and Innovations in Pest Management

An educated choice and application of pest control measures that will guarantee the best possible economic, ecological, and sociological outcomes can be regarded as pest management. It is disastrous to take pest management activity before determining whether it is financially sound. Gaining financial gain is not supported by treating a pest needlessly. Over the years, there have been major breakthroughs and innovations in the pest control industry. Pest control businesses have made strides in reducing the harmful impacts of pests, starting with the introduction of insecticides and continuing with the incorporation of smart technologies. Pest control is predicted to change in the future due to a number of technologies and projections.

11.3.1 Increased use of Integrated Pest Management (IPM) approach

11.3.2 Development of new pesticides

11.3.3 Increased use of smart technology

11.3.4 Use of drones in pest control

11.3.5 Use of semiochemicals

11.3.6 CRISPR/Cas-Mediated Genome Editing for Insect Pest Management

11.3.1 Increased use of Integrated Pest Management (IPM) approach

Integrated Pest Management (IPM) emphasizes the growth of a healthy crop with the least possible disruption to agro ecosystems and encourages natural pest control mechanisms. IPM is the coordinated use of pest and environmental information with available pest control methods to prevent unacceptable levels of pest damage by the most economical means and with the least possible hazard to people, property and the environment. IPM emerged at the start of the new millennium as a political and social force, having only existed as a notion in the early 1960s. IPM's guiding principles and procedures will never stop evolving. Its diversity and the variety of people, fields, and organizations involved in its research, development, and use ensure that it will always be dynamic. If properly applied in the future, a few of the tactics listed below will aid in the promotion of IPM.

11.3.1.1 Training for women: Most pest management activities are being carried out by rural women in many areas in the country and they frequently spend more time on pest control than do men. There is an increasing recognition in developing nations that methods like integrated pest management (IPM) require close consideration of the requirements, perceptions, and understanding of women farmers. The technological needs of women farmers are often different from those of men, requiring low external input, time-saving technologies adapted to small-scale, non-uniform subsistence crop production.

11.3.1.2 Involvement of Voluntary/Non-Governmental Organizations (NGOs): Farmers have discovered that receiving training from non-governmental or volunteer groups is an excellent way to acquire information and skills. It is necessary for these organizations to get more involved in training the farmers. A larger number of NGOs actively participating would be very helpful in spreading the use of environmentally friendly IPM practices among farmers.

11.3.1.3 University Education on IPM: Agricultural colleges and State Agriculture Universities (SAUs) have a major role to play. Making sure that upcoming college graduates in agriculture are prepared to support farmers using the integrated pest management (IPM) method is imperative. The establishment of bio-control laboratories to provide bio-control agents, phyto-pesticide application services, and plant protection equipment maintenance are all very promising areas in the service industry.

11.3.1.4 More weed IPM: The main obstacle to the creation of more sustainable agricultural systems, especially in agronomic crops, is weeds. Herbicides, tillage, cultivation, planting date and pattern, and other weed management techniques are typically to blame for issues with soil erosion and water quality. In the future, research will concentrate on fundamental issues like how to manage soils sustainably rather than symptoms like soil erosion. Weeds, as an important facet of sustainable soil management, will consequently receive more emphasis in IPM or Integrated Crop Management (ICM) programmes.

11.3.1.5 IPM on-line: There is an increasing body of information about production, marketing, and record keeping available to growers via the Internet. The Internet is also a good source of information about IPM, beneficial insects, products, and pest control options for individual crops. IPM specialists are generating high-quality websites as a modern educational delivery tool and many Extension Service leaflets are now being made available in electronic format only. This trend will only accelerate as more and more agriculturists familiarize themselves with the Internet for a thorough listing of IPM resources available on the Internet.

11.3.2 Development of new pesticides

Insecticides, fungicides and herbicides are commonly used for pest control in agriculture. However, insecticides form the highest share in total pesticide use in India. Per hectare use of pesticide in India is much lower as compared to other countries like China (13.06 kg/ha), Japan (11.85 kg/ha), Brazil (4.57 kg/ha) and other Latin American countries (FAOSTAT, 2017). Pesticide consumption is the highest in Maharashtra, followed by Uttar Pradesh, Punjab and Haryana. During the last decade, the total consumption increased in Maharashtra and Uttar Pradesh, while it slightly declined in Punjab and Haryana. States like West Bengal, Gujarat and Karnataka have seen a steep decline in the total consumption. The share of pesticides in the cost of cultivation was 3 per cent in cotton, 1.9 per cent in paddy, further lower in wheat (0.7%) and sugarcane (0.3%) (Subash *et al*., 2017). At least 105 chemical pesticides have been launched during the past decade or are under development: 43 fungicides, 34 insecticides/acaricides, 6 nematicides, 21 herbicides, and 1 herbicide safener. Most of them are safe to humans and environmentally friendly (Umetsu and Shirai, 2020). The most developed fungicides are SDHI (succinate dehydrogenase inhibitors), DMI (demethylation inhibitors), QoI (quinone outside inhibitors), and QiI (quinone inside inhibitors). The most developed fungicides are SDHI (succinate dehydrogenase inhibitors), DMI (demethylation inhibitors), QoI (quinone outside inhibitors), and QiI (quinone inside inhibitors). The trend of insecticide development is changing from organophosphorus, carbamate, and synthetic pyrethroids to nicotinic and diamide insecticides. During the past decade, compounds possessing a variety of novel modes of action have also been launched or are under development. Flupyradifurone and flupyrimin, exhibiting extremely low honeybee toxicity, have been developed and subjected to practical use. Herbicides possessing varied modes of action, such as acetolactate synthase, p-hydroxyphenylpyruvate dioxygenase, protoporphyrinogen oxidase, and very-long-chain fatty acid elongase inhibition, have been developed. Bio-pesticides constitute around

3 per cent of pesticide market in the country. So far 14 bio-pesticides have been registered under the Insecticide Act 1968 in India. Consumption of biopesticides has increased from 219 tonnes in 1996-97 to 683 tonnes in 2000-01, and further to around 3000 tonnes in 2015-16 (Sinha and Biswas, 2008; DAC&FW, 2017). Studies indicate that use of bio-pesticides in integrated pest management can reduce pesticide use by 66 per cent in cotton and by 45 per cent in cabbage (Birthal, 2003). Thus, biopesticides can play an important role in shifting the focus from chemical pesticides to reliable, sustainable and environment friendly options. But the pace of development of market for bio-pesticides is not so impressive.

11.3.3 Increased use of Smart Technology

IoT enabled smart pest monitoring system: An ecosystem known as the Internet of Things (IoT) is one in which humans, animals, and things are outfitted with unique identities that enable them to transfer data across Internet networks without requiring human-to-human or human-computer contact (Gogoi *et al*., 2022). The Internet and mobile apps are two of the greatest ways to make IPM technology accessible to farmers of all experience levels. The Internet of Things (IOT) is a network of interconnected system objects that communicate with one another and share objectives. Instead of just one specific application, these objects must match several. Monitoring disease and pest outbreaks from a micro-soil perspective is possible with IoT. It is more effective because it uses a variety of low-cost sensor nodes to enable real-time disease monitoring, modelling, and insect and disease pest prediction during crop growth (Kim *et al*., 2018)

11.3.3.1 Use of Generative Artificial Intelligence (AI) for pest detection by engineers Rishikesh Amit Nayak, Niharika Haridas, and Gideon Samuel Jacob. They developed a Microbial and Pest Outbreak Prediction System for Precision Agriculture and named it Kishan Know**.**

11.3.3.2 Using Machine Learning for Insect Pest Detection: Farmsense, a California-based agtech startup, is solving the insect pest problem. They used optical sensors and classification systems using machine learning algorithms to detect and track insects in real time.

11.3.3.3 Trapping Insects using Artificial Intelligence (AI): It is an AI startup producing AI-powered insect traps to detect and forecast pest infestation on the farm. The company's invention traps insects by attracting them using pheromones. It then uses built-in cameras to record photographic data of pests. These images are sent to their cloud servers to be processed and produce clear-cut reports for the farmers recommending further actions.

11.3.3.4 Use of Smartphone Camera as a Microscope through AI: GoMicro, a South Australian agtech startup, has developed a way to detect pests and plant diseases with low-cost AI technology. They've designed a phone-attachable, clip-on magnifier that works on any cellular device.The company's software can detect pests and diseases accurately in the early stages of development, significantly reducing the need for chemical remedies. Furthermore, it can also assess the quality of produce, making it possible for farmers to meet consumer expectations.

11.3.3.5 Pest Detection in Horticultural Crops Using AI: Plant Phonemics researchers from the University of Barcelona and Agrotecnio developed a smartphone application that detects early-stage diseases in horticulture crops. The app, called Doctor Nabat, is a project aimed at providing an early response to prevent the loss of crops. The farmer takes a picture of the crop through the app to start the diagnosis. Its algorithm uses deep learning to analyze 25,000 photographs of diseases, abiotic stresses, and nutritional deficiencies uploaded to its repository against the photo taken. The app then gives a precise diagnosis and the probability percentage of the detected pest or disease.

11.3.4 Use of Drones in pest control

The advent of drones has brought about a revolutionary transformation in agriculture, particularly in the domain of crop spraying. Unmanned Aerial Vehicles (UAVs), commonly known as drones, equipped with advanced spraying capabilities, are playing a pivotal role in optimizing the application of fertilizers and pesticides. This comprehensive exploration delves into the opportunities and challenges associated with the use of agriculture drones for spraying in modern agriculture. Drones for spraying pesticides have revolutionized modern agriculture, offering precision and efficiency in crop protection. These unmanned aerial vehicles (UAVs) equipped with advanced technologies enable targeted pesticide application, minimizing waste and environmental impact. In India, the potential value for drone-powered solutions is highest in the infrastructure sector at $45.2 billion according to an analysis by Pricewaterhouse Cooper. The second highest valued is the agriculture sector at $32 billion for such interventions (Sudhir, 2024).

While drones hold immense potential for transforming agriculture in rural India, their widespread adoption faces several challenges and considerations, including:

a) **Cost and Affordability:** The higher costs of purchasing Agri drones as well as handholding training support for the drone pilot could be prohibitive for small farmers and resource-constrained communities of rural India thereby limiting their access to this technology. However, Govt. of India is providing subsidies to FPCs to encourage them to procure and the same can be used by the fellow farmers of the region through custom hiring approach.

b) **Regulatory Hurdles:** The use of drones in agriculture is subject to regulations and restrictions imposed by civil aviation authorities, including airspace regulations, licensing requirements, and restrictions on flight operations, which may pose challenges to farmers seeking to deploy drones for agricultural purposes. The drone operation is particularly difficult in the border adjoining areas.

c) **Limited Connectivity and Infrastructure:** Many rural areas in India lack adequate connectivity and infrastructure, including electricity, internet access, and landing sites for drones, hindering the deployment and operation of drones in these areas.

11.3.5 Use of semiochemicals

Semiochemicals are the chemical signals which transmit information among the same species or different one. Depending upon their functions they can be classified as kairomones, synomones, allomones and apneumone. Pheromones from a large number of insects of different orders have been synthesized and applied in the field condition for the purpose of monitoring and mating disruption. Indirectly, these methods reduce the number of insecticide application in the field and thereby posing greater chances of natural enemy survival. Synomones and kairomones enhance the abilities of natural enemies in the field. "Autoconfusion" technologies and antiaggregation pheromones are two new approaches to insect pest control. Aggregation pheromones are especially prevalent in insects and other arthropods that feed on sporadic and unevenly distributed food sources, drawing in conspecifics of both sexes. These pheromones regulate how a group of people forms in order to mate, overpower predators, or attack in large numbers to overcome host resistance. *Tribolium castaneum*, the red flour beetle, produces 4,8-dimethyldecanal as an aggregation pheromone in its males. Furthermore, the widely dispersed pea and bean weevil, *Sitonia lineatus*, has been mass-trapped using its aggregation pheromone. The aggregation pheromones of conifer-attacking bark beetles are arguably the most researched. For instance, when a pioneering female mountain pine beetle (*Dendroctonus ponderosae*) feeds on host phloem while attacking a tree, it induces the creation of the aggregation pheromone component exobrevicomin. The host's defenses can be overcome and the tree can become colonized if a sufficient number of beetles react to this chemical signal. Diverse multimodal plant protection techniques that rely on gustatory, visual, auditory, or olfactory cues have the potential to enhance current integrated pest management (IPM) approaches. Semiochemicals (syn. infochemicals) and semiophysicals (Hill *et al.*, 2019) combine to generate infosignals, which transmit information about interpersonal encounters by evoking a physiological or behavioral reaction in the recipient. Semiochemicals are part of insect odorscapes and include volatile organic compounds (VOCs) that are used by insects as chemical cues to locate different resources, such as food (allelochemicals, e.g., kairomones), mate (sex pheromones), or enemies (allelochemicals, e.g., kairomones) (Conchou *et al*., 2019). Nieri *et al.* (2022) introduced the term semiophysicals as opposed to semiochemicals and focuses on pest behavioural manipulation. It is the manipulation of pest orientation through attractive/repellent stimuli, the inhibition or promotion of specific pest behaviours, and interferences with intraspecific communication through disruptive stimuli (Gross and Franco, 2022).

11.3.6 CRISPR/Cas-Mediated Genome Editing for Insect Pest Management

Significant progress has been made in the fields of molecular biology and biotechnology, particularly since the CRISPR/Cas9 gene-editing system was first introduced in mammalian cells in 2012.

CRISPR-based Gene Editing in Plants for Resistance against Insect Pests:

a. **Knocking Down Susceptible Genes:** CRISPR technology can be employed to target and modify genes in plants that are essential for insect infestation. By disrupting these genes, plants can become less susceptible to insect attacks (Tyagi *et al.*, 2020). For example, genes responsible for producing compounds that attract or nourish pests can be targeted.

b. **Modification of Plant Volatile Blends:** Plants release volatile compounds that can attract or repel insects. By using CRISPR, it is possible to modify the blend of volatiles emitted by plants to discourage pests or attract their natural predators, which can act as a form of biological pest control (Abbas *et al.*, 2022).

c. **Changing Foliage Color:** Some insects are attracted to specific colours of plant foliage. By altering the pigments responsible for leaf color through gene editing, plants can become less appealing to certain pests.

The CRISPR/Cas9 system has emerged as a sophisticated and affordable genetic tool over the past 10 years, and there are optimistic plans for its widespread deployment in pest management applications to improve crop quality in the near future (Pandey and Kumar, 2023).

11.4 Conclusion

In summary, crop pests pose a complex and dynamic challenge in India that necessitates prompt attention and aggressive solutions. In order to protect food security, farmer incomes, and environmental sustainability, effective pest control measures are essential. The agricultural industry is a vital component of the nation's economy and provides a living for millions of people. Adopting integrated strategies such as Integrated Pest Management (IPM), in conjunction with biotechnology developments and sustainable farming methods, presents viable opportunities for managing pests while reducing detrimental effects on ecosystems and public health. However, addressing this issue requires concerted efforts from policymakers, researchers, farmers, and civil society to foster innovation, enhance capacity-building, and promote holistic approaches to pest management. By investing in resilient and adaptive agricultural systems, India can mitigate the risks posed by crop pests, ensuring a more secure and sustainable future for its agricultural sector and the well-being of its populace.

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