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## Climate-Driven Insecticide Resistance in Indian Agro ecosystems and the Role of Artificial Intelligence in Pest Management

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Insecticide resistance has become a critical constraint to sustainable pest management, particularly in developing countries like India where chemical control remains predominant. The evolution of resistance in major agricultural pests is being further accelerated by climate change, which alters pest biology, distribution, and population dynamics. At the same time, artificial intelligence (AI)-based technologies are emerging as powerful tools for precision pest monitoring and management. This article highlights recent trends in insecticide resistance with special reference to Indian case studies such as fall armyworm (*Spodoptera frugiperda*), cotton whitefly (*Bemisia tabaci*), and brown planthopper (*Nilaparvata lugens*). It also discusses the role of climate change in accelerating resistance and explores how AI-driven approaches can support sustainable pest management.

**Keywords:** climate change, artificial intelligence, fall armyworm, whitefly, brown planthopper, IPM

### Introduction

Insect pests are among the most important constraints in agriculture, causing significant yield losses. Chemical insecticides have long been used for pest control; however, their repeated and indiscriminate use has resulted in the development of resistance. Insecticide resistance is defined as a heritable decrease in susceptibility of insect populations to a toxicant (IRAC, 2022). Globally, resistance has been reported in more than 600 insect species (Sparks & Nauen, 2015). In India, the problem is particularly severe due to intensive cropping systems and high pesticide usage. Climate change further complicates this issue by influencing pest survival, reproduction, and distribution. Rising temperatures and altered climatic conditions can accelerate resistance development (Deutsch et al., 2018). Meanwhile, artificial intelligence (AI) is emerging as a transformative tool in pest management, enabling real-time monitoring and predictive decision-making.

### Mechanisms of Insecticide Resistance

Resistance develops through selection pressure, where resistant individuals survive and reproduce. The major mechanisms include metabolic resistance, target-site modification, behavioral resistance, and reduced penetration. Recent studies indicate increasing complexity of resistance with multiple mechanisms operating simultaneously (Al Naggar et al., 2025).

### Indian Case Studies of Insecticide Resistance

#### 1. Fall Armyworm (*Spodoptera frugiperda*)

Fall armyworm (FAW) is an invasive pest reported in India in 2018 and has rapidly spread across maize-growing regions. Recent studies from India have documented **field-evolved resistance to several insecticides**, including pyrethroids and diamides. For instance, populations from Maharashtra showed significant variability in susceptibility and evidence of

resistance linked to genetic polymorphism (Deshmukh et al., 2023). Similarly, studies on maize genotypes have emphasized the need for host plant resistance and integrated strategies to manage FAW effectively (Kumar et al., 2024).

## 2. Cotton Whitefly (*Bemisia tabaci*)

Cotton whitefly is a major pest in India and has developed resistance to multiple classes of insecticides. Studies conducted in northern India have reported **high levels of resistance to neonicotinoids and pyrethroids**, leading to frequent pest outbreaks. Research by ICAR institutions demonstrated variability in susceptibility among whitefly populations and highlighted the role of excessive insecticide use in resistance development (Singh et al., 2024). Climate factors such as high temperature and humidity further aggravate whitefly outbreaks.

## 3. Brown Planthopper (*Nilaparvata lugens*)

Brown planthopper (BPH) is a serious pest of rice in India. Resistance to several insecticides has been widely reported, making management challenging. Recent studies have shown that BPH populations exhibit **biochemical and enzymatic resistance mechanisms**, including increased detoxification enzyme activity (Reddy et al., 2024). Additionally, research from ICAR-IARI highlights the importance of resistant rice varieties and integrated approaches for sustainable management (IARI, 2024).

## Influence of Climate Change on Resistance

Climate change significantly affects insect pest biology and resistance evolution. Increased temperatures lead to faster development and higher reproductive rates, resulting in more generations per year and increased exposure to insecticides. Climate change also facilitates pest migration and invasion into new areas, accelerating resistance development. These changes highlight the need for adaptive and climate-resilient pest management strategies.

## Artificial Intelligence in Pest Management

Artificial intelligence is revolutionizing pest management by enabling precision agriculture. AI-based tools utilize machine learning and data analytics for pest identification, monitoring, and forecasting. Applications include automated pest detection, real-time surveillance, predictive modeling, and decision support systems. These technologies help reduce unnecessary insecticide applications, thereby lowering selection pressure and delaying resistance development (Zhang et al., 2021).

## Integrated Approach for Sustainable Management

Sustainable management of insecticide resistance requires integration of multiple strategies. Integrated Pest Management (IPM) combines biological, cultural, and chemical methods to minimize reliance on insecticides. Insecticide rotation, biological control, and climate-smart practices are essential components. The integration of AI-based technologies further enhances precision and efficiency, contributing to long-term sustainability.

## Conclusion

Insecticide resistance is a major challenge in modern agriculture, particularly under changing climatic conditions. Indian case studies of fall armyworm, whitefly, and brown planthopper highlight the severity of the problem. However, advancements in artificial intelligence and integrated pest management strategies offer promising solutions. A holistic approach combining ecological principles, climate adaptation, and technological innovation is essential to ensure sustainable pest management and food security.

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