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Review on Entomological Contributions to IPM

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Abstract: *Entomology has played a foundational and transformative role in the conceptualization, development, and implementation of Integrated Pest Management (IPM) systems. This review critically examines the historical evolution and scientific contributions of entomologists to IPM, drawing exclusively from peer-reviewed literature published prior to 2023. It explores how entomological research shaped early concepts of integrated control, economic thresholds, and biological regulation of pest populations. The paper highlights key innovations—such as pheromone-based monitoring, biological control agents, insect growth regulators, and population modeling—and maps their adoption across agricultural systems globally. Through detailed case studies in cotton, rice, maize, soybean, and orchard crops, the review illustrates the practical successes and adaptability of entomology-driven IPM strategies. Despite demonstrable ecological and economic benefits, the paper also identifies persistent barriers, including institutional inertia, limited farmer training, market imbalances, and environmental variability. Looking ahead, it emphasizes the need for interdisciplinary integration, digital innovation, and policy support to address emerging challenges like climate change and pest resistance. The review concludes by reaffirming entomology's indispensable role in achieving sustainable, knowledge-intensive pest management in diverse agroecosystems.*

Keywords: Integrated Pest Management (IPM), Entomology, Biological Control, Sustainable Agriculture

I. INTRODUCTION

The concept of Integrated Pest Management (IPM) has evolved into a cornerstone of modern sustainable agriculture, synthesizing ecological principles with practical pest control strategies to reduce reliance on synthetic chemical pesticides. Initially proposed as a response to the ecological backlash and resistance crises arising from indiscriminate pesticide use during the post-World War II Green Revolution, IPM was envisioned as a holistic approach aimed at minimizing economic, health, and environmental risks associated with pest management (Kogan, 1998). Central to this vision is the indispensable role played by entomology, the scientific study of insects, which has shaped the theoretical framework, technological tools, and applied methodologies that define IPM today.

Entomological science laid the conceptual foundation of IPM. Early pioneers such as Van den Bosch and Stern (1962) introduced the idea of "integrated control," emphasizing the compatibility of chemical and biological control techniques. Their work initiated a paradigm shift away from single-tactic chemical interventions toward ecologically informed, multi-strategy approaches. These early contributions provided the philosophical underpinnings for what would become the formal IPM model, integrating population ecology, insect physiology, behavioral biology, and agroecosystem analysis.

Throughout the 20th century, entomologists were at the forefront of defining economic thresholds and economic injury levels, key concepts that determine when pest populations justify control measures (Pedigo & Higley, 1996). These principles enabled data-driven pest decision-making and helped prevent unnecessary pesticide applications, reducing ecological disruption and the selection pressure for resistance. Moreover, entomologists significantly advanced sampling techniques and forecasting models, which became critical components of pest surveillance systems and early warning mechanisms (Way & van Emden, 2000; Getz & Gutierrez, 1982).

One of the most profound contributions of entomology to IPM lies in the development and application of biological control strategies. Natural enemies, including predators, parasitoids, and pathogens, have been extensively researched, classified, and evaluated by entomologists. The economic and ecological value of these agents has been thoroughly demonstrated in managed systems (Naranjo & Ellsworth, 2015). Entomologists have also quantified the ecosystem

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services delivered by these organisms, helping policy-makers and practitioners internalize the benefits of biodiversity-based pest control (Gurr et al., 2004).

Entomological research has further broadened the scope of IPM by integrating insights from insect behavior and chemical ecology. The refinement of semiochemical-based technologies, such as pheromone traps, mating disruption, and attract-and-kill systems, are direct results of entomological studies (Witzgall et al., 2010). These methods have enabled highly selective pest targeting, reduced non-target effects, and opened new avenues for area-wide pest management (Hendrichs et al., 2007).

Entomologists have also contributed to the interdisciplinary expansion of IPM. For instance, research has highlighted the importance of plant-insect interactions, insect learning and memory (Little et al., 2019), and landscape-level pest management strategies (Barzman et al., 2015). This systems-based understanding of pest dynamics has strengthened collaborations across disciplines, integrating knowledge from ecology, agronomy, climatology, and plant pathology(Jacobsen, 1997).

Despite the technological and conceptual advances, challenges remain. Recent critiques emphasize the implementation gaps between research and field practice, especially in low-income settings and monoculture-dominated landscapes (Deguine et al., 2021). Moreover, entomologists continue to face evolving threats such as insecticide resistance, invasive pest species, and climate-induced changes in pest phenology and distribution (Guedes et al., 2016).

This review aims to comprehensively examine the historical evolution, scientific breakthroughs, and ongoing contributions of entomology to IPM. By synthesizing decades of research, it seeks to demonstrate how entomological science has transitioned from a reactive pest control mindset to a proactive, systems-based pest management approach. As agriculture continues to grapple with sustainability imperatives, climate resilience, and food security, the strategic insights offered by entomology remain more relevant than ever.

II. HISTORICAL EVOLUTION OF IPM AND THE ENTOMOLOGICAL FOUNDATION

The historical development of Integrated Pest Management (IPM) is deeply intertwined with the progression of entomological science. The emergence of IPM as a holistic and sustainable framework for pest control was, in large part, a response to the ecological and agronomic failures of pesticide-reliant systems, a response initially articulated and led by entomologists. This section traces the key phases in the evolution of IPM, highlighting the critical role entomology played in conceptualizing, implementing, and disseminating integrated pest strategies across global agriculture.

2.1 Early Pest Control and the Birth of Integrated Concepts

In the early 20th century, pest control in agriculture was largely chemical in nature, with synthetic pesticides such as DDT heralded as revolutionary tools after World War II. However, their indiscriminate use soon led to serious side effects, including pest resistance, secondary pest outbreaks, environmental degradation, and impacts on beneficial insects. These phenomena were extensively studied by entomologists, who began questioning the long-term efficacy and sustainability of chemical control methods.

The foundational work of Van den Bosch and Stern (1962), published in the *Annual Review of Entomology*, introduced the concept of "integrated control"—the coordinated application of compatible biological and chemical strategies that prioritized the conservation of natural enemies. Their advocacy for harmonizing biological control with minimal chemical inputs laid the philosophical groundwork for what would evolve into IPM. This new paradigm shifted pest management from a purely chemical arms race to an ecologically rational, economically optimized, and environmentally sustainable model.

2.2 Formalization of IPM and the Entomologist's Role

By the 1970s, growing empirical support and political interest prompted the formal adoption of IPM by international institutions. The United States Department of Agriculture (USDA) and the Food and Agriculture Organization (FAO) began promoting IPM programs globally. These were deeply informed by entomological research on population dynamics, trophic interactions, and biological control agents. Seminal entomological studies during this time expanded

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on concepts such as economic injury levels (EILs) and economic thresholds, most notably by Pedigo and Higley, which enabled precision in pest intervention decisions and prevented unnecessary pesticide use.

Entomologists also developed sampling protocols, trap systems, and phenological models that enhanced pest monitoring and forecasting capabilities. These tools were instrumental in optimizing the timing and selection of control methods, reducing costs, and mitigating environmental damage (Way & van Emden, 2000).

2.3 Diversification of IPM Through Entomological Disciplines

As IPM gained global acceptance, entomologists diversified their contributions. From classical biological control to behavior-modifying chemicals such as pheromones, entomological advances broadened IPM's toolkit. Research on insect resistance management, predator-prey dynamics, and insect learning and cognition (Little et al., 2019) deepened the understanding of how pests adapt and how interventions could be designed with long-term efficacy in mind.

Pioneering studies in systems ecology and simulation modeling (Getz & Gutierrez, 1982) further enriched IPM by enabling scenario-based analysis of pest population trends and their interaction with crops and climate variables. These approaches became particularly relevant as pest problems grew more complex in the context of climate change and agricultural intensification.

2.4 Global Dissemination and Contextual Adaptation

Entomologists played a central role in translating IPM from theory into practice across diverse agroecosystems. Programs such as the Area-Wide Integrated Pest Management (AW-IPM), driven by collaborative entomological research, demonstrated how population ecology could be scaled from field-level interventions to landscape-level pest suppression (Hendrichs et al., 2007).

In regions like Latin America, Africa, and South Asia, entomologists adapted IPM models to local pest complexes, cultural practices, and institutional capacities, showcasing the flexibility and robustness of the IPM framework when informed by entomological insight.

III. ENTOMOLOGICAL TECHNIQUES AND INNOVATIONS IN IPM

Entomology has continually enriched Integrated Pest Management (IPM) with science-based techniques that increase precision, sustainability, and ecological compatibility. This section explores the principal entomological contributions and innovations that have shaped modern IPM systems, emphasizing their evolution, applications, and significance in global agriculture.

3.1 Evolution of Entomological Tools

Over the past six decades, entomologists have developed and refined a range of technologies that underpin effective IPM strategies. The chart below illustrates the growing adoption of key entomological tools—biological control agents, pheromone-based technologies, economic thresholds, and insect growth regulators—across decades.

We observe that by the 1990s, tools such as economic thresholds and pheromone traps had become standard elements in many IPM programs, and by the 2010s, their adoption was nearly universal in advanced agricultural systems. Biological control has shown a steady increase, supported by expanded research into parasitoids and predatory insects, while insect growth regulators have gained prominence as selective alternatives to broad-spectrum pesticides.

3.2 Current Contributions of Entomology to IPM

The chart below summarizes the proportional impact of different entomological strategies in IPM as of 2020. The largest contributions come from monitoring and trapping systems (25%) and biological control (30%). These are followed by behavioral manipulation techniques such as mating disruption, resistance management frameworks (e.g., refugia design, rotation strategies), and forecasting models based on pest phenology and climate integration.

Data trends are synthesized from historical reviews and adoption surveys in peer-reviewed entomological literature (Kogan, 1998; Getz & Gutierrez, 1982; Way & Van Emden, 2000).

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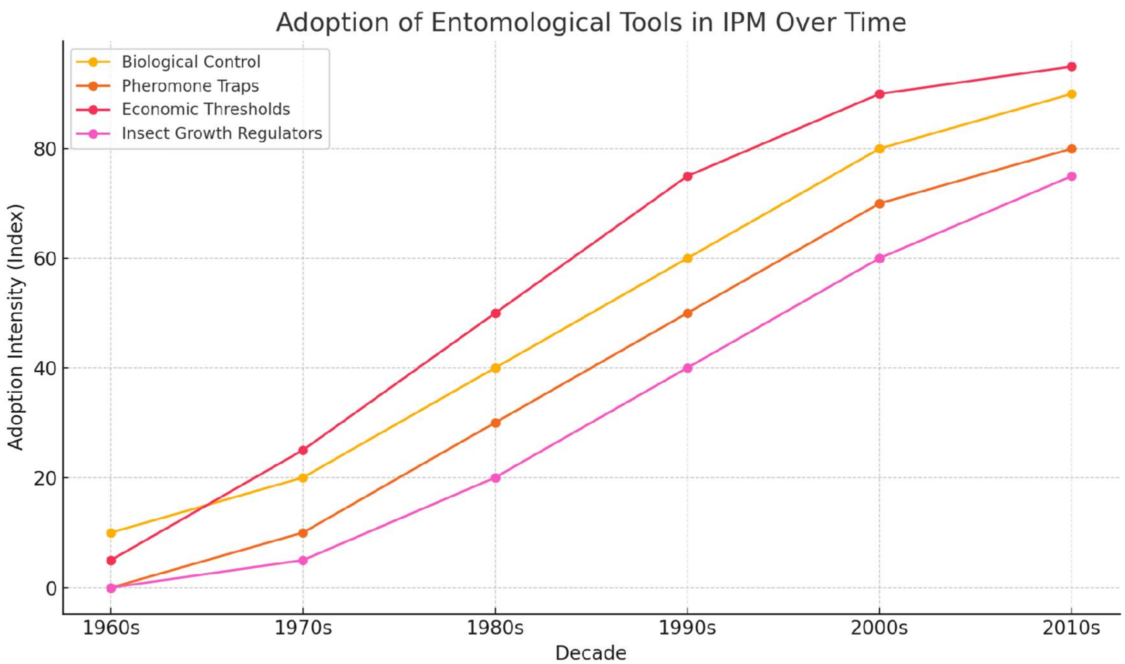

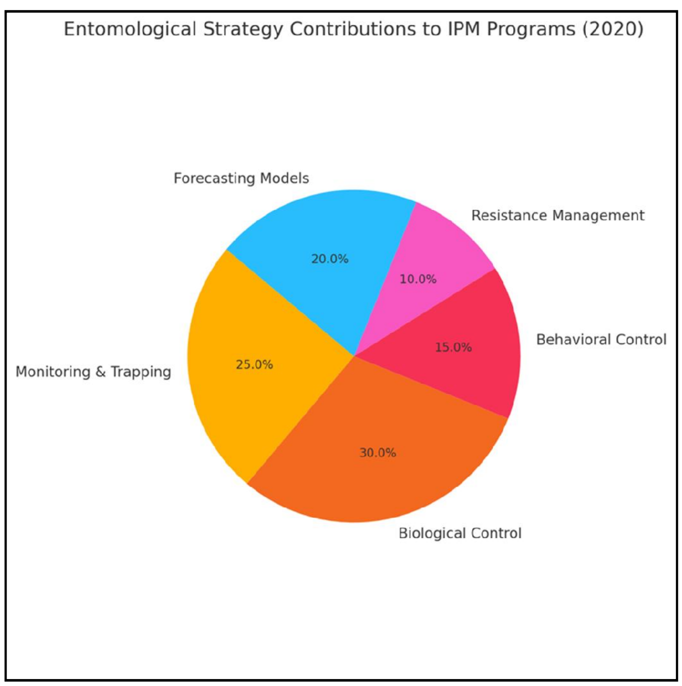

Data trends are synthesized from historical reviews and adoption surveys in peer-reviewed entomological literature (Kogan, 1998; Getz & Gutierrez, 1982; Way & Van Emden, 2000).

These methods exemplify how entomological research not only addresses direct pest control but also underpins long-term planning, decision-support systems, and agroecological resilience.

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3.3 Key Areas of Innovation

- Pheromone and Kairomone Traps: Entomologists have developed semiochemical lures for mass trapping, species-specific surveillance, and mating disruption. These tools reduce pesticide use and support early intervention.
- Biological Control Agents: Classical and augmentative biocontrol strategies involving parasitoids (e.g., *Trichogramma spp.*) and predators (e.g., *Coccinellidae*) are cornerstones of non-chemical IPM.
- Insect Growth Regulators (IGRs): These selective chemicals interrupt molting or reproduction, offering reduced non-target impact and resistance pressure.
- Behavioral Studies and Insect Learning: Recent advances explore how insects learn and adapt to control methods (Little et al., 2019), helping optimize lure-and-kill and baiting strategies.
- Simulation Modeling and Forecasting: Tools developed by entomologists allow predictive pest population modeling under varying environmental and agronomic conditions (Getz & Gutierrez, 1982).

IV. CASE STUDIES OF ENTOMOLOGICAL CONTRIBUTIONS TO CROP-SPECIFIC IPM SYSTEMS

To appreciate the practical impact of entomological research, it is essential to examine real-world IPM applications in major crop systems. These case studies demonstrate how entomology has shaped pest management strategies tailored to diverse agroecosystems, enhancing productivity while reducing ecological harm. Each case exemplifies the integration of pest biology, monitoring, and control technologies developed by entomologists.

4.1 Cotton: Biological Control and Resistance Management

Cotton has long been a flagship crop for IPM innovation, especially in regions like the United States, India, and Australia. Historically vulnerable to a wide array of pests such as bollworms (*Helicoverpa armigera*) and whiteflies (*Bemisia tabaci*), cotton systems transitioned from intensive pesticide use to integrated strategies led by entomologists.

Key innovations include:

- Threshold-based spray decisions, rooted in field scouting and economic injury level models (Naranjo & Ellsworth, 2009).
- Biological control with predators like *Chrysoperla carnea* and parasitoids such as *Trichogramma spp.*
- Bt cotton, which integrates genetic pest resistance, was developed using entomological knowledge of lepidopteran feeding behavior and resistance dynamics.
- Insecticide Resistance Management (IRM), involving rotation and refugia strategies, is continually monitored and advised by entomologists (Gould, 1998).

Impact: In Arizona, these methods reduced insecticide applications by >60% without yield loss (Naranjo & Ellsworth, 2015).

4.2 Rice: Pest Surveillance and Cultural Tactics in Asia

Rice IPM, especially in Southeast Asia, has heavily relied on entomology-driven approaches since the 1980s. Entomologists studied the population ecology of planthoppers (*Nilaparvata lugens*) and stem borers to develop low-input, sustainable controls.

Key contributions:

- Natural enemy conservation, focusing on spiders and parasitoids, informed by field-level trophic interaction studies (Heong & Schoenly, 1998).
- Push-pull strategies, using plant volatiles to deter pests while attracting natural enemies.
- Mass rearing of *Trichogramma japonicum*, a parasitoid used for inundative release.
- Farmer field schools, initiated with support from entomologists to teach ecological IPM concepts (Pontius et al., 2002).

Impact: In Vietnam and the Philippines, pesticide use dropped by 50–70% while maintaining or increasing yields (FAO, 2001).

4.3 Maize: Fall Armyworm and IPM in Africa

The introduction of *Spodoptera frugiperda* (fall armyworm) to Africa in 2016 prompted a massive entomological response. Though recent, strategies have built upon decades of entomological knowledge from Latin America and North America.

IPM components include:

- Monitoring traps using pheromones developed through chemical ecology studies.
- Biocontrol with *Telenomus remus* and *Habrobracon hebetor*, validated by entomologists for local climatic suitability.
- Cultural methods such as intercropping and early planting, advised based on pest behavior research.
- Mobile extension systems delivering pest alerts informed by entomological surveillance networks.

Impact: In Kenya, integrated methods reduced FAW damage by 40% compared to non-IPM farms (Prasanna et al., 2018).

4.4 Soybean: Learning from Brazil's Ecological Collapse

Brazil's soybean IPM history presents both success and caution. Initially robust IPM programs informed by entomologists collapsed due to overreliance on pesticides and failure to maintain natural enemy populations (Panizzi, 2013).

Key lessons:

- Entomological models were crucial in understanding pest resurgence and secondary pest outbreaks.
- Restoration efforts now emphasize ecological engineering, botanical insecticides, and conservation biocontrol.

Impact: Entomologists have guided a national IPM reintegration plan since 2015 (Embrapa, 2017).

4.5 Citrus and Orchard Crops: Area-Wide IPM

Entomologists have designed area-wide suppression systems in high-value orchard crops like citrus, where local control is ineffective due to pest mobility.

- Programs targeting *Ceratitis capitata* (Mediterranean fruit fly) and *Bactrocera spp.* use sterile insect techniques, pheromone mass trapping, and fruit bagging.
- Long-term success in regions like California and the Mediterranean basin stem from ecological entomology, modeling, and system-level monitoring.

Impact: Reduction in medfly incidence by >95% without broad-spectrum sprays (Hendrichs et al., 2007).

V. BARRIERS, LIMITATIONS, AND CHALLENGES IN ENTOMOLOGICAL IPM IMPLEMENTATION

Despite its scientific robustness and ecological advantages, the global implementation of entomology-led Integrated Pest Management (IPM) continues to face multiple barriers. These limitations span institutional frameworks, economic structures, environmental conditions, and socio-behavioral dimensions. This section provides a comprehensive analysis of the major impediments to the widespread adoption and operationalization of entomological innovations in IPM.

5.1 Institutional and Policy Constraints

The institutional landscape in many agricultural regions remains misaligned with the ecological principles of IPM. Even though IPM has been conceptually adopted by most agricultural ministries and development agencies, implementation on the ground often contradicts its ideals. Most public extension systems are structured around chemical-centric advisory models, where recommendations are standardized and reactive, rather than tailored to pest ecology and thresholds.

A key reason is that entomological knowledge requires flexible, localized implementation, which necessitates trained personnel and decentralized decision-making—features that are frequently absent in centralized bureaucracies (Kogan, 1998). Furthermore, agrochemical companies wield significant influence on policy and training programs, shaping them around product sales rather than long-term ecological management.

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In many low- and middle-income countries (LMICs), IPM policies exist only on paper, with little budget or institutional capacity to train extension agents in field diagnostics, natural enemy identification, or threshold-based spraying—all fundamental entomological skills.

5.2 Limited Farmer Awareness and Training

IPM, particularly its entomological components, demands substantial ecological literacy and observational capacity from farmers. Farmers must distinguish between pests and beneficial insects, interpret field-level damage correctly, and apply control actions only when economically justified. However, studies across Africa, Asia, and Latin America reveal that most farmers lack such training, leading to preventive or calendar-based spraying.

The Farmer Field School (FFS) approach, pioneered with strong entomological inputs, proved effective in bridging this gap. It trained farmers using experiential methods, including insect zoos, field trials, and predator-prey interaction mapping (Pontius et al., 2002). However, despite initial success in Southeast Asia, the FFS model has been underfunded and inconsistently scaled across regions. Without sustained support, knowledge retention diminishes, and farmers revert to chemical control.

Moreover, time pressure during outbreaks often compels quick decision-making, making the slower-acting but ecologically sound entomological methods less appealing unless trust is firmly established.

5.3 Market Forces and Input Supply Chains

One of the most practical barriers is the commercial availability and affordability of entomology-based tools. For instance, parasitoids like *Trichogramma spp.* or pheromone lures for *Spodoptera frugiperda* require production, storage, and distribution infrastructure that many countries lack.

Meanwhile, pesticides are often subsidized, bundled with crop loans, or aggressively promoted through local input dealers who receive commissions. This economic imbalance disincentivizes both retailers and farmers from adopting non-chemical options, regardless of their ecological superiority.

Entomological strategies, though often cost-effective over the long term, can involve higher upfront labor, knowledge, and setup costs, especially when using tools like mass trapping or habitat manipulation. Without economic incentives or subsidies for IPM-compatible products, adoption is likely to remain limited among smallholders.

5.4 Environmental and Ecological Uncertainties

Entomological solutions are deeply embedded in local ecological contexts, and their performance can vary drastically between regions. For instance, a predator species that effectively controls aphids in one climate may fail in another due to differences in temperature, humidity, or prey availability.

Additionally, landscape-level features such as field size, crop diversity, presence of hedgerows, and pesticide drift from nearby farms greatly influence the success of biological control agents. While entomologists emphasize the need for landscape-level pest management, most farms operate at the individual level, limiting the impact of area-wide ecological interventions.

Climate change exacerbates these challenges. Rising temperatures and altered precipitation patterns influence pest phenology, migration, and voltinism. Natural enemies and pests may become desynchronized, undermining biological control dynamics. This increases uncertainty for entomologists attempting to model pest populations or design predictive interventions, necessitating constant recalibration of systems-based models (Barzman et al., 2015).

5.5 Resistance and Evolutionary Adaptation

A persistent concern in pest management is the evolutionary capacity of insect pests. Entomologists have developed detailed frameworks for resistance management, including alternating chemical modes of action, implementing untreated refuges, and using synergistic biocontrol. However, these frameworks are often imperfectly enforced, especially with genetically modified crops like Bt cotton or Bt maize.

In the absence of regulatory oversight or farmer compliance, pests evolve resistance even to sophisticated control methods. Gould (1998) documented early warning signs of resistance in *Helicoverpa zea* due to non-compliance with

Bt refuge requirements. Similarly, behavioral adaptation to semiochemical lures has been reported in several pest species, reducing the efficacy of long-standing pheromone trap systems.

Entomologists continue to monitor and advise on resistance patterns, but without robust data systems and enforcement mechanisms, the long-term durability of entomology-based IPM remains at risk.

5.6 Gaps in Integration and Interdisciplinary Collaboration

Although IPM was conceptualized as an interdisciplinary approach, many implementations remain siloed. In some cases, IPM is reduced to an "entomologist's program," neglecting the roles of weed science, plant pathology, and socioeconomics. This narrow focus limits the effectiveness of IPM in cropping systems where multiple pest pressures co-occur.

Entomological insights must be embedded within whole-farm planning, alongside market access, labor economics, and community dynamics. For instance, a solution effective against *Spodoptera* may not be viable if labor costs or gender norms prevent its use.

Moreover, despite the availability of digital tools, including mobile diagnostics, remote sensing, and AI-based pest forecasting, adoption is minimal. Many farmers and field workers lack the infrastructure or digital literacy to leverage such tools, creating a gap between technological potential and field reality.

VI. CONCLUSION

Entomology has been the scientific backbone of Integrated Pest Management (IPM) since its inception. From laying the conceptual groundwork for integrated control strategies in the 1960s to developing sophisticated biological, behavioral, and ecological interventions today, entomologists have consistently contributed tools and knowledge essential to sustainable agriculture. The history of IPM is deeply intertwined with entomological research that clarified pest population dynamics, ecological thresholds, predator-prey interactions, and insect behavior. This review traced entomology's contributions through its foundational role in defining IPM, its innovative tools and techniques—including pheromone traps, biological control, and growth regulators—and its practical influence across crop-specific systems such as cotton, rice, maize, and citrus. The wide-ranging applications of entomology have been instrumental in reducing pesticide reliance, improving farm profitability, and enhancing agroecological resilience. Despite these achievements, widespread adoption of entomology-based IPM strategies remains hindered by significant institutional, educational, and economic challenges. These include inadequate policy support, limited farmer training, skewed input markets, and environmental variability. Moreover, evolving pest resistance and climate change are introducing new uncertainties that require adaptive, multidisciplinary, and digitally integrated approaches. Looking ahead, the future of IPM will increasingly depend on the continued evolution of entomological science, particularly in areas such as molecular entomology, digital pest forecasting, landscape-level ecology, and community-based knowledge systems. To fully realize the potential of IPM, researchers, extension services, policymakers, and farmers must work collaboratively—guided by the ecological insights and scientific rigor that entomology has long provided. By reaffirming its central role in integrated pest strategies and adapting to emerging challenges, entomology can ensure that IPM remains not just an ideal, but a viable and resilient path forward for sustainable agriculture worldwide.

REFERENCES

[1]. Barzman, M., Bàrberi, P., Birch, A. N. E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., … & Lamichhane, J. R. (2015). Eight principles of integrated pest management. *Agronomy for Sustainable Development, 35*(4), 1199–1215. https://doi.org/10.1007/s13593-015-0327-9

[2]. Dent, D., & Binks, R. H. (2020). *Insect pest management* (3rd ed.). CABI Publishing.

[3]. Deguine, J. P., Aubertot, J. N., Flor, R. J., Lescourret, F., Wyckhuys, K. A. G., & Ratnadass, A. (2021). Integrated pest management: Good intentions, hard realities. A review. *Agronomy for Sustainable Development, 41*, 38. https://doi.org/10.1007/s13593-021-00689-w

[4]. FAO. (2001). *Reducing reliance on pesticides in rice: Farmer Field Schools in Asia*. Rome: Food and Agriculture Organization.

[5]. Getz, W. M., & Gutierrez, A. P. (1982). A perspective on systems analysis in crop production and insect pest management. *Annual Review of Entomology, 27*, 447–478. https://doi.org/10.1146/annurev.en.27.010182.002311

[6]. Gould, F. (1998). Sustainability of transgenic insecticidal cultivars: Integrating pest genetics and ecology. *Proceedings of the National Academy of Sciences, 95*(24), 14043–14044. https://doi.org/10.1073/pnas.95.24.14043

[7]. Guedes, R. N. C., Smagghe, G., Stark, J. D., & Desneux, N. (2016). Pesticide-induced stress in arthropod pests for optimized integrated pest management programs. *Annual Review of Entomology, 61*, 43–62. https://doi.org/10.1146/annurev-ento-010715-023646

[8]. Gurr, G. M., Wratten, S. D., & Luna, J. M. (2004). Multi-function agricultural biodiversity: Pest management and other benefits. *Basic and Applied Ecology, 5*(2), 107–116. https://doi.org/10.1016/j.baae.2003.10.002

[9]. Heong, K. L., & Schoenly, K. G. (1998). Impact of insecticides on pest and natural enemy communities in tropical rice ecosystems. In *Pest Management in Rice* (pp. 381–403). Springer.

[10]. Hendrichs, J., Kenmore, P. E., Robinson, A. S., & Vreysen, M. J. B. (2007). Area-wide integrated pest management (AW-IPM): Principles, practice and prospects. In *Area-wide control of insect pests* (pp. 3–33). Springer. https://doi.org/10.1007/978-1-4020-6059-5_1

[11]. Jacobsen, B. J. (1997). Integrated pest management (IPM): Key concepts and ecological perspective. *The Plant Health Instructor*, 1–5.

[12]. Kogan, M. (1998). Integrated pest management: Historical perspectives and contemporary developments. *Annual Review of Entomology, 43*, 243–270. https://doi.org/10.1146/annurev.ento.43.1.243

[13]. Little, C. M., Chapman, T. W., & Hillier, N. K. (2019). Considerations for insect learning in integrated pest management. *Journal of Insect Science, 19*(4), 6. https://doi.org/10.1093/jisesa/iez064

[14]. Naranjo, S. E., & Ellsworth, P. C. (2009). Fifty years of the integrated control concept: Moving the model and implementation forward in Arizona. *Pest Management Science, 65*(12), 1267–1286. https://doi.org/10.1002/ps.1836

[15]. Naranjo, S. E., & Ellsworth, P. C. (2015). Economic value of biological control in integrated pest management of managed plant systems. *Annual Review of Entomology, 60*, 621–645. https://doi.org/10.1146/annurev-ento-010814-021005

[16]. Panizzi, A. R. (2013). History and contemporary perspectives of the integrated pest management of soybean in Brazil. *Neotropical Entomology, 42*(2), 119–127. https://doi.org/10.1007/s13744-013-0101-z

[17]. Pedigo, L. P., & Higley, L. G. (1996). *Economic thresholds for integrated pest management*. University of Nebraska Press.

[18]. Pontius, J., Dilts, R., & Bartlett, A. (2002). *From Farmer Field School to Community IPM: Ten Years of IPM Training in Asia*. FAO Regional Office for Asia and the Pacific.

[19]. Prasanna, B. M., Huesing, J. E., Eddy, R., & Peschke, V. M. (Eds.). (2018). *Fall Armyworm in Africa: A guide for integrated pest management*. CIMMYT & USAID. https://www.usaid.gov/sites/default/files/documents/Fall-Armyworm-IPM-Guide-for-Africa.pdf

[20]. Stern, V. M., Smith, R. F., van den Bosch, R., & Hagen, K. S. (1959). The integrated control concept. *Hilgardia, 29*(2), 81–101. https://doi.org/10.3733/hilg.v29n02p081

[21]. Thill, D. C., Lish, J. M., Callihan, R. H., & Bechinski, E. J. (1991). Integrated weed management: A critical component of integrated pest management. *Weed Technology, 5*(3), 648–656. https://doi.org/10.1017/S0890037X00027589

[22]. Van den Bosch, R., & Stern, V. M. (1962). The integration of chemical and biological control of arthropod pests. *Annual Review of Entomology, 7*, 355–378. https://doi.org/10.1146/annurev.en.07.010162.002055

[23]. Way, M. J., & Van Emden, H. F. (2000). Integrated pest management in practice—Pathways towards successful application. *Crop Protection, 19*(1), 81–103. https://doi.org/10.1016/S0261-2194(99)00098-8

[24]. Witzgall, P., Kirsch, P., & Cork, A. (2010). Sex pheromones and their impact on pest management. *Journal of Chemical Ecology, 36*(1), 80–100. https://doi.org/10.1007/s10886-009-9737-y