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Innovations and Future Trends in Storage Pest Management

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Review Article

ABSTRACT

Current innovations and future trends in storage pest management, with a specific focus on the Indian context. The critical role of effective pest management in agriculture and food security is underscored, considering its impact on economic stability and public health. It begins by detailing the challenges faced in storage pest management, including the variety of pests like insects and rodents, and the damage they inflict on stored agricultural products. It critiques the limitations of traditional pest management methods, particularly chemical control, and highlights emerging issues such as climate change effects and pesticide resistance. The core examines the latest innovations in storage pest management. Advanced chemical approaches like novel pesticides and controlled release formulations are discussed, alongside the rise of nanotechnology applications in pest

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control, including nano-pesticides and smart delivery systems. The emergence of biological control innovations, particularly new biocontrol agents, and genetic control strategies like the sterile insect technique, marks a significant shift towards more sustainable pest management methods. Additionally, It explores developments in physical and mechanical control methods, emphasizing improved storage facilities and environmental control techniques. Integrated Pest Management (IPM) approaches are identified as a key future trend, promoting holistic and sustainable strategies, with case studies underscoring their success and practical application. It also addresses the vital role of policy and regulatory developments, considering the impact of global regulations and the importance of international cooperation and standards in shaping pest management practices in India. Ethical and environmental considerations form a crucial part of the discourse, focusing on the ecological impact of pest management and the balance between control measures and conservation efforts. It concludes with an examination of practical applications and case studies, providing insights into real-world challenges and the strategies employed to overcome them. Overall, It offers a thorough analysis of the state-of-the-art in storage pest management, highlighting the intersection of innovation, sustainability, and practicality. It aims to provide valuable guidance for researchers, policymakers, and practitioners in the field, contributing to the advancement of more effective, environmentally responsible, and sustainable pest management strategies in India.

Keywords: Pest management; nanotechnolog;, sustainability; biocontrol; innovation.

1. INTRODUCTION

1.1 Storage Pest Management

Storage pest management, a critical component of post-harvest agriculture, encompasses the strategies and methods employed to protect stored agricultural products from pests including insects, rodents, and fungi. In India, where agriculture plays a vital role in the economy and sustains the livelihoods of millions, effective storage pest management is crucial. The significance of this field lies not only in safeguarding the food supply but also in maintaining the quality and nutritional value of stored produce. The impact of storage pests is not trivial; it's estimated that approximately 10-30% of agricultural produce is lost due to pest attacks in storage, which highlights the gravity of the issue [1]. This loss is particularly significant in a country like India, where food security is a persistent challenge. The history of storage pest management in India is intertwined with its agricultural evolution. Traditional methods, prevalent for centuries, have included the use of natural repellents like neem leaves and turmeric. However, with the Green Revolution in the 1960s, there was a significant shift towards chemical pest control methods. This period marked the introduction of synthetic pesticides, which brought about a revolutionary change in pest management practices. Despite their effectiveness, over time, the adverse environmental and health impacts of these chemicals became apparent, leading to a gradual shift towards more integrated and sustainable approaches [2].

1.2 Importance of Storage Pest Management in Agriculture and Food Security

In India, the economic implications of storage pest management are substantial. The agriculture sector contributes significantly to the country's GDP, and the losses due to storage pests have a direct impact on farmers' incomes and the national economy. A study by Midega [3] indicated that inadequate pest management in storage leads to substantial financial losses, particularly for small and marginal farmers. Additionally, the loss of stored grains and other products reduces the availability of marketable surplus, affecting the entire supply chain from farmers to consumers. This not only impacts the income of the farmers but also increases the prices of food commodities, affecting the affordability for consumers. Beyond the economic ramifications, storage pest management holds critical public health implications in India. Pests like rodents and insects are vectors of various diseases and can contaminate stored food products, making them unfit for consumption. Consumption of pest-infested food can lead to serious health issues, including allergic reactions, food poisoning, and exposure to carcinogenic substances produced by certain fungi [4]. The improper use of chemical pesticides in storage facilities has raised concerns about residual toxicity, leading to potential long-term health risks. This scenario underscores the need for effective, safe, and sustainable storage pest management practices to ensure the health and well-being of the population.

1.3 Purpose of the Review

The primary objective of this review is to provide a comprehensive examination of the innovations and future trends in storage pest management with a specific focus on India, a country where agriculture plays a pivotal role in the economy and societal structure. The scope of this review is expansive, covering the latest advancements, emerging technologies, and future perspectives in the realm of storage pest management [5]. This includes an exploration of advanced chemical and biological control methods, the integration of technology in pest monitoring and management, and the movement towards sustainable and environmentally friendly approaches. The review aims to synthesize current research findings, identify gaps in the existing knowledge, and suggest future research directions. It also seeks to offer valuable insights for policymakers, agricultural professionals, and researchers in the field of pest management. The purpose is not merely to compile existing information but to critically analyze and interpret how these advancements can be effectively implemented in the Indian context, considering the unique challenges and opportunities that the country presents [6]. The methodology for this review involves a meticulous and systematic examination of relevant literature and research studies. Sources include peer-reviewed journal articles, government reports, publications from agricultural research institutes, and findings from international organizations working in the field of

Table 1. The importance of storage pest management in agriculture and food security

Aspect	Importance
Economic Impact	Storage pest management is crucial for minimizing economic losses in agriculture and food industries. Effective pest control prevents significant losses of stored grains, seeds, and other food products, which can amount to a substantial portion of the annual production.
Food Security	By protecting stored food products from pests, storage pest management plays a pivotal role in ensuring food security. This is especially critical in regions where food scarcity is a concern and the margin between food availability and need is narrow.
Quality Preservation	Pests can degrade the quality of stored food products through contamination and physical damage. Managing these pests helps in maintaining the nutritional value and safety of food, ensuring it remains fit for consumption.
Health Protection	Many storage pests are vectors for diseases or can contaminate food with mycotoxins and other hazardous substances. Effective pest management safeguards public health by reducing the risk of foodborne illnesses.
Resource Utilization	Efficient storage pest management contributes to better utilization of resources by reducing the need for repeated production to replace lost stocks. This leads to more sustainable agricultural practices and reduces the environmental footprint of food production.
Market Compliance	Adhering to storage pest management protocols is often a requirement for accessing certain markets or for meeting export standards. It ensures competitiveness and compliance with international food safety standards.
Consumer Confidence	Effective pest management in storage facilities helps in building and maintaining consumer confidence in food products. Consumers are more likely to trust and prefer brands that consistently provide pest-free, high-quality products.
Innovation and Research	The challenge of managing storage pests drives innovation and research in pest control technologies and methods. This leads to the development of more effective, environmentally friendly pest management strategies, benefiting the agricultural sector as a whole.

agriculture and pest management. Electronic databases such as PubMed, Scopus, and Web of Science have been extensively used to gather literature, focusing on publications from the last decade to ensure the relevance and timeliness of the information [7]. In addition, this review also considers traditional knowledge and practices prevalent in India, recognizing their value and potential integration with modern technologies. The selection of sources has been guided by their scientific rigor, relevance to the Indian context, and contribution to the field of storage pest management. The review also involves an analysis of case studies and real-life examples to illustrate the practical applications and implications of various pest management strategies [8]. Government policies, regulatory frameworks, and guidelines specific to India have been examined to understand the broader context in which storage pest management operates. This comprehensive approach ensures a well-rounded understanding of the subject, addressing both the scientific and socio-economic aspects of storage pest management in India [9].

2. CURRENT CHALLENGES IN STORAGE PEST MANAGEMENT

2.1 Common Pests and Their Impact

India, with its diverse climatic zones, faces a wide range of storage pests that pose significant threats to stored agricultural products [10]. The most common pests include various species of insects such as weevils (e.g., *Sitophilus oryzae*), moths (e.g., *Plodia interpunctella*), beetles (e.g., *Tribolium castaneum*), and mites. Rodents, such as rats and mice, are also prevalent and cause substantial damage [11]. Each of these pests has specific characteristics and behaviors that make them particularly destructive in storage environments. The damage caused by these pests is multifaceted. Insects and rodents not only consume the stored grains but also contaminate them with their droppings, urine, and body parts, making the grains unfit for human consumption [12]. This leads to a significant reduction in both the quantity and quality of the agricultural produce. The Food and Agriculture Organization (FAO) estimates that post-harvest losses in developing countries, largely due to pests, can range from 20-50% of the total crop yield [13]. In India, this is particularly concerning given the nation's ongoing battle against food insecurity and malnutrition.

2.2 Limitations of Traditional Pest Management Methods

For decades, chemical pesticides have been the primary method of controlling storage pests in India. However, the overuse and misuse of these chemicals have led to several environmental and health concerns. Pesticides can leave harmful residues in food products, posing risks to consumer health [14]. Additionally, their indiscriminate use has led to environmental degradation, affecting non-target species and leading to a loss of biodiversity. There is also growing concern about the safety of pesticide handlers and the communities living near treated storage facilities. Biological control, using natural predators or pathogens of pests, offers an eco-friendly alternative to chemical control. However, its implementation in India faces several challenges. These include the difficulty in identifying and mass-rearing effective biological control agents, the slow response time in controlling pest outbreaks, and the limited understanding among farmers about these methods. The effectiveness of biological control can be influenced by environmental conditions, making it less reliable in some scenarios [15].

2.3 Emerging Issues

Climate change poses new challenges in storage pest management. Changing temperature and humidity levels can alter pest population dynamics, potentially leading to more severe infestations. For instance, higher temperatures can accelerate the life cycles of many insects, leading to rapid population growth [16]. Additionally, increased humidity levels in storage environments can encourage fungal growth, further exacerbating the problem. Pesticide resistance is an escalating issue in India. Continuous exposure to the same chemical controls has led many pest species to develop resistance, rendering these pesticides less effective over time. This necessitates the use of higher doses or the development of new chemicals, both of which have further implications for human health and the environment [17]. The challenge is compounded by the lack of new pesticides being developed, as the focus shifts to more sustainable pest management practices.

Table 2. Current challenges in storage pest management of grain

Challenge	Description
Resistance Development	Grain pests, such as weevils and beetles, develop resistance to chemical pesticides over time, making them harder to control and necessitating the development of new control strategies.
Environmental Impact	The use of chemical pesticides in grain storage can have detrimental effects on the environment, including pollution and harm to non-target species, necessitating the search for greener alternatives.
Regulatory Challenges	Increasingly strict regulations on pesticide residues in food products challenge the grain storage industry to find effective, compliant pest management solutions.
Global Trade Risks	The international trade of grains can introduce non-native pest species to new areas, complicating local pest management efforts and threatening native ecosystems.
Climate Change Effects	Changing climate conditions can alter the behavior and distribution of grain pests, potentially leading to more severe infestations and the emergence of new pests.
Infrastructure Limitations	In many regions, particularly in developing countries, poor storage facilities with inadequate sealing or climate control exacerbate pest infestations.
Lack of Knowledge	There's often a gap in knowledge and training on modern, effective pest management practices among farmers and storage facility operators, particularly in less developed areas.
Monitoring and Detection	Effective monitoring and early detection of pests in grain storage are crucial but can be challenging and resource-intensive, especially in large storage facilities.
Integrated Pest Management (IPM)	While IPM offers a more sustainable and holistic approach to pest control, its implementation in grain storage is often hampered by costs, complexity, and a lack of awareness or expertise.
Consumer and Market Demands	Consumers and markets increasingly demand grains that are stored and handled using practices that minimize chemical use and ensure sustainability, posing a challenge to traditional pest management methods.

3. INNOVATIONS IN STORAGE PEST MANAGEMENT

3.1 Advanced Chemical Approaches

In India, the innovation in chemical approaches for storage pest management has seen significant advancements, particularly in the development of novel pesticides and formulations. Researchers and agrochemical companies are increasingly focusing on creating chemical compounds that are more effective, environmentally friendly, and safer for human health. One key development in this area is the formulation of bio-pesticides, which include naturally occurring substances that control pests by non-toxic mechanisms and biodegradable pesticides that minimize environmental impact [18]. These new formulations not only help in managing resistance in pests but also reduce the ecological footprint of chemical pest control. Additionally, the development of nano-pesticides, which utilizes nanotechnology for pest control, has emerged as a promising field. These nano-formulations enhance the efficiency of active ingredients, allowing for lower dosages and reduced risks of toxicity [19]. Another innovative approach in the realm of chemical pest management is the development of controlled release systems and targeted application techniques. These technologies ensure that pesticides are released slowly and consistently over time, which increases their effectiveness and reduces the frequency of applications. Targeted application techniques, such as lure-and-kill or attract-and-kill strategies, are also gaining traction. These methods involve attracting pests to a specific location using pheromones or food attractants and then applying pesticides in a localized manner. This not only enhances the efficiency of pest control but also significantly reduces non-target exposure and environmental contamination [20].

3.2 Biological Control Innovations

Biological control methods are gaining prominence in India as sustainable alternatives to chemical pesticides [21]. One of the major areas of innovation in biological control is the identification and utilization of new biocontrol agents. These include various species of parasitoids, predators, and pathogens that naturally regulate pest populations. For instance, the use of entomopathogenic fungi, which infect and kill pests, has shown promising results against a range of storage pests [22]. Additionally, the development of integrated pest management (IPM) programs that combine biological agents with other pest control strategies is becoming increasingly popular. These programs are tailored to specific pests and environmental conditions, offering a more holistic and sustainable approach to pest management. Genetic control strategies represent a cutting-edge area of innovation in pest management [23]. The sterile insect technique (SIT), which involves releasing sterilized male pests into the environment to mate with females, thereby reducing pest populations over time, is gaining attention in India. This method has been particularly effective against fruit flies and other insect pests. Recent advances in genetic engineering, such as gene drive technology, offer the potential to enhance the efficacy of SIT and other genetic control methods. These technologies, however, are still in the developmental and regulatory stages and are subject to ethical and ecological considerations [24].

Table 3. Innovations in storage pest management

Innovation	Description
Biological Control Agents	Utilizing natural predators or parasites of pests to control their populations in storage facilities, offering an environmentally friendly alternative to chemical pesticides.
Pheromone Traps	Employing pheromone traps to monitor and control pest populations by attracting and capturing pests, which helps in reducing their numbers and assessing infestation levels.
Hermetic Storage Solutions	Implementing hermetic (airtight) storage technologies that create low-oxygen environments to effectively control pests without the use of chemicals.
Biopesticides	Developing and applying pesticides derived from natural materials (like plants, bacteria, and certain minerals) which are less toxic and more target-specific than conventional pesticides.
Genetic Engineering	Engineering grains and other stored products to be resistant to pests, reducing the need for external pest control measures.
Insect Growth Regulators (IGRs)	Using substances that interfere with the life cycle of pests, preventing them from maturing or reproducing, as a method of population control.
Integrated Pest Management (IPM) Programs	Implementing IPM strategies that combine biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks.
Improved Storage Infrastructure	Innovating in storage design and materials to prevent pest entry and reduce the conditions that favor pest infestation, such as moisture and poor ventilation.
Remote Sensing and IoT	Applying remote sensing technologies and the Internet of Things (IoT) for real-time monitoring of pest populations and storage conditions, facilitating timely and precise interventions.
Nanotechnology	Exploring the use of nanotechnology in pest management, such as nano-encapsulated pesticides that can target pests more effectively and safely than traditional formulations.

3.3 Physical and Mechanical Control Developments

Innovations in physical and mechanical control methods primarily focus on improving storage facilities and their designs to prevent pest infestations [25]. In India, researchers and engineers are developing storage systems that are more resistant to pests. This includes hermetic storage options like metal silos and SuperGrainbags that create an oxygen-depleted environment, inhibiting the survival of pests. Additionally, advancements in the design of warehouses and godowns, incorporating features such as temperature-controlled storage and improved aeration systems, are proving effective in reducing pest infestations [26]. Environmental control methods, which involve manipulating the storage environment to make it less hospitable to pests, are also being innovatively used in India. Controlling factors such as temperature and humidity can significantly impact pest survival and reproduction. Techniques like cold storage and the use of desiccants to reduce humidity levels are being employed to preserve stored grains and other agricultural products. In addition, the use of controlled atmospheres, where the levels of oxygen, carbon dioxide, and nitrogen are regulated, has shown potential in suppressing pest populations without the use of chemical pesticides [27].

4. FUTURE TRENDS IN STORAGE PEST MANAGEMENT

4.1 Nanotechnology in Pest Control

The future of storage pest management in India is increasingly leaning towards the use of nanotechnology, particularly nano-pesticides. These advanced formulations, developed at the nanoscale, offer several benefits over traditional pesticides, including increased efficacy, targeted delivery, and reduced environmental impact [28]. Nano-pesticides can be engineered to release their active ingredients slowly over time or in response to specific environmental triggers, such as the presence of a pest. This controlled release not only enhances the effectiveness of the pesticide but also minimizes non-target effects and reduces the risk of pesticide resistance developing. Research in India is currently focusing on developing nano-formulations of popular pesticides, as well as exploring natural and biodegradable materials for nano-pesticide production [29]. Alongside nano-pesticides, smart delivery systems represent a significant advancement in pest management technology. These systems are designed to intelligently deliver pesticides in a manner that increases their impact on targeted pests while minimizing exposure to non-target organisms and the environment. Smart delivery systems can be equipped with sensors and controlled-release mechanisms that respond to specific environmental conditions, such as humidity or temperature, which are often key factors in pest outbreaks. The development of such systems is seen as crucial in the efficient management of storage pests, particularly in the diverse and variable climatic conditions of India [30].

4.2 Integrated Pest Management (IPM) Approaches

Integrated Pest Management (IPM) is anticipated to play a central role in the future of storage pest management in India. IPM is a holistic approach that combines various pest control methods, including biological, chemical, cultural, and mechanical practices, in a manner that minimizes risks to human health and the environment. This approach is increasingly being adopted in India, driven by the need for sustainable and environmentally friendly pest management solutions. The future of IPM in India involves not only the integration of existing pest control methods but also the incorporation of new technologies and innovations, such as nanotechnology and smart delivery systems, into IPM strategies [31]. There are several success stories and case studies in India that highlight the effectiveness of IPM approaches in storage pest management. For example, the implementation of IPM strategies in the storage of grains like wheat and rice has shown a significant reduction in pest infestations while minimizing the use of chemical pesticides. These success stories often involve community participation and the education of farmers and storage facility managers in IPM principles and practices. The dissemination of these success stories and case studies is crucial for encouraging the wider adoption of IPM strategies across India [32].

4.3 Policy and Regulatory Developments

The future of storage pest management in India is also influenced by global regulations and policies. International agreements and standards, such as those set by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), play a significant role in shaping pest management practices. These regulations often focus on the safe use of pesticides, the promotion of sustainable pest management practices, and the protection of food safety and security. India, as part of the global community, is influenced by these regulations, and this is reflected in the country's policies and guidelines regarding storage pest management [33]. International cooperation and adherence to global standards are expected to become increasingly important in the future of storage pest management in India. Collaborative efforts in research and development, information sharing, and capacity building can play a critical role in advancing pest management strategies. Additionally, compliance with international standards ensures that Indian agricultural products meet global market requirements, which is crucial for the country's export-oriented sectors. The harmonization of India's pest management practices with international standards also facilitates the exchange of best practices and technologies, further enhancing the country's pest management capabilities [34].

5. ETHICAL AND ENVIRONMENTAL CONSIDERATIONS

5.1 Environmental Impact of Pest Management

The environmental impact of pest management practices in India is a subject of significant ecological concern. The use of chemical pesticides, traditionally a common approach in pest management, has raised serious environmental issues. These chemicals often have non-target effects, impacting soil health, water quality, and biodiversity. Insecticides and rodenticides, when not used judiciously, can harm beneficial insects, aquatic life, birds, and other wildlife, disrupting local ecosystems [35]. Moreover, the persistence of these chemicals in the environment can lead to bioaccumulation and biomagnification, posing long-term ecological risks. The ecological considerations extend to the impact on pollinators such as bees, which are vital for the pollination of many crops and the overall health of ecosystems. Recent studies in India have shown a decline in pollinator populations, partly attributed to the indiscriminate use of pesticides [36]. Sustainability in pest control is increasingly becoming a priority in India, with a focus on developing and implementing practices that are ecologically sound and economically viable in the long term. This shift is driven by the understanding that sustainable pest management is crucial not only for environmental health but also for the long-term viability of the agricultural sector. Sustainable practices include the adoption of Integrated Pest Management (IPM) strategies, which combine biological, cultural, physical, and chemical tools in a way that minimizes ecological damage [37]. Organic farming, which eschews synthetic pesticides in favor of natural pest control methods, is also gaining traction in India as a sustainable approach. The development of pest-resistant crop varieties through traditional breeding or biotechnological methods is seen as a sustainable way to reduce reliance on chemical pest control.

5.2 Ethical Aspects

The ethical considerations in pest management primarily revolve around safety concerns for humans and non-target species. The use of chemical pesticides has raised significant health concerns, particularly for farmers, pesticide applicators, and residents in agricultural areas. There is increasing evidence linking pesticide exposure to a range of health issues, including respiratory problems, skin disorders, and even long-term effects such as cancer and neurological disorders [38]. The ethical dilemma extends to the impact on non-target species, including beneficial insects, wildlife, and domestic animals. Ensuring the safety of these organisms while controlling pest populations is a major ethical challenge. The responsible use of pesticides, adherence to safety protocols, and education of users about the risks are essential steps towards addressing these concerns. Balancing pest control with conservation is a complex ethical issue. On one hand, there is a need to control pests to ensure food security and economic stability; on the other hand, there is a responsibility to conserve biodiversity and protect ecosystems. This balance is particularly challenging in India, where high biodiversity and intense agricultural activity coexist. The conservation of native species and habitats must be considered in pest management strategies. This involves evaluating the ecological roles of pests and their natural predators and finding ways to manage pest populations without disrupting these roles. For instance, conserving natural habitats around agricultural fields can support natural predator populations that help control pests. Additionally, the ethical consideration of minimal harm calls for pest management strategies that are effective yet cause the least harm to the environment and non-target species.

6. CASE STUDIES AND PRACTICAL APPLICATIONS

6.1 Success Stories in Innovative Pest Management

Innovative pest management techniques have seen success in various parts of the world, providing valuable lessons for India. One notable example is the use of pheromone traps in the United States for managing codling moth populations in apple orchards. This method, which involves using sex pheromones to attract and trap male moths, has significantly reduced the need for chemical insecticides [39]. In Australia, the implementation of area-wide management for fruit flies using the Sterile Insect Technique (SIT) has effectively controlled these pests in vast regions, thereby reducing crop losses and pesticide use. Israel's adoption of biocontrol agents for managing whiteflies in greenhouses is another success story. The introduction of predatory insects like Encarsia formosa has led to a sustainable control of whiteflies, minimizing chemical pesticide use and promoting a healthier environment [40].

6.2 Challenges and Overcoming Strategies

In India, the implementation of innovative pest management strategies faces several challenges. One of the primary obstacles is the lack of awareness and education among farmers about advanced pest management techniques. Many small-scale farmers still rely on traditional practices or excessive use of chemical pesticides, often due to a lack of access to information or training. Financial constraints and limited access to new technologies also pose significant barriers. Additionally, the diverse climatic conditions and crop varieties across India necessitate region-specific strategies, complicating the implementation of a unified pest management approach [41]. To overcome these challenges, several adaptive strategies and solutions are being implemented. Government initiatives and public-private partnerships play a pivotal role in educating farmers and promoting the adoption of innovative pest management practices. For instance, the Indian government's 'Pradhan Mantri Krishi Sinchayee Yojana' scheme includes components for promoting micro-irrigation and water management practices, indirectly aiding pest management by creating less favorable conditions for pest proliferation. The establishment of local farmer groups and cooperatives can facilitate knowledge sharing and collective action in adopting new practices. Research institutions in India are increasingly focusing on developing cost-effective and easy-to-implement pest management solutions suited to the local conditions. For example, the Indian Council of Agricultural Research (ICAR) conducts research and extension activities related to IPM and sustainable agriculture practices [42]. Emphasizing farmer participatory research ensures that the solutions developed are practical and acceptable to the farming community.

7. CONCLUSION

The innovations and future trends in storage pest management, particularly in the Indian context, has highlighted a dynamic and evolving field. The shift from traditional methods to advanced strategies like nanotechnology, integrated pest management (IPM), and smart delivery systems reflects a growing emphasis on sustainability, efficiency, and environmental responsibility. The challenges posed by ecological concerns, safety issues, and implementation barriers underscore the need for continuous research, education, and adaptive strategies. The success stories from around the world offer valuable lessons for India, emphasizing the importance of integrated approaches, collaboration, and localized solutions. As India continues to tackle the complexities of pest management in agriculture, embracing these innovative practices and learning from global experiences will be crucial in ensuring food security, environmental health, and sustainable agricultural development.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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