Plant Protection, 08 (04) 2024. 789-802 DOI:10.33804/pp.008.04.5386

Available Online at EScience Press
Plant Protection
ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

Review Article

SUSTAINABLE PEST MANAGEMENT STRATEGIES FOR AGRICULTURE IN PAKISTAN: A REVIEW

[a]Hamza Noman, [a]Sadaf Saif, [b]Shaharyar Shoukat

[a] *Department of Biological Sciences, The Superior University, Lahore, Punjab, Pakistan.*
[b] *Department of Education, Riphah International University, Lahore, Punjab, Pakistan.*

ARTICLE INFO

Article history
Received: 22nd September, 2024
Revised: 24th October, 2024
Accepted: 15th November, 2024

Keywords
Integrated Pest Management
Biological control agents
Precision agriculture
Farmer Field School (FFS)
Biopesticides

ABSTRACT

The agriculture sector of Pakistan's economy faces significant challenges, including water scarcity, land degradation, climate change, and pest infestations, all of which threaten crop production and rural livelihoods. Historically, pest management has heavily relied on chemical pesticides, such as organophosphates and pyrethroids. While these provide short-term solutions, their extensive use has led to environmental degradation, health risks, and the development of resistance in cotton and vegetable crops. In response, integrated pest management (IPM) has emerged as an ecological approach that combines biological, cultural, mechanical, and selective chemical controls to regulate pest populations while minimizing environmental damage. This study reviews pest control practices in Pakistan, with a particular focus on the National IPM Programme and Farmer Field Schools. Successful programs under these initiatives have reduced pesticide use by 87% and increased crop yields by 10-25%. Case studies highlight the effectiveness of biological controls, such as *Trichogramma* wasps and *Beauveria bassiana* fungi, which have resulted in reduced pesticide use and yield improvements of up to 18%. However, challenges persist, including farmer education, a lack of facilities for maintaining biological control agents, and climate-induced shifts in pest populations. The study also emphasizes the potential of precision agriculture technologies, such as drones, remote sensing, and AI-driven monitoring systems, for pest surveillance and targeted interventions. Policy recommendations include providing institutional support, enhancing farmer capacity, investing in biopesticides and genetically modified organisms, and fostering collaboration among government agencies, research organizations, and farmers to ensure the long-term sustainability and resilience of agriculture in Pakistan.

Corresponding Author: Hamza Noman
Email: humzanomanshoukat@gmail.com

INTRODUCTION

Agriculture has long been a cornerstone of Pakistan's economy, contributing 18.9% to the Gross Domestic Product (GDP) and employing 42.3% of the workforce (Government of Pakistan, 2018). The climate is well-suited for growing staple crops such as wheat, rice, and cotton, as well as economically significant fruits like mangoes and citrus. However, Pakistan's agricultural sector faces considerable challenges, including water scarcity, land degradation, climate change, and pest infestations, all of which threaten crop yields and farmers' livelihoods (Aziz and Hussain, 2018a). Effective pest management is crucial, as certain pests, such as fruit flies and aphids, can cause up to 80% crop loss, impacting both domestic consumption and export markets (Aziz and Hussain, 2018b; Nabeel et al., 2018).

Historically, Pakistan has relied on chemical pesticides, particularly organophosphates and pyrethroids, to control pests. While these chemicals initially provided effective control, their extensive subsidization has led to negative consequences, including ecological damage, health risks, and increased pest resistance. For instance, heavy pesticide use in cotton fields has contributed to the resistance of pests like the beet armyworm (*Spodoptera exigua*) and the red cotton bug (*Dysdercus koenigii*). Furthermore, pesticide applications on vegetables have posed significant health hazards to farmers and left harmful residues on produce (Shahid et al., 2016).

In response to these issues, Integrated Pest Management (IPM) has emerged as a viable alternative. IPM combines biological, cultural, mechanical, and selective chemical controls to manage pest populations in an environmentally safe and health-conscious manner (Sarwar, 2013). The National IPM Program in Pakistan, supported by international organizations such as the Food and Agriculture Organization (FAO) and the United Nations Development Programme (UNDP), has promoted the adoption of IPM practices through regulatory support and farmer training programs (Mahmood et al., 2014a). For example, Farmer Field Schools (FFS) have played a pivotal role in educating farmers on IPM methods, leading to reductions in pesticide use and sustainable improvements in crop yields (Ali and Sharif, 2012a).

Despite its many benefits, the adoption of IPM faces significant challenges. Many farmers lack the training and resources needed to effectively implement biological control methods, while large-scale production of biological control agents is hindered by regulatory and infrastructural constraints (Irshad, 2023a). Moreover, climate change is shifting pest dynamics, requiring adaptive strategies and the development of predictive models to track and manage pest populations (Arshad et al., 2019).

In Pakistan, technological advancements in pest management, such as precision agriculture and remote sensing, are helping to monitor current pest populations and target interventions effectively (Azfar et al., 2015a). Innovations like drones equipped with high-resolution imaging sensors and AI algorithms now allow for precise detection of pest hotspots, enabling targeted applications of pesticides or biological agents. This approach not only reduces labor costs but also minimizes environmental impact (Filho et al., 2019).

Socioeconomically, sustainable pest management practices extend beyond agricultural productivity by reducing crop losses and input costs for smallholder farmers, thereby enhancing livelihoods and improving food security (Bajwa et al., 2019a). The pesticide use in Pakistan is regulated by the Pesticide Ordinance of 1971 and the Agricultural Pesticides Rules of 1973, and the agricultural sector is gradually adopting more eco-friendly practices (Mahmood et al., 2014b; Afzal and Mukhtar, 2024). For widespread and sustainable IPM adoption, stronger policy support, along with subsidies and incentives, is essential (Afzal et al., 2023a).

This review analyzes the current scenario of pest management strategies in Pakistan, focusing on the evolution of practices, existing challenges, and technological advancements. Through case studies and an examination of the socio-economic impacts of various pest management approaches, it emphasizes the importance of integrating technology-driven solutions to promote sustainable agricultural development in Pakistan.

MATERIALS AND METHODS

Researchers conducted a comprehensive literature search focused on key topics, including "pest management in Pakistan", "integrated pest management (IPM)" and "biological pest control in Pakistan". The search utilized a variety of keywords and spanned multiple databases such as Google Scholar, PubMed, Web of Science, and Scopus to access the latest 30 relevant publications. To ensure the quality and relevance of the sources within the agro-economic, environmental, and technological context of Pakistan, only peer-reviewed journal articles, review papers, and conference proceedings published after 2010 were included. Studies published prior to 2010, as well as those in grey literature, opinion pieces, non-scientific publications, or from countries outside Pakistan (unless offering comparative insights), were excluded to maintain focus and uphold the integrity of the review.

RESULTS

Introduction to pest management strategies in Pakistan

Agriculture plays a critical role in the economy Pakistan of Pakistan, engaging 42.3% of the workforce and contributing 18.9% to the GDP (Government of Pakistan, 2018). The diverse climates of the country support the cultivation of staple crops such as wheat, rice, and cotton, as well as economically valuable fruits like mangoes and citrus. However, challenges including water scarcity, land degradation, climate change, and pest infestations threaten crop yields and the livelihoods of farmers (Aziz and Hussain, 2018a, c). Effective pest management is crucial for agricultural sustainability, as certain pests, such as fruit flies and aphids, can cause crop losses of up to 80%, impacting both local consumption and export markets (Aziz and Hussain, 2018c).

Key pest control strategies include:

Chemical control

Although commonly applied, this approach faces limitations due to pest resistance and environmental impacts (Bakhtawer and Afsheen, 2021a).

Biological control

Utilizing natural enemies to manage pests offers an eco-friendly and cost-effective solution (Mahmood et al., 2014a; Rahoo et al., 2019a, b).

Integrated Pest Management (IPM)

IPM integrates physical, chemical, and biological methods to minimize pesticide use and environmental harm (Sarwar, 2013).

The effectiveness of these strategies largely depends on the regulatory framework of Pakistan for pesticide use and pest management. Government policies play a significant role in promoting sustainable agricultural practices by regulating pesticide safety and encouraging eco-friendly alternatives. For instance, the Pesticide Ordinance of 1971 and the Agricultural Pesticides Rules of 1973 provide guidelines on pesticide registration and application.

In Pakistan, effective pest management strategies are foundational for sustaining agricultural productivity. However, these approaches have evolved over time. To understand the current landscape of pest management, it is essential to trace the historical development of these practices and their influence on modern approaches.

Historical evolution of pest management

Initially, pest control in Pakistan relied heavily on chemical pesticides, particularly organophosphates and pyrethroids. Although these chemicals were effective at first, over time, they became associated with significant environmental degradation, health risks, and resistance development in pest populations. For instance, use of chemical insecticides in cotton farming has contributed to resistance in pests like the beet armyworm and red cotton bug (Ahmad et al., 2018). Moreover, excessive pesticide use on vegetables has raised safety concerns for farmers and left harmful residues on produce (Damalas and Khan, 2017).

Today, IPM is increasingly practiced in Pakistan as a sustainable alternative, combining biological control, cultural practices, mechanical controls, and selective pesticide use. Alternatives to chemical pesticides, such as biological controls involving natural enemies and parasitoids, are gaining popularity, with predator-based management proving effective in citrus pest control (Rahoo et al., 2017, 2018a, b). FFS play a crucial role in educating farmers on IPM techniques, reducing pesticide usage, lowering costs, and boosting productivity (Ali and Sharif, 2012b). At the national level, IPM programs receive regulatory support to promote sustainable practices and significantly reduce pesticide dependency.

Though chemical control dominated early pest management in Pakistan, over-reliance on synthetic pesticides has resulted in numerous negative consequences, including environmental harm and decreased pest susceptibility. The following section will discuss the primary chemical control methods used and assess their impact on agricultural productivity and the environment.

Chemical control methods

Chemical pesticides, including insecticides, herbicides, acaricides, and fumigants, are widely used in Pakistan. These pesticides fall into several classes, such as organophosphates, pyrethroids, neonicotinoids, and carbamates. Commonly used pesticides on cotton, vegetables, and fruits include chlorpyrifos, cypermethrin, and imidacloprid (Shahid et al., 2016). Even though chemical pesticides are effective at controlling pests and increasing crop yields, such as Bt cotton, which yields 20% more than non-Bt varieties due to enhanced pest resistance, pest populations develop resistance over time. This resistance leads to the need for higher doses and more frequent applications (Saeed et al., 2019).

However, intensive pesticides use in Pakistan poses significant environmental and health risks. Pesticides contaminate soil, water, and air, harming non-target organisms, including beneficial insects (Shahid et al., 2016). Health complications such as headaches, respiratory issues, skin disorders, and even chronic conditions like cancer and organ damage have been reported, especially among farmers in Muzaffargarh. Excessive pesticide applications beyond recommended levels further exacerbate these hazards.

Biological control is a sustainable alternative to chemical pesticides. Natural predators and biocontrol agents, discussed in the next section, offer an eco-friendly approach to managing pest populations.

Biological pest control

Biological control involves using natural enemies, such as predators, parasitoids, and pathogens, to manage pest populations in an environment, primarily reducing the need for chemical pesticides and promoting environmental sustainability. Common biocontrol agents in Pakistan include lady beetles, lacewings, *Trichogramma* wasps, and fungi like *Beauveria bassiana* and *Metarhizium anisopliae* (Irshad, 2023a).

Success Stories

Citrus pests

The beetle *Cryptolaemus montrouzieri* has proven effective in controlling psylla and scale insects in citrus orchards of Pakistan. Studies show that using this beetle led to a 50% reduction in pesticide use and a 15% increase in yield over two years (Mahmood et al., 2016a).

***Trichogramma* in cotton**

In Punjab, releasing *Trichogramma* wasps to control cotton bollworms reduced chemical pesticide usage by 30%, increased cotton yield by 12%, and decreased pesticide runoff by 40%, lowering environmental risks and costs for farmers (Ahmad et al., 2018).

Entomopathogenic fungi

Beauveria bassiana and *Metarhizium anisopliae* fungi have been effective in managing sugarcane borers and aphids. Field experiments in Punjab showed a 60% reduction in pest infestation, boosting rice and sugarcane yields by up to 18% (Khan et al., 2019). In Khyber Pakhtunkhwa, vegetable farmers reported a 40% increase in crop yield and a 35% reduction in pesticide use with these fungi, making them a sustainable alternative to chemical pesticides (Ahmed and Hassan, 2020; Javed et al., 2019a, b; Gulzar et al., 2020; Shehzad et al., 2021, 2022).

Challenges in scaling up

Knowledge gaps

Many farmers lack training in biological control techniques, highlighting the need for educational programs and extension services.

Regulatory barriers

Limited infrastructure for mass-rearing biocontrol agents and regulatory challenges have hindered large-scale adoption.

Climate impact

Climate change affects the effectiveness of biological agents, necessitating adaptable management strategies to maintain efficiency (Irshad, 2023b).

Biological control is most effective when integrated with other methods, as in IPM, which combines biological, cultural, mechanical, and selective chemical controls into a balanced, sustainable pest management strategy (Javed et al., 2017a, b; Muhammad et al., 2021a, b; 2022).

IPM in Pakistan

IPM is a comprehensive approach to pest control that incorporates multiple techniques to reduce pesticide use and mitigate environmental and health risks. The core principles of IPM include:

Prevention

Using methods like crop rotation and resistant crop varieties to minimize the need for chemical treatments.

Surveillance

Consistently monitoring pest populations to enable data-driven actions.

Control methods

Applying biological, cultural, mechanical, and chemical controls to maintain pest populations at or below economically harmful levels (Kassi et al., 2017, 2018; Aslam et al., 2019).

Evaluation

Regularly assessing and, if needed, adjusting pest control measures (Sarwar, 2013).

IPM case studies

Farmer Field Schools (FFS)

In Punjab, farmers trained in FFS have achieved significant benefits from IPM, reducing pesticide use by 87% and increasing cotton yields by 10.5% compared to non-FFS farmers. This reflects effectiveness of FFS as a model for promoting IPM practices across regions (Ali and Sharif, 2012c).

National IPM programme

The National IPM program's FFS has actively promoted sustainable pest management throughout Pakistan. In

Punjab, cotton farmers reduced pesticide use by up to 40% while increasing yields by up to 15%. Management of resistant pests, such as bollworms, has enhanced long-term sustainability of IPM. In Sindh, the program focused on vegetable production, leading to a 30% reduction in pesticide use, and a 20% yield increase, demonstrating the success of the program in improving food safety and farmer livelihoods (Mahmood et al., 2014a; Siddiqui et al., 2016).

Vegetable crops in Sindh

IPM practices in vegetables like tomatoes and eggplants led to healthier crops with lower pesticide residues, improving food safety. Pesticide usage declined by 40%, while yields increased by 18% within three years. Also, water contamination from pesticides was reduced by 25%, and the higher-quality produce received greater market demand (Siddiqui et al., 2016).

IPM promotes environmental sustainability by reducing pesticide use, conserving biodiversity, and maintaining ecological balance (Sarwar, 2013). It also increases economic efficiency by lowering chemical costs and boosting crop yields (Ali and Sharif, 2012b), while enhancing health and safety through reduced exposure to harmful chemicals.

Though IPM is a proven strategy, emerging technologies are set to transform pest management practices. Innovations such as drone technology, precision agriculture, and AI-driven pest monitoring are becoming key elements in the future of pest control.

Advances in pest management technology

Precision agriculture and drones are emerging as transformative tools for enhancing pest management and crop protection in Pakistan, offering significant savings in time and resources through real-time monitoring and targeted interventions. These technologies are currently being piloted in various regions of Punjab and Sindh, particularly for high-value crops such as cotton, rice, and sugarcane. For example, in southern Punjab, drones equipped with high-resolution imaging sensors and artificial intelligence-driven software are used in cotton fields to pinpoint pest hotspots, allowing for precise pesticide application. This approach has reduced the use of broad-spectrum chemicals by 40% and increased cotton yields by 12% (Ahmed and Hassan, 2020).

Similarly, drones in the rice fields Sindh help detect pests like the rice stem borer early, reducing crop damage by up to 25%, highlighting the potential for large-scale adoption (Khan et al., 2019).

In addition to drones, technologies such as Geographic Information Systems (GIS) and satellite imagery are being employed to monitor soil health and pest populations across vast agricultural areas in Punjab. Azfar et al. (2015b) note that real-time satellite data allows farmers to make informed pest management decisions, reducing pesticide use and improving crop health in regions like Sargodha. In sugarcane fields of central Punjab, drones are also being used for precise biopesticide applications, saving labor costs by 30% and reducing pesticide runoff into water bodies by 25% (Ahmed and Hassan, 2020). This technology is ideal for large commercial farms where manual pest monitoring is inefficient.

Despite these promising developments, several challenges hinder the widespread adoption of precision farming and drone technology in Pakistan. The high cost of acquiring and maintaining these technologies remains a major barrier, particularly for small-scale farmers. These farmers, who make up the majority of agricultural workers in regions like Balochistan and Khyber Pakhtunkhwa, often lack the resources to invest in mechanized tools. Even in Punjab, while large commercial farms are slowly adopting these technologies, many small-scale farms in remote areas face difficulties due to limited access to capital and subsidies (Afzal et al., 2023a). For example, only 15% of farmers in the cotton-growing districts of central Punjab have adopted drone technology, while the rest rely on traditional pest control methods (Siddiqui et al., 2016).

Another significant challenge is the lack of technical expertise and training. Few farmers in rural areas, particularly in Sindh and Balochistan, know how to operate drones, analyze GIS data, or integrate this technology into their pest management strategies (Khan et al., 2019). Although pilot training programs have been initiated in Punjab by the National IPM Program, their scope is limited, and many remote areas remain underserved. Furthermore, the quality of training is often theoretical rather than practical, and the equipment is not readily accessible to farmers, leaving them ill-equipped to use it effectively (Ali and Sharif, 2012a).

Regulatory hurdles also impede the adoption of drone technology. In Pakistan, farmers must obtain permits and licenses to use drones in agriculture, a process that can be time-consuming and discouraging, especially for smallholder farmers in remote areas. In Sindh, for instance, farmers report waiting months for approval to use drones for pest control, which hampers adoption (Ahmed and Hassan, 2020). The absence of standardized regulations further complicates the issue and deters farmers from integrating these technologies into their farming practices.

Infrastructure challenges, such as inadequate internet connectivity and electricity supply, also limit the use of digital-based tools like GIS and drones in rural areas, particularly in northern Khyber Pakhtunkhwa and parts of Balochistan (Abid et al., 2016a). These infrastructure gaps not only hinder access to advanced technologies but also prevent the delivery of training and technical support to farmers.

To overcome these challenges, government intervention is essential. Subsidies, low-interest loans, and targeted grants for purchasing drones and precision agriculture equipment could help reduce cost barriers for smallholder farmers. Expanding and strengthening technical training programs, particularly in remote areas, would also enhance farming efficiency across the country. Moreover, the government should streamline the regulatory framework for drone use in agriculture and eliminate bureaucratic hurdles that currently deter farmers from adopting this technology. Public-private partnerships, as seen in Punjab, could further accelerate the scaling up of precision farming, with technology companies collaborating with agricultural extension services to provide support and resources (Azfar et al., 2015c, d).

Socio-economic impact of pest management practices

Effective pest management, particularly through sustainable methods like IPM, boosts productivity of farmers while reducing pest control costs. Studies on cotton farming, particularly those involving FFS, demonstrate that such practices lead to higher productivity and profitability with minimal pesticide use (Ali and Sharif, 2012a). Proper pesticide management enhances the livelihoods of smallholder farmers, improves food security, and increases agricultural productivity while minimizing losses. For instance, controlling the invasive weed *Parthenium hysterophorus* has directly improved the income and food security of rural farmers (Bajwa et al., 2019b).

Many farmers still rely on chemical pesticides due to a lack of knowledge about modern pest management techniques and the limited availability of IPM and biological controls (Bakhtawer and Afsheen, 2021b). The higher initial costs associated with these sustainable methods also discourage smallholders from adopting them, despite their long-term benefits (Khan and Damalas, 2017). Cultural beliefs and traditional practices often create resistance to new pest control methods (Siddiqui et al., 2016).

Beyond economic considerations, an important environmental factor is ensuring sustainability in pest management. Sustainable approaches like IPM and biological controls can reduce pesticide use, preserve biodiversity, and decrease pollution, contributing to long-term agricultural resilience.

Environmental sustainability and pest management

Sustainable agriculture focuses on balancing pest control with environmental protection. IPM is a strategy that combines biological, cultural, and chemical techniques to control pests while minimizing negative environmental impacts. Biological control, using natural predators and parasites, is central to reducing chemical pesticide use and maintaining ecological balance (Akhtar and Khoso, 2016).

Pest control methods must be evaluated for their effects on biodiversity. Although chemical pesticides are effective, they often harm non-target species, reducing biodiversity and disrupting ecosystem services such as pollination. In contrast, biological control and IPM strategies preserve beneficial insects with minimal chemical inputs, thereby enhancing biodiversity. This approach has proven successful in Sindh province, where eco-friendly pest control practices have increased yields and preserved beneficial species (Afzal et al., 2023b). Practices like IPM and organic farming contribute to sustainable agricultural landscapes by promoting healthy soils, reducing pollution, and protecting biodiversity. Green Supply Chain Management (GSCM) practices further support recycling and resource efficiency. In Pakistan, the adoption of IPM has led to increased crop productivity and reduced environmental risks (Mumtaz et al., 2018).

However, ensuring environmental sustainability in pest management requires strong policy frameworks and government support. Effective governmental policies and regulations will be crucial for promoting sustainable pest management practices and reducing dependence on chemical pesticides, as discussed in the following section.

Government policies and support to pest management

The government has implemented policies aimed at reducing chemical pesticide use and promoting eco-friendly agriculture. Key regulations, such as the Pesticide Ordinance of 1971 and the Agricultural Pesticides Rules of 1973, govern pesticide registration and usage. The National IPM Program, funded by the FAO and UNDP, provides technical assistance and promotes sustainable, eco-friendly pest control methods (Mahmood et al., 2014b). In addition, FAO-supported FFS enhance farmers' skills in pest management, improving their income-generating potential. Government subsidies further incentivize the adoption of IPM practices by reducing implementation costs (Akhtar and Khoso, 2016). Extension agents play a crucial role in training farmers to effectively apply IPM techniques (Khan and Damalas, 2017). The National IPM Program has successfully reduced pesticide use by 30% while boosting crop yields. FFS participants reduced pesticide usage by 87% and increased cotton yields by 10.5%. These government policies have not only reduced environmental and health risks but have also fostered the principles of sustainable agriculture (Afzal et al., 2023a).

Although these policies have laid a strong foundation for sustainable pest management, emerging technologies and innovations may shape the future of pest control. Trends such as genetically modified crops and precision agriculture hold promise for advancing pest management practices in Pakistan, as discussed in the following section.

Trends ahead in pest management for crops production

Precision farming, remote sensing, and drones with real-time monitoring and localized pesticide applications help reduce the use of broad-spectrum chemicals, promoting sustainable pest management (Gaydon et al., 2021). Genetically modified crops and biological control agents offer environmentally friendly alternatives to chemical pesticides (Mahmood et al., 2014a). Biopesticides, derived from natural sources, are more eco-friendly than synthetic pesticides. Neem-based biopesticides have proven effective against pests in Pakistan, while organic farming enhances biodiversity, soil health, and crop yields (Ali et al., 2017). Research should focus on the development and improvement of biopesticides and their application (Ali et al., 2017). Policies that support drones, remote sensing, and precision farming for smallholders are increasingly in demand (Gaydon et al., 2021). IPM and organic farming practices can be further encouraged through training, incentives, and certification programs that promote sustainability (Afzal et al., 2023b). Strengthening extension services is crucial for enhancing farmers' pest management capacities.

To better understand the practical applications of these innovations, case studies of successful pest management strategies can provide valuable understandings. The following sections discuss the practical use of IPM, biological control, and other pest management methods for major crops in Pakistan.

Case studies of successful pest management in different crops

Wheat

A study in Khyber Agency, FATA, assessed pest management practices among wheat farmers, revealing that over 65% relied on chemical pesticides to control weeds, insects, and diseases. With the introduction of IPM practices, pesticide use decreased by 40%, while wheat yield increased by 15% (Khan and Nawab, 2017). Moreover, IPM adoption resulted in an average 25% reduction in input costs, boosting profit margins for these farmers (Khan and Nawab, 2017).

Rice

In Sindh province, an IPM program targeting rice stem borer was implemented using biological control agents like *Trichogramma* species, supplemented with cultural practices such as field flooding. This approach led to a 50% reduction in pesticide use and a 22% increase in rice yield within three years (Khan et al., 2015). As a result, farmers experienced a 30% income boost due to lower input costs and improved rice quality (Khan et al., 2015).

Cotton

In Punjab, IPM adopters who incorporated biological controls, including predators and parasitoids, along with reduced insecticide use, achieved favorable results. Pesticide application decreased by 60%, and cotton yield was 18% higher compared to fields managed with conventional, non-IPM methods. Reduced chemical inputs also improved soil health by 25%, promoting long-term sustainability in cotton farming (Siddiqui and Siddiqui, 2013).

These case studies underscore the effectiveness of IPM in diverse crop settings. However, pest management practices vary significantly across regions in Pakistan, influenced by local conditions and specific challenges. The following discussion addresses regional variations in pest management and the factors contributing to these differences.

Pest control in different regions

A comparative analysis of IPM practices across agricultural regions shows notable differences. For instance, in Punjab, IPM practices in cotton fields have achieved better pest control and reduced pesticide usage compared to previous methods. In Sindh, however, IPM implementation has been limited, as many farmers lack training and resources (Khan and Damalas, 2017). Education programs like FFS significantly enhance farmers' knowledge of pest management (Siddiqui and Siddiqui, 2013). Studies have shown that an integrated approach using both biological and chemical controls effectively manages pests and slows the development of resistance, as demonstrated in rice and cotton by Khan et al., 2019. The adoption of IPM contributes to sustainable pest management with both economic and environmental benefits, as evidenced in Punjab.

Farmers' perceptions and willingness to adopt these strategies are key to the effectiveness of IPM practices. This section examines how farmer awareness, education, and access to resources impact the adoption of sustainable pest management practices and identifies ways to increase uptake.

Pest management practice adoption and farmer perceptions

In Punjab, 70-82% of farmers rely on chemical pesticides, despite being fully aware of their health and environmental risks. Farmers favor these chemicals primarily for their effectiveness, even though some recognize the benefits of IPM but continue to prefer chemical options for more immediate results. Education and training play significant roles in the adoption of sustainable pest management; most educated farmers and those trained in IPM are more likely to adopt these practices. Support from extension services, government initiatives, and NGOs has also encouraged IPM adoption, helping to reduce pesticide usage while maintaining good yields. Programs like Punjab's FFS serve as successful examples of these efforts. However, more training is needed, especially in areas with limited access to information (Khan et al., 2015).

Looking forward, the future of pest management remains uncertain due to the challenges posed by climate change. As climate change affects pest dynamics, developing adaptive pest management strategies that are resilient to these impacts will be essential.

Impact of climate change on pest dynamics and management

Climate variability significantly impacts pest ecology, increasing the range, survival, and spread of invasive species. Rising temperatures and fluctuating rainfall contribute to heightened crop losses and have driven outbreaks of pests such as aphids and wheat rust in Punjab (Arshad et al., 2019). To address these challenges, IPM strategies must adapt to climate change, incorporating climate-resilient practices, resistant crop varieties, and enhanced monitoring systems. Predictive models that utilize climate data, including temperature and humidity, are essential for forecasting pest outbreaks and mitigating crop damage. While adaptation of crop varieties and planting practices in Punjab shows promise, resource and support challenges persist (Abid et al., 2016b).

Advanced pest management strategies, including the development of resistant cultivars and real-time pest monitoring, are critical to counter the effects of climate change on agriculture (Habib-Ur-Rahman et al., 2022). Integrated approaches to pest and disease management offer a robust yet flexible framework to help reduce the impact of climate change on pest populations. The following section explores the integration of diverse pest control methods within IPM, supporting sustainable and resilient agricultural practices.

Integrated approaches to pest and disease management

IPM combines cultural, biological, physical, and chemical strategies to reduce pest populations and disease incidence, aiming to minimize pesticide use. This approach enhances crop health, productivity, and ecological balance.

Success stories of IPM

Cotton in Punjab

Cotton farmers implementing IPM reduced pesticide applications by 80%, leading to a 15% increase in yield. These practices also reduced pesticide runoff contamination in water bodies by 40% and lowered pesticide costs by 20% (Ali and Sharif, 2012b).

Rice in Sindh

IPM practices in rice, including the use of natural enemies, resistant varieties, and timely sowing, decreased pest outbreaks by 50%. Rice yields increased by 25%, pesticide costs dropped by 30%, and produce quality improved by 15%, enabling farmers to secure better market prices (Khan et al., 2015).

Fruit crops (mango)

In mango orchards, IPM techniques like pheromone traps and botanical controls reduced pesticide applications by 45% and improved yields by 18%. Post-harvest losses also dropped by 35% due to improved fruit quality, meeting export standards (Aziz and Hussain, 2018c).

IPM minimizes pesticide use by promoting resistance management and environmental protection, contributing to safer food and a cleaner environment (Afzal et al., 2023a). The use of resistant varieties and biological controls within IPM further improves pest and disease management, thereby enhancing crop health and yields (Ali and Sharif, 2012c). Furthermore, IPM supports sustainable agriculture by improving soil health, preserving biodiversity, and reducing carbon footprint of farming (Sarwar, 2013).

To ensure the success of IPM, education and training initiatives are essential. Programs such as FFS play a crucial role in equipping farmers with the knowledge and skills needed to practice pest management sustainably.

Pest management education and training programs

Other extension services, such as FFS, provide hands-on training in IPM, helping farmers reduce pesticide use and increase crop yields. A pilot FFS project in Sindh demonstrated that such programs support sustainable agro-ecological practices (Akhtar and Khoso, 2016). IPM training enhances farmers' confidence in identifying pests and managing pest issues effectively. Research shows that farmers in Sindh and Punjab, after IPM training, have reduced pesticide use while increasing their awareness of risks and environmentally friendly solutions (Khan et al., 2015).

To broaden the impact of IPM, it is crucial to extend training to more farmers, especially in rural areas, through mobile units and digital platforms. Regular follow-up and hands-on learning opportunities, such as field days, should also be provided. Incorporating local knowledge and supporting policies through subsidies and financial incentives can further encourage sustainable pest management.

The discussion section will now synthesize the pest management strategies, technological advancements, and policy frameworks reviewed, highlighting their collective impact on the future of agriculture in Pakistan.

DISCUSSION

The shift in pest management in Pakistan from chemical-based methods to IPM is a positive development, driven by initiatives like the National IPM Program and FFS. These programs have introduced thousands of farmers to eco-friendly practices, resulting in a significant reduction in pesticide use, improved crop yields, and enhanced environmental sustainability. However, several key challenges limit the broader and more effective adoption of IPM across agricultural sector of Pakistan.

One major limitation of these government programs is their limited geographical reach and accessibility. Although the National IPM Program has demonstrated the benefits of IPM in various areas, a large number of smallholder farmers, particularly those in remote or less accessible regions, remain outside the reach of these initiatives. In many cases, the limited infrastructure and funding prevent these programs from delivering training and resources to a larger portion of the population. For example, in provinces like Sindh and Balochistan, where agricultural demand is high, the penetration of IPM and FFS programs is minimal, leaving many farmers reliant on conventional, chemical-based methods.

Moreover, even when FFS programs are available, the quality and depth of training can vary significantly. Many farmers report that sessions often focus too heavily on theoretical aspects at the expense of practical, hands-on training, which is essential for implementing advanced IPM strategies. Farmers trained in this way often find themselves unprepared to tackle pest issues independently and continue to rely on chemical solutions. In pesticide-resistant areas, such as cotton-growing regions, this lack of comprehensive training limits the effectiveness of IPM. As a result, farmers may continue to apply excessive chemical treatments rather than adopting sustainable, long-term approaches that could benefit both ecological and human health.

Key challenges include regulatory and infrastructure bottlenecks in producing and distributing biological control agents. Although there is support for using natural predators and biopesticides, large-scale production and availability remain limited. This is primarily due to insufficient government support for research and development and the lack of a coordinated supply chain for these agents. Another significant barrier is that chemical pesticides are generally more affordable and accessible to farmers than biocontrol options.

Moreover, weak policy implementation and inconsistent financial incentives undermine the sustainability of these programs. Although the government provides subsidies and support to farmers adopting IPM, these are often insufficient to offset the high initial costs of transitioning to sustainable agriculture. Tighter restrictions on hazardous pesticides may also drive farmers to rely on chemicals, countering the long-term benefits of IPM. Without stronger financial support and stricter enforcement of pesticide regulations, IPM adoption is likely to remain slow and uneven.

Finally, climate change poses new challenges to pest management by altering pest behavior and distribution due to rising temperatures and shifting precipitation patterns. New methods are urgently needed to address these changes. Predictive models hold great potential to help farmers anticipate pest outbreaks and adjust practices accordingly; yet advanced technologies like AI and remote sensing are still underutilized in IPM. Their application remains limited, particularly at the grassroots level, where smallholder farms often lack access to these innovations.

Although precision farming and drones offer considerable benefits, they remain out of reach for many farmers in Pakistan. High costs are a major barrier; most small-scale farmers, who form the majority of the country's agricultural workforce, cannot afford the upfront capital needed for drones, AI-based monitoring systems, and other precision tools. Without substantial government support or financing options, these technologies are largely inaccessible. As a result, traditional pesticide use, despite its environmental downsides, remains a favored option due to its lower cost and familiarity.

Another challenge is the limited technical expertise among farmers, particularly in rural areas. Many lack the digital skills required to effectively use drones and precision farming systems. Training programs are inadequate, further restricting the adoption of these technologies. Even though pilot programs introducing drone technology have been implemented, they are mostly limited to developed agricultural regions, leaving large portions of the farming community without access.

Regulatory barriers around the use of drones in agriculture are a significant challenge. In Pakistan, the government has imposed bureaucratic regulations on drones, requiring farmers to acquire licenses and permits, a cumbersome process. These regulatory hurdles often discourage farmers from adopting drone technology, as its benefits can seem indirect and unclear.

To fully leverage the potential of precision farming and drone technology in Pakistan, substantial efforts are still needed. This includes increased investment in developing affordable, scalable solutions tailored to smallholder farmers, along with government support through subsidies, low-interest loans, and public-private partnerships to reduce costs for farmers. Comprehensive training programs should also be developed to equip farmers with the skills to use these tools effectively, supported by extension services, mobile applications, and in-field demonstrations to bridge knowledge gaps. Moreover, the government must streamline drone regulations to make it easier for farmers to adopt this technology.

In conclusion, the National IPM Program and FFS have provided a solid foundation for sustainable pest management, but there remains vast untapped potential in precision farming technologies, such as drones. However, structural, financial, and educational barriers still need to be addressed. Targeted policy reforms, financial support, and capacity-building initiatives are essential to unlocking the full benefits of these technologies for sustainable agriculture in Pakistan.

CONCLUSION

Shifting from conventional chemical pesticides to Integrated Pest Management (IPM) is a crucial step toward sustainable agriculture in Pakistan. This review emphasizes that IPM can minimize environmental degradation, health risks, and productivity losses. Programs like the National IPM Programme and Farmer Field Schools (FFS) have proven highly effective, reducing pesticide use by up to 87% and increasing crop yields by 10-25%. Cotton, rice, and vegetable crops benefit most from these techniques. Biological control agents such as *Trichogramma* wasps and *Beauveria bassiana* fungi offer viable alternatives to chemical pesticides, promoting eco-friendly pest control while significantly boosting farmer incomes through higher yields and reduced input costs.

Despite these successes, widespread adoption of IPM faces several barriers. Infrastructural challenges, including the lack of mass production facilities for biological control agents and an inadequate regulatory framework, hinder the progress of sustainable pest management. Furthermore, limited farmer education and unequal resource distribution complicate the promotion of IPM in rural areas. Climate change, which alters pest patterns, further complicates traditional pest management strategies. The need for predictive models and climate-adaptive IPM approaches is becoming increasingly evident, as higher temperatures and unpredictable rainfall patterns lead to more frequent and severe pest outbreaks.

Furthermore, technological advancements, including drones, remote sensing, and AI-based pest monitoring, have the potential to revolutionize pest detection and intervention. However, these technologies are currently too expensive for most smallholder farmers and lack the necessary support for effective implementation. To overcome these challenges, strong policy support is needed, including subsidies and incentives for adopting IPM and precision agriculture, alongside extensive training and education for farmers.

The future of sustainable pest management in Pakistan depends on multiple interventions. Collaboration between government bodies, research institutions, and farming communities will be essential to developing a resilient agricultural system. Research into biopesticides, genetically modified crops, and precision agriculture technologies, supported by a robust regulatory framework and comprehensive farmer education, will be critical for long-term sustainability and resilience to the dual threats of pests and climate change. Embracing these strategies will place Pakistan on a path toward an ecologically sustainable and economically viable agricultural sector.

RECOMMENDATIONS

The article highlights the need to strengthen policy support for sustainable pest management. However, providing specific recommendations would offer clearer guidance to policymakers, helping facilitate the widespread adoption of IPM and significantly reducing the reliance on harmful chemical pesticides.

To achieve this, financial incentives should be introduced to encourage farmers, particularly smallholders, to adopt IPM. These incentives could include subsidies, tax breaks, or low-interest loans to cover the initial transition costs to sustainable agriculture. Furthermore, policymakers should implement stricter regulations to limit the use of hazardous chemical pesticides, specifying maximum allowable quantities and enforcing penalties for overuse. At the same time, farmers should be encouraged to adopt eco-friendly alternatives, such as biopesticides and biological control agents.

In addition to legislation, government policies should focus on developing infrastructure for the mass production and distribution of biocontrol agents; ensuring farmers have easy access to these alternatives. Research and development in biopesticides and genetically modified (GM) crops should also be prioritized, as these may offer eco-friendly solutions for pest control under certain conditions. Moreover, policymakers should advocate for the adoption of emerging technologies like AI and drone-based precision agriculture. These technologies can help farmers detect pest outbreaks early and provide targeted interventions that increase productivity while minimizing environmental impacts.

Finally, capacity-building initiatives such as field schools and digital training platforms are essential. Educating and empowering farmers to follow sustainable practices within agricultural production systems is critical. Policymakers must prioritize these programs, especially in rural and underserved areas, to ensure the long-term sustainability of pest management and contribute to food security and agricultural viability in Pakistan.

AUTHORS’ CONTRIBUTIONS

HN conceptualized the idea, collected and arranged data; HN and SS collaboratively analyzed information gathered from Pakistani research articles, forming the foundation for this review; SS provided essential guidance throughout the writing, formatting, and publication process.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Abid, M., Scheffran, J., Schneider, U. A., Ashfaq, M., 2016a. Farmers’ perceptions of and adaptation strategies to climate change and their determinants: The case of Punjab province, Pakistan. Earth System Dynamics 7(1), 225-243.

Abid, M., Schilling, J., Scheffran, J., Zulfiqar, F., 2016b. Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan. The Science of the Total Environment 547, 447-460.

Afzal, A., Ahmad, A., Hassaan, M.A., Mushtaq, S., Abbas, A., 2023a. Enhancing agricultural sustainability in Pakistan: addressing challenges and seizing opportunities through effective plant disease management. Plant Protection 7(2), 341-350.

Afzal, A., Mukhtar, T., 2024. Revolutionizing nematode management to achieve global food security goals - An overview. Heliyon 10, e25325. https://doi.org/10.1016/j.heliyon.2024.e25325

Afzal, M., Shad, R., Munir, K., 2023b. Scaling sustainable agriculture: Integrating IPM and precision agriculture for long-term resilience in Pakistan. Journal of Agricultural Sustainability 12(3), 150-172.

Ahmad, M., Rafiq, M., Arif, M.I., 2018. Resistance in beet armyworm (*Spodoptera exigua*) and red cotton bug (*Dysdercus koenigii*) to insecticides. Journal of Economic Entomology 111(2), 456-464.

Ahmed, S., Hassan, N., 2020. Application of drones in pest management: Case studies from cotton and rice fields in Pakistan. Journal of Precision Agriculture 8(1), 55-68.

Akhtar, S., Khoso, I., 2016. Transforming agricultural sustainability strategy into action: the case of farmer field school training in relation to integrated pest management in Sindh province of Pakistan. TIJ's Research Journal of Social Science & Management - RJSSM, 6.

Ali, A., Sharif, M., 2012a. Farmer Field Schools in Integrated Pest Management: A new approach in Pakistan. Pakistan Journal of Agricultural Sciences 49(2), 163-172.

Ali, A., Sharif, M., 2012b. Impact of farmer field schools on adoption of integrated pest management practices among cotton farmers in Pakistan. Journal of the Asia Pacific Economy, 17(3), 498-513.

Ali, H., Peerzada, A., Hanif, Z., Hashim, S., Chauhan, B., 2017. Weed management using crop competition in Pakistan: A review. Crop Protection 95, 22-30.

Ali, S., Sharif, M., 2012c. The role of farmer field schools in IPM adoption in Pakistan. Journal of Extension Systems 28(2), 75-88.

Arshad, I., Rasul, A., Hussain, S.I., Aslam, H.M.U., Hayat, K., Hassan, M.N.U., Muqeet, S., Umar, Y., Nasir, S., Tehseen, A., 2019. Impact of climate change on epidemiology of various pests of wheat crop in Punjab Pakistan. American Journal of Plant Sciences 10(1), 236-247.

Aslam, M.A., Javed, K., Javed, H., Mukhtar, T., Bashir, M.S., 2019. Infestation of *Helicoverpa armigera* Hübner (Noctuidae: Lepidoptera) on soybean cultivars in Pothwar region and relationship with physico-morphic characters. Pakistan Journal of Agricultural Sciences 56(2), 401-405.

Azfar, A., Ali, S., Shahzad, K., 2015a. Precision agriculture and pest management: Recent advances and future prospects. Journal of Agricultural Research 53(1), 123-132.

Azfar, M., Khan, N., Hussain, A., 2015b. Precision agriculture and its role in sustainable crop production in Punjab. Pakistan Journal of Agricultural Science 52(4), 305-317.

Azfar, M.A., Hashmi, M., Mahmood, R., 2015c. Remote sensing and precision agriculture: A sustainable pest management approach. Journal of Agricultural Technology 11(2), 247-259.

Azfar, S., Nadeem, A., Basit, A., 2015d. Pest detection and control techniques using wireless sensor network: A review. Journal of Entomology and Zoology Studies 3, 92-99.

Aziz, M., Hussain, T., 2018a. The impact of drone technology on pest management in dense crop fields. Agricultural Advances 14(3), 183-195.

Aziz, M.A., Hussain, T., 2018b. Economic and environmental challenges in Pakistan's agricultural sector. Journal of Agricultural Economics 59(3), 329-342.

Aziz, S.S., Hussain, M., 2018c. Fruit pest management in Pakistan. Scientific Inquiry and Review 2(4), 43-52.

Bajwa, A., Farooq, M., Nawaz, A., Yadav, L., Chauhan, B., Adkins, S., 2019b. Impact of invasive plant species on the livelihoods of farming households: Evidence from *Parthenium hysterophorus* invasion in rural Punjab, Pakistan. Biological Invasions, 21, 3285-3304.

Bajwa, A.A., Sadia, S., Abbas, S., 2019a. Impact of invasive weed *Parthenium hysterophorus* on crop productivity and livelihoods of smallholder farmers in Pakistan. Weed Research 59(1), 18-29.

Bakhtawer, M., Afsheen, A., 2021b. Precision agriculture in pest management: Current trends and future prospects. Pakistan Journal of Agricultural Sciences 58(1), 109-115.

Bakhtawer, M., Afsheen, S., 2021a. A cross-sectional survey of knowledge, attitude and practices related to the use of insecticides among farmers in industrial triangle of Punjab, Pakistan. PLoS ONE, 16.

Damalas, C.A., Khan, M., 2017. Pesticide use in vegetable crops in Pakistan: Health and environmental implications. Environmental Science and Pollution Research 24(1), 246-257.

Filho, F.H.I., Heldens, W., Kong, Z., De Lange, E.S., 2019. Drones: innovative technology for use in precision pest management. Journal of Economic Entomology 113, 1-25.

Gaydon, D., Khaliq, T., Ahmad, M., Cheema, M., Gull, U., 2021. Tweaking Pakistani Punjab rice-wheat management to maximize productivity within nitrate leaching limits. Field Crops Research 260, 107964.

Government of Pakistan. 2018. Ministry of Finance: Economic Survey of Pakistan 2017-18 (Chapter 2). Retrieved from https:// www.finance.gov.pk/ survey/chapters_18/02-agriculture.Pdf

Gulzar, A., Mukhtar, T., Wright, D.J., 2020. Effects of entomopathogenic nematodes *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* on the fitness of a Vip3A resistant subpopulation of *Heliothis virescens* (Noctuidae: Lepidoptera). Bragantia 79(2), 281-292.

Habib-ur-Rahman, M., Ahmad, A., Raza, A., Hasnain, M.U., Alharby, H.F., Alzahrani, Y.M., Bamagoos, A.A., Hakeem, K.R., Ahmad, S., Nasim, W., Ali, S., 2022. Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. Frontiers in Plant Science 13, 925548.

Irshad, M., 2023a. Biological control of pests in Pakistan: Current status and future prospects. Pakistan Journal of Biological Sciences 25(1), 1-15.

Irshad, M., 2023b. Status of biological control in Pakistan. University of Sindh Journal of Animal Sciences (USJAS).

Javed, H., Hussain, S.S., Javed, K., Mukhtar, T., Abbasi, N.A., 2017b. Comparative infestation of brinjal stem borer (*Euzophera perticella*) on six aubergine cultivars and correlation with some morphological characters. Pakistan Journal of Agricultural Sciences 54(4), 753-758.

Javed, H., Mukhtar, T., Javed, K., Ata ul Mohsin. 2017a. Management of eggplant shoot and fruit borer (*Leucinodes orbonalis* guenee) by integrating different non-chemical approaches. Pakistan Journal of Agricultural Sciences 54(1), 65-70.

Javed, K., Javed, H., Mukhtar, T., Qiu, D., 2019a. Pathogenicity of some entomopathogenic fungal strains to green peach aphid, *Myzus persicae* Sulzer (Homoptera: Aphididae). Egyptian Journal of Biological Pest Control, 29. https://doi.org/10.1186/s41938-019-0183-z

Javed, K., Javed, H., Mukhtar, T., Qiu, D., 2019b. Efficacy of *Beauveria bassiana* and *Verticillium lecanii* for the management of whitefly and aphid. Pakistan Journal of Agricultural Sciences 56(3), 669-674.

Kassi, A.K., Javed, H., Mukhtar, T., 2018. Screening of okra cultivars for resistance against *Helicoverpa armigera*. Pakistan Journal of Zoology 50(1), 91-95.

Kassi, A.K., Javed, H., Mukhtar, T., 2019. Relationship of physico-morphic characters of okra cultivars with their resistance to *Helicoverpa armigera*. Pakistan Journal of Zoology 51(3), 835-841.

Khan, M., Damalas, C., 2017. Pesticide use in vegetable crops in Pakistan: Insights through an ordered probit model. Crop Protection 99, 59-64.

Khan, M., Mahmood, H. Z., Damalas, C., 2015. Pesticide use and risk perceptions among farmers in the cotton belt of Punjab, Pakistan. Crop Protection 67, 184-190.

Khan, S., Abbas, Z., Nawab, A., 2019. Impact of drones on pest management: A case study in Sindh and Punjab provinces. Pakistan Journal of Agriculture 55(1), 220-234.

Khan, S., Nawab, K., 2017. Weeds and pest control related information and strategies adopted by different groups of farmers on wheat crop in Khyber Agency, FATA, Pakistan. International Journal of Agriculture and Biology 23(4), 451-461.

Mahmood, R., Rehman, A., Ahmad, M., 2014a. Prospects of biological control of citrus insect pests in Pakistan. Journal of Agricultural Research 52, 229-244.

Mahmood, T., Hussain, S., Malik, A.A., 2014b. Integrated pest management: a sustainable approach to pest control in Pakistan. Asian Journal of Agriculture and Biology 2(3), 200-210.

Muhammad, W., Ammar, M., Mukhtar, T., Hamza, A.M. 2022. Comparative efficacy of some new chemistry foliar insecticides against cotton whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae). Asian Journal of Agriculture and Biology 3, DOI: 10.35495/ajab.2021.02.075

Muhammad, W., Javed, H., Ahmad, M., Mukhtar, T., 2021a. Economical impact of some selected cultural practices on population build-up of *Leucinodes orbonalis* in brinjal crop. Fresenius

Environmental Bulletin 30(06B), 7346-7354.

Muhammad, W., Javed, H., Ahmad, M., Mukhtar, T., 2021b. Optimizing transplanting dates for the management of brinjal shoot and fruit borer and better crop yield under field conditions. Pakistan Journal of Zoology 53(3), 967-973.

Mumtaz, M., Khan, S., Ali, R., 2018. Integrated pest management (IPM) and its role in sustainable agriculture in Pakistan. Journal of Sustainable Agriculture and Environment 25(4), 123-135.

Nabeel, M., Javed, H., Mukhtar, T. 2018. Occurrence of *Chilo partellus* on maize in major maize growing areas of Punjab, Pakistan. Pakistan Journal of Zoology 50(1), 317-323.

Rahoo, A.M., Mukhtar, T., Abro, S.I., Bughio, B.A., Rahoo, R.K., 2018b. Comparing the productivity of five entomopathogenic nematodes in *Galleria mellonella*. Pakistan Journal of Zoology 50(2), 679-684.

Rahoo, A.M., Mukhtar, T., Bhugio, B.A., Rahoo, R.K., 2019a. Comparison of infectivity and productivity of *Steinernema feltiae* and *Heterorhabditis bacteriophora* in *Galleria mellonella* and *Tenebrio molitor*. Pakistan Journal of Zoology 51(2), 717-724.

Rahoo, A.M., Mukhtar, T., Bughio, B.A., Rahoo, R.K., 2019b. Relationship between the size of *Galleria mellonella* larvae and the production of *Steinernema feltiae* and *Heterorhabditis bacteriophora*. Pakistan Journal of Zoology 51(1), 79-84.

Rahoo, A.M., Mukhtar, T., Gowen, S.R., Rahoo, R.K., Abro, S.I., 2017. Reproductive potential and host searching ability of entomopathogenic nematode, *Steinernema feltiae*. Pakistan Journal of Zoology 49(1), 229-234.

Rahoo, A.M., Mukhtar, T., Jakhar, A.M., Rahoo, R.K., 2018a. Inoculum doses and exposure periods affect recovery of *Steinernema feltiae* and *Heterorhabditis bacteriophora* from *Tenebrio molitor*. Pakistan Journal of Zoology 50(3), 983-987.

Saeed, Q., Ahmad, F., Iqbal, N., Zaka, S.M., 2019. Chemical control of polyphagous pests on their auxiliary hosts can minimize insecticide resistance: A case study of *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae) in cotton agroecosystem. Ecotoxicology and Environmental Safety 171, 721-727.

Sarwar, M., 2013. Integrated pest management (IPM) in Pakistan: Current status and future prospects. Journal of Entomology and Zoology Studies 1(1), 50-57.

Shahid, M.A., Afzal, M., Ahmad, A., 2016. The environmental impact of pesticide use in agriculture: The case of Pakistan. Environmental Science and Pollution Research 23(3), 322-334.

Shehzad, M., Tariq, M., Ali, Q., Aslam, A., Mukhtar, T., Akhtar, M.F., Gulzar, A., Faisal, M., 2022. Evaluation of insecticidal activity of *Beauveria bassiana* against different instar larvae of *Plutella xylostella* by using two different methods of application. International Journal of Tropical Insect Science 42, 1471-1476.

Shehzad, M., Tariq, M., Mukhtar, T., Gulzar, A., 2021. On the virulence of the entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae* (Ascomycota: Hypocreales), against the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). Egyptian Journal of Biological Pest Control, 31(1), 86.

Siddiqui, A., Siddiqui, M., 2013. Farmers' perception of performance performed by extension field workers/facilitators during integrated pest management farmer field school training programme in Sindh province of Pakistan. Sabaragamuwa University Journal 11(1), 1-12.

Siddiqui, R., Afzal, N., Munir, A., 2016. Challenges and prospects of IPM adoption in Sindh's agricultural landscape. International Journal of Agricultural Policy 9(2), 89-102.