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CROP YIELD LOSSES IN INDIA

Economic Impact of Insect Pests and Diseases



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Economic Impact of Insect Pests and Diseases

Indian Council of Agricultural Research
New Delhi

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शिवराज सिंह चौहान
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सत्यमेव जयते

D,O.No.....408...../AM :

कृषि एवं किसान कल्याण और
ग्रामीण विकास मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली
Minister of Agriculture & Farmers
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MESSAGE

Agriculture constitutes the backbone of the Indian economy, underpinning both national food security and rural livelihoods. With a population exceeding 1.4 billion and more than half of the workforce directly or indirectly dependent on agriculture, the sector plays a critical role in sustaining socio-economic stability. Recent estimates highlight significant progress, as per the Second Advance Estimates (2025-26), India's total foodgrain production is projected to reach a record 348.66 million tonnes, while horticultural production is estimated at approximately 377.77 million tonnes. These achievements are the result of the collective efforts of India's farmers, the nation's annadata alongside the progressive adoption of scientific and technological advancements in agricultural systems.

Despite these advancements, substantial challenges persist. Crop losses due to insect pests and diseases continue to impose a significant constraint on productivity, profitability and export potential. Addressing these challenges requires the adoption of sustainable, evidence-based and locally adaptive solutions that are aligned with India's diverse agro-ecological conditions. In this context, the initiative by the Indian Council of Agricultural Research to publish a document on ***"Crop Yield Losses in India: Economic Impact of Insect Pests and Diseases"*** is both timely and significant. This document provides a comprehensive, data-driven assessment of yield and economic losses across major agricultural and horticultural crops. By synthesizing inputs from multiple research institutions nationwide, it offers a robust evaluation of the extent and distribution of pest- and disease-induced damages.

Importantly, the document lays a scientific foundation for strengthening national pest surveillance systems and developing early warning frameworks at the grassroots level. Such systems are essential for enabling proactive, preventive and climate-resilient crop protection strategies. It is anticipated that this report will serve as a critical reference for researchers, policymakers and stakeholders in prioritizing targeted interventions, promoting sustainable and technology-driven agricultural practices and safeguarding India's agricultural gains. Collectively, these efforts will contribute to building a resilient, productive and self-reliant (Atmanirbhar) agricultural sector.

(Shivraj Singh Chouhan)

भागीरथ चौधरी
BHAGIRATH CHOUDHARY

सत्यमेव जयते

कृषि एवं किसान कल्याण
राज्यमंत्री
भारत सरकार
Minister of State For
Agriculture & Farmers Welfare
Government of India



MESSAGE

Farming remains the cornerstone of our country's economy, safeguarding food and nutrition security while supporting the livelihoods of millions of farming families. However, the significant yield and economic losses caused by insect pests and diseases remain a major challenge. In this context, this document assumes great importance as it provides a scientific and evidence-based assessment of crop losses across major crop groups.

It gives me immense pleasure to learn that this comprehensive document on "Crop Yield Losses in India: Economic Impact of Insect Pests and Diseases" has been prepared through the collaborative efforts of scientific institutions and stakeholders across the country.

The information presented in this publication will be highly useful for policymakers in designing targeted interventions, prioritizing investments and strengthening national strategies for pest management and crop protection. At the same time, it offers valuable insights for farmers and extension functionaries by highlighting vulnerable crops, major pest and disease issues and the need for timely and effective management practices.

The focus on Integrated Pest Management (IPM), including the use of bio-agents, eco-friendly methods and better pest monitoring, is very important. It encourages farmers to use a combination of practices such as crop rotation, use of resistant varieties, timely sowing and biological control instead of depending only on chemical pesticides. By adopting these approaches, farmers can effectively control pests and diseases more safely and sustainably. This not only helps reduce crop losses but also lowers cultivation costs by minimizing unnecessary pesticide use. At the same time, it protects soil health, beneficial insects and the environment. Overall, IPM practices can improve farm productivity, ensure safer food and increase farmers' income in the long run.

I am confident that this document will serve as a practical guide for improving decision-making at both the policy and field levels. It will play an important role in strengthening pest management frameworks, enhancing productivity and ensuring long-term agricultural sustainability in the country.

I congratulate all the scientists and institutions involved in bringing out this valuable publication and extend my best wishes for its wide dissemination and effective utilization for the benefit of farmers and the agricultural sector.

(Bhagirath Choudhary)

डॉ. एम. एल. जाट
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Dr M. L. Jat
Secretary (DARE) & Director General (ICAR)



सत्यमेव जयते

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FOREWORD

Indian agriculture remains the bedrock of the nation's economic stability, ensuring food security and providing livelihoods to a large proportion of the population. However, the sustainability and profitability of Indian agriculture are increasingly threatened by the persistent and evolving challenges posed by insect pests and diseases. These biotic stresses result in substantial crop yield losses, undermining national food security, farmers' incomes and the overall resilience of our agricultural systems. In this context, the present document, ***"Crop Yield Losses in India: Economic Impact of Insect Pests and Diseases,"*** prepared by the ICAR-National Research Institute of Integrated Pest Management (ICAR-NRIIPM), New Delhi, is both timely and highly relevant.

This comprehensive analysis provides valuable insights into the magnitude and distribution of yield losses caused by major insect pests and diseases affecting important crops across the country. It also highlights the substantial economic burden borne by farmers and the nation due to avoidable crop losses, often exacerbated by indiscriminate pesticide use, pest resistance, pest resurgence and ecological imbalances. The document underscores the importance of science-based, environmentally sustainable pest management practices, with Integrated Pest Management (IPM) identified as a key strategy for reducing crop losses while protecting environmental quality and human health. By promoting a judicious integration of cultural, biological, mechanical and need-based chemical control measures, IPM reduces dependence on pesticides, conserves natural enemies and enhances long-term crop productivity. The publication further underscores the importance of pest surveillance, forecasting, farmer awareness and capacity building in strengthening IPM adoption at the grassroots level. I commend the efforts of ICAR-NRIIPM in compiling this valuable resource, which will serve as an important reference for researchers, policymakers, extension personnel and other stakeholders. It is expected to facilitate evidence-based decision-making and strategic planning for sustainable crop protection in India.

I am confident that this publication will make a significant contribution towards minimizing crop losses, enhancing agricultural productivity and promoting resilient and sustainable farming systems in the country.

Dated: 16.07.2026
New Delhi

(M. L. Jat)

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MESSAGE

Agriculture is the backbone of India's economy, ensuring food and nutritional security while supporting millions of farming families. However, crop productivity across the country's diverse agro-ecological regions is continually threatened by insect pests, diseases, nematodes and invasive species, leading to significant yield and quality losses.

India's tropical and subtropical climate further favours the rapid spread of pests and pathogens, intensifying crop damage and economic losses. Reliable estimation of these losses is therefore essential for assessing their economic impact and guiding research, extension and policy interventions.

The present compilation on ***"Crop Yield Losses in India: Economic Impact of Insect Pests and Diseases"*** of ICAR-NRIIPM, New Delhi provides a timely and systematic documentation of crop losses across major crops. By highlighting the magnitude of yield reductions, the dataset underscores the urgent need to strengthen pest surveillance, early warning systems and climate-resilient management strategies. Beyond quantification, such information is vital for evaluating the effectiveness of current pest management practices and identifying gaps. It enables researchers and extension agencies to design targeted interventions, improve farmer advisories and promote integrated pest management (IPM) approaches that combine cultural, biological, mechanical and chemical methods. Strengthening IPM not only reduces yield losses but also minimizes excessive pesticide use, thereby safeguarding environmental sustainability and human health.

I appreciate the efforts of ICAR-NRIIPM in compiling this valuable resource, which will guide researchers, policymakers, extension workers and stakeholders. It will facilitate informed decision-making and strategic planning for sustainable crop protection in India, contributing to reduced crop losses and strengthening resilient, sustainable agricultural systems nationwide.

देवेन्द्र कुमार यादव

Dated: 15.07.2026
New Delhi

(D.K. Yadava)

PREFACE

Agriculture continues to be the cornerstone of India's economy, ensuring food and nutritional security, sustaining rural livelihoods and contributing significantly to national growth. However, the productivity of this vital sector is persistently challenged by biotic stresses, particularly insect pests and plant diseases, which cause substantial yield and quality losses across diverse cropping systems. Despite the magnitude of this problem, comprehensive national-level assessments quantifying both yield losses and their economic implications have remained limited. This document has been prepared to address this critical gap by presenting a systematic assessment of crop yield and economic losses attributable to insect pests and diseases across major crop groups in India.

The compilation draws upon multi-institutional datasets generated during 2021–2025, incorporating contributions from ICAR institutes, State Agricultural Universities (SAUs), All India Coordinated Research Projects (AICRPs) and Krishi Vigyan Kendras (KVKs). By standardizing and consolidating these datasets, the study provides robust estimates of yield losses and their economic value across cereals, pulses, oilseeds, commercial crops, fruits, vegetables, spices, plantation crops and floricultural crops. Beyond quantifying the losses, the document underscores the importance of systematic crop loss assessment as a foundation for evidence-based policymaking. Such assessments facilitate the prioritization of research and development investments, identification of vulnerable crops and regions and formulation of climate-resilient pest management strategies. They also strengthen pest surveillance systems, early warning mechanisms and farmer advisory services, thereby contributing to enhanced farmer incomes and national food security. The analysis further highlights crop-specific vulnerabilities, with pulses being disproportionately affected by diseases, oilseed crops such as mustard and groundnut experiencing severe insect pest pressure and vegetable crops including tomato, potato and onion suffering significant production losses.

This document is intended to serve as a valuable reference for researchers, policymakers, extension professionals and other stakeholders. It provides a scientific basis for promoting Integrated Pest Management (IPM) and identifies priority areas for technological innovation, capacity building and strategic resource allocation. By comprehensively assessing crop losses due to insect pests and diseases, it supports informed agricultural planning and resilient, sustainable production systems. We hope that this compilation will guide research, inform policy and support efforts to mitigate biotic stresses. Reducing crop losses will be crucial for enhancing agricultural productivity, improving farmers' livelihoods and ensuring long-term food and nutritional security..

Dated : 16.07.2026

Editors

ICAR-National Research Institute for
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Executive Summary

Agriculture constitutes a fundamental pillar of India's economy, underpinning food and nutritional security, rural livelihoods and macroeconomic stability. Nevertheless, agricultural productivity remains substantially constrained by biotic stresses, particularly insect pests and plant diseases which lead to significant quantitative and qualitative yield losses across major crop groups. Despite the scale of these impacts, comprehensive national-level data on yield losses and their associated economic costs remain limited. The present document addresses this critical knowledge gap by providing an integrated assessment of crop yield and economic losses across diverse crop categories, including cereals, pulses, oilseeds, commercial crops, horticultural crops, spices, plantation crops and floriculture.

A systematic evaluation of crop losses establishes a robust scientific foundation for evidence-based policymaking, enabling the prioritization of strategic investments and targeted interventions. Such analyses facilitate the identification of high-risk crops and vulnerable agro-ecological regions, thereby guiding research toward the management of high-impact pests and diseases. Furthermore, these assessments are instrumental in strengthening pest surveillance frameworks, developing early warning systems and formulating climate-resilient agricultural strategies. They also enhance resource allocation efficiency, improve farmer advisory services and contribute to income stabilization by mitigating losses arising from biotic stresses. In the absence of comprehensive assessments, insect pest and disease management efforts tend to remain suboptimal.

This document serves as a critical reference for key stakeholders, including researchers, policymakers and agricultural extension professionals. It provides a scientific basis for advancing Integrated Pest Management (IPM) approaches that integrate cultural, biological, mechanical and chemical control methods. Additionally, the compiled dataset enables the identification of priority domains for technological innovation and capacity development. By offering a holistic and data-driven perspective on crop loss assessment, the report contributes to enhanced agricultural planning and the promotion of sustainable production systems.

The estimation of crop yield and associated monetary losses was conducted using a structured multi-stage methodological framework. Yield loss data for the period 2021-2025 were collected from various institutions of Indian Council of Agricultural Research, State Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras. These datasets were standardized and aggregated to generate crop-specific estimates of both average and minimum yield losses attributable to insect pests and diseases. The economic valuation of crop production was derived using production statistics in conjunction with Minimum Support Price (MSP) for field crops and production value estimates for horticultural

crops. Subsequently, monetary losses were quantified by applying the estimated yield loss percentages to the respective production values.

The findings indicate that crop losses induced by insect pests and diseases are both pervasive and economically substantial. Diseases contribute marginally higher monetary losses compared to insect pests, although both exert substantial negative effects on productivity. Cereals account for the largest proportion of total monetary losses due to their extensive cultivation, followed by vegetables and fruits. Pulses are particularly affected by diseases, while oilseed crops such as mustard and groundnut demonstrate considerable monetary losses. Among commercial crops, sugarcane records the highest losses, whereas banana, mango and citrus dominate losses within fruit crops. Among vegetable, tomato, potato and onion are the most severely affected. Among spices, ginger and garlic exhibit higher monetary losses. The key findings of the study are summarized below:

- The aggregate yield losses attributable to insect pests and diseases underscore the substantial impact of biotic stress across cropping systems. Overall, combined yield losses are estimated to range from 18.77 to 42.81%, with a mean loss of 31.87%.
- Among major crop groups, cereals exhibit the lowest proportional yield loss, with 12.31% attributed to insect pests and 11.61% to diseases, suggesting comparatively greater resilience and/or more effective crop protection practices in staple crops.
- Yield losses display considerable variability across crops, ranging from 10.26 to 27.20% due to insect pests and from 8.51 to 23.56% due to diseases, reflecting differences in crop susceptibility and the intensity of pest and disease pressure.
- In monetary terms, the total average annual loss is estimated at approximately ₹6.15 lakh crore with a lower-bound estimate of ₹5.14 lakh crore.
- Cereals account for the largest share of monetary losses, estimated at ₹1,41,803 crore, primarily due to their extensive cultivation area. This is followed by vegetables (₹1,30,056 crore) and fruits (₹1,00,310 crore), reflecting both high production volumes and market value.
- Oilseeds contribute an estimated ₹92,509 crore in losses, followed by commercial crops (₹54,866 crore) and pulses (₹44,322 crore). Although relatively lesser in magnitude, spices (₹16,722 crore), flowers (₹20,358 crore) and plantation crops (₹13,586 crore) have significant economic losses.

Overall, the analysis underscores the enormous burden of biotic stresses on Indian agriculture. The magnitude of yield and monetary losses highlights the urgent need to strengthen pest surveillance, promote integrated and climate-resilient pest management strategies and enhance the availability of quality IPM inputs at an affordable price. Addressing these challenges is essential for improving agricultural productivity, securing farmer livelihoods and achieving long-term food and nutritional security in the country.

1
Introduction

Agriculture supports more than half of the global population and constitutes a critical foundation for food and nutritional security, rural livelihoods and economic stability, particularly in developing economies such as India. Despite significant advancements in crop improvement, nutrient and water management and mechanization, agricultural productivity remains constrained by biotic stresses, including insect pests, plant pathogens, nematodes and parasitic weeds. These stresses lead to substantial quantitative and qualitative yield reductions, underscoring the importance of systematic crop-loss assessment for prioritizing research and optimizing pest-management strategies. At the global scale, insect pests and plant diseases are estimated to reduce crop yields by approximately 20-40% annually, with diseases only leading to economic losses of nearly $220 billion (Food and Agriculture Organization, 2019). In India, cumulative losses due to biotic stresses, including weeds, insect pests, diseases, nematodes and rodents, are estimated at 15-25%, resulting in annual economic losses of approximately ₹0.9-1.4 lakh crore (NITI Aayog, 2015). The 37th Standing Committee on Petroleum & Chemicals (2002) observed that pest infestations are a major constraint to Indian agriculture, causing losses estimated at nearly 50% of food production and affecting 20–30% of sown crops, causing a loss of 90,000 crores. However, updated and crop-specific estimates of yield losses attributable to insect pests and diseases under Indian agro-ecological conditions remain limited.

Globally, staple crops such as rice, wheat and maize experience significant yield reduction due to pest and disease pressures. In rice, diseases such as blast can result in yield losses of up to 70-80%, while bacterial leaf blight may cause losses up to 75%. Rice sheath blight can also cause yield losses of up to 40%. Major insect pests, including rice hispa and the brown planthopper, can lead to yield reductions of up to 62 and 44%, respectively, whereas gall midge infestations under severe conditions may result in complete crop failure. In maize, the invasive fall armyworm has emerged as a major constraint, causing yield losses ranging from 21 to 53%, while diseases such as turcicum leaf blight and maydis leaf blight can

result in losses between 25 and 90%. In wheat, diseases contribute approximately 22% yield losses, with stem rust alone capable of causing up to 90% yield reduction under severe epidemics.

Pulse crops are similarly vulnerable, particularly in India, where they play a crucial role in nutritional security. For instance, Fusarium wilt in chickpea can result in yield losses of up to 80-100% under severe conditions, while dry root rot and collar rot also cause substantial damage. Wilt disease in chickpea and pigeon pea frequently lead to severe yield losses. Pod borer complex infestations can reduce yields by up to 73.50%. Oilseed crops are likewise affected; soybean rust can cause yield losses ranging from 10 to 90%. Mustard aphid outbreaks have been reported to cause yield losses exceeding 80% and may result in losses of up to 97%. Horticultural crops are also severely impacted, with diseases such as banana fusarium wilt and leaf spot diseases, mango anthracnose, mango fruit fly, mango hoppers etc., and citrus greening leading to significant production declines.

In India, diverse agro-climatic conditions favour the proliferation and persistence of insect pests and diseases. The situation is further exacerbated by the emergence and spread of invasive species, such as fall armyworms and invasive thrips, which are expanding their geographical range and host range under changing climatic conditions. Moreover, sucking insect vectors such as aphids, thrips and whiteflies not only inflict direct damage but also transmit viral pathogens, thereby amplifying crop losses and posing significant challenges to agricultural sustainability.

The present compilation provides a comprehensive dataset on crop yield losses due to insect pests and diseases across major crop groups cultivated in India, including cereals, pulses, oilseeds, commercial crops, vegetables, fruits, spices, flowers and plantation crops. Analyses indicate that the mean yield loss attributable to insect pests is approximately 16.85%, while plant diseases account for an additional 15.02% loss across crop categories. The associated economic burden is substantial, with an estimated average annual monetary loss of approximately ₹6,14,532 crore and a minimum estimated loss of ₹5,13,859 crore. Cereals account for the largest share of monetary losses (₹1,41,803 crore), followed by vegetables (₹1,30,056 crore), fruits (₹1,00,310 crore), oilseeds (₹92,509 crore) and commercial crops (₹54,866 crore). Pulses incur losses of approximately ₹44,322 crore, while spices, flowers and plantation crops contribute losses of ₹16,722 crore, ₹20,358 crore and ₹13,586 crore, respectively. These estimates highlight the substantial economic burden imposed by biotic stresses on Indian agriculture.

Beyond quantifying economic impacts, the dataset underscores the urgent need to strengthen pest surveillance systems, develop robust early warning mechanisms and implement climate-resilient Integrated Pest Management (IPM) strategies.

Factors such as climate variability, agricultural intensification, expansion of monocropping systems and increased global trade have accelerated the emergence and dissemination of invasive pests and pathogens. Without effective intervention, these drivers are likely to exacerbate crop losses in the coming decades. Therefore, the development of reliable and up-to-date crop loss databases is essential for guiding research priorities, improving risk assessment frameworks, framing national pest management policies and promoting sustainable agricultural systems.

Furthermore, access to high-quality crop loss data is critical for evaluating the effectiveness of existing pest and disease management practices and identifying gaps in current strategies. Such evidence enables researchers and extension systems to design targeted interventions, enhance farmer advisory services and promote the adoption of IPM approaches that integrate cultural, biological, mechanical, host resistance and chemical methods. Strengthening these integrated approaches not only reduces yield losses due to pests but also minimizes excessive pesticide use, thereby contributing to environmental sustainability and human health.

From a broader policy perspective, systematic documentation and quantification of crop losses provide a scientific basis for evidence-driven decision-making and resource allocation. By assessing the economic impacts of pests and diseases across crop sectors, policymakers can prioritize investments in research and development, pest monitoring infrastructure, resistant cultivar development and farmer capacity-building initiatives. Ultimately, mitigating crop losses due to biotic stresses will be pivotal in enhancing agricultural productivity, improving farm incomes and ensuring long-term food and nutritional security for a growing population.

2
Methodology for crop yield and monetary loss estimation

To estimate the monetary losses attributable to insect pests and plant diseases in major agricultural and horticultural crops in India, a structured multi-stage methodology was employed. An insect pest refers to an insect that damages crop and causes yield losses. A plant disease refers to damage or yield loss in plants caused by microorganisms such as fungi, bacteria and viruses. This approach involved (i) compilation of primary yield loss data, (ii) aggregation of pest and disease-specific losses at the crop level and (iii) monetary valuation using production and price statistics. The analysis encompassed crops covered under the mandates of the All India Coordinated Research Project (AICRP), including field crops (cereals, pulses, oilseeds and commercial crops) as well as horticultural crops (fruits, vegetables, spices, plantation crops and flowers). All monetary values in this report are expressed in crores (1 crore = 10,000,000 Indian Rupees).

2.1 Compilation and aggregation of yield loss data

The initial dataset comprised raw observations on yield loss caused by various insect pests and diseases affecting individual crops. These data were collected from multiple ICAR research institutions and its AICRP centres, State Agriculture Universities and KVKs across several cropping seasons and locations during the last five years from 2021 to 2025. For each crop, the raw data contained multiple entries for different insect pests and diseases across different years. To derive a consolidated estimate for each crop, the following aggregation procedure was followed:

Data Segregation: For each crop, all records to insect pests were grouped and diseases were grouped separately.

Treatment of Individual Records: For each insect pest or disease record, if a range of loss (minimum and maximum) was reported, the average yield loss was computed. If a single point estimate was reported that value was uniformly adopted as the minimum and average for that specific record.

Crop-Level Aggregation: After processing individual records, all loss percentages related to insect pests and diseases for a given crop were aggregated

to derive a single, representative value: minimum per cent loss and average per cent loss due to insect pests and diseases. For each crop, the average yield loss was calculated separately for insect pest and disease-related records.

A consolidated yield loss profile was developed for each crop by capturing both the range minimum and average of yield losses attributed to insect pests and diseases over the study period.

2.2 Estimation of the value of produce

To translate the per cent yield loss into absolute monetary terms, the total monetary value of production for each crop was determined. The approach used to estimate this value differed between field crops and horticulture crops, owing to differences in pricing mechanisms and data availability.

Value of produce for field crops

For field crops, including cereals, pulses, oilseeds and commercial crops, the value of produce was derived from the production volume and the Minimum Support Price (MSP). Production data (in Lakh Tonnes) were sourced from the official government Unified Portal for Agricultural Statistics (UPAg (https://upag.gov.in)). MSP data (in Rupees per Quintal) were obtained from the Commission for Agricultural Costs and Prices (CACP), Government of India. If MSP is not available for a particular crop, the average price during last three years was taken from UPAg portal.

To compute the total value in crores, production volume and price were harmonized. The production and MSP data used for this calculation represent the average data from the years 2020-21 to 2024-25.

Value of Produce (*crores*) =Production (Lakh Tonnes) × MSP (₹/Tonnes)

Where:

Production (Lakh Tonnes): The average annual production of the crop in Lakh Tonnes (One Tonnes = 1000 kg).

MSP (₹/Tonnes): The Minimum Support Price declared by the government per Quintal (One Quintal = 100 kg).

Value of produce for horticulture crops

For horticultural crops comprising fruits, vegetables, spices, flowers and plantation crops, a formal MSP mechanism is generally not applicable. Therefore,

the total value of production was obtained directly from official horticulture statistics (https://agriwelfare.gov.in/en/PublicationReports). These statistics report on the value of production in Lakhs. To maintain uniformity across the report, these values were converted into Crores. The production value data used for this calculation represents the average values for the years 2019-20 to 2022-23.

2.3 Calculation of monetary loss

Consolidated per cent yield loss and the total value of produce for each crop were used for the calculation of absolute monetary loss. This was performed separately for insect pests and diseases under each of the two loss scenarios, i.e. minimum and average. The fundamental principle applied was that monetary loss equals the total value of the crop multiplied by the proportion of yield lost.

Monetary loss due to insect pests:

$$Loss_{ins} = V \times L_{ins}/100$$

Where:

$Loss_{ins}$ = Monetary loss due to insect pests (in ₹ crores)

V = Value of produce (in ₹ crores)

L_{ins} = Yield loss due to insect pests (%)

This formula was applied using the specific values for minimum and average insect pests damage percentages to derive the corresponding minimum and average monetary loss estimates for insect pests.

Monetary loss due to diseases:

$$Loss_{Dis} = V \times L_{Dis}/100$$

Where:

$Loss_{Dis}$ = Monetary loss due to diseases (in ₹ crores)

V = Value of produce (in ₹ crores)

L_{Dis} = Yield loss due to diseases (%)

Similarly, this formula was applied using the minimum and average loss percentages caused by the diseases to derive the corresponding monetary loss estimates for diseases.

2.4 Estimation of combined monetary loss due to insect pests and diseases

To provide a holistic view of the monetary impact, losses from insect pests and diseases were combined. Two key combined monetary loss metrics were derived for each crop.

Minimum combined monetary loss: This metric represents the most optimistic scenario, assuming the simultaneous occurrence of the minimum estimated losses from both insect pests and diseases.

$$\text{Combined Loss}_{min} = \text{Loss}_{ins}^{min} + \text{Loss}_{dis}^{min}$$

Average combined monetary loss: This metric represents the most probable scenario, based on the average estimated losses from both insect pests and diseases.

$$\text{Combined Loss}_{avg} = \text{Loss}_{ins}^{avg} + \text{Loss}_{dis}^{avg}$$

Following the calculation of these metrics for individual crops, the losses were systematically aggregated. The monetary losses associated with all crops within a particular category, such as cereals or pulses, were combined to estimate the total loss for that crop category. Subsequently, the totals obtained for each crop category were aggregated to derive the overall monetary loss across all crop groups included in the study.

Where only a single value for yield loss was available and no range was reported, it was considered as both minimum loss and average loss.

3
Yield and monetary loss assessment

3.1 Cereals

Cereal crops experience substantial yield reductions due to biotic stresses, with average losses estimated at 12.31% from insect pests and 11.61% from diseases. The average total monetary loss is approximately ₹1,41,803 crores, while the minimum estimated total monetary loss is ₹1,19,724 crores. The distribution of losses is uneven, with rice, wheat and maize accounting for the dominant share. Rice is the most affected crop, incurring an average total monetary loss of ₹85,871 crores, driven by significant yield reductions of 19.06% due to insect pests and 11.61% due to diseases, indicating high susceptibility to biotic stresses. Wheat shows comparatively low losses from insect pests (2.83%) and diseases (6.50%), contributing an average total monetary loss of ₹22,567 crores. Maize also represents a major contributor, with average yield losses of 17.58% due to insect pests and 12.17% due to diseases, resulting in an average total monetary loss of ₹21,954 crores (Table 1).

Among *Shree anna*/millets, sorghum exhibits higher average losses due to insect pests (17.20%) than due to diseases (13.15%), resulting in an average total monetary loss of ₹4,059 crores and indicating the need for targeted pest control strategies. Millets show comparatively lower absolute monetary losses but remain agronomically significant. Pearl millet records an average total monetary loss of ₹5,897 crores, with yield losses of 11.14% due to insect pests and 11.85% due to diseases, while finger millet (ragi) incurs an average total monetary loss of ₹1,296 crores, primarily driven by disease pressure that resulted in 14.38% average yield loss. Small millets, though limited in cultivation scale, exhibit notable yield reductions (13.21% due to insect pests), corresponding to monetary loss of ₹159 crores (Table 1). Collectively, these findings highlight a considerable economic burden and underscore the necessity for crop-specific IPM strategies to enhance cereal productivity, safeguard farmer livelihoods and ensure food security.

Table 1: Yield and monetary loss due to insect pests and diseases in cereals

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Rice	13.44	19.06	11.33	11.61	37,646	53,358	31,735	32,513	69,381	85,871
2	Wheat	2.83	2.83	6.50	6.50	6,845	6,845	15,722	15,722	22,567	22,567
3	Maize	14.56	17.58	9.31	12.17	10,744	12,971	6,873	8,983	17,617	21,954
4	Finger millet (Ragi)	5.13	5.13	11.75	14.38	341	341	781	955	1,122	1,296
5	Pearl millet	11.14	11.14	9.92	11.85	2,858	2,858	2,543	3,039	5,401	5,897
6	Sorghum	17.20	17.20	8.80	13.15	2,300	2,300	1,177	1,759	3,477	4,059
7	Small millet	13.21	13.21	–	–	159	159	–	–	159	159
Average yield loss (%)		11.07	12.31	9.60	11.61						
Total monetary loss (₹ crores)						60,893	78,832	58,831	62,971	1,19,724	1,41,803

3.2 Pulses

Pulse crops exhibit substantial vulnerability to biotic stresses, with average yield losses estimated at 14.37% due to insect pests and 18.58% due to diseases, resulting in a total annual monetary loss of approximately ₹44,322 crores. The distribution of losses varies across crops, with chickpea and mungbean accounting for the largest share, followed by urdbean and pigeon pea, while lentil and field pea contribute relatively smaller yet economically significant losses. Chickpea was the most affected pulse crop, incurring the highest monetary loss of ₹18,371 crores. This is primarily driven by pronounced insect pests (14.37%) and diseases (14.30%). Mungbean also shows high susceptibility, with yield losses of 14.64% due to insect pests and 25.50% due to diseases, resulting in monetary loss of ₹10,946 crores. Similarly, urdbean experiences considerable losses, with 21.00% yield reduction from insect pests and 25.50% from diseases, translating to monetary loss of ₹7,544 crores. Pigeon pea records moderate losses, with yield reductions of 15.50% due to insect pests and 9.03% due to diseases, corresponding to monetary loss of ₹6,186 crores. In comparison, lentil and field pea exhibit lower absolute monetary losses, but remain important at regional scales. Lentil shows a yield loss of 7.43% due to insect pests resulting in monetary loss of ₹687 crores. Field pea records a yield loss of 13.30% from insect pests, with monetary loss of ₹588 crores (Table 2). Overall, the analysis indicates that diseases contribute more substantially than insect pests to total yield losses in pulses. The findings highlight a significant monetary burden and emphasize the need for crop-specific, IPM strategies to enhance productivity, stabilize farmer incomes and ensure nutritional security.

Table 2: Yield and monetary loss due to insect pests and diseases in pulses

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Chickpea	4.51	14.37	4.17	14.30	2,890	9,208	2,672	9,163	5,562	18,371
2	Mungbean	11.34	14.64	23.00	25.50	3,091	3,992	6,272	6,954	9,363	10,946
3	Urdbean	16.00	21.00	23.00	25.50	2,596	3,407	3,731	4,137	6,327	7,544
4	Pigeon pea	12.30	15.50	6.84	9.03	3,103	3,905	1,729	2,281	4,832	6,186
5	Lentil	3.05	7.43	–	–	282	687	–	–	282	687
6	Field pea	13.3	13.3	–	–	588	588	–	–	588	588
Average yield loss (%)		10.08	14.37	14.25	18.58						
Total monetary loss (₹ crores)						12,550	21,787	14,404	22,535	26,954	44,322

3.3 Oilseeds

On average, oilseed crops have yield reductions of 16.52% due to insect pests and 23.56% due to diseases, resulting in an estimated total annual monetary loss of ₹92,509 crores. The distribution of losses is dominated by mustard, soybean and groundnut, with castor and sesame also contributing moderate losses, while sunflower, safflower and linseed contribute relatively smaller but regionally significant losses. Mustard accounts for the highest monetary loss (₹33,084 crores), followed by soybean (₹29,973 crores) and groundnut (₹22,481 crores). Moderate losses are observed in castor (₹3,508 crores) and sesame (₹2,858 crores), whereas sunflower (₹303 crores), safflower (₹155 crores) and linseed (₹147 crores) contribute relatively smaller losses (Table 3).

At the crop level, mustard has an average yield loss estimated at 23.38% due to insect pests and 27.52% due to diseases. Soybean exhibits comparatively lower yield losses than mustard, with average reductions of 18.57% due to insect pests and 31.72% due to diseases. Groundnut constitutes a significant proportion of total losses within the oilseed sector, with average yield reductions of 26.00% attributable to insect pests and 9.68% to diseases (Table 3). Castor shows greater susceptibility to diseases, with an average disease-related yield loss of 21.55% compared with 11.15% due to insect pests, indicating the need for integrated management approaches. Sesame follows a similar trend, with lower insect pest-related yield losses (13.27%) but higher losses due to diseases (29.91%), emphasizing the importance of effective disease control. Sunflower records comparatively low average yield losses of 6.24% due to insect pests and 12.51% due to diseases. Linseed experiences moderate yield losses from insect pests (13.77%) and relatively lower losses from diseases

(6.93%), while safflower demonstrates considerable vulnerability to both insect pests (17.02%) and diseases (32.00%).

The findings highlight a significant economic burden on the oilseed sector and underscore the urgent need for crop-specific IPM strategies to enhance productivity, improve farmer profitability and ensure sustainable oilseed production systems.

Table 3: Yield and monetary loss due to insect pests and diseases in oilseeds

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Mustard	23.38	23.38	27.52	27.52	15,198	15,198	17,886	17,886	33,084	33,084
2	Soybean	7.09	18.57	25.97	31.72	4,226	11,068	15,478	18,905	19,704	29,973
3	Groundnut	20.46	26.00	9.32	9.68	12,892	16,382	5,872	6,099	18,764	22,481
4	Castor	10.88	11.15	21.04	21.55	1,167	1,196	2,258	2,312	3,425	3,508
5	Sesame	12.86	13.27	23.85	29.91	851	878	1,579	1,980	2,430	2,858
6	Sunflower	5.96	6.24	11.49	12.51	96	101	186	202	282	303
7	Safflower	17.02	17.02	27.33	32.00	54	54	86	101	140	155
8	Linseed	13.07	13.77	6.21	6.93	93	98	44	49	137	147
Average yield loss (%)		13.95	16.52	20.93	23.56						
Total monetary loss (₹ crores)						34,577	44,975	43,389	47,534	77,966	92,509

3.4 Commercial Crops

Commercial field crops experience yield reductions of 10.96% due to insect pests and 9.90% due to diseases, resulting in an estimated total annual monetary loss of ₹54,866 crores. The distribution of losses is skewed, with sugarcane accounting for the dominant share, followed by cotton and jute & mesta, while tobacco contributes a comparatively smaller but regionally important loss. Sugarcane emerges as the most affected crop, incurring the highest monetary loss (₹42,833 crores), driven by yield reductions of 16.90% due to insect pests and 14.20% due to diseases, indicating pronounced vulnerability to biotic stresses. Cotton records substantial monetary losses of ₹10,549 crores, with an average yield reduction of 14.43% from insect pests and 16.35% from diseases, reflecting its susceptibility to multiple biotic constraints, including historically significant pest pressures such as bollworms. Jute and Mesta exhibit relatively lower yield losses due to insect pests (6.20%) and diseases (5.60%), resulting in a monetary loss of ₹961 crores, which is significant in regions where it serves as a key fibre crop and livelihood source (Table 4).

Tobacco crops have comparatively lower yield loss, with 6.29% due to insect pests and 3.44% due to diseases, leading to a monetary loss of ₹523 crores. The findings underscore a considerable economic burden and highlight the urgent need for crop-specific IPM strategies to sustain commercial crop productivity and protect farmer livelihoods.

Table 4: Yield and monetary loss due to insect pests and diseases in commercial crops

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Sugarcane	13.40	16.90	12.00	14.20	18,456	23,276	16,527	19,557	34,983	42,833
2	Cotton	13.43	14.43	13.66	16.35	4,603	4,946	4,681	5,603	9,284	10,549
3	Jute and Mesta	5.80	6.20	5.20	5.60	472	505	423	456	895	961
4	Tobacco	6.29	6.29	3.02	3.44	338	338	162	185	500	523
Average yield loss (%)		9.73	10.96	8.47	9.90						
Total monetary loss (₹ crores)						23,869	29,065	21,793	25,801	45,662	54,866

3.5. Fruit crops

An analysis of yield losses and economic impacts across major fruit crops demonstrates the substantial burden imposed by insect pests and diseases on India's horticultural sector. On average, yield losses are estimated at 19.42% due to insect pests and 15.24% due to diseases, resulting in an annual monetary loss of approximately ₹1,00,310 crores. The distribution of losses is higher in banana and mango, followed by citrus, while other crops contribute moderately to lower economic loss.

Banana incurs the highest monetary loss (₹30,157 crores), primarily driven by disease-related yield reductions (26.68%) compared to insect pests (10.50%), underscoring the critical importance of disease management. Mango also exhibits substantial vulnerability, with yield losses of 20.43% due to insect pests and 13.51% due to diseases, resulting in monetary loss of ₹29,472 crores. Similarly, citrus also ranks among the most affected crops, due to yield reductions from insect pests (23.75%) and diseases (25.00%), contributing to monetary loss of ₹22,704 crores. Papaya showed high susceptibility to biotic stress, with severe yield losses of up to 48.00% due to insect pests and 20.00% due to diseases, leading to monetary loss of ₹8,146 crores. Guava also experiences notable impacts, with yield losses of 18.13% from insect pests and 12.18% from diseases, resulting in a loss of ₹3,833 crores. Pomegranate shows moderate losses, with 9.70% yield reduction due to insect pests and 14.63% due to diseases, leading to monetary loss of ₹2,949 crores. Litchi

records relatively high yield losses due to insect pests (24.08%) compared to diseases (8.90%), resulting in monetary loss of ₹1,255 crores. Grapes exhibit comparatively lower yield reductions due to insect pests (3.47%) and diseases (4.49%), which account for a notable monetary loss of ₹906 crores. Sapota shows high susceptibility to insect pests, with an average yield loss of 27.50% resulting in monetary loss of ₹707 crores. Apple records relatively lower losses with yield reductions of 8.60% due to insect pests and 11.80% due to diseases, leading to monetary loss of ₹181 crores (Table 5).

Overall, the findings highlight a significant economic burden on the fruit sector and emphasize the need for crop-specific, IPM strategies to enhance productivity, reduce losses and ensure sustainable horticultural production systems.

Table 5: Yield and monetary loss due to insect pests and diseases in fruit crops

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Banana	8.00	10.50	25.86	26.68	6,489	8,516	20,975	21,641	27,464	30,157
2	Mango	18.97	20.43	11.63	13.51	16,467	17,739	10,093	11,733	26,560	29,472
3	Citrus	20.00	23.75	20.00	25.00	9,314	11,061	9,314	11,643	18,628	22,704
4	Papaya	34.00	48.00	13.50	20.00	4,073	5,750	1,617	2,396	5,690	8,146
5	Guava	16.47	18.13	11.27	12.18	2,082	2,293	1,426	1,540	3,508	3,833
6	Pomegranate	9.70	9.70	13.34	14.63	1,176	1,176	1,617	1,773	2,793	2,949
7	Litchi	19.98	24.08	5.20	8.90	760	916	198	339	958	1,255
8	Grapes	3.47	3.47	4.49	4.49	395	395	511	511	906	906
9	Sapota	25.00	27.50	–	–	643	707	–	–	643	707
10	Apple	8.60	8.60	11.80	11.80	76	76	105	105	181	181
Average yield loss (%)		16.42	19.42	13.01	15.24						
Total monetary loss (₹ crores)						41,475	48,629	45,856	51,681	87,331	1,00,310

3.6. Vegetable crops

On an average, vegetables experience yield losses of 17.68% due to insect pests and 22.88% due to diseases, resulting in an estimated annual monetary loss of ₹1,30,056 crores. Among vegetable crops, loss was higher in potato, tomato and onion, while crops such as chilli, brinjal, cauliflower, okra, cabbage and cassava/ tapioca also contribute significantly. Potato incurs the highest monetary loss (₹35,662 crores), largely driven by higher disease pressure, with the yield reductions of 37.86% due to diseases compared to insect pests (13.79%), underscoring the

importance of disease-resistant varieties and improved crop management. Tomato is similarly affected, with the yield losses of 28.10% due to insect pests and 31.60% due to diseases, resulting in monetary loss of ₹26,971 crores which indicates its high susceptibility to biotic stresses. Onion also contributes substantially, with yield losses of 22.30% from insect pests and 22.10% from diseases, corresponding to monetary loss of ₹22,319 crores. Among other vegetables, chilli records yield reductions of 13.64% due to insect pests and 26.38% due to diseases, resulting in monetary loss of ₹13,248 crores, while brinjal shows yield losses of 17.45% and 14.43%, due to insect-pests and diseases, respectively, with an associated monetary loss of ₹9,734 crores. Cauliflower records yield reductions of 19.25% due to insect pests and 10.00% due to diseases, leading to monetary loss of ₹6,949 crores, while okra has yield reductions due to insect pests (7.68%) and diseases (26.30%), resulting in monetary loss of ₹6,205 crores. Cabbage records yield reductions of 19.25% due to insect pests and 12.00% due to diseases, leading to monetary loss of ₹5,947 crores. In cassava/tapioca, diseases led to a yield reduction of 25.21% with monetary loss of ₹3,021 crores, highlighting vulnerability to disease outbreaks (Table 6). Overall, the findings demonstrate a considerable monetary burden on the vegetable sector and emphasize the need for crop-specific IPM strategies to mitigate losses, enhance productivity and support farmer incomes.

Table 6: Yield and monetary loss due to insect pests and diseases in vegetable crops

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Potato	12.00	13.79	35.71	37.86	8,286	9,520	24,662	26,142	32,948	35,662
2	Tomato	28.10	28.10	31.60	31.60	12,695	12,695	14,276	14,276	26,971	26,971
3	Onion	22.30	22.30	14.20	22.10	11,205	11,205	7,132	11,114	18,337	22,319
4	Chilli	13.00	13.64	16.95	26.38	4,304	4,516	5,612	8,732	9,916	13,248
5	Brinjal	15.52	17.45	14.43	14.43	4,739	5,328	4,406	4,406	9,145	9,734
6	Cauliflower	6.25	19.25	10.00	10.00	1,485	4,573	2,376	2,376	3,861	6,949
7	Okra	6.51	7.68	12.05	26.30	1,189	1,402	2,201	4,803	3,390	6,205
8	Cabbage	6.25	19.25	12.00	12.00	1,189	3,663	2,284	2,284	3,473	5,947
9	Cassava/ tapioca	–	–	22.92	25.21	–	–	2,746	3,021	2,746	3,021
Average yield loss (%)		13.74	17.68	18.87	22.88						
Total monetary loss (₹ crores)						45,092	52,902	65,695	77,154	1,10,787	1,30,056

3.7. Spices

The analysis indicates substantial monetary losses due to both insect pests and diseases constraining farmer incomes. Across spice crops, the mean yield loss is estimated at 10.26% due to insect pests and 8.51% due to diseases, resulting in a total annual monetary loss of approximately ₹16,722 crores. The distribution of losses is dominated by garlic, followed by ginger, cumin, coriander, cardamom, turmeric, black pepper and fennel. Garlic emerges as the most affected spice crop in monetary terms, with yield losses of 21.14% due to insect pests and 6.62% due to diseases, with monetary loss of ₹7,161 crores. Ginger records yield losses of 7.22% due to insect pests and 9.46% due to diseases, resulting in monetary loss of ₹3,085 crores. Cumin shows yield reductions of 11.60% due to insect pests and 12.72% due to diseases, corresponding to monetary loss of ₹2,796 crores (Table 7).

Table 7: Yield and monetary loss due to insect pests and diseases in spices

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Garlic	21.14	21.14	6.62	6.62	5,454	5,454	1,707	1,707	7,161	7,161
2	Ginger	1.67	7.22	2.86	9.46	309	1,335	529	1,750	838	3,085
3	Cumin	11.60	11.60	12.72	12.72	1,334	1,334	1,462	1,462	2,796	2,796
4	Coriander	9.60	9.60	10.06	10.06	699	699	733	733	1,432	1,432
5	Cardamom	6.08	11.17	6.05	12.25	221	405	220	445	441	850
6	Turmeric	1.01	4.17	1.88	5.07	84	348	157	424	241	772
7	Black pepper	1.38	3.21	2.27	7.24	53	124	88	280	141	404
8	Fennel	14.00	14.00	4.70	4.70	166	166	56	56	222	222
Average yield loss (%)		8.31	10.26	5.89	8.51						
Total monetary loss (₹ crores)						8,320	9,865	4,952	6,857	13,272	16,722

Coriander records yield losses of 9.60% from insect pests and 10.06% from diseases, resulting in a monetary loss of ₹1,432 crores. Cardamom demonstrates susceptibility to both biotic stresses, with yield losses of 11.17% due to insect pests and 12.25% due to diseases, leading to monetary loss of ₹850 crores. Turmeric records yield reductions of 4.17% due to insect pests and 5.07% due to diseases, corresponding to monetary loss of ₹772 crores. Black pepper experiences yield reductions of 3.21% due to insect pests and 7.24% due to diseases, resulting in monetary loss of ₹404 crores. Fennel, although less extensively cultivated, recorded yield losses of 14.00% due to insect pests and 4.70% due to diseases, resulting in a comparatively lower monetary loss of ₹222 crores (Table 7).

3.8. Plantation crops

The analysis indicates substantial monetary losses and highlights crop-specific vulnerabilities that constrain productivity. On an average, plantation crops have yield reductions of 22.89% due to insect pests and 9.31% due to diseases, resulting in an estimated annual monetary loss of approximately ₹13,586 crores. The distribution of losses shows that cashewnut is predominantly affected by insect pest damage, whereas arecanut and coconut exhibit disease-related impacts. Arecanut represents a distinct case, where losses are entirely disease-driven, with an average yield reduction of 13.28% and an associated monetary loss of ₹6,080 crores, indicating strong susceptibility to disease outbreaks. Cashewnut emerges as the most severely affected crop, with high yield losses of 40.00% due to insect pests and 7.50% due to diseases, resulting in a combined monetary loss of ₹3,884 crores. Coconut shows moderate but economically significant losses, with a yield reduction of 5.78% due to insect pests and 7.15% due to diseases, leading to a monetary loss of ₹3,622 crores (Table 8).

Overall, the findings underscore a considerable economic loss in plantation crops and emphasize the need for crop-specific, IPM strategies, along with improved surveillance and orchard management practices, to enhance productivity and sustain farmer incomes.

Table 8: Yield and monetary loss due to insect pests and diseases in plantation crops

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Arecanut	–	–	13.28	13.28	–	–	6,080	6,080	6,080	6,080
2	Cashewnut	40.00	40.00	5.00	7.50	3,271	3,271	409	613	3,680	3,884
3	Coconut	4.30	5.78	5.90	7.15	1,205	1,618	1,653	2,004	2,858	3,622
Average yield loss (%)		22.15	22.89	8.06	9.31						
Total monetary loss (₹ crores)						**4,476**	**4,889**	**8,142**	**8,697**	**12,618**	**13,586**

3.9. Flower crops

The findings underscore the high susceptibility of floriculture systems to biotic stresses and the significant economic loss. On an average, flower crops experience yield losses of 27.20% due to insect pests and 15.61% due to diseases, resulting in an estimated annual monetary loss of approximately ₹20,358 crores. The distribution of losses indicates that rose contributes the largest share in yield reduction due to insect pests (36.67%) and diseases (15.00%), followed by tuberose and chrysanthemum. Tuberose showed substantial yield losses of 27.50% due to insect pests and 11.83%

due to diseases, reflecting its high vulnerability to biotic stress. Chrysanthemum also shows considerable susceptibility, with yield reductions of 21.35% from insect pests and 20.00% from diseases. Jasmine records the highest insect pest-related yield loss among the flower crops, at 30.50%, indicating pronounced vulnerability. Marigold similarly experiences notable insect pest-induced losses (20.00%) and despite the absence of disease-related estimates, the extent of insect damage alone suggests a considerable economic impact (Table 9). Overall, these findings emphasize the need for targeted, crop-specific IPM strategies to mitigate losses and enhance the sustainability of floriculture production systems.

Table 9: Yield and monetary loss due to insect pests and diseases in flowers

S. No.	Crop	Yield loss (%)				Monetary loss (₹ crores)				Total monetary loss (₹ crores)	
		Insect pests		Diseases		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg
1	Tuberose	24.00	27.50	11.83	11.83						
2	Chrysanthemum	18.80	21.35	20.00	20.00						
3	Jasmine	28.00	30.50	–	–	12,122	12,935	7,423	7,423	19,545	20,358
4	Marigold	20.00	20.00	–	–						
5	Rose	36.67	36.67	15.00	15.00						
Average yield loss (%)		25.49	27.20	15.61	15.61						
Total monetary loss (₹ crores)						12,122	12,935	7,423	7,423	19,545	20,358

3.10. Comparative analysis of monetary and yield losses across crop groups

The compilation of the data across different crop groups clearly demonstrated that insect pests and diseases have a severe impact on agricultural production and the economy. The total monetary loss due to insect pests and diseases was estimated to be minimum of ₹5.14 lakh crore, with an average monetary loss of ₹6.15 lakh crore, highlighting the magnitude of the problem and the urgent need for effective management strategies (Table 10). Among the crop groups, cereals are the most severely affected group, contributing 23.1% of the total monetary loss, estimated at ₹1,41,803 crores. Cereals are followed by vegetables, exhibiting estimated monetary loss of ₹1,30,056 crores, contributing 21.2 % to the overall impact (Fig 1& 2). Fruits were the third most affected crop group with 16.3% share in the total monetary loss with ₹1,00,310 crores. In case of oilseeds, monetary loss of ₹92,509 crores was estimated, accounting for 15.1%. Commercial crops such as sugarcane, cotton, tobacco etc., together contribute about 8.9 % to the total monetary loss with an average monetary loss of about ₹54,866 crores. The monetary losses in pulses were

₹44,322 crores, which accounted for 7.2% of the total monetary loss. A combined contribution of 8.2% to the total monetary loss was exhibited by spices (2.7%), flowers (3.3%) and plantation crops (2.2%), to which ₹16,722, ₹20,358 and ₹13,586 crores of monetary loss respectively were caused by insect pests and diseases (Fig. 1& 2).

Table 10. Summary of monetary losses in major crop groups

S. No.	Crop groups	Economic loss (₹ crores)				Total economic loss (₹ crores)	
		Insect pests		Diseases			
		Min	Avg	Min	Avg	Min	Avg
1	Cereals	60,893	78,832	58,831	62,971	1,19,724	1,41,803
2	Pulses	12,550	21,787	14,404	22,535	26,954	44,322
3	Oilseeds	34,577	44,975	43,389	47,534	77,966	92,509
4	Commercial crops	23,869	29,065	21,793	25,801	45,662	54,866
5	Vegetables	45,092	52,902	65,695	77,154	1,10,787	1,30,056
6	Fruits	41,475	48,629	45,856	51,681	87,331	1,00,310
7	Spices	8,320	9,865	4,952	6,857	13,272	16,722
8	Flowers	12,122	12,935	7,423	7,423	19,545	20,358
9	Plantation crops	4,476	4,889	8,142	8,697	12,618	13,586
Total economic loss (₹ crores)		2,43,374	3,03,879	2,70,485	3,10,653	5,13,859	6,14,532

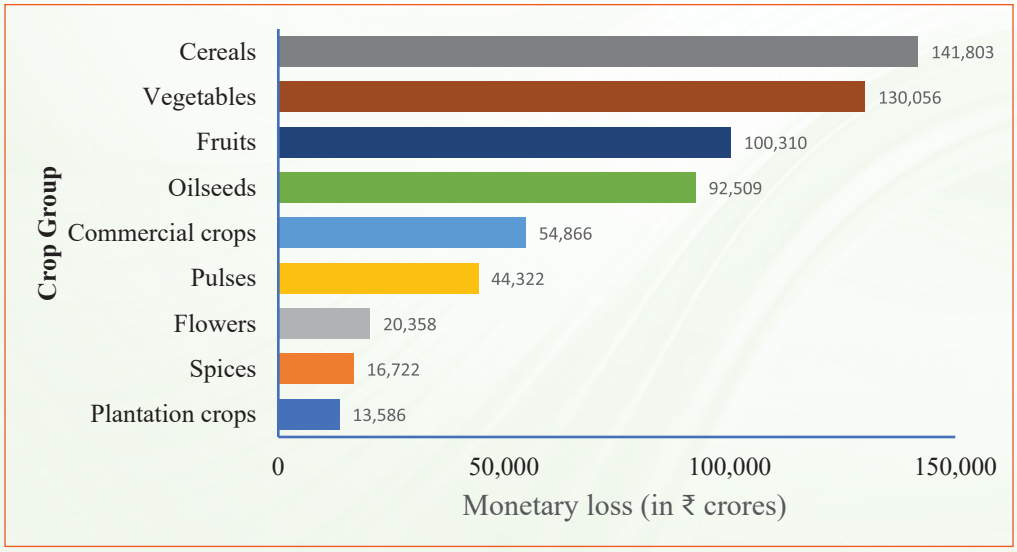


Fig. 1. Total monetary loss (₹ crores) due to insect pests and diseases

The highest per cent average yield losses were observed in flower crops, 42.81%, in which insect pests contribute 27.20% and diseases 15.61% (Fig. 3). This was followed by vegetables with an overall yield loss of 40.56%, in which insect pests contributed 17.68% and diseases 22.88%. Cereals have the lowest overall average per cent yield loss of 23.92 %, in which insect pest contributes 12.31% and diseases 11.61%, indicating relatively better resilience or more effective protection practices in staple crops (Table 11).

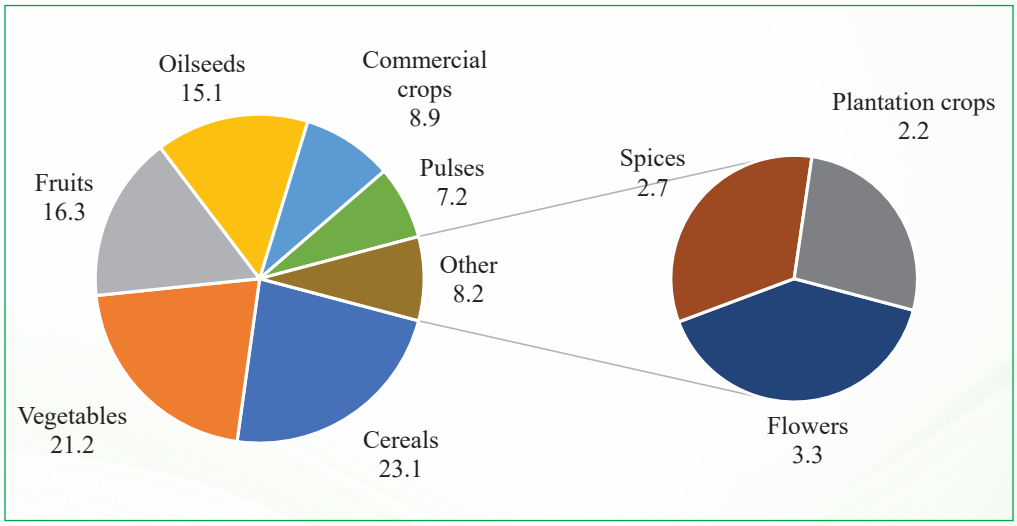


Fig. 2. Percentage share of different crop groups to total yield loss

Table 11. Crop group-wise average yield loss (%) due to insect pests and diseases

S. No.	Crop groups	Yield loss (%)				Combined Yield loss due to insect pests and diseases (%)
		Insect pests		Diseases		
		Min	Avg	Min	Avg	
1	Cereals	11.07	12.31	9.60	11.61	23.92
2	Pulses	10.08	14.37	14.25	18.58	32.95
3	Oilseeds	13.95	16.52	20.93	23.56	40.08
4	Commercial crops	9.73	10.96	8.47	9.90	20.86
5	Vegetables	13.74	17.68	18.87	22.88	40.56
6	Fruits	16.42	19.42	13.01	15.24	34.66
7	Spices	8.31	10.26	5.89	8.51	18.77
8	Flowers	25.49	27.20	15.61	15.61	42.81
9	Plantation crops	22.15	22.89	8.06	9.31	32.20

S. No.	Crop groups	Yield loss (%)				Combined Yield loss due to insect pests and diseases (%)
		Insect pests		Diseases		
		Min	Avg	Min	Avg	
Range (%)		8.31–25.49	10.26–27.20	5.89–20.93	8.51–23.56	18.77–42.81
Average yield loss (%)		14.55	16.85	12.74	15.02	31.87

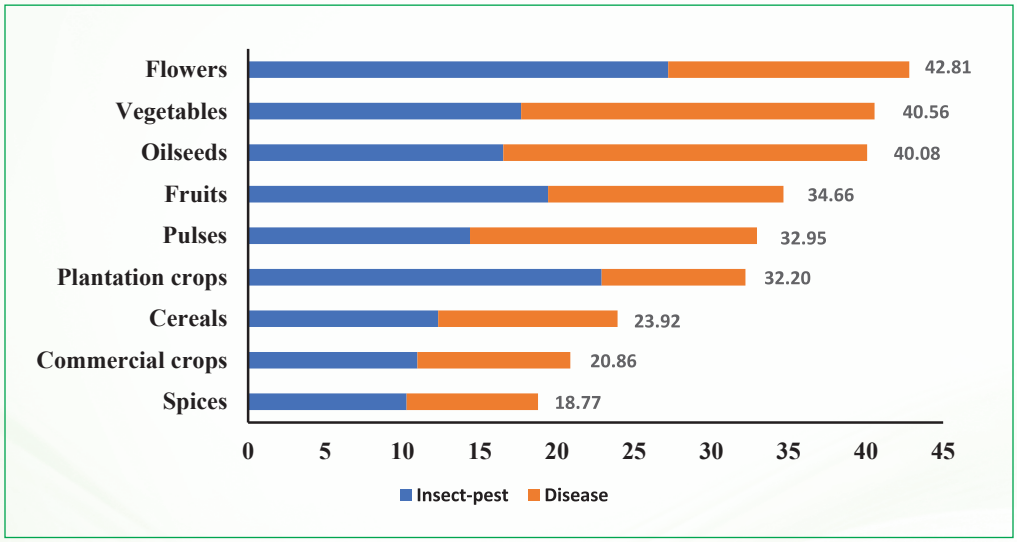


Fig. 3. Crop group-wise average yield loss (%) due to insect pests and diseases

4
Integrated Pest Management in major crops

Integrated Pest Management (IPM) is a science-based, ecosystem-oriented strategy that emphasizes the integration of multiple compatible pest management approaches to maintain pest populations below economically damaging levels, while minimizing risks to human health, natural enemies and the environment. For policy frameworks under ICAR, IPM is positioned as a cornerstone of sustainable agriculture, aligning productivity goals with ecological resilience and reduced dependence on chemical pesticides. The approach combines cultural practices (crop rotation, resistant varieties, optimal sowing time), mechanical and physical methods (traps, barriers), biological control (conservation and augmentation of parasitoids, predators, fungi, bacteria, entomopathogenic nematodes, entomopathogenic fungi, arbuscular fungi, sea weed, etc.), need-based products, etc. and judicious use of pesticides as a last resort (only when the pest crosses economic threshold levels). Therefore, priority should be given for promotion of bioagents, biopesticides and semiochemical-based tools along with agro-ecological engineering to enhance populations of natural enemies. However, overall, IPM strategies across crop groups show a clear pattern wherein insect pest management is largely based on biological agents such as Bacillus thuringiensis, Beauveria bassiana, Metarhizium anisopliae, parasitoids and predators, while disease management relies predominantly on microbial antagonists like Trichoderma spp., Pseudomonas fluorescens and Bacillus spp. Despite significant progress, gaps in bioagent availability in certain crop sectors highlight the need for strengthening production of quality IPM inputs, supply chains and field-level dissemination to enhance the adoption of sustainable IPM practices.

Further, digital pest surveillance, decision support systems and climate-informed advisories must be integrated with IPM to improve timely interventions. Capacity building of farmers through extension activities, farmer field schools and ICT platforms is essential to ensure adoption on a large scale. Policy support should include strengthening of bio-control laboratories, quality regulation of inputs, incentives for IPM adoption and convergence with schemes on soil health, natural farming and climate-smart agriculture. Robust monitoring and impact assessment

frameworks are required to document reductions in pesticide load, improvements in biodiversity and economic gains to farmers. By institutionalizing IPM across cropping systems and agro-ecologies, we can drive a transition toward safer, cost-effective and environmentally sound pest management in Indian agriculture. ICAR-NRIIPM, New Delhi, has developed and validated IPM modules in different field crops and horticultural crops, which will serve as a reference for designing location-specific pest management strategies for sustainable crop production. These modules are detailed below:

4.1. IPM module for cereals

Rice:

1. Green manuring with *Sesbania*/Green gram in the main field.
2. Soaking of seed in 2% salt (NaCl 20 g/L water) water and removal of unhealthy light-weight floated seed, followed by washing with clean water 2-3 times.
3. Seed treatment with *Trichoderma harzianum* 10 g/kg seed or carbendazim (2g/kg seed).
4. Raising healthy nursery and seedling root dip treatment with *Pseudomonas fluorescens* (cfu/mL $2x10^{10}$) @ 5mL/L water for 30 minutes.
5. Balanced nutrition and alternate wetting and drying of fields.
6. Installation of pheromone traps for yellow stem borer @ 5/ha and weekly monitoring of pests and natural enemies.
7. One release of *Trichogramma japonicum* (1.5 lakh eggs/ha) depends on the availability
8. Spray of neem oil, azadirachtin 1500 ppm @ 5mL/L.
9. Use of post-emergence herbicides, mechanical removal of weeds and judicious use of safer label claim pesticides based on ETL, such as Chlorantraniliprole 0.4G and dinotefuran 20SG.

Maize:

1. Seed treatment with *Trichoderma asperellum* @ 10g/kg of seeds.
2. Installation of pheromone traps for fall army worm @ 4/acre; spray of azadirachtin 1500 ppm @ 0.5% at 10 days after planting.
3. Spray of biopesticide *Bacillus thuringiensis* var *kurstaki* @ 400 g/acre or *Metarhizium anisopliae* (1×10^8 cfu/g @ 0.5%) and release of *Trichogramma chilonis* @ 1 card/acre (16,000-20,000 eggs/card).
4. Judicious use of safer label claim pesticides based on ETL, such as Chlorantraniliprole 18.5 SC @ 80 mL/acre.

4.2. IPM module for pulses

Chickpea:

1. Deep summer ploughing and field sanitation and timely sowing of tolerant/ resistant variety in the first fortnight of October.
2. Seed treatment with *T. harzianum* @ 10 g/kg seed.
3. Intercropping with mustard and erection of bird perches @ 20/ha.
4. Installation of *Helicoverpa armigera* pheromone trap for monitoring 5/ha.
5. Need-based application of botanical neem azadirachtin 1500 ppm @5 mL/L and biopesticides *B. thuringiensis kurstaki* (2×10^8 cfu per mL).
6. Judicious use of safer label claim pesticides based on ETL, such as Novaluron 5.25% + Indoxacarb 4.50% SC.

Pigeon pea:

1. Seed treatment using *T. asperellum* 1.0% WP @ 10 g/kg seed.
2. Ridge sowing for soil-borne disease management and application of pendimethalin 30% EC @ 3.0 l/ha for weed management.
3. Installation of pheromone traps @ 25 /ha and T-shaped bird perches @50/ha at a height of 2 ft above the crop for management of fruit borer.
4. Application of neem formulation (azadirachtin1500 ppm) @ 5mL/L and application of *Beavaria bassiana* or *Metarhizium anisopliae* @ 5mL/L to manage pod borer, spotted pod borer, leaf webber, ash weevil, black thrips and aphids.
5. Removal and destruction of disease-affected plants & need-based spray of pesticide against sterility mosaic virus and mite.
6. On the appearance of pod-borer larvae, use neem formulation (1500 ppm) @ 5mL/L, *Bacillus thuringiensis* var *kurstaki* (0.5%WP) @ 1.0 g/L.
7. Judicious use of safer label claim pesticides based on ETL, such as Novaluron 5.25% + Indoxacarb 4.50% SC @ 1.5mL/L or Chlorantraniliprole 09.30 % + Lambda-cyhalothrin 04.60 % ZC @ 2.5mL/L, for the management of pod borer, spotted pod borer, pod sucking bug and pod fly.

Field Pea:

1. IPM strategies consisted of high-yielding and pest tolerant varieties.
2. Seed treatment with *T. asperellum* (1.0% WP) 10g/kg seed.
3. Installation of *H. armigera* pheromone traps 25 /ha.
4. Yellow sticky traps (30 /ha) and bird perches (50 /ha).
5. Need-based application of botanical neem azadirachtin 1500 ppm @ 5 mL/L and biopesticides *B. thuringiensis var kurstaki* (2×10^8 cfu per mL) @ 1g/L.
6. Judicious use of safer label claim pesticides based on ETL such as Indoxacarb 14.5% SC @ 0.1% for pod-borer management and Carbendazim 50% WP @ 0.1% for foliar disease.

4.3. IPM module for oilseeds

Mustard:

1. Soil augmentation with *T. asperellum* @ 2.5 kg/ha and seed treatment with *T. asperellum* @ 10 g/kg
2. Foliar spray of freshly prepared aqueous garlic bulb extract @ 2% (w/v), one hand hoeing at 25-30 DAS
3. Need based spray of neem oil (azadirachtin 300 ppm) @ 0.5%
4. Judicious use safer label claim pesticides such as Thiamethoxam 25 WG @ 0.04% when aphid population cross ETL (25 aphid / 10 cm central shoot); foliar spray of Metalaxyl 4% + Mancozeb 64% @ 0.25% on disease appearance

Groundnut:

1. Crop rotation; deep summer ploughing; soil application of decomposed FYM enriched with *T. asperellum* @ 2 kg/acre; destruction of queen termite and termataria
2. Seed treatment with *T. asperellum* @ 10 g/kg seed
3. Spraying of demarcated host trees (one tree within a radius of 15 m area) with chlorpyriphos 20 EC @ 2mL/L after the first showers and mass trapping of adult white grubs using methoxy benzene (3 traps/tree).
4. Judicious use of safer label claim pesticides based on ETL, such as Chlorpyriphos 20 EC or Chlorantraniliprole 18.5% SC.

4.4. IPM module for commercial crops

Cotton:

1. Timely sowing along with refugia, clean cultivation, border crop with bajra/ maize/sorghum and intercrop with cowpea for natural enemy conservation.
2. Installation of pheromone traps for pink bollworm (05/ha) 45 DAS for monitoring.
3. Collection and destruction of infested squares/flowers/bolls, application of SPLAT (Gossyplure 4% RTU) @125 g/acre, four times (Aug–Nov); dollops placed at 400–500 spots/acre (3 m apart, zigzag) for mating disruption in pink bollworm.
4. Need-based application of azadirachtin (1500 ppm @ 2.5 l/ha) against sucking pests and pink bollworm, need-based spray of copper oxychloride 50 WP @25 g/10 L of water to manage boll rot.
5. Foliar applications of potassium nitrate (NPK 13:0:45) @ 2%, 2-4 times during flowering to boll formation.
6. Judicious use of safer label claim pesticides based on ETL, such as Spinetoram

11.7 SC or Profenophos 50 EC or Emamectin benzoate 5 SG for pink bollworm.
7. Termination of the crop by December and destruction of crop residues.

Sugarcane:

1. Sett treatment with *T. asperellum* 1.0% against red rot, wilt and twisted top (pokkah boeng) diseases.
2. Place three pheromone (synthetic pheromone-anisole) dispensers at a 15-meter radius for three consecutive evenings after the first monsoon rains for white grub.
3. Detrashing at 5 and 7-month stages of the crop for stalk and internode borers.
4. Use of pheromone traps for early shoot borer in May-June and top shoot borer in August-September @ 4-6 per acre.
5. Field release of egg parasitoid, *T. chilonis* @50,000 eggs/ ha at 10-day intervals, three times for early shoot and internode borers from May to July.
6. Field release of egg parasitoid *T. japonicum* 50,000 eggs/ ha at 10-day intervals, three times for top shoot borer from July to October.
7. Spray application of neem oil (1000 ppm) 3-4 mL/L of water in May-June for early shoot borer and August- September top shoot borer.
8. Judicious use of safer label claim pesticides based on ETL, such as Fipronil 00.60%w/w GR @ 12.5kg/ha for termites and early shoot borer; Chlorantraniliprole 18.50%SC @ 375 mL/ha in 1000 litres of water for top borer; Azoxystrobin 18.2% + Difenoconazole 11.4% SC @ 1mL/L of water for red rot, twisted top and rust diseases.

4.5. IPM module for fruit crops

Sweet orange/Kinnow:

1. Application of *T. asperellum* (2×10^8 cfu/g) at 200 g/ plant with carrier material of FYM (10 kg) or use of Cymoxanil 8%+ Mancozeb 64% WP for tree trunk @ 250 gram per 100 litres of water (10 litres per tree) for management of gummosis disease.
2. Pruning of dried twigs, field sanitation, weeding, ploughing and spray of copper oxychloride 50 WP @ 3g/L or 1% starch against dieback, sooty mould, canker and anthracnose diseases.
3. Spray mixture of 2, 4-D @ 0.1mL + propiconazole 25 EC @10mL/ 10 L water or need-based spray of Fludioxonil 20.4% w/w SC @3mL/L to manage fruit rot and fruit drop.
4. Installation of yellow and blue sticky traps @ 50/ha for sucking pests.
5. Need-based spray of neem formulation (azadirachtin 1500 ppm) @ 5mL/L

or application of *Beavaria bassiana* or *Metarhizium anisopliae* @ 5mL/L.

6. Conservation of natural enemies through ecological engineering (Marigold, sunflower, onion, garlic) to manage thrips, ash weevil, leaf miner, blackfly & other sucking pests.
7. Installation of fruit fly traps @ 10/acre against fruit fly.
8. Use of neem cake 1 kg/plant for nematode management
9. Judicious use of safer label claim pesticides based on ETL, such as Imidacloprid 17.8SL @ 200mL in 500 litres of water and Thiamethoxam 25% WG in 50g/500 L water to manage psylla and leaf miner of sweet orange.

Mango:

1. Pruning of overcrowded branches and malformed flowers followed by use of Bordeaux mixture and spraying NAA (100-200 ppm) and carbendazim (0.1%) against mango malformation.
2. Mechanical removal of leaf webber nests, raking soil around the tree trunk & ploughing operations and flooding the orchard.
3. Alkathene stem banding for mealy bug.
4. Installation of yellow & blue sticky traps @20/ha against Leaf hoppers & thrips.
5. Use of Arka borer control and installation of Light traps against the stem borer.
6. Installation of fruit fly traps (methyl eugenol) @ 20 traps/ha & bait splash on the tree trunk against fruit fly.
7. Hand picking of adult weevils and destruction, ploughing to expose pupae & grubs to predators, spraying *Metarhizium anisopliae* or neem oil against Ash/ grey weevil, leaf cutting weevil, thrips.
8. Judicious use of safer label claim pesticides based on ETL, such as Sulphur 80% WP. (2g/L) and Lambda cyhalothrin 05% EC (0.5-1 mL/L) or Buprofezin 25% SC (1-2 mL/L) and Tolfenpyrad 15% EC (0.5 mL/L) against mites and powdery mildew.

4.6. IPM module for vegetables

Cole crops:

1. Raised bed (15 cm) nursery to avoid damping off and root rot.
2. Soil application of decomposed FYM @ 3 kg/m^2 enriched with *T. asperellum* @ 150 g for soil-borne diseases and @ 20-25 t/ha in the main field.
3. Application of neem cake @ 50 g/m^2 to manage root knot nematode.
4. Seed treatment with *T. asperellum* 1.0% WP @ 4 g/kg and need-based use of Captan 75% WP @ 0.25% in nursery.
5. Seedling dip in *T. asperellum* 1.0% WP @ 1% for 30 minutes.

6. Installation of pheromone traps against *Spodoptera litura*.
7. Collection and destruction of egg masses and larvae of *S. litura*.
8. Judicious use of safer label claim pesticides based on ETL such as like Cyantraniliprole 10.26% OD @ 60 g a.i./ha and or Fenvalerate 20% EC @ 60-75 g a.i./ha against insect pests and fungicides like Mancozeb 75% WP @ 3 gm/L of water and or combination of product i.e. Azoxystrobin 4.8% w/w + Chlorothalonil 40% w/w SC @ (0.144+1.2) kg a.i./ha (formulation dose 3 L/ha).

Chilli:

1. Seed treatment with *T. asperellum* (2 x 10^9 /g) @ 10g/ kg seed followed by Thiamethoxam 30 FS@ 7mL/kg seed.
2. Raised nursery beds (3 m^2) of about 10 cm incorporated with *T. asperellum* 150g enriched with 3 kg FYM.
3. Protection of nursery beds with 40-50 mesh nylon net.
4. Soil application of vermicompost @ 10 q / acre, neemcake @ one q/acre and *T. asperellum* @ 2 kg/ acre enriched with well-decomposed FYM at the time of planting.
5. Nip seedlings five days before transplanting; seedling root dip in imidacloprid 17.5 SL @ 0.7% followed by *P. fluorescens* @1% for 20 minutes before transplanting.
6. Installation of yellow sticky trap/blue sticky traps @ 20 / acre to manage thrips, black thrips and whitefly; installation of pheromone traps @ 10/ acre for *H. armigera*
7. Prophylactic spraying of neem oil (azadirachtin 1500 ppm) @ 0.5% against sucking pests; spraying *P. fluorescens* @ 1% at 45 DAT; two sprays of *Beauveria bassiana* (UAS, Raichur, Karnataka) to manage black thrips; following clean cultivation; removal and destruction of borer-damaged fruits.
8. Judicious use of safer label claim pesticides based on ETL, such as Fenpyroximate 5 % EC @ 0.1%; Azoxystrobin 23SC @ 0.1%.

Tomato:

1. Seed and seedling treatment with talc-based formulation of *T. harzianum/ Pseudomonas fluorescens* @ 5 g/kg.
2. Soil application of *T. harzianum* @ 2 kg/acre enriched FYM (100 kg); neem cake (@ 500 kg/acre) for root knot nematodes (RKN); marigold as trap crop (16:1) for fruit borers and RKN; maize – barrier crop (3-4 rows) for sucking insects.
3. Yellow sticky traps and blue sticky traps, for whiteflies and thrips.
4. Pheromone traps for tomato pinworm and fruit borer.
5. Neem oil (azadirachtin 1500 ppm) application @ 0.5% for pin worm and NPV

formulation 250 LE for tomato fruit borer; *Trichogramma chilonis* @ 1,50,000/ ha for tomato pin worm and fruit borer.

6. Judicious use of safer label claim pesticides based on ETL, such as Thiomethoxam 25% WP @ 0.4 g/L; Cyantraniliprole 10.26% OD @ 1.2 mL/L; Fluxapyroxad 75 g/L + Difenoconazole 50 g/L SC and Azoxystrobin 18.2% + Difenoconazole 11.4% w/w SC.

Cucurbitaceous crop:

1. Seed treatment with *T. asperellum* @ 10 g/ kg seed.
2. Use of yellow sticky traps for sucking pest and installation of cue lure traps (MAT) @ 5/acre for fruit fly management.
3. Spray of neem oil for red pumpkin beetle.
4. Raking of soil for exposing fruit fly and leaf miner pupae to sunlight.
5. Spray of food baits and judicious use of safer label claim pesticides based on ETL, such as Thiophenate methyl 70 WP & Carbendazim 50 WP @ 2 g/L for anthracnose and Cercospora management.

Onion:

1. Raised bed seedlings for soil-borne disease.
2. Seed treatment with *T. asperellum*.
3. Soil application of *T. harzianum* @ 2 kg/acre enriched FYM (100 kg).
4. Grow maize as a barrier crop.
5. Need-based spray of neem oil and judicious use safer of label claim pesticides based on ETL, such as Spinosad 45 SC @ 0.12 mL/L for thrips and triazole fungicide /Tricyclazole 0.1% spray for Stemphylium blight and anthracnose.

The list of pesticides/formulations approved by Central Insecticides Board & Registration Committee (CIBRC) for use on different crops in India can be accessed at https://www.ppqs.gov.in/en/divisions/cib-rc/major-uses-of-pesticides.

5
Bio-agents for various insect pests and diseases in major crops

5.1. Cereals

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Rice	Stem borer, BPH, leaf folder, GLH, gundhi bug	*Bacillus thuringiensis*, *Beauveria bassiana*	Blast, bacterial blight, sheath blight, brown spot, false smut	*Trichoderma* spp., *Pseudomonas fluorescens*
Maize	Fall armyworm, stem borer, cutworm, aphids	*Trichogramma chilonis*, *Metarhizium anisopliae*, *Beauveria bassiana*	Downy mildew, turcicum leaf blight	*Trichoderma harzianum*, *Pseudomonas fluorescens*
Wheat	Aphids, armyworm, Helicoverpa	*Bacillus thuringiensis*	Yellow rust	*Trichoderma* spp., *Pseudomonas* spp.
Sorghum	Shoot fly, stem borer, FAW	*Metarhizium rileyi*	Grain mould, downy mildew, anthracnose	*Trichoderma asperellum*, *Pseudomonas chlororaphis*
Millets	Shoot fly	—	Blast, ergot, downy mildew	*Trichoderma* spp.

5.2. Pulses

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Chickpea	Pod borer (*Helicoverpa*)	HaNPV, *Beauveria bassiana*	Wilt, collar rot	*Trichoderma harzianum, Bacillus velenzensis, B. subtilis*
Pigeon pea	Pod borer, mites	*Beauveria bassiana*	Wilt	*Pseudomonas fluorescens*, *Trichoderma viride*
Black gram	Whitefly, aphids	*Bacillus thuringiensis*	Cercospora, anthracnose	*Pseudomonas* spp., *Trichoderma* spp.
Lentil	Beetles, mites	*Metarhizium rileyi*	Wilt	*Trichoderma harzianum, Bacillus* spp.
Cowpea	Aphids	*Verticillium lecanii*	Wilt	*Trichoderma* spp.

5.3. Oilseeds

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Groundnut	Leaf miner, Spodoptera, thrips	*Metarhizium anisopliae*, *Beauveria bassiana*	Leaf spot, rust, and collar rot	*Trichoderma harzianum*, *Pseudomonas fluorescens*, *Bacillus* spp.
Mustard	Aphids	*Bacillus thuringiensis*	Alternaria blight, white rust	*Trichoderma harzianum*
Sesame	Leaf webber, Plant hopper, capsule borer	*Trichogramma chilonis*, SNPV	Root rot, leaf spot, phyllody, Phytophthora stem blight	*Trichoderma viride*, *Pseudomonas fluorescens*
Sunflower	Helicoverpa, thrips	*Trichogramma chilonis*	Alternaria blight, powdery mildew	*Trichoderma* spp., *Bacillus subtilis*
Castor	Capsule borer, semilooper	*Beauveria bassiana*	Wilt, root rot	*Trichoderma harzianum*
Linseed	Bud fly	—	Wilt, powdery mildew	*Trichoderma* spp.

5.4. Commercial crops

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Cotton	Pink bollworm, whitefly	*Trichogramma bactriae*, *Metarhizium anisopliae*	Leaf spot, boll rot, wilt	*Trichoderma* spp.
Sugarcane	Borers, pyrilla, white grub	*Trichogramma chilonis*, *Cotesia flavipes*	Red rot, smut, wilt, twisted top, grassy shoot	*Trichoderma* spp., *Bacillus* spp., *Paenibacillus alvei*
Jute	Semilooper, hairy caterpillar	—	Stem rot	—
Tobacco	Caterpillar	—	Hollow stalk	*Paecilomyces lilacinus*

5.5. Fruits

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Mango	Hopper, fruit fly, thrips	*Beauveria bassiana*, *Metarhizium anisopliae*	Anthracnose, powdery mildew	*Trichoderma harzianum*
Banana	Weevil, whitefly	*Beauveria bassiana*, *Lecanicillium lecanii*	Panama wilt, Sigatoka	*Trichoderma asperellum*, *Pseudomonas fluorescens*
Citrus	Psylla, leaf miner	*Bacillus thuringiensis*	Canker, gummosis	*Trichoderma harzianum*
Grapes	Thrips, mealybug	*Metarhizium brunneum*	Downy mildew, anthracnose	*Bacillus subtilis*, *Trichoderma asperelloides*
Apple	Aphids, mites	*Trichogramma* spp.	Apple scab	*Trichoderma harzianum*

5.6. Vegetables

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Tomato	Fruit borer, pinworm, whitefly	*Trichogramma chilonis*, *Beauveria bassiana*	Blight, wilt, TLCV	*Trichoderma harzianum*, *Pseudomonas fluorescens*
Brinjal	Shoot & fruit borer	*Beauveria bassiana*	Wilt	*Trichoderma* spp.
Cabbage	DBM	*Bacillus thuringiensis*	Black rot	*Pseudomonas fluorescens*
Potato	White grub, tuber moth	*Steinernema* spp.	Late blight	Endophytic bacteria
Ginger	Shoot borer	*Metarhizium pingshaense*	Soft rot	*Trichoderma asperellum*, *Bacillus* spp.

5.7. Spices

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Black pepper	Pollu beetle	—	Foot rot, Phytophthora wilt	*Pochonia chlamydosporia*
Coriander	Aphids	*Verticillium lecanii*	Powdery mildew, wilt	*Trichoderma* spp.
Turmeric	Shoot borer	*Metarhizium pingshaense*	Rhizome rot	*Trichoderma asperellum*

5.8. Plantation crops

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Coconut	Rhinoceros beetle, whitefly	*Metarhizium anisopliae*, OrNV	Ganoderma, stem bleeding	*Trichoderma viride*
Arecanut	Spindle bug, mites	—	Leaf spot, bud rot	*Trichoderma harzianum*
Oil palm	Whitefly	*Aspergillus* sp. R55 and *Isaria fumosorosea* pfu 5	Basal stem rot	*Trichoderma afroharzianum*

5.9. Flowers

Crop	Major Insect pests	Bioagents	Major Diseases	Bioagents
Rose	Thrips, mites	*Beauveria bassiana*	Powdery mildew	*Trichoderma harzianum*
Sunflower	Helicoverpa, thrips	*Trichogramma chilonis*	Alternaria blight	*Trichoderma* spp., *Bacillus subtilis*
Tuberose	Mealybug, midge		Stem rot, leaf blight	—

6
Way forward

The comprehensive synthesis of crop yield loss data generated from multiple ICAR research institutes, AICRPs, KVKs and agricultural universities across India, clearly demonstrates the severe economic burden imposed by insect pests and plant diseases on agriculture in India. The analysis indicates that combined yield losses due to these biotic stresses range from 18.77 to 42.81%, underscoring their pervasive and economically critical impact across all major crop groups. The total monetary loss estimated at approximately ₹6.15 lakh crores annually, highlights the magnitude of the problem and the urgent need for effective, sustainable and environmentally compatible pest management strategies. In this context, future crop protection strategies must offer considerable potential for reducing crop losses while maintaining ecological integrity capable of supporting long-term agricultural sustainability.

Minimizing crop yield losses caused by insect pests and diseases always remained a central priority, leading to reliance on synthetic chemical pesticides, that has provided a significant short-term pest suppression, but simultaneously created serious ecological and agronomic challenges, including pesticide resistance, pest resurgence, accumulation of residues in agricultural commodities and food products, non-targeted impacts of beneficial organisms, environmental contamination and adverse effects on human and animal health. The adoption of biointensive Integrated Pest Management (IPM) approaches can substantially mitigate crop losses while preserving agroecosystem balance by minimizing the impacts of synthetic chemicals by prioritizing the ecological regulation of pest populations.

Biointensive IPM integrates biological control, habitat management, crop diversification, resistant varieties, cultural practices and need-based chemical applications into a holistic pest management framework. Among these components, the use of biological control represents one of the most promising and sustainable approaches for large-scale pest suppression by offering long-term ecological stability while preserving biodiversity and environmental quality. The timely and judicial use of high-quality biological agents such as parasitoids, predators, microbial agents and botanical formulations can significantly reduce pest populations and limit disease outbreaks in major crop ecosystems. The use of natural enemies already

present within agro-ecosystems further benefits the management strategies, hence native biocontrol populations should be identified, conserved and augmented through scientifically designed management strategies. Habitat manipulation through border crops, trap crops, refuge plants and conservation agriculture practices can significantly enhance populations of beneficial insects such as pollinators, parasitoids and predators, thereby improving natural pest regulation. The promotion of ecological engineering in agriculture should be established as a central pillar of future crop protection policy.

However, the widespread adoption of biological control technologies has several institutional and operational challenges and the availability of reliable and high-quality bioagents is one among them. Therefore, strengthening production systems for biological control agents through public-private partnerships, farmer-producer organisations (FPOs), agri-startups, rural bio-input production units and institutional biocontrol laboratories operational at regional levels need priority. Establishing standardized protocols for mass multiplication, formulation development, packaging, storage and transport will be essential for maintaining bioagent viability and field performance. The implementation of strict quality assurance mechanisms, certification systems and regulatory monitoring frameworks to prevent the circulation of sub-standard biological products in the market is equally important.

Farmer awareness on IPM and confidence in bio-based pest management solutions will also play a decisive role in future adoption. Therefore, strengthened extension efforts are essential to promote the adoption of biointensive IPM technologies. However, the widespread use of chemical pesticides continues to dominate pest management practices across most parts of the country due to farmers' greater familiarity with them, their quick and visible effects and the aggressive commercial promotion of chemical products over biological alternatives, which are often perceived as slower acting. Bridging this perception gap will require large-scale capacity building initiatives, including farmer training programs, field demonstrations, participatory learning approaches, exposure visits, village-level extension campaigns and digital advisory platforms focused on biological pest management. Demonstrating successful field-level case studies where biological control has effectively reduced pest incidence and improved profitability can greatly strengthen farmer confidence. In addition, agricultural curricula, vocational education and extension training modules should increasingly incorporate ecological pest management principles to build long-term institutional capacity.

The pest management strategies should also be equipped with precision agriculture and digital pest surveillance systems. Remote sensing technologies, artificial intelligence-based pest forecasting, drone-based field monitoring, GIS-

enabled pest mapping, weather-linked advisory systems and mobile-based decision support systems can facilitate pest and disease forecasting and help in timely interventions before reaching economic threshold levels and avoiding pest or disease outbreaks. Such innovations can greatly improve the efficiency, precision and sustainability of biointensive IPM-based crop protection systems. Furthermore, knowing the fact that pest complexes vary significantly across agro-ecological regions, recognizing the location-specific pest complexes, crop and location-specific pest management strategies must be prioritized. Biointensive IPM modules should be developed and validated under farmer field conditions in the specific regions. Such customized packages will ensure greater effectiveness and farmer acceptance.

Overall, there is a critical need to transition from input-intensive chemical control to ecology-driven, knowledge-intensive and biologically based crop protection systems. By integrating scientific innovation, decentralized bioagent production, strong regulatory mechanisms, farmer-centric extension services, digital technologies and location-specific ecological management approaches, India can substantially reduce crop yield losses caused by insect pests and diseases. Such a transformation will not only enhance agricultural productivity and farm profitability but also safeguard environmental health, conserve biodiversity, improve food safety and build resilient agroecosystems capable of meeting future food security challenges sustainability.

Annexure

List of the contributing institutions

S. No.	Name of the Institutions
	ICAR Institutes/Directorate/Research Centres
1.	ICAR–National Research Institute for Integrated Pest Management, New Delhi
2.	ICAR–NIRCA, Rajahmundry, Jeelugumilli, West Godavari, Andhra Pradesh
3.	ICAR–Central Institute for Subtropical Horticulture, Lucknow, Uttar Pradesh
4.	ICAR–National Institute for Research on Commercial Agriculture, East Godavari Andhra Pradesh
5.	ICAR–Central Institute for Cotton Research, Nagpur, Maharashtra
6.	ICAR–Indian Institute of Rapeseed Mustard Research, Bharatpur, Rajasthan
7.	ICAR–NIRCA Research Station, Dinhata, West Bengal
8.	ICAR–Directorate of Cashew Research, Puttur, Dakshina Kannada, Karnataka
9.	ICAR Krishi Vigyan Kendra, Konehalli, Tiptur, Tumkur Distt., Karnataka
10.	ICAR–Central Citrus Research Institute, Nagpur, Maharashtra
11.	ICAR–Indian Institute of Horticultural Research Bengaluru, Karnataka
12.	ICAR–Krishi Vigyan Kendra, Hadonahalli, Doddaballapura, Bangalore Rural, Karnataka
13.	ICAR–National Research Centre for Banana, Tiruchirappalli, Tamil Nadu
14.	ICAR–National Research Centre for Grapes, Pune, Maharashtra
15.	ICAR–National Research Centre on Litchi, Muzaffarpur, Bihar
16.	ICAR–National Research Centre on Pomegranate, Solapur, Maharashtra
17.	ICAR–Indian Institute of Spices Research, Kozhikode, Kerala
18.	ICAR–Central Potato Research Institute, Shimla, Himachal Pradesh
19.	ICAR–Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala
20.	ICAR–Sugarcane Breeding Institute, Coimbatore, Tamil Nadu
21.	ICAR–Indian Institute of Oil Palm Research, Pedavegi, Andhra Pradesh
22.	ICAR–Central Plantation Crops Research Institute, Kasaragod, Kerala
23.	ICAR Directorate of Floricultural Research, Pune, Maharashtra
24.	ICAR–Indian Institute of Horticultural Research, Bengaluru, Karnataka
25.	ICAR–Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand

S. No.	Name of the Institutions
26.	ICAR–Indian Institute of Millets Research, Hyderabad, Andhra Pradesh
27.	ICAR–Indian Institute of Rice Research, Hyderabad, Andhra Pradesh
28.	ICAR–Indian Institute of Pulse Research, Kanpur, Uttar Pradesh
29.	ICAR–Indian Grassland and Fodder Research Institute, Jhansi, RRS Dharwad, Karnataka
30.	ICAR–Indian Institute of Oil Palm Research, Pedavegi, Eluru district, Andhra Pradesh
31.	ICAR–Indian Institute of Maize Research, Ludhiana, Punjab
32.	ICAR–Indian Institute of Wheat and Barley Research, Karnal, Haryana
33.	ICAR–Central Institute of Temperate Horticulture, Srinagar, Jammu & Kashmir
34.	ICAR–Directorate of Cashew Research, Puttur, Dakshina Kannada, Karnataka
	State Agricultural Universities and their Research Stations/Centres
35.	SKUAST–Kashmir, Jammu & Kashmir
36.	Faculty of Agriculture, Wadura and Mountain Research Centre for Field Crops, Khudwani
37.	Agricultural Research Station, Amreli, Junagadh Agriculture University, Junagadh, Gujarat
38.	Agricultural Research Station, Annigeri, University of Agricultural Sciences, Dharwad, Karnataka
39.	Agriculture University, Jodhpur, Rajasthan
40.	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra
41.	Assam Agricultural University–Zonal Research Station, Shillongani, Assam
42.	Centre for Oilseeds Research, S.D. Agricultural University, Sardar Krushinagar, Gujarat
43.	Dr. BRC Agricultural Research Station, Mandor Agriculture University, Jodhpur, Rajasthan
44.	Regional Research Station, Arupukotai, Tamil Nadu Agriculture University, Tamil Nadu
45.	Oilseeds Research Station, Jalgaon, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra
46.	Main Oilseeds Research Station, Junagarh Agriculture University, Junagadh, Gujarat
47.	Regional Agricultural Research Station, Palem, Nagarkurnool, Telangana Agricultural University, Telangana
48.	Main Agricultural Research Station, University of Agricultural Sciences, Raichur, Karnataka
49.	Regional Research Station, Tamil Nadu Agricultural University, Tamil Nadu
50.	Regional Research Station, Tamil Nadu Agricultural University, Vriddhachalam, Tamil Nadu

S. No.	Name of the Institutions
51.	Regional Research and Technology Transfer Station, Mohisapat, Odisha University of Agriculture & Technology, Odisha
52.	Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan
53.	University of Agricultural Sciences, Bengaluru, Karnataka
54.	University of Agricultural Sciences, Dharwad, Karnataka
55.	Agriculture Experimental Station, Navsari Agriculture University, Paria, Maharashtra
56.	Banana Research Station, Kerala Agricultural University, Kannara, Thrissur, Kerala
57.	Bihar Agricultural University, Sabour, Bhagalpur, Bihar
58.	Fruit Research Station, Navsari Agricultural University, Gandevi, Gujarat, Navsari, Gujarat
59.	Citrus Research Station, RHRS, Dr YSR Horticultural University, Tirupati, Andhra Pradesh
60.	Govind Ballabh Pant University of Agriculture & Technology, Udham Singh Nagar, Pantnagar, Uttarakhand
61.	Fruit Research Station, Sangareddy, Sri Konda Laxman Telangana Horticultural University, Telangana
62.	Horticulture Research Station, Anantapuramu, Dr Y.S.R. Horticultural University, Telangana
63.	Regional Fruit Research Station, Vengurla, Sindhudurg, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Maharashtra
64.	Banana Research Station, Jalgaon, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra
	AICRPs
65.	AICRP on Small millets, Karnataka, Bengaluru, Karnataka
66.	AICRP ZARS, UAS, GKVK, Bengaluru, Karnataka
67.	AICRP on Castor, TCRS, Yethapur, Tamil Nadu
68.	AICRP on Groundnut, MARS, UAS, Dharwad, Karnataka
69.	AICRP on Linseed, Bihar Agricultural University, Sabour
70.	AICRP on Linseed, College of Agriculture, Dr PDKV, Akola, Maharashtra
71.	AICRP on Linseed, Oilseeds Research Center, Mauranipur, BUAT, Banda, Uttar Pradesh
72.	AICRP on Safflower, MPKV, Solapur, Maharashtra
73.	AICRP on Sesame & Niger, MARS, UAS, Dharwad, Karnataka
74.	AICRP on Sesame, ARS, Mandor, Agriculture University, Jodhpur

S. No.	Name of the Institutions
75.	AICRP on Sesame, RRTTS, Dhenkanal, Odisha
76.	AICRP on Sunflower, CCS Haryana Agricultural University, Hisar, Haryana
77.	ICAR–AICRP on Sesame and Niger, Jabalpur, Madhya Pradesh

Krishi Vigyan Kendras	
78.	ICAR–Krishi Vigyan Kendra, Kandali, Hassan, Karnataka
79.	Ramkrishna Ashram Krishi Vigyan Kendra, Nimpith Ashram, West Bengal
80.	JNKVV–Krishi Vigyan Kendra, Rewa, Madhya Pradesh
81.	ICAR–Krishi Vigyan Kendra, Chamarajanagara, Karnataka
82.	ICAR–Krishi Vigyan Kendra, V.C. Farm, Mandya, Karnataka
83.	ICAR–Krishi Vigyan Kendra, Hadonahalli, Doddaballapura, Bengaluru Rural District, Karnataka
84.	ICAR–Krishi Vigyan Kendra, Chintamani, Chikkaballapura district, Karnataka
85.	ICAR Krishi Vigyan Kendra, Konehalli, Tiptur, Tumkur District, Karnataka
86.	ICAR–Krishi Vigyan Kendra, Ramanagara, Bengaluru South, Karnataka
87.	JNKVV–Krishi Vigyan Kendra, Tikamgarh, Madhya Pradesh

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