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Sustainable Management of Insect Pests of Crops and Productive Insects

A.K. Dhawan, S.V.S. Gopala Swamy[1]*, G.V. Suneel Kumar[1] and C. Kathirvelu[2]

Indian Ecological Society, PAU Ludhiana-141 004, India
[1]Acharya N.G. Ranga Agricultural, University, Guntur, Lam-522 034, India
[2]Department of Entomology, Annamalai University-608 002, India
**E-mail: svs.gopalaswamy@angrau.ac.in*

Insect pests remain among the most pervasive constraints to agricultural productivity and ecological stability in India, where diverse cropping systems from rice–wheat plains of the Indo-Gangetic belt to pulse, cotton, and horticultural landscapes support the livelihood of millions. In an era of climate variability, warming trends, and altered monsoon patterns, insect pest dynamics have become increasingly unpredictable, with expanded geographic ranges, extended breeding seasons, and frequent outbreak cycles reported across major crops such as rice (e.g., brown planthopper), cotton (e.g., bollworms), pulses (e.g., pod borers), and vegetables (e.g., fruit borers and sap feeders) (Oerke, 2006; Vishal et al., 2025). These pest pressures translate into yield losses that markedly undermine food and nutritional security, equitable growth, and rural resilience (Deutsch et al., 2018).

In India, the ecological and socio-economic implications of insect pest damage are profound. Rice yield losses attributed to stem borers and planthoppers often exceed 10–15 %, cotton losses to bollworm complexes may reach 20–30 % in susceptible cultivars and pod borer infestations have significantly limited pulse productivity, compounding the nation's pulse deficit (Dhaliwal et al., 2010). Moreover, indiscriminate pesticide use has exacerbated secondary pest outbreaks, escalated resistance in target pests and threatened productive insects such as pollinators and silkworms, which are vital components of India's agricultural biodiversity and rural economies (Ndakidemi et al., 2016).

Ensuring food and nutritional security for a rapidly growing population under such conditions demands a fundamental transition from reactive, input-intensive pest control strategies to ecologically informed, sustainable pest management frameworks. Integrated Pest Management (IPM), rooted in ecological principles and systems thinking has emerged as the backbone of sustainable insect pest management in India. Nevertheless, the emergence of invasive pests, rapid development of insecticide resistance, loss of natural enemies and heightened vulnerability of productive insects have exposed the limitations of conventional approaches and highlighted the need for renewed scientific innovation and policy support.

In response to these imperatives, the Indian Ecological Society (IES), Ludhiana initiated this Special Issue of the *Indian Journal of Ecology* on **"Sustainable Management of Insect Pests of Crops and Productive Insects."** The manuscripts compiled in this special issue exemplify the advanced research, practical innovations, interdisciplinary integration and applied relevance required to address the converging ecological, climatic and socio-economic challenges of contemporary insect pest management. Collectively, these contributions reposition insect pest management within a broader ecological and sustainability discourse emphasizing long-term resilience over short-term control.

Reframing Pest Management: From Control to Ecological Regulation

Modern insect pest management must transcend the narrow objective of pest suppression and instead embrace the ecological regulation of pest populations. Agro-ecosystems are complex, dynamic systems in which pests, natural enemies, host plants and environmental drivers interact across spatial and temporal scales. Disruptions to these interactions often caused by indiscriminate pesticide use across rice, wheat, pulses, cotton, sugarcane and horticultural crops have led to pest resurgence, secondary pest outbreaks and the collapse of natural biological control mechanisms (Pimentel and Burgess, 2014).

The research presented in this special issue reinforces the centrality of ecologically based IPM, emphasizing the integration of cultural practices, habitat manipulation, biological control, host plant resistance, and judicious use of chemical inputs. Several studies demonstrate that cropping system diversification, optimized planting schedules, and conservation of non-crop habitats enhance natural enemy abundance and contribute to effective suppression of pest populations. These approaches promote ecological

manipulation, farmer participatory learning, and crop- and region-specific IPM modules. Collectively, these findings reaffirm that sustainable pest management is not a standalone intervention but an emergent outcome of well-managed and ecologically balanced agro-ecosystems (Altieri and Nicholls, 2017). Contributions in this issue demonstrate the importance of pest forecasting, phenology-based interventions and climate-responsive IPM modules that anticipate pest pressure rather than merely reacting to damage.

Insect Biosystematics, Bioecology and Emerging Pest Scenarios

Accurate insect biosystematics and sound understanding of pest bioecology form the foundation of effective and sustainable pest management strategies. The manuscripts included under this section underscore the critical role of taxonomy, distributional records, and population ecology in responding to emerging and re-emerging pest threats in Indian agro-ecosystems. Contributions dealing with the taxonomic description and diagnostic differentiation of *Spodoptera frugiperda* and *S. litura*, along with detailed accounts on the predominance, seasonal dynamics, and demographic traits of fall armyworm across diverse agro-climatic regions, provide essential baseline information for surveillance, forecasting, and timely management interventions. Similarly, new pest records and studies on population ecology highlight the dynamic nature of pest assemblages under changing cropping patterns and climate variability.

The insect fauna associated with crop ecosystems further emphasize the importance of regional pest inventories for developing location-specific IPM modules. Inclusion of studies on Indian Odonata and ecosystem engineering broadens the ecological perspective of this section by drawing attention to beneficial insect diversity, trophic regulation, and ecosystem services beyond crop protection alone. These contributions reaffirm that robust pest diagnostics, continuous monitoring, and ecological understanding are indispensable for managing invasive pests, anticipating pest outbreaks, and designing resilient, ecosystem-based pest management strategies in Indian agriculture (Day et al., 2017; Prasanna et al., 2018).

Biological Control and Conservation of Beneficial Insects

Biological control constitutes one of the most ecologically sound and economically viable components of sustainable insect pest management. The manuscripts included under this section of the special issue provide substantial evidence on the role of predators, parasitoids, entomopathogens, and microbial agents, encompassing both classical and conservation biological control approaches. The studies collectively demonstrate that strengthening trophic interactions within agro-ecosystems contributes to stable and long-term suppression of insect pest populations, while simultaneously reducing dependence on chemical insecticides.

Considerable emphasis has been placed on the conservation of productive and beneficial insects, including pollinators such as honey bees and native bees, natural enemies, silkworms, and other economically important insects that play a crucial role in sustaining agricultural productivity and rural livelihoods. Pollinator decline has emerged as a global concern with direct implications for crop yields, ecosystem functioning, and nutritional security (Potts et al., 2016). The manuscripts highlight the adverse effects of pesticide exposure, habitat loss, and monoculture-based production systems on these beneficial organisms and propose ecologically compatible strategies such as habitat diversification, provision of floral resources, reduced-risk pesticide use and ecological engineering for their conservation. The collective findings reinforce the principle that conservation of beneficial insects is an integral component of sustainable pest management rather than a subsidiary objective.

Botanicals, Biopesticides, and Biorational Innovations

The shift towards sustainable pest management necessitates the adoption of safer and environmentally benign alternatives to conventional synthetic insecticides. Manuscripts presented under this section emphasize the growing importance of botanicals, microbial formulations, semi chemicals, and other biorational approaches for the management of key insect pests in major crops such as rice, maize, pulses, cotton and horticultural crops. These interventions are characterized by target specificity, biodegradability, reduced non-target effects, and compatibility with IPM programmes. Several studies document the efficacy of plant-derived compounds, microbial agents such as *Bacillus thuringiensis* and entomopathogenic fungi and pheromone-based techniques for monitoring and management of insect pests across diverse agro-ecological regions. Importantly, the research also addresses the issue of insecticide resistance indicating that diversification of pest management strategies through botanicals and biopesticides can contribute to resistance management and improve the long-term sustainability of pest control programmes (Sparks and Nauen, 2015).

Host Plant Resistance and Emerging Molecular Approaches

Host plant resistance represents one of the most sustainable, cost-effective and farmer-friendly strategies for

insect pest management. The contributions included under this section of the special issue address resistance mechanisms across major cropping systems, with studies focusing on resistant rice genotypes against gall midge, groundnut lines exhibiting enhanced tolerance to *Caryedon gonagra*, and cotton germplasm with improved resistance to sucking pests. Such resistance-based approaches play a crucial role in reducing pest pressure and minimizing reliance on external chemical inputs (Smith, 2005). Several manuscripts examine resistance-linked morphological, physico-chemical, and biochemical traits that influence pest preference, survival, and population buildup. Investigations on specific plant traits that contribute to resistance against insect pests, demonstrate the befitting role of host plant resistance in integrated pest management. These findings enhance the understanding of host–pest interactions and provide valuable trait-based information for incorporation into crop improvement programmes (Smith and Clement, 2012).

Advances in genomics, molecular breeding, and marker-assisted selection are also reflected in the contributions, highlighting their potential as transformative tools for the development of insect pest-resistant crop varieties. Modern breeding approaches facilitate precise identification and deployment of resistance genes, thereby accelerating the development of resilient cultivars adapted to diverse agro-ecological conditions (St Clair, 2010). In addition, manuscripts dealing with the molecular characterization of native *Bacillus thuringiensis* strains and the morphological and molecular identification of indigenous entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium rileyi*) complement host plant resistance by strengthening biological components of IPM, enhancing overall system robustness (Lacey et al., 2015). The studies under this section align closely with sustainability goals by improving yield stability under pest pressure, lowering production costs, and minimizing environmental risks. They emphasize the integration of host plant resistance with biological control, cultural practices, and other IPM components for sustainable insect pest management.

Technology, Decision Support and Precision Pest Management

Technological innovation is increasingly reshaping insect pest management by enhancing precision, timeliness and operational scale. The manuscripts included in this special issue highlight the application of unmanned aerial vehicles (UAVs) for pest management, demonstrating their potential in pest management. Such technologies contribute to reduced pesticide use, thereby minimizing unnecessary chemical inputs and associated environmental risks (Huang et al., 2013). However, as emphasized across the contributions, technological tools must function as enablers of ecologically sound pest management rather than as substitutes for ecological understanding. Precision pest management when aligned with IPM principles, emerging technologies such as UAVs and digital surveillance systems can support informed decision-making, reduce selection pressure for resistance, and strengthen the long-term sustainability of pest management strategies (Pedigo and Rice, 2014).

Governance, Policy and Farmer-Centric Approaches

Sustainable pest management is ultimately shaped not only by technological and biological innovations but also by enabling institutional frameworks, coherent policy support and meaningful farmer engagement. The collective evidence presented highlights the critical role of policy frameworks that encourage ecological pest management, rationalize pesticide use, and promote the development and deployment of biopesticides and other safer alternatives. Strengthening linkages among researchers, extension agencies, policymakers and farming communities remains essential for translating IPM principles into field-level impact, thereby ensuring that pest management interventions are productive, profitable and environmentally responsible (Pretty and Bharucha, 2015; van den Berg et al., 2020).

Way Forward

The collective insights from the manuscripts in this special issue demonstrate that sustainable management of insect pests and productive insects is both scientifically feasible and operationally achievable. However, realizing this potential requires a decisive shift from short-term, input-intensive control measures toward integrated, ecology-driven and climate-resilient pest management frameworks. As agriculture confronts escalating pressures from climate change, biodiversity loss and resource constraints, insect pest management must be reimagined as a central component of agro-ecosystem sustainability. The research compiled in this special issue provides robust evidence, practical innovations and conceptual clarity to guide this transition.

The Indian Ecological Society's initiative in curating this special issue reflects a commitment to advancing ecological science in service of sustainable agriculture. It is hoped that the knowledge synthesized herein will inform future research, shape policy discourse and support practitioners in building resilient, productive and environmentally responsible agricultural systems.

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