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Bibliometric Analysis of Integrated Pest Management in Sustainable Agriculture

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ABSTRACT

Integrated Pest Management (IPM) has emerged as a sustainable alternative to conventional pest control methods, emphasizing the integration of biological, cultural, mechanical, and chemical approaches. This study conducts a bibliometric analysis of IPM research using data exclusively from the Scopus database and analyzed through VOSviewer. The findings reveal a significant increase in IPM-related publications over the past two decades, indicating growing global interest in sustainable pest management. Key research themes identified include pesticide reduction, biological control, policy frameworks, and technological advancements such as artificial intelligence for pest monitoring. The study also highlights the dominance of developed countries, particularly the United States, United Kingdom, and China, in IPM research, while collaboration between developed and developing nations remains limited. Major challenges to IPM adoption include economic constraints, lack of technical knowledge, and regulatory barriers. Future research should focus on enhancing global collaboration, improving accessibility to biopesticides and digital technologies, and strengthening farmer education and policy support. This study provides valuable insights into the evolution of IPM research and its role in promoting sustainable agriculture.

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1. INTRODUCTION

Agriculture is a fundamental sector that ensures food security, economic stability, and environmental sustainability worldwide. However, agricultural productivity is constantly threatened by various factors, including climate change, soil degradation, and most notably, pests and diseases [1]. The presence of pests in agricultural systems often leads to significant yield losses, compelling farmers to adopt various control strategies. Historically, chemical pesticides have been the dominant solution to pest management due to their effectiveness in rapidly eliminating pests [2]. However, excessive reliance on synthetic pesticides has resulted in several adverse consequences, including pesticide resistance, non-target species harm, environmental pollution, and human health hazards [3]. Therefore, a more sustainable approach to pest management is needed to

balance agricultural productivity and environmental conservation.

Integrated Pest Management (IPM) has emerged as a comprehensive and ecologically sound strategy that seeks to minimize the negative impacts of pest control while maintaining agricultural productivity. IPM integrates multiple pest control techniques, including biological control, habitat manipulation, cultural practices, and judicious use of pesticides [3]. Unlike conventional pest control methods that rely heavily on chemical applications, IPM emphasizes a holistic approach by combining preventive and curative measures tailored to specific pest problems [4]. The concept of IPM aligns with the principles of sustainable agriculture by promoting biodiversity, reducing chemical dependency, and enhancing soil health. Over the years, researchers and policymakers have increasingly recognized the importance of IPM in achieving long-term agricultural sustainability.

The adoption of IPM has been widely encouraged by international organizations, including the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP). These organizations have launched various initiatives to promote IPM implementation in different agricultural landscapes [5]. Despite its recognized benefits, the widespread adoption of IPM faces several challenges, such as the lack of technical knowledge, insufficient extension services, and the economic constraints faced by smallholder farmers [6]. Additionally, the effectiveness of IPM strategies varies based on local environmental conditions, pest species, and farmer adoption rates. These complexities necessitate a thorough understanding of the trends and patterns in IPM research and development.

Bibliometric analysis is a valuable tool for assessing the research landscape of a given field, including IPM. By examining academic publications, citation patterns, and collaboration networks, bibliometric analysis provides insights into the evolution of knowledge, key research contributors, and emerging trends [7]. This method helps in identifying influential studies, research gaps, and potential future directions in IPM research. Over the past few decades, there has been a growing body of literature on IPM, covering diverse aspects such as policy frameworks, technological innovations, and farmer perceptions. However, a systematic analysis of the existing literature is required to synthesize key findings and provide a comprehensive overview of the progress made in IPM research.

Given the global emphasis on sustainable agricultural practices, understanding the scholarly landscape of IPM is crucial for guiding future research and policymaking. A bibliometric analysis of IPM research can reveal how scientific efforts have evolved over time and which thematic areas require further investigation. Moreover, such an analysis can highlight the geographical distribution of research contributions, enabling stakeholders to identify regions where IPM adoption has been successful and where further interventions are needed [8]. By employing bibliometric methods, this study aims to offer a data-driven perspective on the development and impact of IPM in sustainable agriculture.

Despite the well-documented benefits of Integrated Pest Management (IPM) in promoting sustainable agriculture, its adoption and implementation remain inconsistent across different regions. There is a significant knowledge gap regarding the global research trends, key contributors, and thematic focus areas in IPM studies. While numerous studies have explored specific aspects of IPM, such as biological control methods and farmer adoption rates, a comprehensive bibliometric analysis is lacking. Without such an analysis, policymakers, researchers, and practitioners may struggle to identify critical research gaps and emerging areas of interest. Therefore, there is a pressing need to systematically analyze the existing body of literature on IPM to gain a clearer understanding of its development, challenges, and future

prospects. This study aims to (1) identify the publication trends and key contributors in IPM research, (2) analyze citation patterns and research collaborations, (3) determine the thematic focus areas in IPM studies, and (4) highlight research gaps and potential directions for future studies.

The Concept of Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a holistic approach to pest control that combines multiple strategies to minimize the negative effects of pests while reducing reliance on chemical pesticides [9]. The concept of IPM emerged in response to the growing concerns over pesticide resistance, environmental degradation, and human health risks associated with excessive pesticide use [10]. IPM incorporates biological, cultural, mechanical, and chemical control methods to create a sustainable pest management system [11]. The primary goal of IPM is to maintain pest populations at manageable levels rather than completely eradicating them, which aligns with the principles of sustainable agriculture [12]. Several researchers have highlighted the advantages of IPM over conventional pest control methods. For instance, [13] argue that IPM contributes to long-term ecological balance by enhancing biodiversity and reducing pesticide residues in the environment. Additionally, IPM is known to improve soil health and water quality, making it an environmentally friendly alternative to traditional pest management strategies [14]. Despite these advantages, the adoption of IPM remains limited due to various socio-economic and institutional barriers. Understanding these barriers is crucial for designing policies that promote the widespread implementation of IPM in agricultural systems.

Adoption and Challenges of IPM Implementation

Despite its proven benefits, the adoption of IPM practices varies significantly across different regions and farming systems [15]. One of the main challenges is the lack of awareness and technical knowledge among farmers, particularly in developing countries [16]. Many farmers continue to rely on chemical pesticides due to their immediate efficacy, despite the long-term risks associated with their use [17]. Economic constraints also pose a significant barrier to IPM adoption. The initial costs of implementing IPM strategies, such as purchasing biopesticides, training farmers, and investing in pest monitoring tools, can be prohibitive for smallholder farmers [18]. Additionally, the success of IPM programs depends on effective collaboration among farmers, researchers, and policymakers [19]. Without proper institutional support and extension services, the widespread adoption of IPM remains a challenge.

Role of Policy and Institutional Support in IPM Promotion

Government policies and institutional support play a crucial role in promoting IPM adoption. Several countries have implemented regulatory frameworks to reduce the use of hazardous pesticides and encourage the adoption of sustainable pest management practices [20]. For example, the European Union has established strict regulations on pesticide use, leading to increased research and investment in IPM strategies [21]. Similarly, the United States Department of Agriculture (USDA) has launched various programs to support farmers in transitioning to IPM-based practices [22]. International organizations, such as the FAO and the World Bank, have also been instrumental in promoting IPM in developing countries through capacity-building programs and financial assistance. However, the effectiveness of these programs depends on the commitment of local governments and the willingness of farmers to adopt IPM practices [23]. To enhance the adoption of IPM, policymakers must address the economic and social barriers that hinder its implementation.

2. METHODS

This study employs a bibliometric analysis approach to examine the research landscape of Integrated Pest Management

(IPM) in sustainable agriculture. Data for the analysis were collected exclusively from the Scopus database, covering a period from the earliest available records to the present. The analysis includes publication trends, citation patterns, key authors, leading institutions, and influential journals. The bibliometric tool VOSviewer was utilized to visualize co-authorship networks, keyword co-occurrence maps, and thematic clusters. Additionally, content analysis was performed to identify major research themes and gaps within the IPM literature.

3. RESULTS AND DISCUSSION

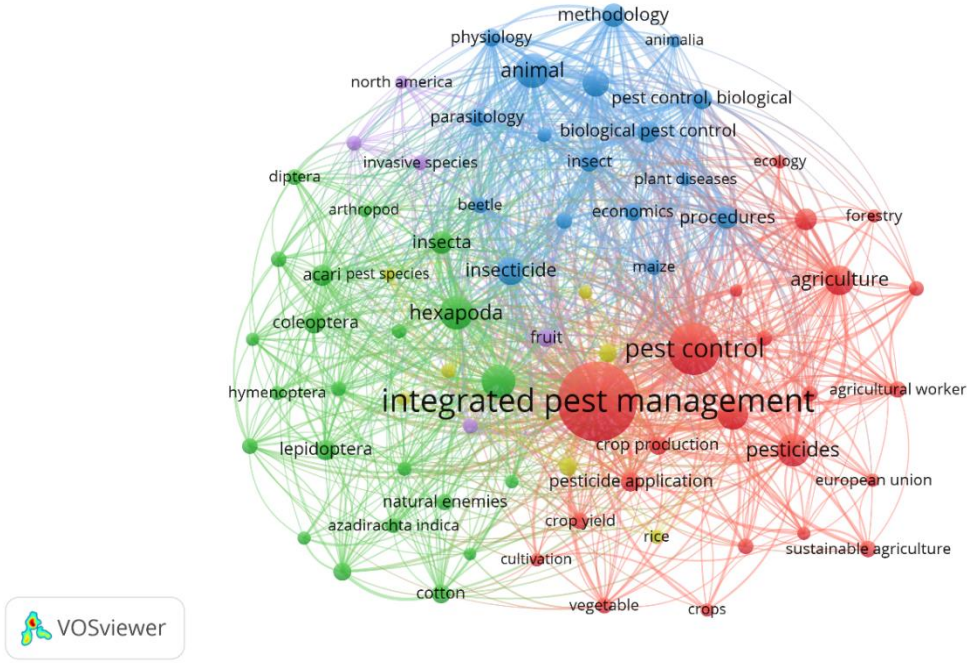

Figure 1. Network Visualization
Source: Data Analysis, 2025

This VOSviewer visualization represents a bibliometric analysis of Integrated Pest Management (IPM) research, highlighting the co-occurrence of key terms in the academic literature. The network graph is divided into multiple clusters, each represented by different colors, indicating the relationships between various topics in the field of IPM. The size of each node corresponds to the frequency of the term in the dataset, with larger nodes signifying higher occurrences. The connectivity between nodes, represented by lines, indicates co-occurrence relationships, with thicker lines suggesting stronger associations between terms. The red cluster focuses on agricultural and pesticide-related terms, with "pest control," "pesticides," and "sustainable agriculture" appearing prominently. This suggests that a significant portion of IPM research is centered on the role of pesticides, their application in agriculture, and the need for sustainable alternatives. The presence of terms like "crop production" and "pesticide application" indicates a strong focus on the practical aspects of managing pests while maintaining agricultural productivity. The European Union's mention suggests that policy and regulatory frameworks related to pesticide use are a relevant topic in IPM studies.

The green cluster appears to be centered around entomological and biological control aspects of IPM, with terms like "insecta," "hexapoda," "natural enemies," and "hymenoptera." This reflects the emphasis on biological pest control methods, including the use of natural predators and parasitoids to manage pest populations. The presence of specific insect groups such as "coleoptera" and

"lepidoptera" indicates that research in this area includes studies on both pests and beneficial insects. The term "azadirachta indica" (neem) suggests interest in botanical pesticides as part of IPM strategies. The blue cluster represents a more methodological and ecological perspective on IPM, with terms like "methodology," "biological pest control," "plant diseases," and "economics." This indicates that a portion of the research focuses on evaluating the economic viability of IPM strategies, as well as the ecological interactions between pests, crops, and biological control agents. The inclusion of terms like "north America" and "parasitology" suggests that research in this domain spans regional and ecological perspectives, incorporating studies on how pest management interacts with broader ecological and economic systems.

This visualization provides a comprehensive overview of the major themes in IPM research. The strong connections between terms demonstrate the interdisciplinary nature of the field, bridging entomology, agriculture, ecology, and policy. The clustering patterns highlight the balance between chemical, biological, and sustainable pest control methods, emphasizing the ongoing need for research on integrating these approaches. Additionally, the presence of economic and methodological terms suggests that researchers are actively studying the cost-effectiveness and practical implementation of IPM strategies to ensure their widespread adoption.

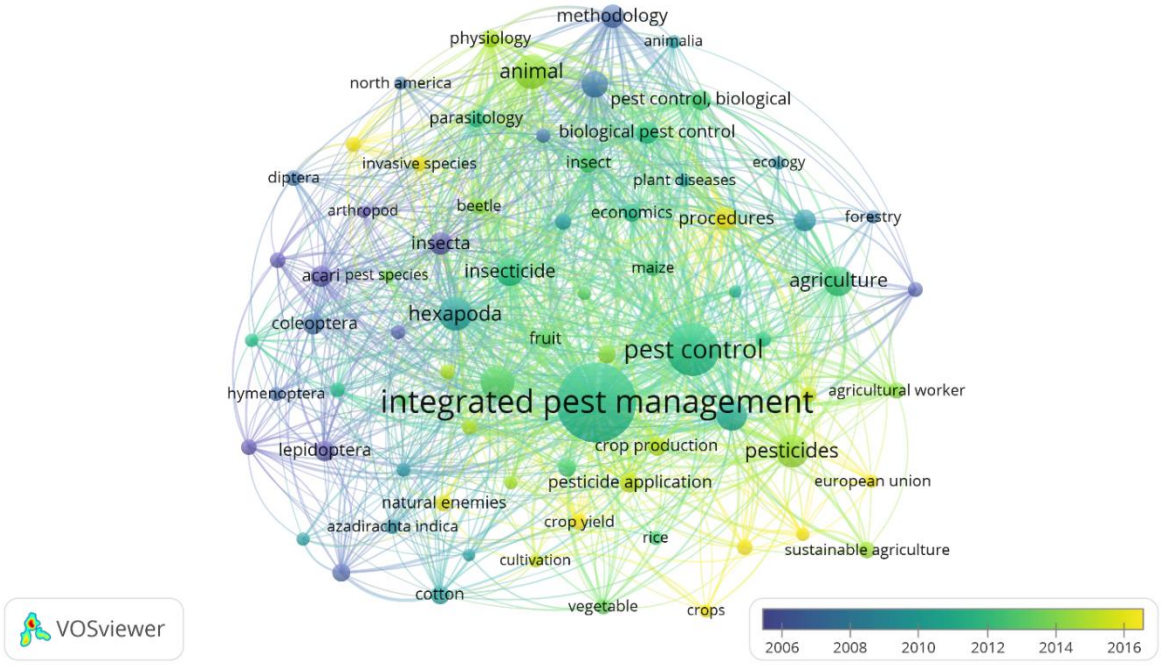

Figure 2. Overlay Visualization
Source: Data Analysis, 2025

This VOSviewer visualization represents a bibliometric analysis of Integrated Pest Management (IPM) research, using a temporal color gradient to illustrate the evolution of key terms over time. The color scale at the bottom right indicates the average publication year of studies related to each term, with purple representing older research (around 2006) and yellow representing more recent studies (around 2016). The visualization shows that "integrated pest management" remains the central theme, with strong co-occurrences among various related terms, including "pest control," "pesticides," "crop production," and "sustainable agriculture." The connectivity of nodes indicates the interdisciplinary nature of IPM research, encompassing topics from entomology to agronomy and policy. The temporal distribution of research terms provides insights into how the focus of IPM studies has evolved over the years. Older

terms (in purple and blue) such as "coleoptera," "hymenoptera," and "azadirachta indica" suggest that early research concentrated on biological control methods and botanical pesticides. Meanwhile, more recent terms (in yellow and green) such as "sustainable agriculture," "crop yield," and "pesticide application" indicate a shift toward broader agricultural sustainability issues, including the economic and ecological aspects of pest management. The growing prominence of terms like "economics," "procedures," and "policy" suggests an increasing focus on the implementation and regulatory aspects of IPM.

This bibliometric analysis reveals that IPM research has transitioned from a primarily entomological and biological control focus to a more holistic and interdisciplinary approach that integrates environmental sustainability, policy frameworks, and technological advancements. The strong connections among diverse terms emphasize the increasing complexity of pest management strategies and the need for a multi-faceted approach that balances agricultural productivity with ecological conservation. The visualization underscores the importance of continuous research to adapt IPM strategies to emerging agricultural challenges, ensuring long-term sustainability in pest management practices.

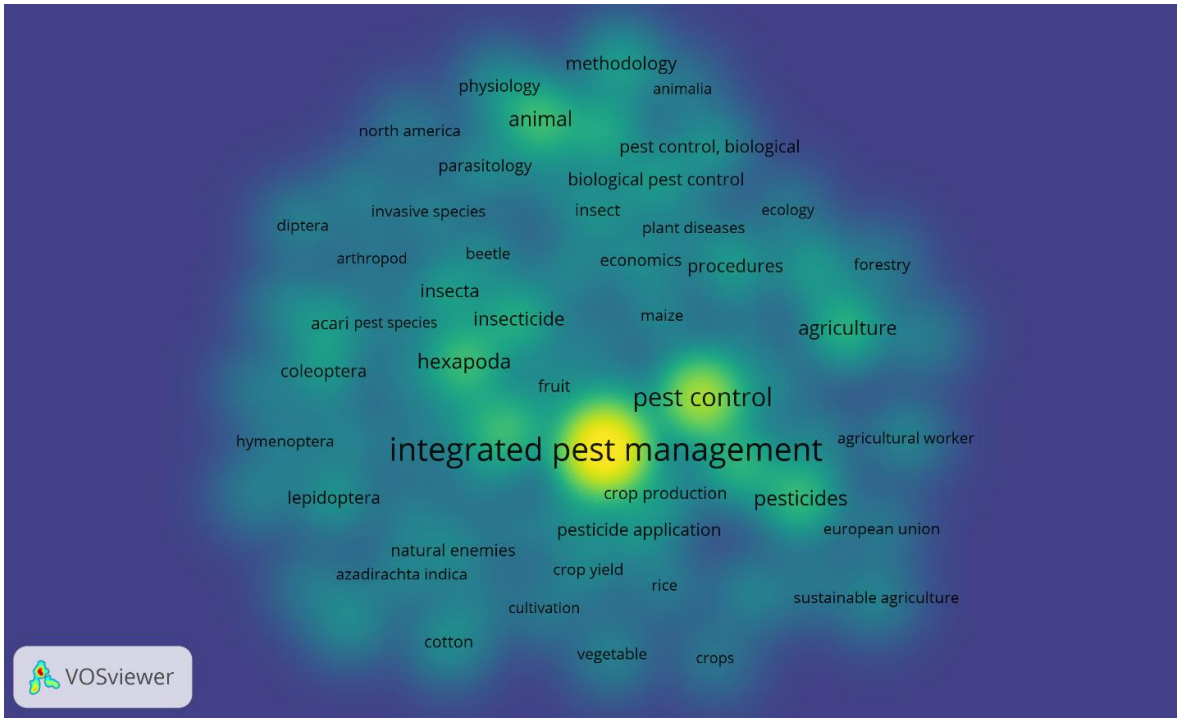

Figure 3. Density Visualization
Source: Data Analysis, 2025

This VOSviewer visualization represents a density map of keywords related to Integrated Pest Management (IPM) research. The color intensity in the heatmap indicates the concentration of studies focusing on specific topics, with bright yellow areas representing high research density and dark blue areas indicating lower research density. The most prominent term in the center, "integrated pest management," has the highest research concentration, highlighting its centrality in the field. Surrounding this core are highly researched terms such as "pest control," "pesticides," "crop production," and "sustainable agriculture," suggesting that these aspects are heavily studied in relation to IPM. This reflects the ongoing research emphasis on balancing pest control efficiency with environmental sustainability. The peripheral terms in green and blue, such as

"natural enemies," "biological pest control," "hymenoptera," and "azadirachta indica," indicate areas with relatively lower research density but still contribute significantly to the broader IPM framework. The presence of economic and policy-related terms like "economics," "procedures," and "European Union" suggests an increasing focus on regulatory frameworks and the cost-effectiveness of IPM strategies.

3.1 Citation Analysis

Table 1. Top Cited Literature

Title	Citations
The use of push-pull strategies in integrated pest management [24]	1180
Integrated pest management: Historical perspectives and contemporary developments [2]	862
Eight principles of integrated pest management [1]	636
Sterile insect technique: Principles and practice in area-wide integrated pest management [25]	630
A review of the invasion of Drosophila suzukii in Europe and a draft research agenda for integrated pest management [26]	588

Source: Scopus, 2025

3.2 Co-Authorship Analysis

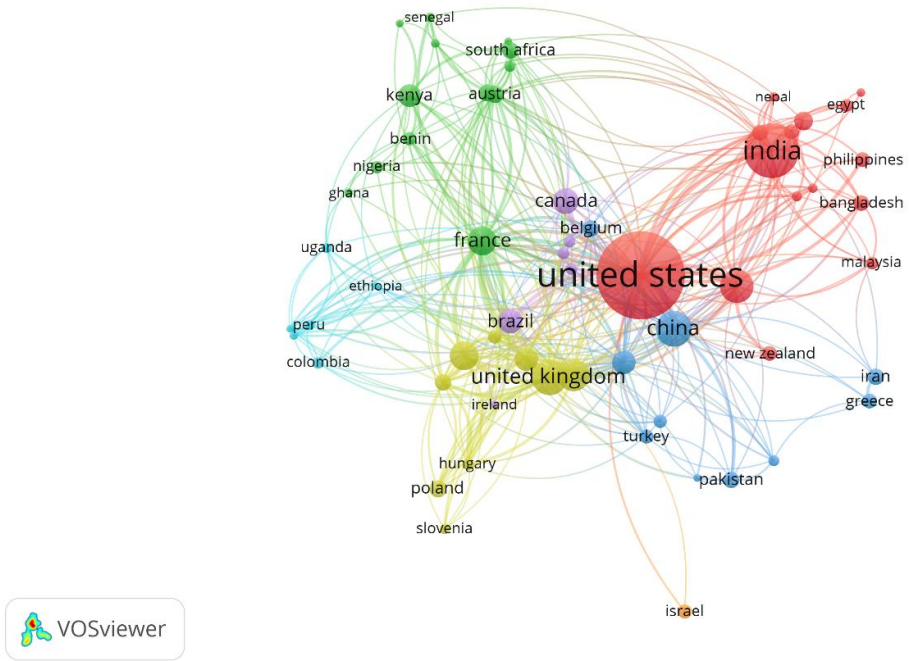

Figure 4. Country Visualization
Source: Data Analysis, 2025

This VOSviewer visualization represents a network map of international research collaborations in Integrated Pest Management (IPM). The size of each node corresponds to the research output of a country, with larger nodes indicating higher contributions to IPM literature. The United States, India, China, and the United Kingdom appear as the most prominent contributors, signifying their central role in global IPM research. The colored clusters represent regional or collaborative research groups, where countries within the same cluster frequently collaborate. For instance, India is closely linked with neighboring countries like Nepal, Bangladesh, and Malaysia, while the

United States collaborates extensively with China, Canada, and European nations. African and South American countries, such as Kenya, Ethiopia, and Peru, form another interconnected cluster, reflecting regional research partnerships. The presence of multiple interconnecting lines suggests strong global collaborations, but also indicates that certain regions, particularly in Africa and South America, have fewer direct connections with dominant research hubs. This visualization highlights both the strengths in global IPM research collaboration and potential areas for expanding international partnerships.

DISCUSSION

The findings from the bibliometric analysis of Integrated Pest Management (IPM) research reveal significant trends, challenges, and opportunities within the field. The increasing number of publications over the past two decades reflects the growing interest in sustainable pest management solutions. The co-occurrence network highlights that research on IPM has expanded beyond traditional entomology to include policy, economics, and technological innovations. The strong connections between terms such as "pesticide application," "biological control," and "sustainable agriculture" indicate that IPM research is highly interdisciplinary. The integration of artificial intelligence and machine learning for pest monitoring and decision-making is an emerging trend that could enhance IPM strategies in the future.

The analysis of international research collaboration demonstrates that developed countries such as the United States, United Kingdom, and China play a central role in advancing IPM research. However, collaboration between developed and developing countries remains limited, potentially hindering the widespread adoption of IPM in regions where it is most needed. Strengthening global research partnerships could facilitate knowledge transfer and capacity-building in developing countries. Additionally, the discussion on economic and policy barriers suggests that while IPM offers sustainable alternatives to chemical pesticides, its adoption is still constrained by factors such as farmer awareness, initial implementation costs, and regulatory frameworks. Addressing these issues requires an integrative approach that combines governmental support, industry participation, and active involvement of farming communities.

Furthermore, the bibliometric analysis suggests that while technological advancements, such as AI-based pest monitoring systems, are gaining attention, their practical application in real-world agricultural settings remains a challenge. Many smallholder farmers in developing countries lack access to these technologies due to high costs, lack of training, and inadequate digital infrastructure. Bridging this technological divide will require targeted initiatives that promote affordable innovations and provide farmers with the necessary training and resources to implement modern IPM solutions effectively. Another key discussion point emerging from this analysis is the role of biopesticides and natural pest control mechanisms. While research into botanical pesticides and microbial biopesticides has gained momentum, their large-scale adoption is often hindered by issues related to market availability, regulatory approvals, and effectiveness in diverse agro-climatic conditions. Policymakers must streamline regulatory processes and invest in research that improves the efficacy and scalability of biopesticides as a viable alternative to synthetic chemical pesticides. Additionally, integrating biopesticides with other IPM strategies, such as crop rotation and habitat management, could enhance their effectiveness and sustainability. The role of education and extension services is also crucial in increasing IPM adoption. Studies have shown that farmers who receive hands-on training and continuous technical support are more likely to implement IPM strategies successfully. Strengthening extension networks and facilitating knowledge-sharing through digital platforms, farmer

cooperatives, and agricultural training programs can accelerate the dissemination of IPM knowledge. In addition, fostering farmer-to-farmer learning initiatives can help build trust and encourage broader adoption of sustainable pest management practices.

Lastly, future research in IPM should focus on assessing the long-term socio-economic impacts of different pest management strategies. While the environmental benefits of IPM are well-documented, more empirical evidence is needed to quantify its economic viability for different farming systems. Conducting comprehensive cost-benefit analyses and impact assessments will help policymakers and stakeholders make informed decisions that support the transition to more sustainable agricultural practices. Moreover, interdisciplinary research that integrates ecological, economic, and social perspectives will be critical in shaping the next generation of IPM policies and strategies. Moving forward, policymakers and researchers must work together to promote the adoption of IPM through targeted extension programs, financial incentives, and regulatory support. Increasing investment in alternative pest control methods, such as biopesticides and pest-resistant crops, can reduce dependency on chemical pesticides. Moreover, interdisciplinary research that integrates technological advancements with socio-economic considerations will be crucial in shaping the future of IPM. The bibliometric analysis underscores the need for a multi-stakeholder approach to achieving sustainable pest management in agriculture. Moving forward, policymakers and researchers must work together to promote the adoption of IPM through targeted extension programs, financial incentives, and regulatory support. Increasing investment in alternative pest control methods, such as biopesticides and pest-resistant crops, can reduce dependency on chemical pesticides. Moreover, interdisciplinary research that integrates technological advancements with socio-economic considerations will be crucial in shaping the future of IPM. The bibliometric analysis underscores the need for a multi-stakeholder approach to achieving sustainable pest management in agriculture.

4. CONCLUSION

This bibliometric analysis of Integrated Pest Management (IPM) research highlights the evolving landscape of sustainable pest control strategies, emphasizing the shift from conventional pesticide reliance to more ecologically balanced approaches. The study reveals that while research in IPM is growing, challenges such as economic constraints, technological accessibility, and policy barriers continue to hinder its widespread adoption. Collaboration between researchers, policymakers, and farmers is crucial to overcoming these barriers and ensuring that IPM strategies are effectively implemented. The integration of artificial intelligence, biopesticides, and precision agriculture techniques represents a promising avenue for future research and innovation in IPM. Strengthening international research collaborations and improving knowledge dissemination through extension services can further enhance the adoption of IPM practices. Ultimately, a multi-stakeholder approach that combines scientific advancements with farmer-centered solutions will be essential for achieving sustainable pest management and agricultural resilience.

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