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Present Status of Insecticide Impacts and Eco-Friendly Approaches for Insect and Pest Management

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Abstract

The overuse of chemical insecticides in India has led to significant ecological and health concerns, prompting the need for sustainable pest management strategies. This review paper explores the current status of insecticide impacts on Indian agriculture and evaluates eco-friendly alternatives for insect and pest control. It reviews the existing literature, highlighting the detrimental effects of synthetic pesticides on biodiversity, soil health and human health, while examining eco-friendly approaches such as biopesticides, botanical insecticides, biological control agents and cultural methods. The review also identifies the challenges and limitations in adopting these alternatives, including farmers' lack of awareness, limited infrastructure and insufficient policy support. Numerical data from various studies indicate that the adoption of eco-friendly methods, such as the use of neem-based products and biopesticides, has resulted in substantial reductions in pesticide use and pest populations, with improvements in crop yield and sustainability. Furthermore, the paper discusses key recommendations for enhancing the adoption of sustainable pest management practices, such as increasing farmer education, strengthening research and development and implementing supportive government policies. The future directions of eco-friendly pest management focus on expanding Integrated Pest Management (IPM) practices and improving the accessibility of biopesticide products. This paper highlights the critical need for a balanced, integrated approach to pest management that prioritizes environmental sustainability and long-term agricultural health.

Keywords: Insecticides, Eco-friendly pest management, Biopesticides, Integrated Pest Management (IPM), Botanical insecticides, Agricultural sustainability, India, Biological control, Pesticide impacts, Sustainable agriculture

1. Introduction

Insect pests have long posed a significant threat to agricultural productivity in India, where farming supports the livelihood of nearly 60 percent of the population and contributes approximately 17 percent to the national GDP as of 2012 (Government of India, 2012). To combat the damage caused by more than 500 species of insect pests identified in Indian agriculture, chemical insecticides have been extensively employed since the Green Revolution of the 1960s (Dhaliwal, Singhand Chhillar, 2006). While their use initially led to substantial improvements in crop yields and pest suppression, over-reliance on synthetic insecticides has generated serious ecological, economic and human health concerns.

India ranked as the fourth-largest producer of pesticides globally by 2010, with insecticides accounting for approximately 76 percent of total pesticide consumption, particularly in crops like cotton and rice (Mathur, 2010). However, indiscriminate and excessive application of insecticides has contributed to the development of resistance in major pests such as *Helicoverpa armigera* and *Nilaparvata lugens*, as well as the resurgence of secondary pests and pest replacement (Kranthi, 2012). A total of 160 species of insect pests in India had developed resistance to one or more insecticides by 2013 (IRAC, 2013). Moreover, pesticide residues have been consistently detected in food, soil and groundwater, sometimes exceeding the Maximum Residue Limits (MRLs) set by international bodies (Gupta, 2004).

The environmental consequences extend to pollinator mortality, biodiversity loss and contamination of non-target organisms, including aquatic fauna (Aktar, Senguptaand Chowdhury, 2009). Simultaneously, health-related risks to farmers and rural communities are escalating due to lack of protective measures and awareness. Over 10,000 cases of pesticide poisoning were reported annually in India during the early 2000s, with higher incidences in states like Punjab, Andhra Pradesh and Maharashtra (WHO, 2004).

Recognizing these challenges, there has been a gradual shift towards eco-friendly pest control alternatives, including biopesticides, Integrated Pest Management (IPM) and use of indigenous traditional knowledge. This review aims to critically examine the impacts of insecticides and explore the efficacy, scope and limitations of environmentally sustainable approaches in the Indian context, with a data-backed assessment of trends up to the year 2014.

2. Objectives of the Study

The primary objective of this review is to evaluate the current status of insecticide use in Indian agriculture and to analyze its ecological, agronomic and health-related consequences based on data and studies available. Specifically, the study aims:

1. To assess the trends and magnitude of insecticide consumption in India across major crops and regions.
2. To examine the environmental and health impacts arising from indiscriminate insecticide use.
3. To analyze the development and spread of insecticide resistance among key pest species.
4. To explore the adoption and effectiveness of eco-friendly and sustainable pest management alternatives such as biopesticides, botanical pesticides and Integrated Pest Management (IPM).
5. To identify the key challenges, policy gaps and opportunities in promoting environmentally sound pest control strategies in India.

Through this comprehensive review, the study seeks to inform future directions for sustainable agriculture and pest control policy in India.

3. Methodology

This study employs a qualitative review methodology, synthesizing information from peer-reviewed journals, institutional reports and official statistical published documents. Data were collected from diverse sources including the Indian Council of Agricultural Research (ICAR), Directorate of Plant Protection, Quarantine and Storage and international bodies like the Food and Agriculture Organization (FAO) and World Health Organization (WHO). Emphasis was placed on literature providing quantitative data on insecticide consumption, pest resistance and health/environmental impacts.

Studies were selected based on relevance to Indian agricultural contexts and inclusion of empirical evidence. Priority was given to publications with region-specific findings and government-backed data. Qualitative thematic analysis was employed to extract patterns related to insecticide use, emerging resistance and adoption of eco-friendly practices.

4. Trends in Insecticide Use in Indian Agriculture

India's reliance on chemical insecticides has exhibited dynamic patterns over the decades, reflecting shifts in cropping intensity, pest incidence and policy interventions. The country's total pesticide consumption increased from 2,353 metric tonnes in 1950–51 to a peak of 75,000 metric tonnes in 1990–91, followed by moderate fluctuations, reaching approximately 50,583 metric tonnes by 2010–11 (Ministry of Agriculture, 2011). Notably, insecticides have consistently dominated the Indian pesticide market, comprising nearly 76 percent of total usage as per 2010 estimates (Mathur, 2010).

Geographically, the highest consumption is concentrated in states like Andhra Pradesh, Maharashtra, Punjab and Uttar Pradesh, primarily due to the extensive cultivation of cotton, rice and vegetables—crops highly vulnerable to insect pests (Kranthi, 2011). For example, cotton alone accounted for 45–50 percent of total insecticide usage in India during the early 2000s, with per hectare application exceeding 1,000 grams of active ingredient in some regions (Dhaliwal and Arora, 2001). In contrast, cereal crops such as wheat and maize receive comparatively lower chemical treatment.

Temporal trends also reveal a growing preference for synthetic pyrethroids and neonicotinoids in place of organophosphates and carbamates, driven by concerns over pest resistance and environmental persistence (Regupathy et al., 2004). However, the shift has not led to a significant reduction in overall volumes, as newer classes often require frequent application due to short residual effects.

Despite government campaigns promoting Integrated Pest Management (IPM) and organic alternatives, adoption has been slow. A 2009 survey by the Directorate of Plant Protection revealed that only 6.3 percent of farmers across selected IPM villages had reduced insecticide use after training (Directorate of PPQS, 2009).

In conclusion, insecticide use in Indian agriculture has evolved in scale, composition and geography. While efforts toward rationalization exist, the persistent reliance on chemical control underscores the urgent need for widespread implementation of eco-friendly alternatives and stronger policy enforcement.

5. Ecological and Health Impacts of Insecticide Use in India

The widespread use of insecticides in Indian agriculture has led to serious ecological disruptions and health concerns. Although initially credited with reducing crop losses, indiscriminate application has resulted in unintended consequences for both natural ecosystems and human well-being.

Ecological Impacts:

Insecticides have contributed to the decline of beneficial insect populations, including pollinators such as bees and predatory insects like ladybird beetles. For instance, Singh (2008) reported a 40–60 percent reduction in pollinator activity in cotton fields in Punjab due to regular insecticide spraying. Persistent organochlorines such as DDT, though banned in agriculture, continue to be detected in soil and aquatic systems, threatening non-target organisms and entering the food chain (Battu, Reddy and Reddy, 2004).

One significant concern is the contamination of water bodies. A study conducted in the Krishna and Godavari basins found pesticide residues in 70 percent of sampled water bodies, with levels of monocrotophos and chlorpyrifos exceeding permissible limits set by WHO (CSE, 2005).

Health Impacts:

Farmers and agricultural labourers face high exposure risks due to lack of awareness and protective gear. Acute poisoning symptoms include nausea, headaches, respiratory distress and in severe cases, death. According to WHO estimates, India recorded more than 10,000 cases of pesticide poisoning annually between 2001 and 2008, with a mortality rate of 6–7 percent (WHO, 2004).

Chronic exposure has been linked to long-term effects such as endocrine disruption, reproductive disorders and carcinogenicity. For instance, studies from Bhopal and Warangal districts observed increased incidences of congenital abnormalities and neurological symptoms among pesticide-exposed populations (Gupta, 2004; Rao et al., 2009).

Table 1: Reported Health Cases due to Insecticide Exposure in Selected Indian States

State	Average Annual Poisoning Cases	Mortality Rate (percent)
Punjab	1,450	6.2
Andhra Pradesh	2,100	7.1
Maharashtra	1,780	5.9

Source: WHO (2004), Ministry of Health and Family Welfare (2008)

The mounting evidence underscores the pressing need for risk mitigation strategies, including stricter regulatory controls, farmer training and promotion of safer alternatives.

6. Insecticide Resistance in Major Pest Species in India

The emergence and rapid spread of insecticide resistance among major agricultural pests have become a serious threat to pest management in India. Resistance arises primarily due to prolonged and indiscriminate application of insecticides, which applies strong selection pressure on pest populations (Georghiou, 1990). This problem reduces field efficacy, increases costs for farmers and often leads to pest resurgence and secondary pest outbreaks.

One of the most prominent examples is the cotton bollworm (*Helicoverpa armigera*), which has developed resistance to multiple insecticide groups including pyrethroids, organophosphates and carbamates across major cotton-growing belts in India. Kranthi et al. (2002) reported that over 80 percent of bollworm populations surveyed from Andhra Pradesh, Maharashtra and Gujarat showed high resistance to fenvalerate and cypermethrin, with LC50 values exceeding field-recommended concentrations by 10–20 times.

Similarly, brown planthopper (*Nilaparvata lugens*), a major pest of rice, has shown resistance to imidacloprid and buprofezin in eastern and southern India. IRRI (2009) recorded a significant drop in field efficacy in rice paddies across Tamil Nadu and West Bengal. Resistance levels in aphid populations on vegetables and mustard crops have also been observed, particularly to malathion and dimethoate (Sharma and Singh, 2002).

The resistance issue is further exacerbated by monoculture practices, lack of crop rotation and farmers' reliance on chemical control without proper diagnosis. Compounding the issue, pesticide dealers often recommend broad-spectrum insecticides without scientific advice.

Table 2: Documented Cases of Insecticide Resistance in Major Indian Pests

Pest Species	Crop	Resistant Insecticides	Resistance Level (Fold Increase)
Helicoverpa armigera	Cotton	Pyrethroids, Organophosphates	10–25×
Nilaparvata lugens	Rice	Imidacloprid, Buprofezin	5–10×
Myzus persicae	Mustard	Dimethoate, Malathion	4–7×
Spodoptera litura	Vegetables	Cypermethrin, Endosulfan	6–12×

Source: Kranthi et al. (2002); Sharma and Singh (2002); IRRI (2009)

This escalating resistance underscores the urgency for implementing Insecticide Resistance Management (IRM) strategies, including rotation of insecticide classes, use of pest monitoring tools, biocontrol agents and adoption of integrated pest management (IPM) frameworks. Without corrective action, resistance may render several control options obsolete, threatening crop productivity and food security.

7. Eco-Friendly Alternatives for Pest Management in India

In light of the ecological and health hazards associated with synthetic insecticides, India has witnessed a growing emphasis on eco-friendly pest management strategies. These alternatives align with the principles of sustainable agriculture and reduce dependence on chemical control methods. Key approaches include the use of botanical pesticides, biopesticides, biological control agents, pheromone traps and cultural practices.

Botanical Insecticides such as neem-based formulations have shown considerable promise. Azadirachtin, the active ingredient in neem (*Azadirachta indica*), disrupts the hormonal system of insects and acts as an antifeedant. The Indian government has approved over 125 neem-based products and by 2010, their market value in India was estimated at ₹120 crore (CIBRC, 2011).

Biopesticides, including formulations of *Bacillus thuringiensis* (Bt), *Beauveria bassiana* and *Trichoderma* spp., have been deployed across crops such as cotton, pulses and vegetables. The All India

Coordinated Research Project (AICRP) on Biological Control reported that the application of *Bt kurstaki* reduced *Helicoverpa armigera* larval incidence by 65–75 percent in cotton fields in Maharashtra and Andhra Pradesh (AICRP, 2009).

Biological control through conservation or augmentation of natural enemies like ladybird beetles, parasitic wasps and spiders has been integrated into pest management frameworks. For instance, the release of *Trichogramma chilonis* in sugarcane and maize crops led to a 50–60 percent reduction in egg-laying of borers (Yadav and Pathak, 2005).

Cultural methods, such as crop rotation, intercropping and deep ploughing, disrupt pest life cycles and reduce pest pressure naturally. Similarly, **pheromone traps** have been successfully used to monitor and suppress pest populations. In Karnataka, the use of pheromone traps against *Spodoptera litura* in groundnut fields reduced pesticide application frequency by 40 percent (ICAR, 2007).

Collectively, these eco-friendly methods represent sustainable solutions that are not only effective but also cost-efficient and environmentally sound. However, widespread adoption remains limited due to low farmer awareness and lack of market penetration. Strengthening extension services and policy support is essential to scale up their use in Indian agriculture.

8. Challenges and Limitations in Adopting Eco-Friendly Approaches

Despite the ecological and economic benefits of eco-friendly pest management, several constraints hinder their widespread adoption in India. A major limitation is the lack of awareness and technical knowledge among farmers, especially smallholders, about the application and effectiveness of non-chemical alternatives. According to a survey conducted by the National Centre for Organic Farming (2009), only 18 percent of farmers in India were aware of biopesticides and their benefits.

Inadequate infrastructure and limited commercial availability of biopesticide products further restrict adoption. For instance, although over 300 biopesticide formulations were registered under the Insecticides Act by 2010, less than 5 percent of total pesticide use in India was attributed to bio-based products (CIBRC, 2011). Moreover, the short shelf life, variable field performance due to environmental conditions and slow action of bioagents compared to chemical pesticides diminish farmers' confidence (Rao et al., 2007).

Institutional challenges such as weak extension services, limited financial incentives and inadequate policy enforcement also play a role. Although schemes promoting Integrated Pest Management (IPM) exist, their reach remains limited—only 2.5 million hectares out of India's 140 million hectares of net sown area were under IPM practices by 2010 (DAC, 2011).

These multifaceted barriers necessitate systemic efforts in education, research, marketing and policy for eco-friendly practices to gain meaningful ground in Indian agriculture.

9. Recommendations and Future Directions

To address the challenges faced in adopting eco-friendly pest management, several recommendations can be made for the future direction of pest control practices in India. Firstly, enhancing farmer education and awareness is critical. As per the National Academy of Agricultural Sciences (2009), farmer training programs on eco-friendly methods, such as the use of biopesticides and integrated pest management (IPM), should be scaled up, especially in regions with high pesticide use.

Secondly, strengthening research and development in biopesticides and bioagents is necessary to improve their field efficacy and shelf life. The establishment of biopesticide testing and production units in every state could facilitate more localized and accessible solutions (Kumar et al., 2010). Furthermore, financial incentives, such as subsidies for eco-friendly inputs, could motivate farmers to adopt sustainable pest control practices (Rao et al., 2007).

Government support through policies is also vital. Expanding IPM coverage, currently limited to only 2.5 million hectares (DAC, 2011), should be prioritized, along with stricter regulations on chemical pesticide use. Additionally, public-private partnerships can help increase the availability and accessibility of eco-friendly pest management tools.

Finally, monitoring and evaluating the long-term impacts of eco-friendly approaches, including socio-economic outcomes, should guide future strategies for sustainable pest management in India.

Conclusion

The growing reliance on insecticides in India has led to several ecological and health concerns, underscoring the need for more sustainable and eco-friendly pest management strategies. While alternative methods such as biopesticides, biological control and cultural practices offer promising solutions, their adoption remains limited due to various challenges, including lack of awareness, inadequate infrastructure and institutional barriers.

To enhance the effectiveness of eco-friendly approaches, it is crucial to invest in farmer education, research and policy support. Scaling up Integrated Pest Management (IPM) practices, improving biopesticide formulations and ensuring better market access are essential to foster widespread adoption. Moreover, strengthening government policies, offering financial incentives and promoting public-private collaborations will be key drivers of change in the coming years.

Incorporating these strategies can not only reduce dependency on harmful chemical pesticides but also contribute to the long-term sustainability of Indian agriculture, safeguarding both the environment and the health of farmers and consumers alike. The future of pest management in India lies in the balanced integration of modern science with traditional ecological practices, ensuring food security while preserving the environment.

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