Policy Paper

CLIMATE CHANGE EFFECTS ON INSECT PESTS AND ECONOMIC LOSSES IN INDIA

भाकृअनुप - राष्ट्रीय जैविक स्ट्रैस प्रबंधन संस्थान, रायपुर, छत्तीसगढ़
ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh
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ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana

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Message

Climate change has emerged as one of the defining challenges of our time, profoundly impacting agriculture, natural ecosystems, and human livelihood. Among its many consequences, the changing dynamics of insect pests pose a critical threat to India's food security and economic constancy. Rising temperatures, altered rainfall patterns, and increasing climatic variability are not only reshaping pest distribution and survival but also undermining the effectiveness of traditional management practices. These changes demand scientific understanding, timely action and proactive policy responses. This policy paper, *Climate Change Effects on Insect Pests and Economic Losses in India*, provides a comprehensive assessment of the complex interactions between climate change and pest ecology. It synthesizes emerging scientific evidence, case studies, and projections to highlight the risks posed by climate-driven pest outbreaks and offers practical strategies for adaptation and mitigation. The insights presented here are particularly valuable for policymakers, researchers, extension agencies, and farmers, as they underscore the urgency of integrating pest resilience into climate-smart agricultural policies and practices.

I commend the authors for their rigorous efforts in addressing this pressing issue. Their work will not only support informed decision-making but also serve as a guiding document for developing sustainable, climate-resilient pest management strategies for India's diverse agricultural systems.

With its clarity, scientific rigor, and policy relevance, this publication will be an invaluable resource for researchers, policymakers, students, and professionals engaged in climate-resilient agriculture, insect pest management and biosecurity. It will serve not only as a reference document but also as a strategic guide for anticipating and managing the dynamic and growing challenge of climate-driven pest outbreaks in India's farming systems.

I acknowledge the dedicated and meticulous work of the authors at ICAR-NIBSM. Their continued commitment to addressing the challenges of biotic stress is evident in this significant contribution, which will undoubtedly support national efforts to strengthen preparedness, response, and resilience in Indian agriculture.

(Devendra Kumar Yadava)

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Place : New Delhi

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Summary

Climate variability is emerging as a major driver of biotic and abiotic stresses in Indian agriculture, posing significant threats to pest management and food security. Rising temperatures, erratic rainfall, and elevated CO_2 levels are altering pest biology, distribution, and survival, leading to more frequent and severe outbreaks. Extreme weather events such as heatwaves, droughts, and cyclones exacerbate these risks by triggering sudden pest surges and facilitating long-distance migration, as seen in recent locust and fall armyworm invasions. Conventional pesticide-based approaches are increasingly ineffective under these changing climatic conditions due to rapid pest resistance development and the disruption of natural enemies. Therefore, a transition towards climate-resilient Integrated Pest Management (IPM) anchored in biological control, ecological approaches, and reduced chemical dependence is critical for safeguarding agricultural sustainability.

To address these challenges, several strategic policy actions are recommended. Establishing a National Pest Forecasting and Early Warning Network that integrates weather data, pest ecology, and real-time surveillance will enable region-specific predictive models and timely advisories to farmers through digital platforms and mobile alerts. It is equally important to mainstream pest–climate linkages into the State Action Plans on Climate Change (SAPCCs) and align them with the objectives of the National Mission on Sustainable Agriculture (NMSA) to ensure coordinated and climate-responsive pest management. Promotion of climate-resilient IPM practices should focus on scaling up the use of biopesticides, natural predators, intercropping, and habitat management, alongside incentivizing pest- and climate-resilient crop varieties through extension programs and subsidies. Strengthening plant quarantine systems will also be crucial to prevent and manage transboundary pest incursions.

In addition, expanding risk management instruments such as crop insurance to cover pest-induced losses and integrating pest risk assessments into the Pradhan Mantri Fasal Bima Yojana (PMFBY) will help reduce farmers' vulnerability. Capacity building and farmer awareness must be enhanced through Krishi Vigyan Kendras (KVKs) and extension systems to promote adoption of climate-smart pest management practices. Finally, effective implementation requires multi-stakeholder collaboration among ICAR institutes, State Agricultural Universities, state departments, and the private sector, coupled with regional and international cooperation for shared data, joint pest surveillance, and coordinated responses to transboundary pest threats.

An integrated, science-based, and participatory approach linking research, policy, and grassroots action is essential to build climate-resilient pest management systems that can protect India's agricultural productivity, ensure food security, and enhance farmer resilience under a changing climate.

1. Introduction

Climate change poses one of the most critical challenges to agriculture in the 21st century. According to the Intergovernmental Panel on Climate Change (IPCC), global surface temperatures have already risen by 1.1°C above pre-industrial levels, with projections indicating a further rise of 1.5–2.0°C in the next few decades under moderate emission scenarios. In South Asia, the IPCC projects increased heat stress, erratic rainfall, and pest-related yield losses as major risks to food security (IPCC, 2021).

In India, mean surface temperature has increased by about 0.7°C since 1901, with faster warming after the 1980s (Krishnan, 2021). These climatic shifts are already reshaping pest ecology and crop losses. For instance, the fall armyworm (*Spodoptera frugiperda*), first detected in 2018, rapidly spread across more than 20 Indian states within two years, causing maize yield losses of up to 35–50% in major growing areas (Suby *et al*., 2018). Similarly, whitefly (*Bemisia tabaci*) outbreaks devastated cotton crops in northern India in 2014–15, reducing yields by up to 40% and severely impacting smallholder incomes (Kumar *et al*., 2020; Chandi *et al.*, 2021). Such examples highlight how warmer winters, prolonged dry spells, and erratic rainfall are enhancing pest survival, fecundity, and migration across agro-climatic zones.

The Representative Concentration Pathways (RCPs) describe four possible greenhouse-gas concentration trajectories leading to different levels of radiative forcing by 2100. RCP2.6 represents a strong mitigation pathway, limiting radiative forcing to about 2.6 W/m², achievable only with rapid emission reductions. RCP4.5 and RCP6.0 are intermediate stabilization scenarios, reaching 4.5 W/m² and 6.0 W/m² respectively, reflecting moderate emission controls. RCP8.5, the high-emission scenario, leads to about 8.5 W/m² of forcing by 2100 and

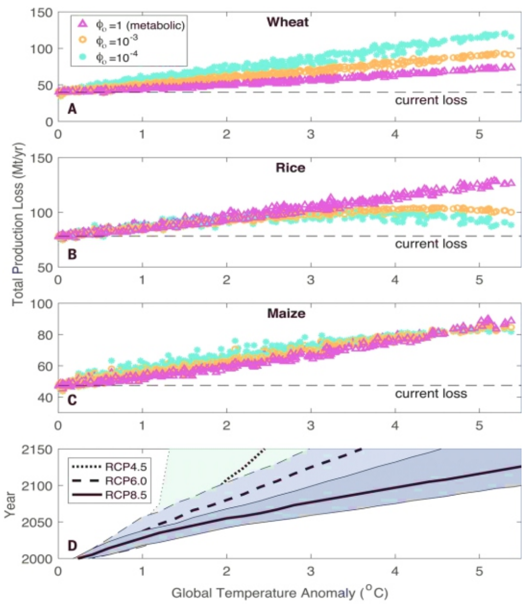


Figure 1.1: Global loss of crop production owing to the impact of climate warming on insect pests. Source: Deutsch *et al.*, 2018.

represents a fossil-fuel-intensive development path with the highest climate risks. These RCP values help model future temperature rise, precipitation shifts, and related impacts such as pest outbreaks in agriculture. Figure 1.1. illustrates that rising global temperatures are intensifying insect pest metabolism and feeding activity, leading to greater yield losses across major crops. The figure highlights how even a small increase in mean temperature can translate to significant production losses, particularly in cereals such as rice, maize, and wheat. These losses are expected to be more severe in tropical regions where baseline pest pressures are already high, emphasizing the urgency for adaptive pest management under a warming climate.

Rising atmospheric CO_2 further complicates these interactions. While it enhances plant growth, it lowers tissue nitrogen, compelling chewing insects to consume more foliage, and favors sap-feeders like aphids and whiteflies through increased sugar content. Combined with warming, these factors accelerate pest development, leading to more generations per season and greater yield losses. Indian studies have reported 18–25% increases in fecundity and feeding rates in *Bemisia tabaci* and *Plutella xylostella* under elevated CO_2 and temperature conditions (Wei *et al*., 2013; Sridhar *et al*., 2020).

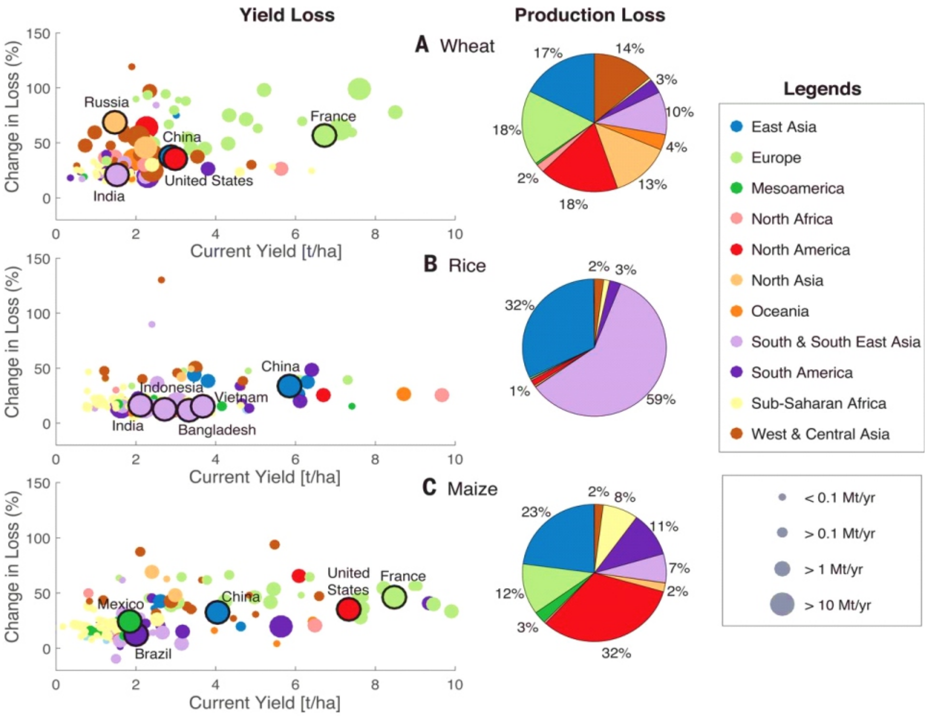


Figure 1.2: Predicted regional increases in crop losses to insect pests in a 2°C-warmer climate. Source: Deutsch *et al.*, 2018.

This figure 1.2 projects the spatial variation in crop losses due to pest outbreaks under a 2°C warming scenario. The data suggest that tropical and subtropical regions, including India and Southeast Asia, will experience the steepest increases in pest-induced damage. The findings underscore regional disparities in climate vulnerability and the need for targeted policy interventions to safeguard smallholder farmers in high-risk zones.

The socio-economic implications of these pest–climate linkages are profound. Nearly 86% of Indian farmers are small and marginal, and their limited access to pest management technologies, weather advisories, and insurance makes them particularly vulnerable to climate-induced pest shocks. Pest-related yield losses already account for 15–25% of total production losses annually, amounting to economic damages exceeding ₹50,000 crore (Ignacimuthu, 2002). Escalating input costs and reduced yields threaten farm profitability, food security, and rural livelihoods, especially in rainfed regions.

Given this evidence, strengthening pest management under climate change requires a dual focus on scientific and socio-economic. Understanding how elevated CO_2, rising temperatures, and extreme weather affect pest populations, natural enemies, and yield losses is crucial for developing climate-resilient Integrated Pest Management (IPM) systems and regionally tailored adaptation policies.

1.1. Objectives

This policy paper aims to synthesize evidence on how climate change drivers including elevated CO_2, rising temperature, and extreme events like droughts and floods affect insect pest populations, natural enemies, and pest distribution under future climate scenarios, with a special focus on Indian agriculture. The specific objectives are to:

1. To synthesize scientific evidence on the impacts of elevated CO_2, temperature, and climatic extremes on key insect pests and their natural enemies.
2. To evaluate projected changes in pest distribution, abundance, and crop loss risks under future climate scenarios in Indian agriculture.
3. To analyze climate-driven pest outbreak case studies and extract policy-relevant lessons for adaptive management.
4. To identify policy and institutional gaps in pest management and propose climate-resilient IPM strategies aligned with national adaptation priorities.
5. To integrate stakeholder perspectives through consultations and policy dialogues for actionable and farmer-oriented recommendations.

1.2. Methodology

The study employs a mixed-method approach, combining systematic literature review, case study analysis, and stakeholder consultations to construct a robust, evidence-based policy framework.

- **Literature Review:** Peer-reviewed studies, national reports, and climate model projections were systematically reviewed to evaluate the influence of elevated CO_2, temperature rise, and extreme weather on pest biology (e.g., fecundity, voltinism, survival), natural enemy interactions, and pest migration. Emphasis was placed on Indian agro-ecosystems such as rice, wheat, pulses, cotton and horticultural crops.
- **Case Studies:** Documented examples such as locust invasions after cyclones and fall armyworm spread in drought-prone regions were analyzed to illustrate real-world manifestations of climate–pest interactions and adaptive strategies.
- **Policy Dialogue:** Consultations with scientists, policymakers, and extension experts were conducted to validate findings, capture ground-level experiences, and co-design actionable policies.

Together, these methods provide a foundation for evidence-informed, climate-resilient IPM policies, focusing on early warning systems, risk assessment, insurance mechanisms, and capacity building to mitigate pest risks in a changing climate.

1.3. Impact of Climate Change on Pest Populations

1.3.1 Effect of Elevated CO_2

The combined effect of global warming and elevated CO_2 is establishing a new ecological baseline for insect pests. Warmer winters now permit tropical and subtropical pests to expand into temperate regions, while elevated CO_2 alters plant-insect interactions in complex ways. Higher CO_2 levels often reduce plant nitrogen content and alter the C:N ratio, compelling chewing insects to consume more foliage and sap-feeders to benefit from increased sugar availability (Coviella & Trumble, 1999; Bezemer & Jones, 1998).

In India, the northward expansion of the diamond back moth (*Plutella xylostella*) and whitefly (*Bemisia tabaci*) demonstrates this trend. Both species have shown increased fecundity under elevated CO_2 (Cheema *et al*., 2022), with *B. tabaci* populations rising by nearly 18–22% in fecundity and 15% in feeding rate under doubled CO_2 conditions (Srinivasa Rao *et al*., 2022). Similar responses are observed in aphids on wheat and cotton, where CO_2 enrichment increases population growth and honeydew production

(Blanchard *et al.*, 2022). Experimental findings summarized in Table 1.1 confirm increased fecundity and feeding rates.

Elevated CO_2 can also weaken synchrony between pests and their natural enemies, leading to pest resurgence and increased outbreak potential. These shifts highlight the urgency of understanding insect–climate interactions for developing climate-resilient pest management systems (Figure 1.3).

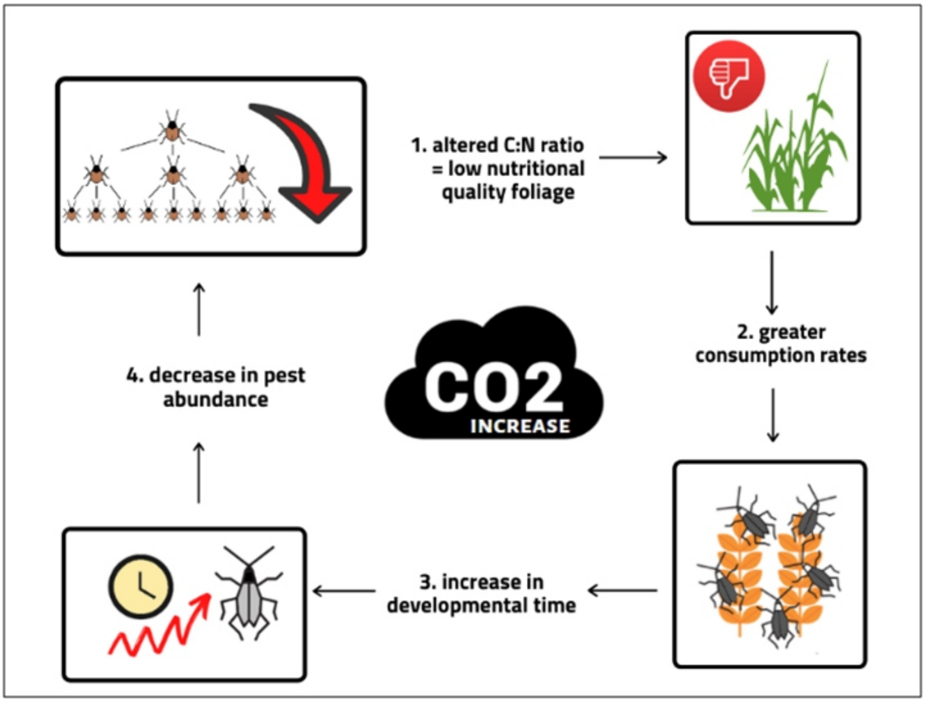


Figure 1.3. Effect of elevated CO_2 on insect pests
(Source: Skendžić *et al.*, 2021).

Figure 1.3 illustrates that the elevated atmospheric CO_2 modifies plant nutritional quality by lowering nitrogen content and increasing carbohydrate levels, compelling herbivorous insects to feed more to meet their metabolic needs. The figure depicts how these changes enhance pest fecundity and feeding rates, leading to increased crop damage. It also shows the potential mismatch between pests and their natural enemies, illustrating cascading effects on ecosystem balance.

Table 1.1. Comparative responses of major pests to elevated CO_2

Crop System	Major Pest	Response to Elevated CO_2	Reported Change	Source
Cotton	*Bemisia tabaci*	Increased fecundity and feeding rate	+18–22% fecundity	Srinivasa Rao *et al*., 2022
Cabbage	*Plutella xylostella*	Increased fecundity and leaf consumption	+12% leaf damage	Haripriya *et al*., 2024
Wheat	*Rhopalosiphum padi*	Higher reproduction rate	+15% population growth	Blanchard *et al*., 2022; Moreno-Delafuente *et al*., 2020
Rice	*Nilaparvata lugens*	Enhanced feeding and multiplication on N-poor plants	+10–13% survival	Prasannakumar *et al*., 2012

1.3.2 Effect of Elevated Temperature

Rising temperatures directly accelerate insect development and shorten life cycles, allowing pests to complete more generations per season. This increase in voltinism results in exponential population growth and severe crop losses.

- *Helicoverpa armigera* may increase from 6–7 generations currently to 8–10 under projected warming (Srinivasa Rao *et al*., 2022).
- *Spodoptera litura* completes its life cycle in 26–28 days at 30°C, compared to 40–45 days at 20°C (Rao *et al*., 2014).
- *Chilo partellus* (maize stem borer) development rate peaks near 32°C, beyond which survival declines (Singh *et al*., 2020).

Warmer winters have allowed pests such as *Bemisia tabaci* and *Spodoptera frugiperda* to expand into Punjab, Haryana, and even hill regions (Kumar *et al*., 2020; Suby *et al*., 2020). *Helopeltis theivora*, the tea mosquito bug, has been increasingly reported at higher altitudes (1,200–1,800 m) in Assam and Meghalaya (Roy *et al*., 2020).

As depicted in this figure 1.4, higher temperatures accelerate pest development and reproductive cycles, allowing multiple generations per season. Warmer winters further extend pest survival and enable migration into new agro-climatic zones. The schematic representation demonstrates the strong positive relationship between temperature and pest voltinism, highlighting the growing threat of pest proliferation in warmer future climates.

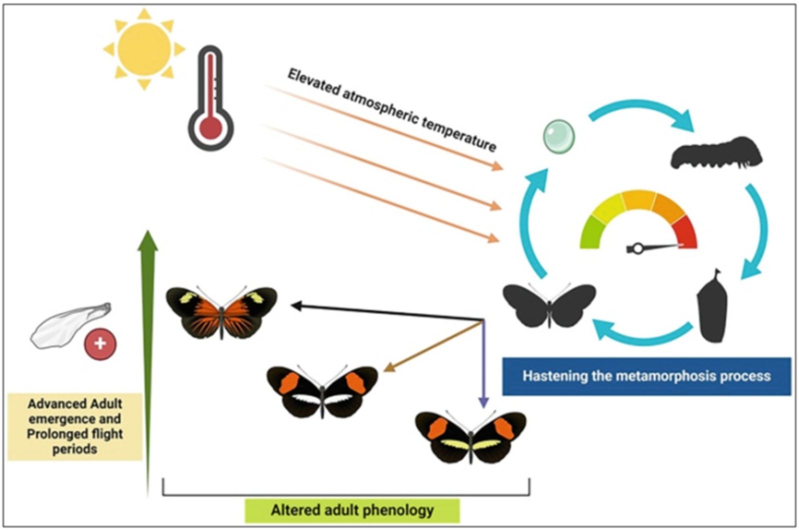


Figure 1.4: Responses of insects to elevated temperature. (Source: Sunil *et al.*, 2025)

1.3.3 Combined Effect of Elevated CO_2 and Temperature

The simultaneous rise in atmospheric CO_2 and temperature creates complex ecological feedbacks that jointly intensify pest pressures in agricultural ecosystems. Elevated CO_2 enhances plant biomass but often dilutes tissue nitrogen, reducing nutritional quality for herbivores. In response, many insect pests compensate by increasing their feeding rates and reproductive output. When coupled with higher temperatures, these changes accelerate metabolic activity and shorten development time, resulting in more generations per cropping season. Empirical studies demonstrate that *Plutella xylostella* and *Bemisia tabaci* exhibit 20–25 % greater leaf consumption and up to 15 % higher fecundity under combined CO_2 (700 ppm) and temperature (+3 °C) conditions (Haripriya *et al*., 2024; Singh *et al*., 2023). Similarly, *Spodoptera litura* and *Helicoverpa armigera* have shown rapid northward expansion and higher survival rates during mild winters, indicating a synergistic enhancement of pest persistence under warming scenarios (Sunil *et al*., 2025). These physiological and behavioral shifts underscore the likelihood of more severe and frequent pest outbreaks in major Indian cropping systems.

Natural enemies, predators, parasitoids, and entomopathogens are generally more sensitive to thermal and CO_2 stress than their pest counterparts. Elevated temperatures can impair their longevity, searching efficiency, and reproduction, while elevated CO_2 indirectly affects host–prey interactions by altering plant volatile cues and host location efficiency. For instance, *Trichogramma* spp. exhibit marked declines in parasitism efficiency beyond 35 °C (Thomson *et al.*, 2010), and coccinellid beetle populations were drastically reduced during the 2010 heatwave in northern India, leading to aphid resurgence in mustard crops (Prasad & Bambawale, 2010). The asynchrony between the accelerated life cycles of pests and the lagging responses of their natural enemies disrupts ecological balance and weakens natural biological control. This imbalance often triggers greater reliance on chemical insecticides, increasing production costs and ecological risks.

Compounding these biological shifts, the combined effects of elevated CO_2 and temperature also accelerate the evolution of insecticide resistance. Continuous generation cycles and extended host availability expose pest populations to higher selection pressure, enabling rapid genetic adaptation. Field observations indicate that *P. xylostella* and *S. litura* populations in regions with prolonged warm periods develop resistance 30–40 % faster than those in cooler zones (Furlong & Zalucki, 2017; Sunil *et al*., 2025). Moreover, enhanced feeding rates under elevated CO_2 increase exposure to sublethal pesticide doses, further selecting for resistant phenotypes. The combined stressors of warming and CO_2 enrichment therefore create a multidimensional challenge: intensified pest damage, diminished biological control, and accelerated resistance development. These patterns highlight the urgent need for climate-resilient Integrated Pest Management (IPM) frameworks that strengthen natural enemy resilience, diversify control tactics, and incorporate adaptive monitoring systems to mitigate emerging pest threats. A comparative summary of these climatic stressors and their impacts is provided in Table 1.2.

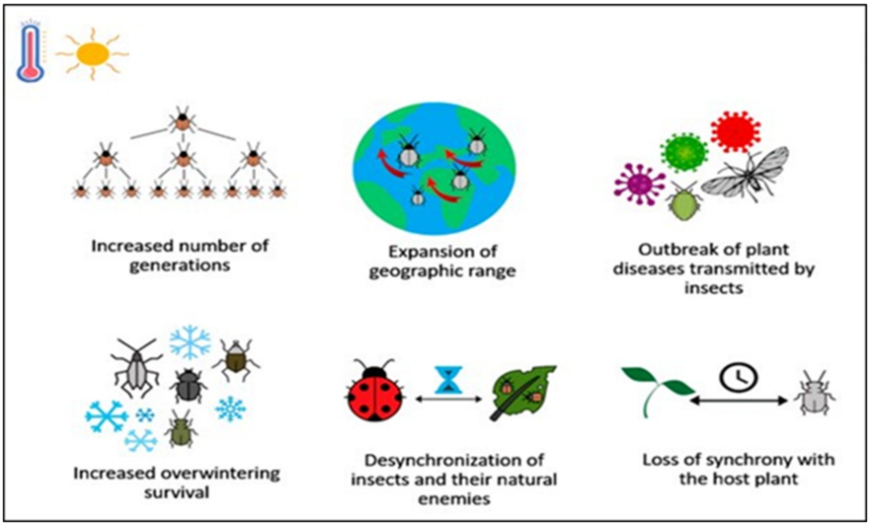


Figure 1.5. Effects of combined CO_2 and temperature elevation on pest dynamics (Source: Skendžić *et al*., 2021).

This figure 1.5 illustrates the synergistic influence of elevated CO_2 and temperature on pest dynamics and ecosystem functioning. Together, these climatic drivers intensify herbivory, increase pest reproductive success, and weaken natural enemy efficiency. The visual emphasizes how these combined effects accelerate pest population growth and resistance evolution, creating major challenges for sustainable pest control and food security.

Table 1.2. Comparative summary of pest responses to key climatic drivers

Climatic Driver	Major Responses in Insect Pests	Representative Examples (India/Global)	Quantitative Impacts	Source
Elevated CO_2	Increased herbivory due to reduced plant nitrogen and enhanced carbohydrate levels	*Plutella xylostella* (Diamond back moth), *Bemisia tabaci* (Whitefly)	Up to 20–25% increase in leaf consumption and 15% rise in fecundity	Cheema *et al.*, 2022; Singh *et al.*, 2023
Elevated Temperature	Shortened life cycle, increased voltinism, expanded geographical range	*Helicoverpa armigera*, *Spodoptera litura*, *Nilaparvata lugens*	Life cycle reduced from 40 to 28 days between 20–30°C; up to 2–3 extra generations/year	Kambrekar *et al.*, 2015; Sunil *et al.*, 2025
Temperature Thresholds	Thermal limits defining survival and reproduction vary by species	*H. armigera*: 12–38°C; *S. litura*: 15–36°C; *B. tabaci*: 10–40°C	Above 35°C, parasitism rates of *Trichogramma* spp. drop by >40%	Wu *et al.*, 2016; Rao Srinivasa *et al.*, 2022
Rainfall Variability / Humidity	Favors planthoppers and mites under humid conditions; suppresses small pests under heavy rain	*Nilaparvata lugens* (BPH), *Tetranychus urticae* (Mite)	BPH density peaks at >80% RH and declines sharply below 60%	Cheng, 2014; Heong & Hardy, 2009; Rao *et al.*, 2018
Drought Stress	Increases nitrogen concentration and palatability of host plants	*Spodoptera exigua*, *Aphis gossypii*	Fecundity increased by 22% under water-stressed soybean	Huberty & Denno, 2004; Showler & Moran, 2003
Extreme Events (Cyclones, Heatwaves)	Promote long-distance pest dispersal and episodic outbreaks	*Schistocerca gregaria* (Locust), *Spodoptera frugiperda* (FAW)	2020–21 locust swarms linked to cyclonic activity; FAW spread across India in <2 years	Salih *et al.*, 2020; Shylesha *et al.*, 2018; Rathnakumar *et al.*, 2025
Combined Elevated CO_2 + Temperature	Synergistic rise in feeding rates, fecundity; decline in natural enemy efficiency	*Trichogramma* spp., Coccinellidae, *Plutella xylostella*	Parasitoid success ↓ 35–50% at >35°C; pest feeding ↑ 20–30%	Furlong & Zalucki, 2017; Srinivasa Rao *et al.*, 2021; Thomson *et al.*, 2010
Resistance Evolution	Faster adaptation and pesticide resistance under continuous thermal exposure	*P. xylostella*, *S. litura*	Resistance development time reduced by 30–40%	Furlong & Zalucki, 2017; Zhang *et al.*, 2015

The combined stressors of elevated CO_2, rising temperatures, and climatic extremes are accelerating pest population growth, range expansion, and resistance evolution while suppressing natural enemies. These shifts call for an urgent reorientation toward climate-resilient IPM, improved early warning systems, and region-specific pest thresholds integrated into national adaptation policies.

1.4. Strategies to Control Losses from Pest Incidences under Climate Change

Building a resilient agricultural system requires integrating technology, ecology, and farmer-focused policies. The following strategies are recommended:

1. **Strengthen Pest and Climate Surveillance Systems**

   Establish a nationwide network of automated weather stations, pheromone traps, and digital pest monitoring linked to ICAR–IMD databases. Advanced forecasting models should generate real-time alerts, shared with farmers through mobile platforms, KVKs, and extension agencies. A centralized National Pest Forecasting Network would enable both rapid farmer response and evidence-based policymaking.

2. **AI-Powered Early Warning and Farmer Advisory**

   Surveillance and climate data must feed into AI-driven models that can predict localized outbreaks. Advisory systems delivered via SMS, IVR, and mobile apps should reach even smallholder farmers. Public-Private Partnerships with agri-tech firms, alongside support from state extension systems and NGOs, will ensure these tools are accessible, reliable, and farmer-friendly.

3. **Agroecological Practices and Soil Health Enhancement**

   Widespread adoption of organic farming, crop diversification, intercropping, and habitat management will strengthen natural pest control. Healthy soils, enriched with compost, manure, and conservation agriculture practices, improve soil biodiversity and enhance resilience. These ecological approaches maintain pests below economic thresholds and reduce reliance on pesticides.

4. **Resistance Management and Biological Control**

   Climate change is accelerating pest adaptation through genetic, physiological, and behavioral changes. To counter this, structured Insect Resistance Management (IRM) strategies must be enforced, including rotational use of pesticides and wider adoption of non-chemical methods. At the same time, natural enemies such as parasitoids, predatory beetles, and entomopathogenic fungi should be conserved and mass-produced through streamlined biopesticide regulation and quality-controlled distribution.

5. **Resilient Crop Varieties and Innovative Breeding**

   Development and dissemination of climate-resilient, pest-tolerant crop varieties (e.g., rice resistant to planthoppers, cotton tolerant to whiteflies) should be accelerated. Breeding programs must integrate climate and pest interactions to ensure varieties perform under variable conditions, reducing yield losses from pest outbreaks intensified by warming and elevated CO_2.

6. **Insurance, Policy, and Institutional Support**

   Comprehensive crop insurance schemes like PMFBY must be strengthened to explicitly cover pest-related risks and ensure timely compensation. Policy incentives should prioritize biopesticides and IPM-compatible technologies over chemical-intensive solutions. At the same time, biosecurity and quarantine systems should be reinforced to block invasive pests such as fall armyworm. Mainstreaming pest–climate resilience into State Action Plans on Climate Change (SAPCCs) will ensure coordinated national and state-level responses.

7. **Farmer-Centric and Inclusive Adaptations**

   Farmers should be supported with practical adaptations such as adjusting sowing dates, intercropping, and diversifying cropping systems. Extension networks KVKs, mobile apps, community pest monitoring groups must be strengthened to deliver timely information. Gender-sensitive approaches are crucial, recognizing women's significant role in pest management.

1.5. Stakeholder Validation of Evidence

To validate the conclusions drawn from the literature review and evidence synthesized in this policy paper, a Brainstorming Policy Dialogue on “Biotic and Abiotic Stress Management and Policy Issues in Indian Agriculture” was convened at ICAR–NIBSM, Raipur, on 21–22 July 2025. The multi-stakeholder consultation brought together scientists, policymakers, extension professionals, and field practitioners to critically examine emerging evidence on the interactions between climate variability and insect pest dynamics, and to deliberate on corresponding policy responses.

The stakeholder discussions reinforced the findings from the literature, confirming that climate change is significantly altering pest biology, distribution, and natural control mechanisms, leading to more frequent and severe outbreaks. Rising temperatures, erratic rainfall, and elevated CO_2 levels were collectively recognized as key drivers reshaping agro-ecosystems to the advantage of major insect pests such as *Helicoverpa armigera*, *Spodoptera litura*, whiteflies, and invasive species like the fall armyworm. Evidence presented during the dialogue further substantiated literature-based insights linking extreme events including heatwaves, droughts, and cyclones with sudden pest flare-ups and long-distance migrations, as witnessed in recent locust invasions.

Stakeholders validated the conclusion that existing pesticide-centric approaches are increasingly inadequate in these evolving contexts, given the rapid evolution of pest resistance and suppression of natural enemies. This consensus aligned with literature advocating for climate-resilient Integrated Pest Management (IPM) approaches that prioritize ecological and biological control solutions over chemical interventions.

The dialogue also echoed the paper's evidence-based recommendation for enhanced pest surveillance and forecasting, calling for the integration of climate models, pest ecology, and real-time monitoring into a National Pest Forecasting Network. Participants agreed that such a network, supported by ICT-enabled advisory systems, is crucial to provide timely, localized warnings to farmers and policymakers. Furthermore, stakeholders endorsed the policy recommendation to mainstream pest–climate interactions into State Action Plans on Climate Change (SAPCCs) and broader agricultural development programs, thereby embedding adaptive strategies within existing institutional frameworks.

In line with the literature review, the workshop emphasized the need for targeted public investments in:

- Development and dissemination of climate-resilient, pest-resistant crop varieties,
- Promotion of biopesticides and sustainable agronomic practices (e.g., intercropping, habitat management, conservation of natural enemies), and
- Strengthened quarantine and biosecurity frameworks to manage invasive species.

The discussion also validated the importance of climate-smart insurance products to mitigate pest-induced losses, complementing findings in the reviewed studies on risk reduction for smallholders.

The participants collectively underscored capacity building as a central pillar for policy implementation, reaffirming the role of Krishi Vigyan Kendras (KVKs) and the extension network in scaling up climate-smart IPM and farmer training. The inclusion of gender-sensitive approaches was also recommended, recognizing women's key contributions to pest management and farm labor.

The validation exercise concluded with a strong call for integrated, multi-stakeholder collaboration across research institutions, policy bodies, extension agencies, and farmer organizations. Stakeholders concurred with the paper's conclusion that a national roadmap for climate-resilient pest management must be developed, supported by regional and international cooperation, given the transboundary nature of many pest species.

Overall, stakeholder insights corroborated and strengthened the conclusions drawn from the literature and evidence analysis in this paper. The convergence of expert opinion and empirical findings underscores the urgency for systemic policy interventions that integrate science-based strategies, institutional coordination, and grassroots participation to safeguard India's food and livelihood security under changing climatic conditions.

1.6. Policy Recommendations

Climate change presents complex and evolving challenges to pest management in Indian agriculture, driven by rising temperatures, altered rainfall patterns, elevated CO_2 concentrations, and the increasing frequency of extreme weather events. These climatic shifts are altering pest biology, distribution, and interactions with crops and natural enemies, as validated by both literature and stakeholder consultations. Therefore, policy responses must be proactive, evidence-based, and integrated with national climate adaptation and food security strategies.

A key policy direction is the promotion of climate-resilient Integrated Pest Management (IPM) strategies that combine ecological, cultural, biological, and chemical methods in a balanced manner (Reddy *et al*., 2024). At present, pest forecasting and surveillance in India largely rely on field observations and conventional weather data, such as those used in the *National Pest Surveillance System* under NCIPM, which issues pest advisories based on trap catches and agro-meteorological information. However, these systems often lack integration with dynamic climate models and real-time satellite data, resulting in limited spatial coverage and delayed alerts. Therefore, pest forecasting and surveillance systems should be modernized to integrate climate models, enabling the development of robust early warning systems and timely interventions against potential pest outbreaks. This will be critical to anticipating and managing pest risks exacerbated by weather variability.

Governments should strengthen pest monitoring infrastructure at both regional and national levels by promoting real-time data sharing across agricultural research institutions, meteorological departments, and extension agencies. The establishment of community-based surveillance networks can empower farmers with locally relevant data and enable rapid response to emerging threats, thereby reducing economic losses associated with unpredictable pest surges.

Policies must also prioritize research, innovation, and cross-disciplinary collaboration to develop pest-resistant crop varieties, biological control agents, and climate-smart farming practices. Interdisciplinary partnerships between entomologists, climatologists, plant breeders, and data scientists should be institutionalized to forecast pest risks and co-design adaptive management strategies. Dedicated funding mechanisms are essential to support long-term research on pest ecology under changing climate scenarios.

Capacity building and farmer awareness must form the cornerstone of implementation. Extension programs should integrate training on climate-smart IPM practices, equipping farmers to recognize pest threats, adopt adaptive techniques, and minimize indiscriminate pesticide use. Such knowledge transfer will enhance resilience, productivity, and environmental sustainability, while also reducing health hazards linked to chemical overuse.

Given that many major pests are migratory and transboundary, policymakers should strengthen regional and international cooperation. Harmonized pest surveillance protocols, cross-border data sharing, and joint research initiatives can collectively improve preparedness and response capabilities.

Finally, pest management policies should be aligned with national climate action and food security frameworks. Incentive structures and subsidies must be redesigned to favor eco-friendly solutions such as biopesticides, habitat management, and conservation of natural enemies over chemical-intensive approaches. Integrating pest management into State Action Plans on Climate Change (SAPCCs) and agricultural development programs will ensure policy coherence and long-term sustainability.

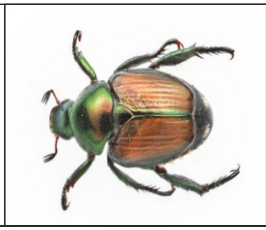
Empirical evidence from this policy paper (Tables 2.1–2.4) clearly demonstrates that climatic stressors significantly influence pest dynamics. Elevated CO_2 increases feeding rates and reproductive success in several herbivorous pests (e.g., aphids, beetles), while higher temperatures accelerate pest development, enable multiple generations per year, and expand pest ranges. Combined CO_2–temperature effects show species-specific outcomes, with some pests thriving while others are suppressed. Extreme events such as droughts and floods exert contrasting pressures weakening certain species but triggering outbreaks in others (e.g., bark beetles). These patterns confirm the urgent need for adaptive, context-specific policies to manage evolving pest complexes under changing climate conditions.

Actionable Policy Priorities

- Develop and scale up climate-resilient IPM integrating ecological, cultural, biological, and chemical approaches.
- Modernize pest forecasting systems by integrating climate models, real-time data, and AI-based analytics for early warnings.
- Strengthen pest monitoring infrastructure and establish community-based surveillance for localized responses.
- Invest in R&D for pest-resistant crop varieties, biological control agents, and climate-smart practices through interdisciplinary collaboration.
- Institutionalize training on climate-smart IPM in extension services and empower farmers through capacity-building programs.
- Foster regional and international cooperation with harmonized protocols and data sharing for transboundary pest management, e.g. the Scientific Animations Without Borders (SAWBO) platform.
- Reform subsidies and incentives to promote biopesticides, habitat management, and sustainable agronomic practices.
- Integrate pest management into State Action Plans on Climate Change (SAPCCs) and national agricultural policies.
- Expand climate-smart insurance schemes to cover pest-induced losses and reduce smallholder vulnerability.

2. Impact of weather parameters on insect pests

Table 2.1: Impact of elevated CO_2 on insect pests

S. No.	Insect	Geographical Distribution	Impact	References	Image
1.	**Japanese beetle** ***Popilia japonica***	China, India, Japan, North and South Korea, Europe, North America	Increase in feeding (57% more damage, soyabean)	Hamilton *et al.*, 2005	
2.	**Potato leafhopper** ***Empoasca fabae***	Africa, India, North, South and Central America, West Indies	Increase in feeding (57% more damage, soyabean)	Hamilton *et al.*, 2005	
3.	**Mexican bean beetle** ***Epilachna varivestis***	United States and Mexico	Increase in feeding (57% more damage, soyabean)	Hamilton *et al.*, 2005	

4.	**Western corn rootworm** ***Diabrotica virgifera virgifera***	Europe and North America	Increase in feeding (57% more damage, soyabean)	Hamilton *et al.*, 2005	
5.	**Brown planthopper** ***Nilaparvata lugens***	Bangladesh, Bhutan, China, India, Indonesia, Japan, North and South Korea, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Australia	Increase in honeydew excretion	Guru-Pirasanna-Pandi *et al.*, 2018	
6.	**Cabbage looper** ***Trichoplusia ni***	Africa, China, India, Iran, Iraq, Israel, Japan, Korea, Malaysia, Thailand, Vietnam, Europe, West Indies; North, South and Central America	Increase in feeding (20% more)	Ha, 2024	

7.	**Buckeye butterfly** ***Junonia coenia***	North and Central America	Increase in mortality and development time	Fajer *et al.*, 1989, 1991, 1993	
8.	**Pea aphid** ***Acyrthosiphon pisum***	Africa, Afghanistan, China, India, Iran, Iraq, Israel, Japan, Nepal, Pakistan, Philippines, Australia, Europe, North and South America	Increase in reproductive rate	Awmack *et al.*, 1997	

Table 2.2: Impact of elevated temperature on insect pests

S. No.	Insect	Geographical Distribution	Impact	References	Image
1.	**European spruce bark beetle *Dendroctonus rufipennis***	Africa, North America	Increase in number of generations/years	Bentz *et al.*, 2010	
2.	**Eight-toothed bark beetle *Ips typographus***	Africa, China, Iran, Japan, North and South Korea, Europe, North America	Increase in number of generations/years	Jönsson *et al.*, 2015	
3.	**Spotted stem borer *Chilo partellus***	Africa, Afghanistan, Bangladesh, India, Indonesia, Iran, Israel, Japan, Nepal, Pakistan, Sri Lanka, Thailand, Vietnam	Increase in number of generations/years	Khadioli *et al.*, 2014	

4.	**Cotton mealybug** ***Phenacoccus solenopsis***	Africa, Bangladesh, China, India, Indonesia, Iran, Iraq, Israel, Japan, Malaysia, Sri Lanka, Thailand, United Arab Emirates, Vietnam, Europe, North and South America	Increase in number of generations/years	Fand *et al.*, 2014	
5.	**Cereal leaf beetle** ***Oulema melanopus***	India, Iran, Pakistan, Europe	Reduction in parasitoid (*Tetrastichus julis*) attack	Evans *et al.*, 2013	
6.	**Scale insect** ***Parthenolecanium quercifex***	United States	Reduction in parasitoid attack	Meineke *et al.*, 2014	

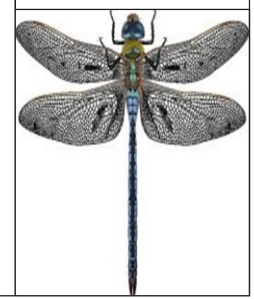
7.	**Green stink bug** ***Acrosternum hilare***	North America	Increase in range shift (185 miles)	Raza *et al.*, 2015	
8.	**European corn borer** ***Ostrinia nubilalis***	Africa, China, India, Indonesia, Iran, Israel, Europe, North America	Increase in range shift (northward of more than 1000 km)	Porter *et al.*, 1991	
9.	**Edith's checkerspot butterfly** ***Euphydryas editha***	North America	Increase in range shift (northward); Changes in population rate	Parmesan, 2006; Singer & Thomas 1996, Thomas *et al.* 1996, Thomas *et al.*, 2001	

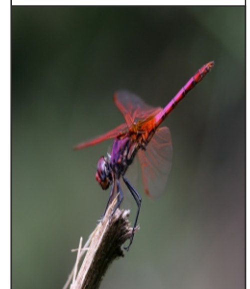
10.	**Black hills beetle** ***Dendroctonus ponderosae***	North America	Increase in number of generations per year; Range shift (northward of more than 180 miles)	Logan & Powell, 2001	
11.	**Argentine ant** ***Linepithema humile***	Africa, North and South America	Decrease in survival rate, Increase in range shift	Abril *et al.*, 2010	
12.	**Spruce budworm** ***Choristoneura fumiferana***	North America	Increase in egg size (50% greater); unaffected by parasitoids	Régnière, 1983; Volney, 2000	

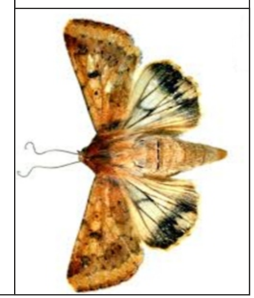
13.	**Pink bollworm** ***Pectinophora gossypiella***	Africa, Afghanistan, Bangladesh, China, India, Iran, Iraq, Israel, Japan, Malaysia, Myanmar, Pakistan, Philippines, North and South Korea, Sri Lanka, Thailand, Vietnam, Europe, North and South America	Increase in range shift	Gutierrez *et al.*, 2006	
14.	**Pine aphid** ***Schizolachnus pineti***	Europe, North America and some parts of Asia	Increase in population rate, fertility and feeding	Holopainen & Kainulainen, 2004	
15.	**Speckled tip moth** ***Argyresthia retinella***	China, Japan, Europe	Outbreak is observed	Tenow *et al.*, 1999	

16.	**Winter moth** ***Operophtera brumata***	Japan, Europe, North America	Increase in range shift	Hagen *et al.*, 2007	
17.	**Oak ambrosia beetle** ***Platypus quercivorus***	China, India, Japan, Thailand, Vietnam, Europe	Increase in range shift	Kamata *et al.*, 2002	
18.	**European pine sawfly** ***Neodiprion sertifer***	Japan, North and South Korea, Europe, North America	Increase in damage; Outbreak is observed	Faccoli, 2007; Andrew & Terblanch, 2013	

19.	**Common pine shoot beetle** ***Tomicus destruens***	Africa, China, Israel, Japan, North and South Korea, Europe, North America	Increase in damage	Faccoli, 2007	
20.	**Meat ant** ***Iridomyrmex purpureus***	Australia (endemic)	Change in diurnal (foraging) activity	Andrew & Terblanch, 2013	
21.	**Dung beetle** ***Onthophagus gibbulus***	United Kingdom, Finland, Mongolia, North America	Change in diurnal (foraging) activity	Andrew & Terblanch, 2013	

22.	**Winter pine processionary moth** ***Thaumetopea pityocampa***	Africa, Israel, Europe, North America	Increase in range shift; Outbreak is observed	Battisti *et al*., 2005; Hodar & Zamora, 2004; Buffo *et al*., 2007	
23.	**Wheat aphid** ***Sitobion avenae***	Africa, Afghanistan, China, India, Iran, Iraq, Israel, Japan, Myanmar, Pakistan, Saudi Arabia, Thailand, Europe, North, South and Central America	Decrease in survival	Zhao *et al*., 2014	
24.	**Blue Emperor dragonfly** ***Anax imperator***	Africa, Afghanistan, India, Iran, Iraq, Israel, Mauritius, Pakistan, Europe	Increase in range shift	Platts *et al*., 2019	

25.	**African Monarch, plain tiger butterfly *Danaus chrysippus***	Africa, India, Pakistan, Europe, North America, Australia	Increase in range shift	Garcia-Barros & Romo Benito, 2010	
26.	**Violet Dropwing dragonfly *Trithemis annulata***	Africa, China, India, Iran, Pakistan, Saudi Arabia, Vietnam, Europe	Increase in range shift	Bonet-Betoret, 2004	
27.	**Brown argus butterfly *Aricia agestis***	India, Europe	Changes in population rate	Singer & Thomas 1996, Thomas *et al.*, 1996, Thomas *et al.*, 2001	

28.	**Green stink bug** ***Nezara viridula***	Europe, India, Indonesia, Iran, Iraq, Israel, Japan, Thailand, Vietnam, Mauritius, Australia, North, Central and South America	Increase in range shift	Yukawa *et al.* 2007, 2009	
29.	**Cabbage root fly** ***Delia radicum***	Africa, China, Israel, Europe, North America	Increase in number of generations per year	Biron *et al.*, 2000	
30.	**Corn earworm** ***Helicoverpa zea***	Europe, North and South America	Increase in crop damage	EPA, 1989	

31.	**Cotton bollworm, corn earworm or Old World bollworm** ***Helicoverpa armigera***	Africa, Afghanistan, Bangladesh, Bhutan, China, India, Iran, Iraq, Israel, Japan, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, North and South Korea, Sri Lanka, Thailand, United Arab Emirates, Vietnam, Europe, Australia, North and South America	Increase in crop damage; Increase in range shift	Sharma, 2010	
32.	**Bean pod borer, soybean pod borer** ***Maruca vitrata***	Africa, India, Bangladesh, Bhutan, China, Indonesia, Japan, Korea, Malaysia, Nepal, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, South and Central America	Increase in range shift	Sharma, 2010	

Table 2.3: Impact of combination of elevated temperature and CO_2 concentration on insect pests

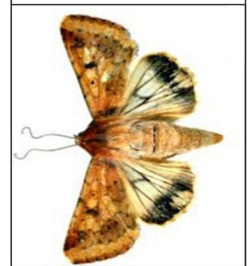
S. No.	Insect	Geographical Distribution	Impact	References	Image
1.	**Beet armyworm** ***Spodoptera exigua***	Africa, China, Japan, Europe, Australia, North and South America	Reduction in duration of life stages	Bharathi *et al*., 2018	
2.	**Cotton bollworm** ***Helicoverpa armigera***	Worldwide	Increase in feeding rate and larval metabolism activity	Akbar *et al*., 2016	

3.	**Mexican beetle** ***Zygogramma bicolorata***	Australia, India, Nepal, South Africa, North America (Mexico)	Increase in feeding rate and decrease in fecundity	Kumar *et al.*, 2021	
4.	**Tobacco caterpillar** ***Spodoptera litura***	Africa, Afghanistan, Bangladesh, China, India, Indonesia, Iran, Iraq, Japan, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, North and South Korea, Sri Lanka, Thailand, Vietnam, Europe, Australia, North America	Limited the survival and development	Srinivasa Rao *et al.*, 2018	

5.	**Cotton whitefly** ***Bemisia tabaci*** **MEAM1**	Africa, Mauritius, China, India, Iran, Israel, Japan, Pakistan, South Korea, Vietnam, Europe, Australia, North and South America	Change in physiological metabolism; Decrease in development time	Li *et al.*, 2017; Chandi *et al.*, 2021	
6.	**Rice brown planthopper** ***Nilaparvata lugens***	Bangladesh, Bhutan, China, India, Indonesia, Japan, North and South Korea, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Australia	Increase in feeding rate, fecundity, population and honeydew excretion	Guru Pirasanna Pandi *et al.*, 2018; Sunil *et al.*, 2024	

7.	**South American tomato moth** ***Phthorimaea absoluta***	Africa, Afghanistan, Bangladesh, China, India, Iran, Iraq, Israel, Japan, Myanmar, Nepal, Pakistan, South Korea, Thailand, United Arab Emirates, Europe, North and South America	Reduction in duration of life stages	Kanle Satishchandra *et al.*, 2018	

Table 2.4: Impact of other adverse weather conditions on insect pests

S. No.	Insect	Geographical Distribution	Impact	References	Image
1.	**Corn earworm** ***Helicoverpa zea***	Europe, North and South America	Reduction in growth rate	Inbar *et al.*, 2001	
2.	**Pine sawfly** ***Neodiprion gillettei***	United States, Mexico	Reduction in survival rate of larvae	Larsson & Bjorkman, 1993; Mcmillin & Wagner, 1995	
3.	**Six toothed spruce bark beetles** ***Pityogenes chalcographus***	Africa, China, Israel, Japan, North and South Korea, Europe, North America	Increase in damage	Rouault *et al.*, 2006	

4.	**Pinyon ips beetle** ***Ips confusus***	Central and North America	Increase in damage	Gaylord *et al.*, 2013	
5.	**Migratory locust** ***Locusta migratoria***	Africa, China, India, Europe, Australia, New Zealand	Mortality due to submergence	Uvarov, 1977	
6.	**Rice brown planthopper** ***Nilaparvata lugens***	Bangladesh, Bhutan, China, India, Indonesia, Japan, North and South Korea, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, Australia	Reduction in population	Way & Heong, 1994	

7.	**Grey-backed mining bee** ***Andrena vaga***	Europe, Iran, Kyrgyzstan, Kazakhstan	Mortality due to submergence	Fellendorf *et al.*, 2004	

3. Case Study I: Climate Change and the Desert Locust Crisis

3.1. Introduction

The desert locust (*Schistocerca gregaria* Forskål, 1775) has historically been among the most devastating migratory pests, periodically threatening food security and rural livelihoods across Africa, the Middle East, and South Asia.

These highly mobile insects form vast swarms capable of traveling hundreds of kilometres in a single day and consuming nearly all green vegetation in their path. Because of their polyphagous nature and rapid reproduction under favourable climatic conditions, even a small outbreak can quickly escalate into a transboundary plague.

In recent years, climate variability has been increasingly recognized as a major factor influencing locust population dynamics. Variations in rainfall, temperature, and wind patterns directly affect breeding, survival, and migration, making locust ecology particularly sensitive to the impacts of global climate change (Salih *et al.*, 2020). The 2019–2021 upsurge, declared by the World Bank Group (2020) as a major food security emergency, affected more than 20 countries and millions of people. Changing climate regimes, especially the increased frequency of extreme rainfall events and cyclones, are now altering the spatial and temporal dynamics of locust breeding and invasion.

This case study synthesizes biological, climatic, and policy evidence to examine how climate change is shaping the biology, distribution, and management of desert locusts, with a particular focus on recent experiences in India.

3.2. Biology and Ecology of the Desert Locust

The desert locust inhabits arid and semi-arid environments where rainfall is scarce and vegetation cover is limited. It exhibits a unique phenomenon known as *phase polyphenism*, where the same species expresses two distinct behavioural and morphological forms, solitary and gregarious depending on population density (Cressman, 2016). In the solitary phase, locusts remain dispersed and inconspicuous, but when dense populations form after rainfall, tactile stimulation triggers physiological and behavioural changes leading to aggregation, collective movement, and eventually swarm formation.

Successful breeding requires moist sandy soils for egg deposition and rapid vegetation growth to provide food for the developing nymphs. Under warm and humid conditions, the life cycle accelerates dramatically generation times can reduce from about three months to six weeks (FAO, 2020a). Migration is an adaptive response that enables locusts to exploit transient resources, and swarms often travel over 100 kilometres per day using prevailing winds. Major plagues arise when several generations breed successfully under consecutive favourable climatic conditions, resulting in exponential population growth (Salih *et al.*, 2020).

Historically, these outbreaks have coincided with periods of unusual rainfall in regions such as the Sahel, the Arabian Peninsula, and the Horn of Africa areas that are otherwise dry for most of the year.

3.3. Climatic Drivers of Locust Plagues

Rainfall remains the most critical driver of desert locust outbreaks, influencing all stages of their life cycle. Moist soils provide the necessary substrate for egg-laying, while subsequent vegetation growth supplies food for hoppers and adults (FAO, 2020b). The 2019–2021 East African crisis, for instance, was closely linked to the record-breaking positive Indian Ocean Dipole (IOD) of 2019, which led to abnormally heavy rains across the Arabian Peninsula and the Horn of Africa. Multiple cyclonic systems during this period such as Mekunu, Luban, and Pawan generated temporary lakes and lush breeding sites that supported successive locust generations (Salih *et al.*, 2020).

Temperature also exerts a strong influence. Warmer conditions accelerate egg incubation and nymphal development, enabling rapid population build-up, while adult survival tends to be prolonged under moderate temperatures. However, flight activity is inhibited below approximately 20°C (Cressman, 2016).

With global warming expected to increase both mean temperature and rainfall variability, locust habitats are likely to shift and expand in unpredictable ways. Thus, climate change adds complexity to predicting outbreaks and developing early warning systems (Guan *et al.*, 2021).

3.4. Historical Plagues and Recent Crises

Desert locust plagues are not new; they have been documented in historical records since ancient Egyptian times. Modern history records several large-scale events, including the prolonged 1949–1963 plague that affected vast parts of Africa and Asia, and the 1986–1989 crisis in West Africa. The 2019–2021 upsurge, however, was the most severe in the past 25 years. Originating in the Empty Quarter of the Arabian Peninsula following intense cyclonic rainfall, it spread rapidly across Ethiopia, Somalia, Kenya, and Uganda (FAO, 2020a). Despite extensive control efforts covering over 2 million hectares, the Food and Agriculture Organization (FAO) estimated that 35 million people faced acute food insecurity due to crop and pasture losses (World Bank, 2020).

India also faced its most serious locust invasion in decades during this period. Swarms migrated from Pakistan into Rajasthan and Gujarat between May 2020 and January 2021, affecting nearly 2 lakh hectares across six states, including parts of Punjab, Haryana, Madhya Pradesh, and Uttar Pradesh (Rai & Sharma, 2020). Crops such as mustard, cumin, wheat, and vegetables were damaged, and estimated losses exceeded ₹200 crore (PIB, 2021). The Directorate of Plant Protection, Quarantine & Storage (DPPQS) led the response, deploying over 6.5 lakh litres of pesticides through vehicle-mounted sprayers, drones, and aerial operations using helicopters (PIB, 2020). These coordinated measures prevented the escalation of damage to national food security levels.

Institutionally, the Locust Warning Organization (LWO), established in 1939 under DPPQS, plays a central role in locust monitoring and control across 2 lakh sq km of the Thar Desert. At the regional scale, India participates in the FAO Commission for Controlling the Desert Locust in Southwest Asia (SWAC) alongside Pakistan, Iran, and Afghanistan, ensuring cross-border coordination and data exchange (FAO, 2020b). Despite these mechanisms, limitations remain in surveillance coverage, dependence on chemical pesticides, and underutilization of modern forecasting technologies. Strengthening predictive modelling, ecological monitoring, and adoption of biological control agents such as *Metarhizium anisopliae* will enhance future preparedness.

3.5. Climate Change and Locust Dynamics

Climate change is redefining the ecological parameters that influence desert locust outbreaks (Figure 3.1). Warmer sea surface temperatures in the Indian Ocean are increasing the frequency of positive IOD events, leading to more frequent cyclones and heavy rainfall over East Africa and the Arabian Peninsula (Salih *et al.*, 2020). Such conditions generate new breeding sites in areas that were previously too dry to support locust reproduction.

At the same time, elevated land temperatures shorten developmental cycles and can increase reproductive output, allowing more generations per year (Guan *et al.*, 2021). Changes in monsoon wind patterns may redirect swarm migrations into areas with little or no prior exposure, posing challenges for local agricultural systems (Cressman, 2016).

However, these impacts are nonlinear. While moderate warming and increased rainfall can enhance locust outbreaks, extreme heat and drought can suppress them. The interplay of these factors introduces uncertainty into future predictions, underscoring the need for dynamic, climate-informed locust management systems. The spatial distribution of key climatic parameters influencing locust suitability is presented in Figure 3.1.

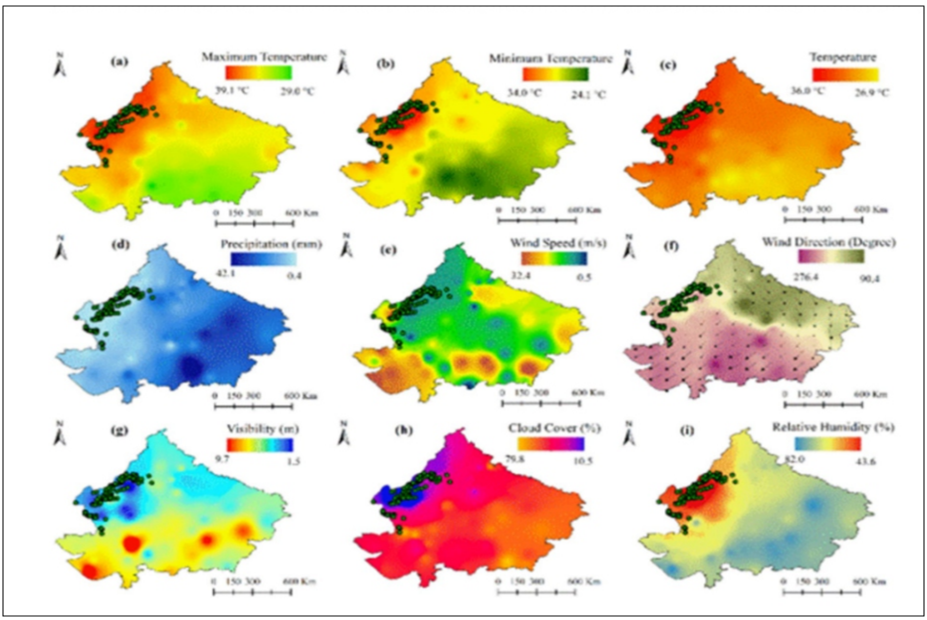


Figure 3.1: Predisposing parameters projected for locust suitability.
(a) maximum temperature, (b) minimum temperature, (c) temperature, (d) precipitation, (e) wind speed, (f) wind direction, (g) visibility, (h) cloud cover, and (i) relative humidity.
Source: https://doi.org/10.1038/s41598-024-73250-w

This figure 3.1 illustrates the major climatic parameters projected to determine desert locust habitat suitability under changing climate conditions. Variables such as temperature, precipitation, wind speed and direction, humidity, and cloud cover are mapped to show regions becoming increasingly conducive to breeding and migration. The model highlights how even slight shifts in temperature and rainfall can significantly expand the potential range of locust activity across arid and semi-arid zones.

3.6. Modelling Future Habitat Suitability

Climate modelling studies project substantial shifts in the potential habitat of desert locusts under different climate change scenarios. Guan *et al.* (2021) suggest that while traditional breeding zones may become too arid under high-emission pathways, higher-altitude and more northerly regions could become suitable.

In India, desert locusts currently breed mainly in western Rajasthan and Gujarat, but during favourable conditions they spread temporarily into

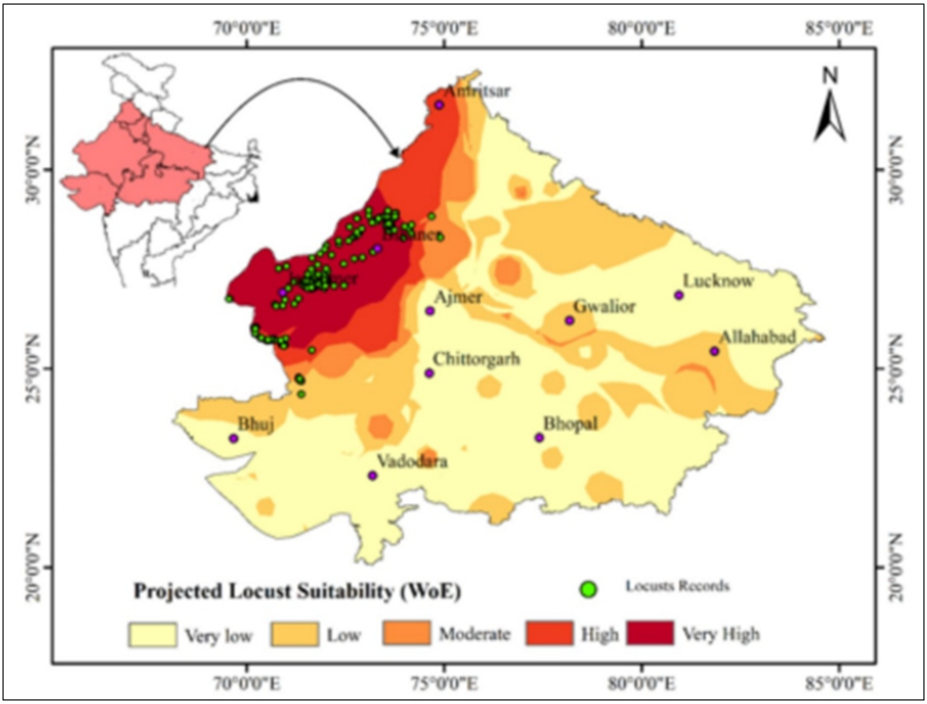


Figure 3.2: The spatial distribution of projected locust suitability maps by WoE model.
Source: https://doi.org/10.1038/s41598-024-73250-w

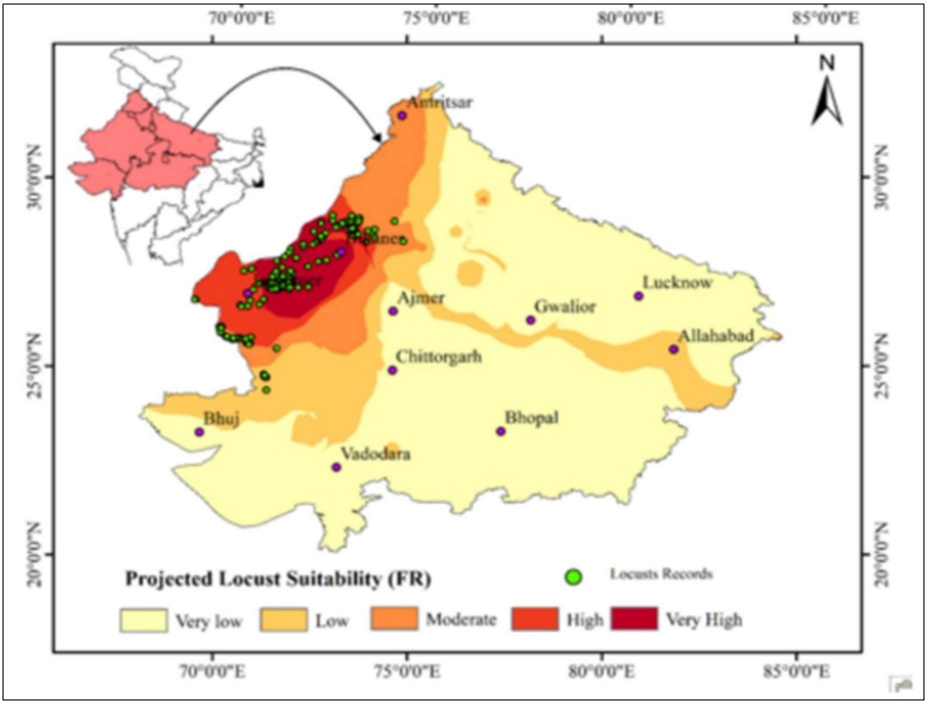


Figure 3.3: The spatial distribution of projected locust suitability maps by FR model.
Source: https://doi.org/10.1038/s41598-024-73250-w

adjoining states. Recent ecological niche models predict that climate change could extend locust habitats eastward and northward, especially under increased rainfall and temperature conditions during monsoon months (Singh & Kumari, 2021; Mitra *et al.*, 2024). This potential redistribution poses significant management challenges, as newly affected regions often lack established surveillance and response mechanisms. Integrating climate data into locust monitoring and preparedness strategies is therefore crucial to pre-emptively identify emerging hotspots and strengthen adaptive management. The spatial variations in future locust habitat suitability under different modelling approaches are shown in Figure 3.2 & 3.3.

Figure 3.2 & 3.3 compares the predicted locust habitat suitability generated using two spatial modelling techniques, the Weight of Evidence (WoE) and Frequency Ratio (FR) models. Both models indicate an eastward and northward expansion of suitable habitats under projected climate scenarios. These findings suggest that regions currently unaffected by locust outbreaks may face increased vulnerability in the future, emphasizing the importance of integrating climate projections into locust surveillance and early warning systems.

3.7. Socio-economic Impacts

Desert locust outbreaks inflict severe direct and indirect socio-economic costs. A single swarm can consume approximately 200 tonnes of vegetation per day, devastating croplands and pastures essential for rural livelihoods (FAO, 2020a). The 2019–2021 upsurge particularly affected smallholder farmers and pastoralists in East Africa, causing damage and control costs exceeding US$1 billion (World Bank, 2020).

In India, historical records such as the 1926–1931 plague show crop losses up to 10% in affected districts (Rao, 1942). During the recent 2019–2021 event, around 2 lakh hectares were impacted, resulting in crop losses worth over ₹200 crore and additional control costs exceeding ₹100 crore (PIB, 2021). Indirect effects included reduced fodder availability, income loss, and increased debt among small farmers.

Strengthening locust risk management within agricultural policies through crop insurance, livelihood diversification, and environmentally safe control options can mitigate these impacts. Community-based monitoring, rapid compensation mechanisms, and farmer training programs can further enhance resilience at the grassroots level.

3.8. Monitoring and Management Systems

The success of locust management depends on early detection and coordinated forecasting. Globally, the FAO's Desert Locust Information Service (DLIS) integrates satellite rainfall and vegetation data with ground surveys to predict breeding and migration (FAO, 2020b). Regional commissions across Africa and Asia ensure data sharing and collective action. However, limited access to remote or conflict-prone breeding areas often delays interventions (World Bank, 2020).

In India, the Locust Warning Organization (LWO) under DPPQS monitors approximately 2 lakh sq km of potential breeding areas through 50 field stations. Data collected through GPS-based devices and drones are transmitted in real time to Jodhpur headquarters for analysis and forecasting. India's participation in SWAC facilitates regional coordination with Pakistan, Iran, and Afghanistan, enabling joint surveillance.

During the 2019–2021 outbreak, early warnings and rapid response using drones, vehicle-mounted sprayers, and aerial operations effectively curtailed the spread beyond Rajasthan and Gujarat (PIB, 2020).

Nevertheless, gaps persist in predictive modelling, eco-friendly technologies, and local training. Future strategies should focus on AI-driven forecasting, use of biological control agents, and integration of locust management within broader climate adaptation frameworks.

3.9. Control Strategies

Conventional control strategies rely heavily on chemical pesticides, particularly ultra-low-volume formulations applied via ground and aerial spraying (FAO, 2020b). While effective, large-scale chemical use can harm non-target species and ecosystems. Consequently, biological control using *Metarhizium acridum* and other mycoinsecticides is gaining attention for its safety and sustainability. These biocontrols act more slowly but are particularly effective against hopper bands.

Integrated pest management (IPM) approaches, combining early warning, targeted intervention, and regional collaboration, represent the most sustainable path forward (Salih *et al.*, 2020). Building institutional capacity and investing in local surveillance infrastructure are critical for sustaining long-term resilience.

3.10. International Response and Funding

The international community's response to the 2019–2021 desert locust crisis was unprecedented. The World Bank and partner agencies committed over US$500 million for emergency control, strengthening national capacities, and enhancing forecasting infrastructure (World Bank, 2020). Despite these efforts, millions remained food insecure, underscoring the importance of shifting from reactive crisis management to proactive, climate-informed prevention systems that link locust monitoring with broader disaster risk reduction frameworks.

3.11. Proposed Solutions in the Era of Climate Change

Looking ahead, locust management must integrate climate science with agricultural planning. Seasonal climate forecasting, combined with locust biology models, can improve early warning accuracy. Expanding biopesticide production and distribution networks will promote sustainable control methods. Regional cooperation through platforms like SWAC should be reinforced, especially for coordinated action in cross-border breeding zones (FAO, 2020a; World Bank, 2020).

At the national level, social protection schemes, livelihood diversification, and insurance support are vital to buffer affected communities. Strengthening linkages between national meteorological departments, agricultural research institutions, and local extension systems can foster adaptive preparedness.

3.12. Discussion and Outlook

The interaction between climate change and desert locust ecology presents both new risks and scientific uncertainties. Some traditional breeding zones may become too hot or dry, while others may become newly suitable due to increased rainfall or vegetation availability (Salih *et al.*, 2020; Guan *et al.*, 2021). This duality makes prediction and planning complex.

Enhanced regional collaboration, investment in climate-informed modelling, and empowerment of local agencies are crucial. Balancing rapid response capabilities with environmental sustainability by transitioning from heavy pesticide reliance to integrated ecological approaches will be key to long-term control and resilience.

Conclusion

The desert locust crisis demonstrates how climate change can magnify transboundary pest threats, challenging national food security systems. Altered rainfall, temperature, and wind patterns are redefining locust breeding zones, demanding proactive adaptation. India's strong institutional framework through the LWO and regional collaboration via SWAC provide a solid base for coordinated action.

Future resilience will depend on integrating locust surveillance into national climate and agricultural policies such as the National Action Plan on Climate Change (NAPCC) and the National Mission for Sustainable Agriculture (NMSA). Investments in AI-based modelling, satellite monitoring, and biocontrol research will strengthen preparedness.

Ultimately, the desert locust crisis serves as both a warning and an opportunity—highlighting the need for a climate-responsive, cooperative, and technology-driven pest management system that safeguards India's food security and sustains rural livelihoods in an era of increasing environmental uncertainty.

4. Case Study II: The Fall Armyworm under Climate Change: Risks, Challenges, and Climate-Smart Management Approaches

4.1. Introduction

The Fall Armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), has emerged as one of the most destructive agricultural pests of global concern. Native to the Americas, FAW has rapidly expanded its invasive range to Africa, Asia, and parts of Oceania since 2016 (Figure 4.1), inflicting substantial economic damage to staple crops, particularly maize (Prasanna *et al.*, 2018; FAO, 2018). Its invasion has been facilitated by its high migratory ability, wide host range, and adaptability to new environments. Climate change, especially increasing global temperatures, has played a pivotal role in reshaping FAW's biology, survival patterns, and geographic spread. Predictive modelling indicates that vast areas in Asia, including China, are becoming increasingly suitable for FAW colonization, raising alarms for food security in these regions (Jiang *et al.*, 2022). At the same time, conventional pest management strategies face challenges such as pesticide resistance, ecological impacts, and sustainability concerns. These factors highlight the urgent need for climate-responsive Integrated Pest Management (IPM) approaches that account for shifting pest risks under changing climate scenarios (FAO, 2018).

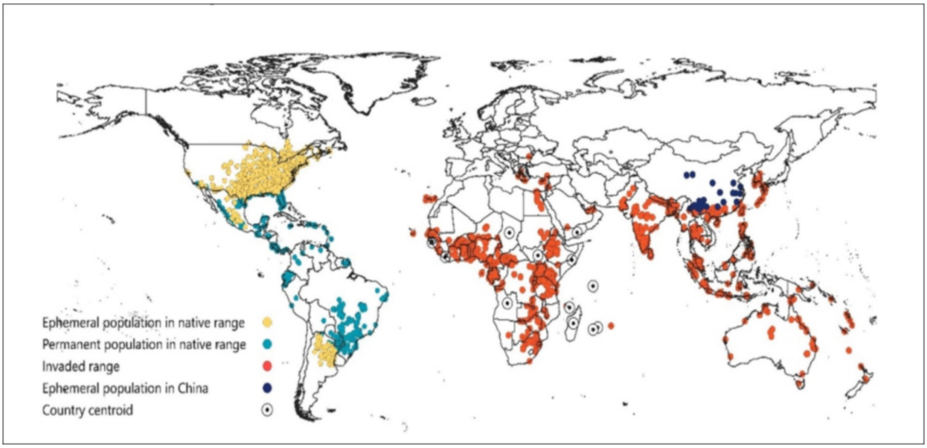


Figure 4.1: Confirmed presence records of *Spodoptera frugiperda* around the globe.
Yellow occurrence records represent seasonal FAW populations within the native range.
Light blue occurrence records show established FAW populations within its native range.
Red occurrence records depict FAW populations within its invasive range.
Dark blue occurrence records show the transient FAW populations based on population limits presented by Huang *et al*., 2022.
Lastly, circled dots represent the centroid of a country/region,
where FAW's presence is confirmed only by a country centroid.
Source: https://doi.org/10.1038/s41598-025-02595-7

Figure 4.1 depicts the global distribution and confirmed presence of the fall armyworm (*Spodoptera frugiperda*). It distinguishes between native, invasive, and transient populations using color-coded occurrence records. The map highlights FAW's rapid invasion across Africa and Asia since 2016, illustrating how favorable climatic conditions and high migratory potential have facilitated its global spread. These patterns underline the pest's transboundary nature and its growing importance under climate change.

4.2. Biology and Damage Potential of Fall Armyworm

FAW is a highly polyphagous pest that feeds on more than 80 plant species, making it a dreadful threat to global agriculture. Its life cycle comprises four main stages viz., egg, larva, pupa, and adult; with the larval stage causing the most damage to crops. Larvae aggressively feed on maize whorls, leaves, tassels, and ears, often leading to severe yield losses ranging from 20% to over 50% during major outbreaks (Prasanna *et al*., 2018; FAO, 2018). Several biological traits contribute to FAW's destructive potential, including its ability to complete multiple generations annually in tropical and subtropical climates, its strong migratory capacity of over 100 kilometres per night, and its remarkable fecundity, with females laying over 1,000 eggs in a lifetime (Goergen *et al.*, 2016). Compounding these traits is FAW's demonstrated resistance to various classes of insecticides, which makes chemical control less reliable and accelerates the need for sustainable management strategies. Together, these biological features establish FAW as one of the most damaging transboundary pests of modern agriculture.

4.3. Temperature as a Critical Driver Under Climate Change

Temperature is a fundamental ecological factor influencing insect physiology, behaviour, and population dynamics, and FAW is no exception. Warming temperatures directly affect FAW's development rate, survival, reproductive output, and dispersal capacity (Early *et al.*, 2018; Rao *et al.*, 2023). For example, warmer conditions shorten its life cycle duration, enabling more generations per year, a phenomenon known as increased voltinism. FAW thrives optimally between 25–30°C, with its development accelerating significantly between 18–30°C, reducing its generation time from approximately 40 days to 20 days (Du Plessis *et al.*, 2020). Its lower developmental threshold is around 10°C, while upper lethal limits are near 35–38°C, indicating considerable adaptability within broad temperature ranges. Under climate change, even modest warming of 1–2°C can result in 2–4 additional generations annually, intensifying pest pressure in vulnerable regions (Early *et al.*, 2018). Although extreme heat events may cause mortality, the overall trend of warmer conditions is expected to enhance FAW's survival, dispersal, and establishment in new regions, making temperature a key driver of its invasive success.

4.4. Modelling FAW Distribution Under Climate Change

Predictive modelling serves as a critical tool for assessing the potential spread and establishment of FAW under different climate change scenarios. Using species distribution models such as CLIMEX and MaxEnt (Figure 4.2), researchers have identified expanding climatic suitability across diverse regions, including northern India, southern China, and Mediterranean ecosystems, particularly under high-emissions scenarios such as RCP 8.5 (Early *et al.*, 2018; Du Plessis *et al.*, 2020). These models also highlight that areas previously too cold, such as higher elevations, are becoming suitable for seasonal or permanent FAW populations. Case studies in China demonstrate that while southern and central provinces are already highly suitable for FAW establishment, continued warming could shift suitability northward to the North China Plain and Northeast China by mid-century (Jiang *et al.*, 2022). Importantly, the models predict that warmer winters will expand overwintering zones, facilitating earlier infestations in spring and intensifying migration into key maize production belts. Such projections underscore the importance of integrating predictive modelling into regional and national pest management strategies to anticipate and mitigate FAW's growing threat. The global climatic suitability for FAW under different irrigation and rainfall scenarios is illustrated in Figure 4.2.

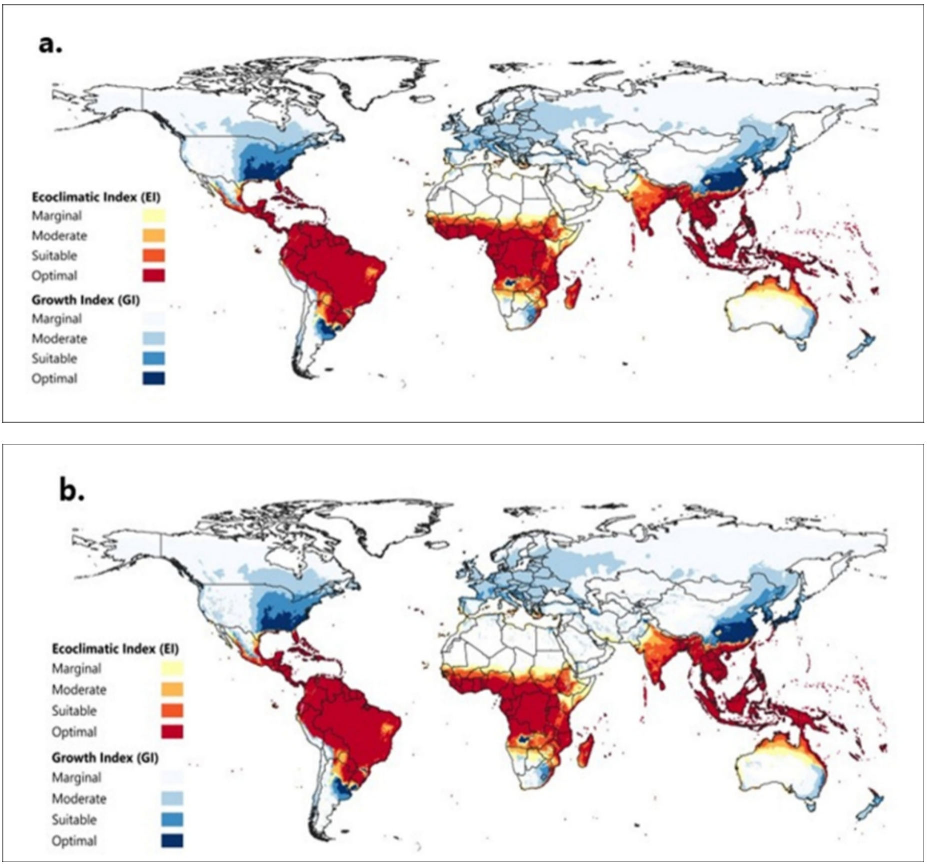


Figure 4.2: Global climatic suitability of *Spodoptera frugiperda* modeled using the Compare Locations module in CLIMEX v4.1.1.0 ran with 30-year average climatic data centred on 1995 (CM_TC10_1995_v1) (a) under rainfed conditions and (b) under a composite irrigation scenario (2.5 mm day-1 applied as top-up). The EI gradient (yellow-red) represents areas suitable for all year-round FAW population establishment. The GIA gradient (light blue-dark blue) depicts areas suitable for seasonal population growth and migration. Source: https://doi.org/10.1038/s41598-025-02595-7

Figure 4.2 illustrates modeled projections of global climatic suitability for FAW using CLIMEX software. The Ecoclimatic Index (EI) and Growth Index (GIA) gradients show regions with conditions suitable for year-round establishment and seasonal population growth. The results indicate that rising temperatures and altered rainfall will expand FAW's potential habitat toward northern India, East Asia, and the Mediterranean region. These projections emphasize the urgent need to incorporate predictive modeling into pest risk management and adaptation planning.

4.5. Climate-Responsive Integrated Pest Management (IPM) Strategies

The global invasion of Fall Armyworm (FAW, *Spodoptera frugiperda*) has already prompted significant research and implementation of IPM strategies, but climate change necessitates further adaptation of these approaches to address evolving pest dynamics. A climate-responsive IPM framework includes multiple components. Monitoring and early warning systems, particularly those integrating temperature-driven phenology models and real-time surveillance networks, are essential for anticipating outbreaks (Reddy *et al.*, 2025; 2025a). For instance, India and China have developed FAW monitoring systems that combine pheromone trap data with climate forecasts to improve advisory services (Jiang *et al.*, 2022). Resistant crop varieties, including Bt maize and conventionally bred resistant lines, play a critical role but require careful resistance management (Prasanna *et al.*, 2018). Biological control agents such as parasitoids (*Trichogramma*, *Telenomus*), predators (lacewings, spiders), and entomopathogens (*Metarhizium*, *Bacillus thuringiensis*) are promising, though their effectiveness may be influenced by local temperature shifts (FAO, 2018). Cultural practices such as adjusted planting dates, intercropping, push–pull systems, and conservation tillage can reduce FAW pressure, but these too must be modified under altered rainfall and temperature patterns. Chemical control remains a last alternative, requiring judicious use and rotation of insecticide classes to slow resistance development (Yu, 1991; Carvalho *et al.*, 2013). Finally, strong policy support, regional coordination, and investment in farmer training are crucial for scaling climate-smart IPM solutions across diverse agricultural landscapes.

In India, the FAW outbreak since 2018 has revealed both the strengths and weaknesses of national pest management systems. The pest initially affected maize-growing states such as Karnataka, Tamil Nadu, Andhra Pradesh, and Maharashtra, later spreading to the northern and eastern regions. By 2020, it had infested more than 1.7 million hectares of maize and sorghum, with estimated yield losses of 8–20%, translating into economic damages exceeding ₹1,200 crore (Khan, 2021). The rapid spread exposed gaps in surveillance infrastructure, diagnostic capacity, and timely farmer advisories. India's institutional response, led by ICAR, the National Bureau of Agricultural Insect Resources (NBAIR), and the National Centre for Integrated Pest Management (NCIPM), helped develop monitoring tools, biological control protocols, and management advisories in multiple languages. However, implementation at the field level has been uneven, particularly among smallholders in rainfed systems.

Policy-wise, India needs a comprehensive national framework for invasive and climate-driven pest management, building on lessons from the desert locust crisis. This includes:

- Strengthening forecasting and surveillance through digital pest networks, AI-based models, and integration with meteorological data;
- Enhancing coordination between ICAR institutes, State Agricultural Universities (SAUs), and the National Agricultural Disaster Management Plan under the Department of Agriculture;
- Promoting eco-friendly control measures, such as microbial biopesticides, habitat management, and natural enemy conservation;
- Developing farmer training programs and participatory pest surveillance through Krishi Vigyan Kendras (KVKs); and
- Institutionalizing rapid response and compensation mechanisms for pest-related crop losses.

A climate-responsive IPM approach for India must therefore be technically adaptive, institutionally coordinated, and socially inclusive, ensuring that pest management strategies align with broader national priorities on food security, climate resilience, and sustainable agriculture.

5. Case Study III: Innovations Supported by a-IDEA @ NAARM for Mitigating Climate Change Effects on Farming

5.1. Introduction

India has undertaken several national initiatives to address the growing challenges of climate variability, extreme weather, and pest outbreaks affecting agriculture. Institutions such as ICAR–CRIDA, ICAR–NCIPM, and NICRA have launched programs that focus on climate-resilient farming, pest surveillance, and early warning systems. For instance, the National Innovations in Climate Resilient Agriculture (NICRA) program emphasizes adaptive technologies for managing biotic and abiotic stresses, while ICAR–NCIPM's Pest Surveillance and Forecasting Network provides advisories based on trap data and weather parameters. Similarly, Digital Agri-Mission and Kisan Sarathi platforms are promoting data-driven decision-making to enhance farm resilience against climate-induced risks.

Building on this national momentum, the National Academy of Agricultural Research Management (NAARM) has taken a pioneering step through its startup incubation program, Association for Innovation Development of Entrepreneurship in Agriculture (a-IDEA). Established in 2015, a-IDEA serves as a unique agri-innovation ecosystem that nurtures startups developing technologies for climate change mitigation and adaptation. Unlike conventional research-led programs, a-IDEA bridges the gap between science, entrepreneurship, and farmers by supporting scalable, market-oriented solutions.

Through its initiatives, a-IDEA has supported more than 350 agri-startups, many of which directly address the impacts of climate change on farming by developing early warning systems, precision agriculture tools, eco-friendly inputs, and digital pest monitoring solutions. These innovations not only help reduce crop losses but also empower farmers to make timely, informed decisions in a changing climate.

5.2. Innovations Supported by a-IDEA

Several startups nurtured by a-IDEA have developed solutions that directly address climate change impacts on farming. A few notable examples include:

- **Bharatrohan Airborne Innovation Pvt. Ltd. (2016):** Developed an imaging-based Decision Support System that enables periodic monitoring of crops and land. The platform provides early warnings of pest and disease outbreaks, diagnoses plant nutrient deficiencies, and integrates both IPM and conventional farm product management. This reduces crop losses and ensures efficient input use.
- **Datair Technology Pvt. Ltd. (2020):** Focuses on building and licensing environmental data using precision agriculture tools, wireless sensor networks (WSN), Artificial Intelligence, IoT, and drones. Its services provide critical weather and soil-related information, helping farmers make climate-smart decisions on irrigation, nutrient management, and pest control.
- **Elai Agritech Pvt. Ltd. (2020):** Offers a remote sensing–based farm analytics platform that proactively monitors farms and predicts risks. With significant traction both in national and international markets, the company specializes in weather-related services that help farmers anticipate and adapt to climatic fluctuations.
- **Visron Pvt. Ltd.:** Specializes in ICT- and IoT-based precision farming solutions, including pest monitoring and management through real-time data processing. Its tools enable farmers to respond quickly to changes in pest population dynamics, reducing crop damage.
- **Vise Innovative Solution Enterprise Pvt. Ltd. (2017):** Provides a range of eco-friendly farm inputs, including organic fertilizers, organic pesticides, and bio-fertilizers. By offering cost-effective, environmentally safe alternatives, the company promotes reduced chemical usage and supports integrated pest management practices.

5.3. Outcomes and Impact

The startups supported by a-IDEA demonstrate how innovation ecosystems can drive climate resilience in Indian agriculture. Their outcomes include:

- **Improved early warning and forecasting:** Digital platforms and imaging tools enhance the ability to predict pest outbreaks and nutrient deficiencies well before visible damage occurs.
- **Data-driven farm decisions:** AI, IoT, and sensor-based technologies provide real-time insights that help farmers optimize inputs, reduce wastage, and improve productivity under uncertain climatic conditions.
- **Reduced reliance on chemical pesticides:** By promoting eco-friendly inputs and IPM-compatible solutions, startups help keep pest populations under the Economic Threshold Level (ETL), minimizing both environmental and health risks.
- **Enhanced climate adaptation capacity:** Farmers gain access to technologies that help them cope with irregular rainfall, droughts, pest surges, and soil degradation, thus lowering vulnerability.
- **Scalability of solutions:** Many of these technologies are being deployed not only in India but also internationally, reflecting their potential for broader impact.

5.4. Conclusion and Policy Implications

The case of a-IDEA @ NAARM demonstrates how innovation-driven ecosystems can play a transformative role in enhancing climate resilience in Indian agriculture. By fostering startups that provide technology-enabled, market-based solutions, a-IDEA bridges the gap between research, entrepreneurship, and field-level application. Its initiatives align closely with India's broader climate and agricultural policies, including NICRA, Digital Agriculture Mission, and the State Action Plans on Climate Change (SAPCCs).

The experience underscores several policy-relevant implications:

1. **Mainstreaming innovation incubation in national programs:** Government-supported incubators like a-IDEA should be integrated into flagship schemes such as NICRA and the National Mission for Sustainable Agriculture (NMSA) to accelerate the diffusion of

climate-smart technologies.

2. **Strengthening public–private partnerships (PPPs):** Startups mentored by a-IDEA illustrate the value of PPPs in delivering scalable digital, bio-based, and precision solutions. Policies should promote PPP frameworks that link research institutions, private innovators, and farmers for co-developing adaptive technologies.
3. **Institutionalizing digital pest and climate surveillance:** a-IDEA's supported innovations show that integrating AI, IoT, and remote-sensing tools into pest surveillance systems can strengthen India's early warning and risk management capabilities. Linking such tools to national databases (IMD, ICAR-NCIPM) should be a policy priority.
4. **Incentivizing sustainable and eco-friendly technologies:** Policies must expand financial and regulatory support for biopesticides, organic inputs, and precision agriculture solutions to reduce chemical dependence and improve environmental health.
5. **Capacity building and inclusion:** The startup ecosystem should be leveraged to strengthen farmer capacity, especially among smallholders and women, through digital advisory services, training, and participatory technology validation.

In essence, the a-IDEA model offers a replicable policy blueprint for promoting innovation-led, climate-resilient agriculture. Integrating such incubator-based approaches into mainstream agricultural and climate policies can ensure faster technology adoption, reduced pest-induced losses, and improved livelihood resilience under changing climatic conditions.

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Appendix A

TWO DAYS BRAINSTORMING SESSION

On

"POLICY PAPER ON BIOTIC AND ABIOTIC STRESS MANAGEMENT IN INDIAN AGRICULTURE"

July 21 and 22, 2025

Inaugural Session Programme **Venue: Auditorium, ICAR-NIBSM, Raipur**

Time	
09:30 AM – 10:00 AM	Registration and Plantation by Guests
10:00 AM – 10:05 AM	ICAR Song by AKMU
10:05 AM – 10:10 AM	Lighting of Lamp
10:10 AM – 10:15 AM	Introduction of Dignitaries on Dais and Welcome Address Dr. A. Amarender Reddy, Joint Director, SCHPSR, ICAR-NIBSM
10:15 AM – 10:30 AM	Floral Welcome and Felicitation of Dignitaries on Dais
10:30 AM – 10:40 AM	Dr. D. K. Marotia, President, Indian Society of Agricultural Economics (ISAE), Mumbai
10:40 AM – 10:50 AM	Dr. K. Sammi Reddy, Director, ICAR-NIASM, Baramati
10:50 AM – 11:00 AM	Distinguished Guest Address Dr. HC Sharma, Ex-Vice Chancellor, HPKV, Palampur, HP
11:00 AM – 11:10 AM	Distinguished Guest Address Dr.PK Chakrabarty, Ex-ADG (PP&B); Member, ASRB, New Delhi
11:10 AM – 11:20 AM	Chief Guest's Address Dr. Gyanendra Mani, Chief General Manager, NABARD, Raipur
11:20 AM – 11:25 AM	Release of Publications (e.g., Atlas)
11:25 AM – 11:30 AM	Chairperson's Address Dr. P.K. Rai, Director, ICAR-NIBSM, Raipur
11:30 AM – 11:40 AM	Vote of Thanks Dr. Kamal Vatta, Secretary, ISAE
11:35 AM – 11:45 AM	High-Tea

Appendix B

Technical Committee of Brainstorming Workshop on Biotic and Abiotic Stress Management and Policy Issues in Indian Agriculture (July 21-22, 2025)

Day 1: 21st July 2025

Session I: Scientific, Technological, and Regulatory Innovations in Biotic Stress Management	
Chair	**Dr. H. C. Sharma, Former Vice Chancellor, HPKV, Palampur, HP**
Co-Chair	Dr. K. K. Mondal, Dr. K. Srinivas
Convener	Dr. Binod Kumar Choudhary
Rapporteur	Dr. Arkaprava Roy, Dr. R. K. Murali Baskaran

Session II: Policy, Institutional, and Regulatory Strategies for Scaling Biotic Stress Management	
Chair	**Dr. P. K. Chakrabarty, Former ADG (PP&B); Member, ASRB, New Delhi**
Co-Chair	Dr. P. K. Agrawal/ Dr. M. Parasuramaiah
Convener	Dr. P. N. Sivalingam
Rapporteur	Dr. Sridhar J., Dr. L. L. Kharbikar

Day 2: 22nd July 2025

Session III: Scientific and Technological Interventions in Abiotic Stress Management	
Chair	**Dr. K. L. Gurjar, Joint Director, DPPQS, Faridabad**
Co-Chair	Dr. Pankaj Sharma/ Dr. (Mrs.) Daisy Basandrai
Convener	Dr. N. P. Kurade, NIASM
Rapporteur	Dr. Mallikarjuna Jeer, Dr. Bhaskar Gaikwad, NIASM

Session IV: Policy, Institutional, and Programmatic Frameworks for Abiotic Stress Resilience	
Chair	**Dr. Anjani Kumar, Senior Research Fellow, IFPRI, New Delhi**
Co-Chair	Dr. Anil Dixit/ Dr. Nalini Ranjan Kumar
Convener	Dr. S. K. Jain
Rapporteur	Dr. Priyanka Meena, Dr. Vinay Kumar

List of Publications

1. Reddy, Amarender A., Suresh, A., Praveen, K. V., Singh, D. R. and P. K. Rai. 2025. Profiling Biotic, Abiotic and Institutional Risks in Rainfed Farming and Coping Strategies (Policy Paper No. 01/2025). ICAR-National Institute of Biotic Stress Management (ICAR-NIBSM), Raipur. Pp. 1-37.
2. Amarender Reddy, A and Prasad Y.G. 2025. Two Decades of Bt Cotton in India: Impact and Policy Imperatives. ICAR-Central Institute for Cotton Research (CICR), Nagpur. Pp. 1-42.
3. Reddy, Amarender A., Kriti Arpana Minz, Priyanka Meena, K. C. Sharma and P. K. Rai. 2025. Atlas of Invasive Insect Species: Status of Geographical Distribution and Economic Losses in India. ICAR-National Institute of Biotic Stress Management (ICAR-NIBSM), Raipur-493225, Chhattisgarh, INDIA. Pp. 1-106.
4. Reddy, Amarender A., Minz, K. A., Tiwari, V. L. and Rai, P. K. 2025.Atlas of Invasive Plant Pathogens: Status of Geographical Distribution and Economic Losses in India. National Institute of Biotic Stress Management (ICAR-NIBSM), Raipur-493225, Chhattisgarh, INDIA. Pp.1-87.
5. P. Mooventhan, Hem Prakash Verma, Suman Singh, Uttam Singh, K. C. Sharma, Priyanka Meena, A. Amarender Reddy, P. Venkatesan, S. Senthil Vinayagam, Gopal Lal and P. K. Rai. 2025. Enhancing Agricultural Productivity among Smallholder Farmers in India through Agricultural Drone Services (Policy Paper No. 2/2025-2), ICAR-National Institute of Biotic Stress Management, Raipur and ICAR-National Academy of Agricultural Research Management. Pp. 1-32.
6. Priyanka Meena, Kriti Arpana Minz, K. C. Sharma, P. Mooventhan, N. Sivaramane, S. Senthil Vinayagam, Anil Dixit, A. Amarender Reddy, Gopal Lal and P. K. Rai (2025). Climate Change Effects on Insect Pests and Economic Losses in India (Policy Paper No. 3/2025). ICAR-National Institute of Biotic Stress Management, Raipur and ICAR-National Academy of Agricultural Research Management. Pp.1-66.
7. Banda Sainath, A. Amarender Reddy, Barun Deb Pal, Anjani Kumar, Ujjwal Kumar, Anup Das and P. K. Rai. 2025. Distributional Consequences of U.S. Tariff Shocks on India's Economy: Insights from a Computable General Equilibrium Model (Policy Paper No. 04/2025), pp. 1-29. ICAR-National Institute of Biotic Stress Management, Raipur. ICAR-Research Complex For Eastern Region, Patna, and International Food Policy Research Institute, New Delhi.

भाकृअनुप - राष्ट्रीय जैविक स्ट्रैस प्रबंधन संस्थान, रायपुर, छत्तीसगढ़

ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh

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भाकृअनुप - राष्ट्रीय कृषि अनुसंधान प्रबंध अकादमी, हैदराबाद, तेलंगाना

ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana