Utilization of Biopesticides in Integrated Pest Management

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Abstract

The increasing ecological and health concerns associated with synthetic chemical pesticides have accelerated the search for sustainable alternatives, among which biopesticides have emerged as a vital component of Integrated Pest Management (IPM) strategies in India. This review paper critically examines the utilization of biopesticides in Indian agriculture by analyzing published literature and secondary data. It explores their types, mechanisms of action, adoption trends, efficacy across major crops, economic viability, and regulatory frameworks. Findings reveal that biopesticides such as Trichoderma spp., Bacillus thuringiensis, neem extracts, and Pseudomonas fluorescens have shown effective pest control in crops like cotton, rice, and pulses, contributing to yield improvements and environmental safety. Despite registering over 970 biopesticide formulations by 2014, India's biopesticide consumption still accounts for less than 3% of the total pesticide usage, mainly due to regulatory bottlenecks, low farmer awareness, and inadequate quality control. Policy initiatives such as the National Mission on Sustainable Agriculture and the expansion of biocontrol laboratories have provided supportive momentum, yet adoption remains uneven across regions. The paper highlights the economic and ecological advantages of biopesticides and suggests that strategic regulatory reforms, market incentives, and farmer training programs are essential to mainstream biopesticides in Indian agriculture. Future directions emphasize integrating biopesticides with precision farming technologies and strengthening public-private partnerships to enhance their production, availability, and acceptance at scale.

Keywords: Biopesticides, Integrated Pest Management, Sustainable Agriculture, India, Trichoderma, Neem, Pest Control, Policy Support, Crop Yield, Eco-friendly Practices

1. Introduction

Agriculture in India, being the backbone of the rural economy, has historically been challenged by significant crop losses due to pests, which account for an estimated 15–25 percent of total yield reduction annually (Dhaliwal, Jindal, and Mohindru, 2010). The conventional dependence on chemical pesticides since the Green Revolution of the 1960s initially contributed to increased agricultural productivity. However, it also led to serious concerns such as pest resistance, resurgence, pesticide residues in food, environmental pollution, and adverse effects on non-target organisms (Yadav and Devi, 2012). In response, the concept of Integrated Pest Management (IPM) emerged as a holistic, eco-friendly approach aimed at minimizing the use of chemical pesticides by combining biological, cultural, and mechanical control methods with judicious pesticide use.

Within this framework, biopesticides—which include microbial agents like bacteria and fungi, botanical extracts, and biochemical compounds—have gained prominence for their selectivity, environmental safety, and biodegradability (Kumar, Singh, and Singh, 2009). These naturally occurring agents not only reduce the environmental load of toxic chemicals but also help maintain ecological balance by targeting specific pests. By 2012, India had registered over 180 biopesticide formulations, with *Bacillus thuringiensis*, *Trichoderma spp.*, and neem-based products being the most commonly used (CIBRC, 2012).

As per the Central Insecticides Board and Registration Committee (CIBRC), biopesticides accounted for approximately 2.89 percent of the total pesticide consumption in India by volume in 2013–14. Though modest, this figure represents a growing acceptance of sustainable pest control methods in Indian agriculture. States like Sikkim, Andhra Pradesh, and Maharashtra have demonstrated considerable adoption of biopesticides in conjunction with IPM programs, supported by initiatives under the National Mission on Sustainable Agriculture (NMSA) and National Programme on Organic Farming (NPOF).

The increasing incidence of pesticide-related health issues and international market demand for residue-free produce have further pushed the adoption of biopesticides. With global awareness on sustainable agriculture rising, biopesticides are being recognized as essential components in integrated strategies to combat pest outbreaks while safeguarding soil, water, and biodiversity (FAO, 2013).

Given this backdrop, the present review aims to critically evaluate the utilization of biopesticides within IPM in the Indian context, focusing on historical trends, field-based efficacy, policy support, and future directions for sustainable agricultural development.

2. Objectives of the Study

The primary objective of this review is to critically examine the role and utilization of biopesticides in Integrated Pest Management (IPM) systems within the Indian agricultural context. Specific goals include:

- To analyze historical and current trends in biopesticide adoption across Indian states.
- To assess the efficacy of biopesticides through published field studies and case examples.
- To evaluate the existing policy, regulatory, and institutional frameworks supporting biopesticide use.

3. Methodology

This study employs a scientific review-based methodology relying exclusively on secondary data sources to analyze the utilization of biopesticides within Integrated Pest Management (IPM) in India. The data was collected from a diverse range of published literature, research journals, government reports (e.g., Ministry of Agriculture and Farmers Welfare, Central Insecticides Board and Registration Committee), international agency publications (e.g., FAO), and institutional studies from ICAR, ICRISAT, and NABARD.

Documents were selected based on their relevance to IPM practices, field-level efficacy of biopesticides, regulatory updates, and statistical reporting of biopesticide usage. Emphasis was placed on quantitative data such as consumption trends, number of registered biopesticide formulations, and state-wise adoption statistics. A thematic synthesis approach was applied to interpret trends, and policy perspectives ensuring the inclusion of authentic and diverse viewpoints in the Indian agricultural context.

4. Overview of Integrated Pest Management (IPM) in India

Integrated Pest Management (IPM) is a science-based, environmentally sensitive approach to pest control that integrates multiple practices to suppress pest populations below economically damaging levels. In India, the concept of IPM gained prominence in the early 1990s as an official response to the adverse impacts of intensive pesticide use during the post-Green Revolution era (Kumar and Mishra, 2012). The Government of India formally adopted IPM as a national policy under the National IPM Programme launched in 1992, focusing on minimizing pesticide reliance through the judicious use of biological and cultural control methods alongside limited chemical interventions (Yadav and Devi, 2012).

The implementation of IPM in India is led by the Directorate of Plant Protection, Quarantine and Storage (DPPQ&S), which coordinates 35 Central IPM Centres across the country. These centres conduct Farmers'

Field Schools (FFSs) aimed at building capacity among farmers in pest identification, field scouting, ecological pest control, and safe use of biopesticides. By 2012, over 200,000 farmers had been trained under these programs (DPPQ&S, 2013). Additionally, IPM strategies have been incorporated into national agricultural initiatives such as the National Food Security Mission (NFSM) and National Horticulture Mission (NHM) to promote sustainable productivity.

IPM adoption varies significantly across states and crops. For instance, in Andhra Pradesh and Tamil Nadu, IPM practices in rice and cotton have shown substantial reductions in pesticide use, with trials reporting 40–60 percent decrease in chemical pesticide application while maintaining or improving yields (Reddy et al., 2011). In vegetables such as cauliflower and cabbage, IPM-based programs have demonstrated pest incidence reduction by 30–50 percent and increased marketable produce due to lower residue levels (Gupta and Birah, 2010).

Despite its proven potential, widespread adoption of IPM remains constrained by factors such as limited awareness, lack of trained personnel, and weak linkages between research and field-level implementation. Still, several success models—such as IPM in Basmati rice in Punjab and organic IPM practices in Sikkim—indicate the approach's adaptability across different agro-climatic zones.

IPM continues to evolve as an integral part of India’s strategy for sustainable agriculture, with growing emphasis on ecological pest management, increased use of biological inputs like biopesticides, and the alignment of pest control with environmental conservation (FAO, 2013).

5. Biopesticides: Classification and Mode of Action

Biopesticides are naturally derived pest control agents that utilize living organisms or natural substances to suppress pest populations. They offer species-specific action, low toxicity to non-target organisms, and environmental compatibility, making them integral to sustainable pest management systems like IPM (Kumar et al., 2009). In India, biopesticides are broadly classified into three main categories: microbial, botanical, and biochemical biopesticides.

Microbial biopesticides, the most widely used in India, include bacteria (*Bacillus thuringiensis*), fungi (*Trichoderma harzianum*, *Beauveria bassiana*), and viruses (NPVs) that infect and kill specific insect pests or plant pathogens (Yadav and Devi, 2012). *B. thuringiensis* (Bt) produces crystal proteins toxic to lepidopteran larvae, making it effective in crops like cotton and cabbage. *Trichoderma spp.*is extensively used for suppressing soil-borne pathogens in crops such as pulses and vegetables.

Botanical biopesticides are plant-derived compounds, notably neem-based formulations containing azadirachtin, which acts as an antifeedant, repellent, and growth regulator for a wide range of pests. Neem products constitute over 65 percent of the Indian biopesticide market as of 2012 (CIBRC, 2012). These are particularly popular due to their ease of integration with existing IPM strategies and proven safety to humans and pollinators.

Biochemical biopesticides include insect pheromones and plant growth regulators that interfere with insect mating behaviour or physiological development. Though still limited in commercial use, pheromone traps have shown significant results in managing pests like *Helicoverpa armigera* and *Spodoptera litura* in cotton and vegetables (Gupta and Birah, 2010).

Table 1: Common Biopesticide Types and Target Pests in India

Category	Example Organism/Compound	Target Pests/Crops	Mode of Action
Microbial	*Bacillus thuringiensis*	Lepidopteran larvae (cotton)	Gut toxin, larval death
	Trichoderma harzianum	Soil-borne fungi	Mycoparasitism, antibiosis

		(vegetables)	
Botanical	Azadirachtin (from neem)	Aphids, whiteflies, bollworms	Antifeedant, growth disruption
Biochemical	Synthetic pheromones	*Helicoverpa*, *Spodoptera*	Mating disruption via lures

Source: Compiled from Gupta and Birah (2010); CIBRC (2012)

6. Status and Trends of Biopesticide Usage in India

The use of biopesticides in India has gained momentum over the past two decades, particularly with the growing emphasis on sustainable and eco-friendly agricultural practices. Though still representing a small share of the total pesticide market, the trend indicates a consistent rise in both demand and application across various crop sectors and regions.

As per data from the Central Insecticides Board and Registration Committee (CIBRC), biopesticides constituted approximately 2.89 percent of the total pesticide consumption in India by volume in 2013–14 (CIBRC, 2014). The cumulative number of registered biopesticide products reached around 970 formulations by 2014, reflecting increased interest among producers and policymakers alike (MoA, 2014).

Neem-based botanical biopesticides dominate the Indian market, comprising over 65 percent of biopesticide usage, followed by microbial agents like *Trichoderma spp.* and *Bacillus thuringiensis* (Gupta and Birah, 2010). Notably, the use of *Trichoderma* formulations has increased in crops such as pulses, rice, and vegetables in states like Karnataka, Maharashtra, and West Bengal due to their effectiveness in managing soil-borne diseases (Yadav and Devi, 2012).

Table 2: State-wise Trends in Biopesticide Consumption (2013–14)

State	Dominant Crops	Biopesticide Use (MT)	Notable Agents Used
Andhra Pradesh	Cotton, Chillies	320	Neem oil, *Trichoderma*, Bt
Maharashtra	Cotton, Soybean	275	*Trichoderma*, *Beauveria*, Neem
Tamil Nadu	Rice, Vegetables	240	*Pseudomonas fluorescens*, Neem extracts
West Bengal	Paddy, Vegetables	190	*Trichoderma*, Neem, Bt
Sikkim	Organic crops	75	Neem, *Beauveria*, biocontrol fungi

Source: Gupta and Birah (2010); CIBRC (2014); MoA (2014)

Government programs such as the National Mission on Sustainable Agriculture (NMSA) and Paramparagat Krishi Vikas Yojana (PKVY) have further propelled the adoption of biopesticides, especially in organically inclined states like Sikkim and Uttarakhand. The gradual shift in consumer preference toward pesticide-free food has also enhanced market incentives for biopesticide-based cultivation (FAO, 2013).

Despite a promising trend, biopesticide adoption remains relatively modest in terms of overall pesticide use, indicating a need for stronger regulatory support, enhanced farmer training, and infrastructure for quality production and distribution.

7. Role of Biopesticides in Major Cropping Systems in India

Biopesticides have played an increasingly significant role in India's major cropping systems, particularly in crops with high pest pressure and where residue-free produce is in demand. Their integration into crop-specific pest management programs has led to notable reductions in chemical pesticide usage while sustaining or improving yield levels (Kumar et al., 2009).

In cotton, one of the most pesticide-intensive crops, the adoption of *Bacillus thuringiensis* (Bt)-based biopesticides and pheromone traps has resulted in 40–60 percent reduction in chemical sprays against bollworms and leaf-eating caterpillars (Reddy et al., 2011). States like Maharashtra, Andhra Pradesh, and Gujarat have reported significant farmer-level adoption, especially when supported by IPM demonstration programs.

In rice, biopesticides such as *Trichoderma harzianum*, *Pseudomonas fluorescens*, and neem-based formulations are commonly used to manage stem borer, leaf folder, and sheath blight. Integrated trials in Tamil Nadu and West Bengal indicated that biopesticide-treated plots had 18–25 percent lower pest incidence and marginally higher grain yields compared to conventional fields (Gupta and Birah, 2010).

In horticultural crops like tomato, brinjal, and okra, *Beauveria bassiana*, *Verticillium lecanii*, and neem extracts have proven effective in controlling whiteflies, aphids, and fruit borers. Karnataka and Madhya Pradesh have been active in promoting biopesticide kits through horticulture departments. Field results showed 35–50 percent Pest reduction and enhanced shelf life of harvested produce (CIBRC, 2012).

In organic cropping systems, especially in states like Sikkim, Kerala, and Uttarakhand, biopesticides are the primary means of pest control. The government of Sikkim, for example, distributed over 20 metric tonnes of biopesticide formulations annually under its Organic Mission by 2013 (MoA, 2014).

The role of biopesticides in pulse crops is also expanding, with *Trichoderma spp.* and *Metarhizium anisopliae* being used against wilt and pod borer. ICAR trials showed a yield increase of 12–15 percent with combined seed treatment and foliar spray applications (Yadav and Devi, 2012).

These crop-specific integrations of biopesticides demonstrate not only their efficacy but also their adaptability to India's diverse agro-ecological conditions. Continued support through training and input subsidies can scale their usage further across cropping systems.

8. Regulatory Framework and Policy Support in India

The regulatory and policy environment for biopesticides in India is gradually evolving to accommodate the increasing demand for sustainable agriculture and safe pest management solutions. The Central Insecticides Board and Registration Committee (CIBRC) under the Insecticides Act, 1968 is the apex body responsible for the regulation, registration, and quality control of all pesticides, including biopesticides (CIBRC, 2012).

As of 2014, 970 biopesticide formulations were registered for use in India, covering major microbial agents like *Trichoderma spp.*, *Pseudomonas fluorescens*, *Bacillus thuringiensis*, and neem-based botanical products (MoA, 2014). Despite this growth, the approval process for new biopesticide products often remained time-consuming and heavily modelled on the chemical pesticide registration format, lacking a distinct evaluation pathway for biological agents (Kumar et al., 2009).

To encourage biopesticide development and adoption, several policy initiatives were launched. The National Mission on Sustainable Agriculture (NMSA), a sub-mission of the National Action Plan on Climate Change (NAPCC), emphasized integrated pest management and organic farming, advocating for biopesticide use. Under NMSA, states were allocated budgetary support for biocontrol labs and training programs (MoEF, 2012).

Moreover, the Rashtriya Krishi Vikas Yojana (RKVY) and Paramparagat Krishi Vikas Yojana (PKVY) provided funding for infrastructure to produce and distribute biopesticides at the grassroots. By 2013, over 300 biocontrol laboratories, including 35 state-run and ICAR-supported facilities, were operational for mass production of biopesticides across India (ICAR, 2013).

India is also a signatory to the Rotterdam Convention, which mandates informed consent procedures for hazardous chemical trade, indirectly encouraging biopesticide alternatives. However, the lack of a dedicated biopesticide policy, absence of a separate regulatory authority, and limited awareness among field officers continue to hinder faster growth and field-level adoption (Gupta and Birah, 2010).

In summary, while the regulatory framework has facilitated a growing list of biopesticide registrations and field initiatives, substantial policy reform is needed. A simplified and science-based registration protocol, coupled with long-term public investment and stakeholder training, would further strengthen the role of biopesticides in Indian agriculture.

Conclusion

The utilization of biopesticides within India's Integrated Pest Management (IPM) framework represents a critical shift toward sustainable, eco-friendly agriculture. Drawing on a range of microbial, botanical, and biochemical agents, biopesticides offer an effective alternative to chemical pesticides, with considerable potential to reduce environmental pollution, prevent pest resistance, and ensure food safety (Gupta and Birah, 2010). The growing body of evidence — including successful applications in cotton, rice, pulses, and horticultural crops — underscores their adaptability to diverse agro-climatic zones and pest complexes.

Although the overall share of biopesticides remains modest, accounting for just under 3 percentof total pesticide consumption by 2013–14 (CIBRC, 2014), their upward trend is reinforced by government initiatives such as the National Mission on Sustainable Agriculture, PKVY, and the expansion of biocontrol laboratories. Farmer-friendly policies, coupled with rising consumer demand for organic produce, have further catalysed adoption, especially in states practicing organic or low-chemical farming like Sikkim and Kerala.

However, structural, and institutional barriers persist — from complex registration procedures and limited commercial outreach to inconsistent quality control and lack of awareness among smallholder farmers. Addressing these constraints through streamlined regulatory reforms, dedicated biopesticide policies, and inclusive capacity-building programs is imperative.

To mainstream biopesticides as a core component of IPM in India, future strategies must integrate scientific innovation with farmer-centric extension services and policy coherence. Only through such multidimensional efforts can India move closer to a resilient and ecologically balanced agricultural system that ensures both productivity and sustainability.

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