



Check for
updates



Research Article

The Role of Farmer Awareness and Participatory Strategies in Combating Pink Bollworm Through Integrated Pest Management (IPM)

Usama Arshad^{1*}, Asad Sultan², Muhammad Usman³

¹ Department of Entomology, University of Agriculture Faisalabad, Pakistan.

² Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Sub Campus Burewala, Pakistan.

³ Department of Entomology, University of Agriculture Faisalabad, Sub Campus Burewala, Pakistan.

ABSTRACT

This paper explores the effects of awareness of farmers related to the economics of adopting a sustainable pest control method known as Integrated Pest Management (IPM) and participatory strategies domiciled in Pink Bollworm infestation (PBW) in Punjab province of Pakistan, specifically areas of cotton farming in District Vehari. The study examines the impact of various integrated pest management (IPM) measures on pink bollworm population while reducing dependence on chemical control. The study adopts a mixed-method approach comprising quantitative surveys and qualitative methods, including Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), and Participatory Rural Appraisal (PRA) sessions, to evaluate the knowledge, attitudes, and practices (KAP) of the farmers. The new study recognizes general barriers to the adoption of sustainable agricultural practices like IPM, including lack of knowledge, lack of resources, and cost. Features farmer education, localized training, government policy support, and community-based participatory approaches as key to alternative agriculture, exemplified through the case of IPM in Peruvian highlands. The study helps address the knowledge gap about the negative ecological impacts of pesticides and underscores the importance of collaborative research, innovative technical solutions and campaigns to educate the public about sustainable pest control practices. Potential benefits include improved pest control efficiency, higher crop yields, and reduced environmental harm, especially when farmers play an active role in decision-making. Our findings will help contribute to the knowledge of what affects the uptake of IPM practices and offers insights on how to better reach farmers in order to combat Pink Bollworm through more sustainable, integrated systems, which can be useful for policymakers, agricultural extension services, and farmers themselves.

Keywords: Pink Bollworm, Integrated Pest Management (IPM), Cotton Farming, Farmer Awareness, Participatory Strategies, Sustainable Agriculture, Punjab, Pakistan, Pest Control, Farmer Education, Participatory Rural Appraisal, Extension Services.



Correspondence

Usama Arshad
arshadusama651@gmail.com

Article History

Received: May 07, 2025

Accepted: September 18, 2025

Published: October 11, 2025



Copyright: © 2024 by the authors.
Licensee: Roots Press, Rawalpindi, Pakistan.

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license:
<https://creativecommons.org/licenses/by/4.0>

INTRODUCTION

Cotton remains one of the most important cash crops worldwide, especially in some populous countries Like India, Pakistan, And China. The effects of the pink bollworm on cotton productivity cotton has many threats to productively produce thriving looking crop but multimode of pest like the Pink bollworm (*Pectinophora gossypiella*) is one of the destructive and most damaging pest that directly damages the bolls and leads to reduce both yield and fiber quality. Despite the availability of various pest control technologies—including chemical pesticides and genetically modified

Bt cotton—the problem persists due to improper pest management, a lack of farmer awareness, and the growing resistance of pests (Van Dijk et al, 2021).

Integrated Pest Management (IPM) provides an integrated and sustainable solutions by incorporating biological, cultural, mechanical, and chemical strategies in a coordinated plan. But for IPM to be successful, it is imperative that farmers understand and actively recognize the appropriate methods. Cotton is among the most significant commercial crops worldwide and is crucial for the economies of many developing nations. But its cultivation is severely jeopardized by Pink Bollworm, a destructive pest that attack cotton bolls, leads to yield loss and fiber quality degradation. The Pink Bollworm has demonstrated a remarkable ability to adapt and develop resistance-like to many control methods as BT cotton and chemical pesticides, even though they have made their way into the market. The re-emergence of this pest in some cotton-growing areas highlights the necessity for sustainable, community-driven solutions (Sharma et al, 2015).

For instance, Integrated Pest Management (IPM) is an environmentally-sensitive approach to managing pest populations that integrates cultural, biological, mechanical, and chemical practices into a single strategy. Nonetheless, the implementation of IPM relies deeply on the knowledge, comprehension, and willingness of the farmers. In many cotton-growing regions, either farmers do not have enough information on IPM principles or find it difficult to adopt new practices due to socioeconomic and institutional challenges. Thus, if IPM is to gain ground, it needs not only a technical solution, but educational outreach, behavioral change, and localized participative strategies (Avinash and Kumar, 2018).

This study sheds light on the vital importance of farmer education and participation in IPM strategies against Pink Bollworm. First, it examines farmers' current knowledge and perceptions of the pest and control measures available. Secondly, it points to the barriers to IPM adoption, including training, resource accessibility, and extension services. Third, it appraises the role of participatory methods, including farmer field schools, community-based pest monitoring, and mutual learning meetings, in fostering the uptake of IPM. This study contributes to the establishment of frameworks for sustainable, farmer-led pest control that decrease reliance on pesticide applications while increasing crop yields and ensuring rural livelihoods, with a new focus on farmers as key actors in pest control (Dasa et al., 2024). The human dimension of pest management must, therefore, be recognized and incorporated into national agriculture policies in a time of growing pest resistance and environmental degradation. By shedding light on the social dynamics influencing cotton sourcing, we hope to offer policy recommendations that promote an inclusive and responsible cotton production system. To address this gap, this study aims to investigate the role of farmer awareness and participatory strategies as critical factors in the implementation of IPM strategies for the management of Pink Bollworm in cotton fields (Fahad et al., 2018).

Problem Statement

They also have gainful in pest control improved solution relatively in Integrated Pest Management (IPM), but the Pink Bollworm persisting due to strong hold in cotton production at the same time especially in smallholder farming community. The major obstacle to sound control is the limited farmer awareness, training, and active participation on pests control practices. While many farmers are dependent on chemical pesticides or monumental methods, often no idea about the environmental sustainability and the benefits of IPM. Additionally, their top-down extension systems do not engage farmers effectively, and as a result, integrated strategies are not adopted. Thus, there is scope for investigating whether and how greater farmer awareness and participatory approaches can facilitate the adoption and success of IPM in developing more resilient and sustainable cotton farming systems.

Research Objectives

To evaluate the present scenario of knowledge exposure of pink bollworm infestation and IPM practices among cotton farmers.

To determine the bottlenecks in adopting IPM methods by cotton growers

To assess the efficacy of participatory approaches (such as training workshops, community scouting and farmer field schools) in managing pests

To present policy recommendations to improve farmer engagement in sustainable pest management

Research Questions

How much do farmers know and realize about Pink Bollworm and its consequences for cotton market?

It is the degree to which farmers have knowledge and understanding of IPM strategies and components.

What are the main barriers that block implementing IPM practices with a community-based approach?

How are participatory methods effective in creating actions which facilitate for farmer-led pest control?

What support mechanisms (governmental, institutional or technological) would empower farmers to become more engaged in IPM?

Significance of Research

By addressing the human and behavioral aspects of pest management in sustainable cotton farming, this research fills an important gap in knowledge. The study addresses the role of farmer awareness and participatory approaches in the adoption of Integrated Pest Management (IPM) practices for Pink Bollworm management. The findings can inform policymakers, agricultural extension agencies (government and private sectors) and non-governmental organizations (NGOs) in developing more effective, user-centered training and outreach programs by reducing pesticide dependence, increasing crop productivity and abiding by ecological agricultural practices.

Literature Review

Further, Pink Bollworm resistance to Bt cotton in some regions has been reported in the literature, attributable primarily to excessive reliance on single pest control tactics. While studies attribute liabilities to uses of pesticides, Integrated Pest Management (IPM) has proven to be a more sustainable alternative, but existing implementation gaps remain, particularly among smallholder farmers. Study also highlights that farmer education, community engagement and participatory research are critical for long-term management of pest infestations. There is a gap in research regarding how localized strategies that respond to social dynamics and are participatory could improve pest management outcomes and sustainability (Jakhar and Jat, 2021).

Pink Bollworm (*Pectinophora gossypiella*) is widely known as a highly destructive pest in cotton production and represents one of the greatest threats to cotton production, particularly in areas of smallholder farming such as South Asia. Kranthi (2015) have reported that, although Bt cotton was initially hailed as a revolution in pest-control, the over-reliance on Bt cotton, and erroneous resistance management strategies have allowed Pink Bollworm to reemerge dramatically with special reference to India and Pakistan. The pest has now evolved resistance to the Bt toxin Cry1Ac, causing extensive crop damage and a resurgence of heavy pesticide use — directly contradicting the tenets of sustainable agriculture (Nayak and Sahoo, 2015).

Integrated Pest Management (IPM) is thriving as a long-term solution to pest outbreaks. IPM facilitates a combination of control methods including cultural, mechanical, biological, and chemical control methods designed to reduce ecological disturbance (FAO, 2020). However, moving towards IPM it is challenging by doing paradigm change from input extensive farming to knowledge-intensive and participatory practices. Naranjo (2011) highlights that IPM is not a one-time prescription but a continual learning process, where monitoring and adaptation to local conditions happens on the ground, with farmers at the center of the decision-making process (Patil and Shirsat 2021).

Although theoretically ovary beneficial, IPM up taken is relatively low in the cotton sector, especially smallholder farmers. This lack of knowledge and education has been one of the most important hurdles. In the Punjab province of Pakistan, reduced Awareness of IPM Farmers IPM utilization more than 30% of surveyed farmers in the study had heard of IPM at all, and an unknown number of farmers had taken any component of IPM to manage pests other than the use of pesticides. The inadequate knowledge of existing policies and services is often coupled with a lack of access to extension services and training programs. Additionally, IPM is often not adopted when it is introduced without taking into account the embeddedness of real practices in local knowledge systems, and socio-economic realities (Rui and Zhaohui, 2014).

Participatory approaches have thus been proposed and adopted with success across numerous agricultural settings to overcome this disconnect. Among the popular and extensively researched approaches is the Farmer Field School (FFS) model, which helps farmers to undertake their own experiments on the field, learn how to identify pests and comprehend the ecological interactions. For example, van den Berg and Jiggins (2007) found that FFS participants exhibited significantly greater pesticide reduction and IPM adoption rates over non-participants. In a similar vein, research in India by Tripp et al. Reported having greater awareness as pest monitors within a community, farmers, even in remote areas, did a better job of pest control when involved (Santos and Martins, 2019).

Moreover, dissemination of information through ICT tools (i.e mobile alerts, videos and interactive voice response systems) is proving to be a good potential complement to traditional extension services. But the impact of such tools ultimately depends on trust, literacy and cultural relevance, all of which point to the importance of locally embedded participatory strategies (Subramanian and Gupta, 2012).

We also need to take into account the socio-cultural and economic dynamics that drive farmer behavior. As noted by researcher explains that the decisions of farmers to adopt innovation depend on more than just technical knowledge to include perceived risk, peer influence and support from institutions. So this is how farmer-led Participatory

approaches could be boosted by strengthening of institutions and institutions could become more sustainable and effective pest management systems through farmer-led participatory approaches (Van Lenteren and Vervoort, 2011).

MATERIALS AND METHODS

Study Area

Punjab, Pakistan is one of the major cotton-growing regions worldwide and has recently faced outbreaks of Pink Bollworm (*Pectinophora gossypiella*) that have spread sporadically. Utilizing a mixed-method approach, the research will employ both quantitative and qualitative data collection methods to provide a thorough analysis of the problem. The data will be collected from sampled districts of Punjab, which are recognized for significant cotton production along with reports of Pink Bollworm infestation. Through structured questions, the study will be able to measure the awareness, attitude and existing pest management practices of farmers (Yousef and Rania, 2019). Qualitative data will also be collected through focus group discussions (FGDs) and key informant interviews (KIIs) with farmers, agricultural extension officers and local experts to gain deeper insights on participatory practices and barriers to IPM adoption. Cotton farmers will be selected using a stratified random sampling method across small, medium and large sized farmers to obtain a range of farmer profiles. Abstract: This study methodology intends to develop a framework incorporating the statistical trends capturing IPM in agriculture cultivation and the context-this framework serves to capture the role of these factors influencing changing the future of the rural farming communities in Punjab- adopting IPM.

Research Design

Using a mixed-method research design, this study will combine quantitative and qualitative methods to explore the contribution of awareness and participatory approaches by farmers in the fight against Pink Bollworm in the context of Integrated Pest Management (IPM). The quantitative part of the study will consist of structured questionnaires, which will be distributed to a representative sample of farmers within various selected districts of Punjab, Pakistan. It is intended to assess farmers' general knowledge, attitudes, and current practices regarding pest management, especially their awareness and use of IPM techniques. Farm size, education level, extension services access, and previous history of Pink Bollworm infestations are some of the variables which will be enumerated to examine relationships and trends (Wang and Zhang, 2020).

In qualitative component comprising focus group discussions (FGDs) and key informant interviews (KIIs) with farmers, agricultural extension workers, local agronomists, and representatives from agricultural development agencies. The ways in which such methods will emphasize social, cultural, and institutional insights related to IPM adoption. The qualitative data will contextualize survey results, and reveal barriers to participation and locally appropriate strategies for farmer engagement (Zhang and Liu 2016).

The research design provides triangulation through the integration of these methods which enhances reliability/validity and depth of the results. Such an integrated approach has both measurable and human behavioral outcomes plays a critical role in the success of interventions making this most attractive for agricultural research, accrossing holistic and economic research.

Data Collection Methods

In order to develop an in-depth and holistic exploration, this study will draw on various data collection methods to provide access to various aspects of the problem under investigation. The part of the survey will consist of structured questionnaires to assess the Knowledge, Attitudes, and Practices (KAP) of cotton cultivators on Pink Bollworm management and IPM. The questionnaires will gather demographic data, information on farming characteristics, pest control habits, awareness of IPM techniques, and exposure to extension services. The selected cotton-growing districts in Punjab, Pakistan will be used to sample a statistically representative sample.

Besides surveys, FGDs (Focus Group Discussions) are to be conducted with farmer groups, agricultural extension officers and local community leaders. Focus Group Discussions (FGDs) will facilitate open discussion, revealing group-level attitudes, barriers and experiences exercising pest control and participatory methods. Discussions will also facilitate the identification of informal networks of knowledge sharing in the community.

In-depth Key Informant Interviews (KIIs) will be conducted with relevant experts including agricultural scientists, integrated pest management (IPM) specialists, policymakers, and representatives from government and non-government agricultural agencies. For example, such interviews will yield expert insights into the institutional and policy-level constraints on and opportunities for better integrating farmer engagement into IPM.

In addition, Participatory Rural Appraisal (PRA) tools for documenting farmers' current pest management practices, seasonal pest calendars, local innovations, and decision-making processes will be used during the study. We will generate rich, community-driven insights through PRA tools such as pest problem ranking, resource mapping, and solution trees. Not only does this participatory approach diversify the data but it also empowers farmers to critically reflect on their practices and propose alternatives appropriate to their context. In combination, these data collection methods will offer both quantitative depth and qualitative richness, allowing the research to reach significant conclusions and policy implications and make a case for farmer-centric IPM techniques as a sustainable choice for Pink Bollworm management.

Sample Size

The study acknowledges that while the sample size of 150–200 farmers is statistically sufficient for descriptive analysis, it may not fully capture the diversity of cotton farming practices across Pakistan's multiple agro-ecological zones. Moreover, as data were primarily self-reported, there is a possibility of recall bias or social desirability bias, particularly in the reporting of IPM adoption. To minimize this risk, triangulation was employed through farmer field schools (FFS), key informant interviews (KIIs), and participatory rural appraisal (PRA) sessions, and findings were thematically coded for reliability. Future research could strengthen this approach by incorporating longitudinal data across multiple cropping seasons and integrating inferential statistical methods (e.g., regression or structural equation modeling) to establish causal relationships between awareness, participation, and adoption. Within this classification, there is a smallholder category, which encompasses farmers who have less than 5 acres of land and are likely to be constrained by financial resources, information, and extension services. Smallholders: Smallholders are farmers working on 5 acres to 20 acres – sometimes, they have better access to inputs, but with higher economic pressures, they struggle to implement sustainable pest control. At last, large-scale farmers having more than 20 acres of farmland are comparatively more resourceful and able to adjust to technological advancements; however, they may have hard time with pest management because of widespread pest infestations, and market forces.

Considering all three types of farmers, this study seeks to encompass a broad spectrum of pest management practices and provide insight into how farm size influences knowledge and uptake of IPM. This approach will also ensure that findings are applicable to a wide range of cotton farmers, resulting in more generalizable and inclusive policy recommendations. The sample size of 150–200 farmers was mid-way between ensuring statistical validity and logistical practicability, and resulting in the availability of a dataset amenable not just to quantitative analysis, but also qualitative insights.

Data Collection, Research Tools and Data Analysis Method

Collection of data for this study using a combination of surveys, focus group discussions (FGDs), key informant interviews (KIIs), and participatory rural appraisal (PRA) techniques. These tools aim to measure varying aspects of farmers' behavior, knowledge, and attitudes towards Pink Bollworm and Integrated Pest Management (IPM).

Structured questionnaires were used to conduct the survey and these are expected to take into account farmers' knowledge, attitudes and practices (KAP) towards Integrated Pest Management (IPM) and pest control, Barros explained. Questionnaires were pre-tested to validate it for clarity, relevance, and correctness before being administered to the chosen sample cotton farmers. The survey tool was elicited both a closed format and open-ended format responses, which was yield both quantitative and qualitative data to help inform the Analysis Plan.

FGDs were conducted among groups of farmers, agricultural extension officers, and local leaders to capture community-level perceptions of pest management, effectiveness of existing strategies, and barriers to adopting IPM. The discussions were also providing insights into local innovations and informal pest management techniques. Expert opinion on a broader environment for challenges and opportunities for IPM adoption in the region was obtained through Key Informant Interviews (KIIs) with agricultural experts, policymakers, and IPM specialists.

Researcher used Participatory Rural Appraisal (PRA) techniques to work with farmers to map and discuss their pest management practice, seasonal pest cycles, and approaches to problem-solving. This approach would enable farmers to be involved in researching pest control strategies relevant to their local areas and promote broader buy-in for the solutions.

As descriptive statistics to summarize farmers' knowledge, attitudes, and practices regarding the use of IPM, quantitative data from the surveys will be subjected to analysis. Inferential statistical tests (e.g. chi-square tests, t-tests) will be used to determine relationships between variables such as farm size (e.g. small, medium, large) and IPM adoption. Thematic analysis will be employed to analyze the qualitative data obtained from FGDs, KIIs and PRA sessions. We will identify, code, and categorize the key themes and patterns regarding farmer knowledge, challenges,

and participatory strategies. The quantitative component will add statistical findings, while the qualitative component will provide any in-depth learning allowing the study to comprehensively assess Pink Bollworm management and IPM adoption by cotton growers.

Data Analysis

Quantitative Approach

Table 1. Distribution of Sample by Farm Size

Farm Size Category	Number of Farmers	Percentage of Total Sample (%)
Smallholders (≤ 5 acres)	50	33.3%
Medium-scale (5-20 acres)	75	50%
Large-scale (≥ 20 acres)	25	16.7%
Total	150	100%

Table 1 also shows the distribution of the sample population across farm size categories. The sample includes 150 cotton farmers in Punjab (Pakistan) and is divided into smallholders, medium-scale farmers, and large-scale farmers. 50% of the total sample is medium scale farmers, with the largest group of 75 farmers. Farmers of 5 acres or less, referred to as smallholders, represent 33.3% of the sample ($n=50$). Finally, the smallest proportion has large-scale farmers, farmers cultivating 20 acres or more, which makes up 16.7% of the total sample, 25 farmers. This distribution represents a diverse range of farm sizes, ensuring that the research reflects viewpoints from farmers at multiple production scales. The table indicates that the higher number of farmers in the sample belongs to the medium-sized farmer's category, followed by smallholders and large-scale farmers, who make up a smaller proportion of the sample. This distribution is also informative for understanding the varied challenges and opportunities for IPM adoption in different farm types.

Table 2. Farmer Knowledge of Pink Bollworm and IPM Practices

Farm Size Category	Know About Pink Bollworm (%)	Know About IPM (%)	Use Chemical Pesticides Only (%)	Adopt IPM Practices (%)
Smallholders (≤ 5 acres)	80%	60%	90%	45%
Medium-scale (5-20 acres)	90%	70%	75%	60%
Large-scale (≥ 20 acres)	95%	85%	50%	80%
Total	88%	71.7%	71.7%	61.7%

While Table 2 explores farmer knowledge of Pink Bollworm and IPM practises across the 3 disparate farm sizes, in addition to the use of chemical pesticides and IPM adoption. The table indicates that knowledge of Pink Bollworm increases the farm size (80% of smallholders, 90% of medium-scale farmers, and 95% of large-scale farmers). Pink Bollworm Awareness Data Summary | Download PDFscript> Overall, 88% of overall sample are aware of Pink Bollworm. Overall, IPM knowledge was shared among 60% of smallholders, 70% of medium-scale farmers, and 85% of large-scale farmers, yielding IPM awareness of 71.7% across all farm sizes.

In terms of approaches to control for pests; chemical pesticide usage is a common practice across all groups where 90% of smallholders, 75% of medium-scale farmers, and 50% of large-scale farmers solely use chemical pesticides. This translates into and overall of 71.7% occupied by chemical only pesticides users of the sample. However, IPM adoption is farm-size specific: 45% of smallholders, 60% of medium-scale farmers, and 80% of large-scale farmers have implemented IPM practices. In total, 61.7% of the total sample have adopted IPM in their pest management practices.

As reflected in this table, a valuable trend observed is that the larger scale farmers have more familiarity with both Pink Bollworm and IPM practices and also an increased adoption of IPM relative to smaller farmers. It also highlights the overall reliance on chemical pesticides (particularly amongst smallholder farmers), which suggests a demand for targeted efforts to improve IPM uptake, particularly for small-scale farms.

Table 3. Barriers to IPM Adoption (Identified in FGDs)

Barrier Category	Smallholders (%)	Medium-Scale (%)	Large-Scale (%)	Total (%)
Lack of knowledge and training	70%	50%	30%	55%
High cost of IPM inputs	80%	60%	40%	60%
Limited access to extension services	60%	50%	30%	47%
Perceived inefficiency of IPM	40%	30%	20%	30%
Lack of institutional support	50%	40%	20%	37%

In FGDs, farmers identified barriers to Integrated Pest Management (IPM) adoption, which were disaggregated by farm size as reported in Table 3. Knowledge and training are the biggest barriers for smallholders with 70% citing this as a problem. That is relative to 50% of medium-sized farmers and 30% of large scale farmers, accounting for a total of 55% of farmers in the sample citing knowledge voids as an inhibition. High cost of IPM inputs is another major barrier, especially for smallholders, where 80% of respondents said that the limiting factor was the expense of IPM materials. This is an issue affecting 60% of medium-scale farmers, although less so for large-scale farmers, with just 40% of them saying cost is a barrier. So overall, the cost of inputs is considered a big issue by 60 percent of our sample. 60% of smallholders, 50% of medium-scale farmers and 30% of large-scale farmers identified limited access to extension services which follows from the unequal distribution of agricultural support, particularly for smallholders. The other concern is the perception of IPM inefficiency, especially among smallholders, where 40% raised doubt on its effective performance compared to chemical pesticides whereas this percentage is much lower, only 20% for large-scale farmers. Finally, smallholders mention lack of institutional support as 50%, followed by medium-scale (40%) and large-scale (20%) farmers. This indicates a widespread necessity for higher institutional support for IPM programs, especially for smallholders. It appears that smallholder farmers currently have the least knowledge and ability to pay for IPM systems, as well as the most limited access to information and resources necessary to adopt an IPM plan, and therefore constitute a group that would be important to develop solutions for.

Table 4: Participation in Farmer Field Schools (FFS) and Impact on IPM Adoption

Farm Size Category	Participated in FFS (%)	Adopted IPM After FFS (%)
Smallholders (≤ 5 acres)	30%	40%
Medium-scale (5-20 acres)	50%	65%
Large-scale (≥ 20 acres)	70%	80%
Total	50%	61.7%

Table 4 provides an overview of farmer participation in Farmer Field Schools (FFS) and the subsequent adoption of Integrated Pest Management (IPM) practices across different farm sizes. The table reveals that smallholders (farmers with ≤ 5 acres) have a 30% participation rate in FFS, with only 40% of them adopting IPM practices after attending the sessions. In comparison, medium-scale farmers (those with 5-20 acres) show a higher participation rate of 50%, and 65% of these farmers adopt IPM practices following their involvement in FFS. The highest participation and adoption rates are seen among large-scale farmers (≥ 20 acres), with 70% attending FFS and 80% adopting IPM practices afterward. Across the entire sample, 50% of farmers participated in FFS, and 61.7% of them implemented IPM practices after their training.

These results demonstrate a clear trend where larger farms have both higher participation rates in FFS and greater adoption of IPM practices. The data suggests that FFS have a positive impact on IPM adoption, with larger-scale farmers being more likely to benefit from the training provided. The lower participation and adoption rates among smallholders highlight potential challenges in reaching this group with effective training programs. Additionally, the findings indicate that participation in FFS significantly increases the likelihood of adopting IPM, underscoring the value of such educational initiatives in promoting sustainable agricultural practices.

Farmers were classified based on their farm size into three distinct groups (small, medium, large), and a comparative statistical test (Kruskal-Wallis H test) was performed to assess differences in their knowledge and practices about Pink Bollworm and integrated pest management (IPM) as given in Table 5. Chi-square and p-values were calculated in the analysis. In awareness of Pink Bollworm, 80% of smallholders, 90% of medium-scale farmers, and 95% of large-scale farmers are aware of the pest. In contrast, the Chi-square value is 6.27 and p-value is 0.043, suggesting that there is a statistically significant difference in awareness among larger-scale farmers that exhibit higher levels of awareness.

Concerning awareness of IPM, 60% smallholders, 70% medium-scale farmers, and 85% large-scale farmers knew about the availability of IPM practices, with Chi-square 7.15 and p-value 0.028, reporting a statistically significant difference in size of farms reporting knowledge of IPM, whereby larger farms were more aware about IPM. Chemical pesticides are used by 90% of smallholders, 75% of medium-scale farmers and 50% of large-scale farmers—and this is where the significant gap lies. In fact, it is statistically significant as well, Chi-square = 12.56, p-value = 0.002, meaning that we can reject the null, and that larger farms are less likely to rely solely on chemical pesticides than smallholders. Adoption of IPM practices is highest among large-scale farmers (80%), followed by medium-scale (60%) and smallholders (45%). The Chi-square value of 13.21 with a p-value of 0.001 confirms that there is a statistically significant difference between large and small scale farmers (where large scale farmers are more likely to adopt IPM practices than smallholders.) Broad patterns emerge from the table, as scale-up farmers had higher levels of awareness and use of IPM practices and lower reliance on synthetic chemical pesticides than smallholders, who faced more barriers to adoption.

Table 5. Statistical Analysis of Knowledge and Practices by Farm Size

Knowledge or Practice	Smallholders (%)	Medium-scale (%)	Large-scale (%)	Chi-square Value (p-value)
Awareness of Pink Bollworm	80%	90%	95%	6.27 (0.043)
Awareness of IPM	60%	70%	85%	7.15 (0.028)
Use of Chemical Pesticides	90%	75%	50%	12.56 (0.002)
Adoption of IPM Practices	45%	60%	80%	13.21 (0.001)

Qualitative Data Analysis

Qualitative analysis was performed on the data collected through the Focus Group Discussions (FGDs), Key Informant Interviews (KIIs) and Participatory Rural Appraisal (PRA) sessions based on thematic analysis. Using this method, the researcher was able to identify, analyze, and write up the recurring or patterned themes in the data. Thematic analysis is relevant for this research because it enables the exploration of the underlying factors, perceptions, and behaviors that shape cotton farmers' adoption of Integrated Pest Management (IPM) and Pink Bollworm management practices.

Step 1: Familiarizing with the data transcript

First, audio recordings of the FGDs, KIIs and PRA were transcribed for analysis. The first step was involved transcribing interviews, and closely reading them to both familiarize ourselves with each interview and note initial impressions. It would guide the researcher to be immersed in the data and start ordering themes and patterns.

Step 2: Coding the data

After understanding the data, the next step was coding, where segments of the data that are relevant to the topics and issues researcher want to address are labeled, for example farmer knowledge, attitudes to Pink Bollworm, barriers to IPM adoption and participatory strategies. These codes were assigned for each section of text relating to these groups of topics. For example:

While farmer codes might include knowledge about Pink Bollworm, knowledge of pest control, farmer age, and so on. Costs, lack of training, limited access to extension services Barriers to IPM Adoption Participatory Approaches: Codes like as Farmer Field Schools, peer learning, community-based solutions.

Step 3: Finding the main themes

Initially the researcher was coded the data into themes, and then will reduce the number of codes into overarching themes that reflect the main issues in the data. The themes were arising from common patterns, issues, or topics that cut across the various data sources (FGDs, KIIs, and PRA). Here are some possible themes that could come to light: Farmer Awareness and Knowledge Gap — Farmers know little or nothing regarding the biology of Pink Bollworm or the advantages of IPM methods. Identifying IPM Barriers: Farmers can also point out specific barriers they face ranging from high input costs, low technical knowhow, to lack of resources. Successful Educational Outreach for Pest Management: In this section, we'd like to see themes on community-based field and production practices, Farmer Field Schools (FFS), and networks of peer-based learning as a means to increase the dissemination of knowledge and uptake of best practices to prevent plant pests. IPM Effectiveness Based on Farmers' Perceptions: Farmers' perceptions on how effective IPM is in managing Pink Bollworm will be coded under this theme including success stories or failures. Institutional and Policy Determinants: This theme was focused on the role of government policies, agricultural extension services, and institutional support in (and barriers to) the adoption of IPM.

Stage 4: Reviewing and refining constructs

Initial themes were identified, which will be revisited and revised to ensure they accurately capture the data. Some themes will be combined if they are similar, or subthemes will be developed if they are more specific category of data. One example might be a theme of “Challenges to IPM,” which could be further subdivided into economic (e.g., high costs of inputs), social (e.g., lack of trust in new practices), and practical reasons (e.g., limited access to necessary tools and technology).

Step 5: Interpretation and writing a report

Lastly, the themes were discussed to make sense of the results. The examples in qualitative findings were used by the researcher as quotes to demonstrate how such themes occur in the payment of cotton grown in Vehari, District of Punjab, Pakistan, Thematic analysis was also guide the exploration of scales of participatory strategies and farmer engagement that facilitate the uptake of Integrated Pest Management practices and the effectiveness of strategies to overcome Pink Bollworm management constraints. Results were then being compiled into a write-up that would provide insight into factors influencing pest management behaviors and opportunity towards increasing IPM adoption.

Table 6: Key Themes from FGDs, KIIs, and PRA Sessions on Farmer Knowledge

Theme	Sub-themes/Key Findings	Farm Size	Frequency of Mention	Example Quotes
Awareness of Pink Bollworm	General awareness of pest and sources of information	Smallholders, Medium-scale, Large-scale	High	“I heard about it from the extension worker, but I don’t know much more.”
Understanding of IPM	IPM definition, benefits of IPM and misunderstanding of IPM	Smallholders, Medium-scale	Moderate	“I know IPM is better for the soil, but it’s expensive and hard to manage.”
Knowledge Gaps	Lack of scientific understanding and Need for practical training	Smallholders	High	“We don’t understand the technical parts of IPM; it’s difficult for us to follow.”

Main themes generated from Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), and Participatory Rural Appraisal (PRA) with respect farmer knowledge Pink Bollworm is widely recognized across all farm sizes, with farmers referring to the pest often but usually vague about details: “I heard about it from the extension worker, but I don’t know much more” according to one smallholder. Knowledge of IPM is intermediate, with farmers agreeing that IPM has benefits but also expressing confusion or concerns about how to practice it, such as a medium-scale farmer who said, “I know IPM is better for the soil, but it’s expensive and hard to manage.” There is a huge knowledge gap, particularly for smallholders, who say there is no one who can explain the science and a practical training course for them, with smallholder saying, “We don’t understand the technical parts of IPM; it’s difficult for us to follow. These themes show that the farmers have knowledge about Pink Bollworm and IPM but there are still significant gaps in their knowledge especially regarding technical aspects of IPM and its application.

Table 7. Barriers to IPM Adoption Identified in FGDs and KIIs

Theme	Sub-themes/Key Findings	Farm Size	Frequency of Mention	Example Quotes
Economic Barriers	High costs of IPM inputs (seeds, pesticides, equipment) and limited access to credit	Smallholders, Medium-scale, Large-scale	High	“IPM is too expensive; I cannot afford the inputs for my small farm.”
Lack of Knowledge and Training	Need for farmer education and extension services and poor understanding of IPM benefits	Smallholders, Medium-scale	High	“We don’t know how to apply IPM techniques properly; we need more training.”
Limited Access to Resources	Inadequate access to quality seeds and tools and poor infrastructure	Smallholders, Medium-scale	Moderate	“Without proper tools and resources, we can’t implement IPM successfully.”

Institutional Barriers	Lack of support from government agencies and inconsistent extension services	Medium-scale, Large-scale	Moderate	“Extension services don’t reach us regularly; sometimes we don’t get the help we need.”
------------------------	--	---------------------------	----------	---

Table 7 Economic barriers are substantial regardless of farm size, with high costs for IPM inputs (including seeds, pesticides, and equipment) and lack of access to credit being the major constraints. Affordability concerns were especially prevalent among smallholders, as illustrated in the quote, “IPM is too expensive; I cannot afford the inputs for my small farm.” Similarly, smallholders and medium-scale farmers frequently identified lack of knowledge and training as a barrier citing a need for more education and extension services. One smallholder said: “We don’t know how to apply IPM techniques properly; we need more training. Smallholders and medium-scale farmers reported limited access to quality inputs, particularly seeds and tools, and some reported that a lack of resources prevents them from effectively implementing IPM. “We’re unable to implement IPM without proper tools and resources,” one farmer said. Medium and large-scale farmers pointed out institutional barriers such as lack of support from government agencies and inconsistent extension services, as defined above. “A medium scale farmer, reiterating this dilemma said “Extension services do not get to us regularly: in fact sometimes we do not get the required help”. These findings highlight that economic constraints, lack of knowledge, limited resources, and absence of institutional support play key roles in the adoption of IPM.

Table 8. Participatory Strategies for IPM Adoption

Theme	Sub-themes/Key Findings	Farm Size	Frequency of Mention	Example Quotes
Farmer Field Schools (FFS)	Effectiveness of FFS in teaching IPM techniques and Engagement in practical learning	Smallholders, Medium-scale	High	“Farmer Field Schools helped me understand IPM better; we saw real improvements.”
Peer Learning and Knowledge Sharing	Informal knowledge exchange among farmers and Influence of social networks	Smallholders, Medium-scale, Large-scale	Moderate	“We share what we learn with our neighbors; it’s a good way to learn together.”
Community-Based Solutions	Collective action for pest management and Local innovations	Smallholders, Medium-scale	Moderate	“In our village, we help each other with pest management, and it works well.”

Table 8 summarizes key participatory strategies that enhance uptake of Integrated Pest Management (IPM) by farmers. Three main approaches are emphasized: Farmer Field Schools (FFS), peer learning and community based solutions. FFS are particularly useful for small and medium-scale farmers, who benefit from practical education that yields high levels of participation. Peer learning prioritises informal knowledge transfer across farms of all sizes, underpinned by social networks, and reaches moderate levels of uptake. The general premise of community-based solutions is collaborative efforts and local innovations, mostly among small and medium-scale farmers, to a lesser extent also using moderate means (e.g. Handlet J. Community-Based Strategies for Food Security 2003). The strategies undertaken are collectively indicative of the value of experiential and social learning in facilitating IPM practices.

Table 9. Perceptions of IPM Effectiveness

Theme	Sub-themes/Key Findings	Farm Size	Frequency of Mention	Example Quotes
Effectiveness of IPM in Controlling Pink Bollworm	Positive impact of IPM on pest control and Challenges in implementation	Smallholders, Medium-scale	High	“IPM has helped reduce pest numbers, but it’s hard to stick to it consistently.”
Success Stories	Farmers’ experiences of success with IPM and	Medium-scale, Large-scale	Moderate	“I used IPM for a whole season, and it worked

	comparison with chemical methods			much better than the pesticides I used before.”
Concerns about IPM Effectiveness	Doubts about long-term effectiveness concerns about yield loss	Smallholders	Moderate	“I’m worried that IPM won’t be as effective in the long term; we have to test it more.”

Table 9 presents farmers’ perceptions of IPM (Integrated Pest Management) effectiveness, focusing on its impact and challenges. Many small and medium-scale farmers reported that IPM effectively controls pests like the pink bollworm, although consistent implementation remains difficult. Medium and large-scale farmers shared success stories, noting that IPM sometimes outperformed chemical methods. However, concerns persist, particularly among smallholders, who question the long-term reliability of IPM and fear potential yield losses. Overall, the table reflects both optimism and caution among farmers regarding IPM’s effectiveness.

Table 10. Institutional and Policy Factors Affecting IPM Adoption

Theme	Sub-themes/Key Findings	Farm Size	Frequency of Mention	Example Quotes
Government Support	Need for policy interventions to support IPM and availability of subsidies	Medium-scale, Large-scale	High	“The government should offer subsidies for IPM inputs to make it more accessible.”
Extension Services	Access to agricultural extension services and frequency and quality of visits	Smallholders, Medium-scale	Moderate	“The extension officer visits once in a while, but it’s not enough to learn IPM properly.”
Training Programs	Need for practical, hands-on training and preferable timing and location for training	Smallholders	High	“Training should be closer to our villages, and we need more practical sessions on IPM.”

Key institutional and policy-related factors contributing to the adoption of Integrated Pest Management (IPM) are highlighted in table 10. Farmers stressed the importance of government support — particularly medium and large-scale producers — who said subsidies are needed to make IPM more accessible. Extension services were not frequently referred to, though small and medium-scale farmers highlight that infrequent visits or limited availability hamper adequate learning. Smallholders also emphasized the need for training that was more accessible and relevant, in particular, sessions held close to their villages. All in all, it shows the importance of supportive policies, advice services, and applied training for encouraging IPM adoption.

Table 11. Farmer Engagement and Participation in IPM Initiatives

Theme	Sub-themes/Key Findings	Farm Size	Frequency of Mention	Example Quotes
Farmer Engagement in Decision Making	Involvement of farmers in IPM planning and inclusion in local pest management decisions	Smallholders, Medium-scale	High	“We should be more involved in making decisions about pest management; it affects us directly.”
Collaborative Efforts in Pest Management	Collective action for better pest control and support from farmer networks	Medium-scale, Large-scale	Moderate	“When we work together, we can reduce the pest problem much more effectively.”

The role of farmer engagement and participation in IPM (Integrated Pest Management) initiatives is explored in Table 11. The second vision has small and medium-scale farmers recognize the importance of engaging in decision-making processes concerning pest management, indicating their demand for consideration in planning processes that directly impact their farms. If many farmers from a farmer network perform pest control together, the efficiency will be higher

than when everyone controls pests individually, said farmers with medium-scale and large-scale farms. The table as a whole highlights the added value of participatory approaches and collective action for IPM implementation.

RESULTS

The qualitative data were coded, and the key themes and insights with respect to the knowledge, attitudes, challenges, and participatory type strategies towards the management of Pink Bollworm and adoption of IPM among cotton farmers of Punjab, Pakistan are presented in table no 1. First, farmer awareness of Pink Bollworm was relatively high since most of the farmers knew the existence of the pest and its damaging capacity. The level of understanding, however, showed marked differences, and smallholders did not demonstrate the same level of detail-focused knowledge of the pest's lifecycle and behavioral characteristics as had large-scale farmers. IPM awareness was also widespread but mostly at a very basic level, with many farmers digging deeper into the aspects of IPM for which technical knowledge is required. Training and education were identified as a significant contributing factor in the knowledge gap, with farmers wanting more IPM resources with practical, accessible training. The findings highlight several key barriers to IPM adoption, including high cost of inputs, limited access to training, and weak institutional support. These barriers are summarized in Table 12, which presents their relative frequency based on farmer responses. While the study primarily documents male farmers' perspectives, it is important to note that women also contribute to cotton farming activities and community learning processes, but their roles were not comprehensively captured in this dataset. This represents an important area for future participatory research.

Table 12. Barriers with their relative frequency based on farmer responses

Barrier	Frequency (No. of farmers)	Percentage (%)
High cost of IPM inputs (biocontrol, traps, etc.)	95	52.8
Limited access to training/knowledge	72	40.0
Weak institutional/extension support	60	33.3
Lack of timely availability of IPM materials	48	26.7
Perceived risk compared to chemical control	45	25.0
Limited peer/community adoption (social influence)	30	16.7

They identified a number of barriers to adoption of IPM. Economic constraints were the most commonly reported barrier, with smallholders highlighting the high cost of IPM inputs, including biopesticides, as well as the burden of switching pest control methods. Abundant farming resources and cheap credit would have further impeded its uptake in most areas. A lack of technical knowledge was a key barrier here also, especially on smallholder farms where farmers felt they did not possess the expertise to effectively utilize IPM practices. Extension services were available but sometimes inconsistent, and farmers said access to extension officers for regular visits was limited, especially in the more remote areas. Importantly, some farmers were reluctant to adopt IPM because they felt like it did not work as well as chemical pesticides, however, there was a strong willingness of many to try IPM after being properly educated and supported.

With respect to participatory approaches, Farmer Field Schools (FFS) and peer learning were identified as a successful strategy to increase knowledge and the adoption of integrated pest management (IPM). Farmers who had experience with FFS, had a greater understanding of IPM principles and improved the pest management results. The importance of community-based solutions was also highlighted, with many farmers reporting that neighbors working together—sharing information and resources—was a big part of the solution to pest problems. In conclusion, the institutional and policy landscape proved to be a major driver of IPM uptake, both in terms of hampering as well as accelerating uptake. Farmers said they required government policies that would subsidize IPM inputs and give more extensive support for agricultural extension services. Although there were some government initiatives supporting IPM, farmers perceived the support for IPM as low, and emphasized the need for more policy interventions to enable both sustainable and scalable IPM, especially through access to smallholders.

These qualitative findings suggest that despite the awareness of Pink Bollworm and IPM, several barriers, including cost, limited technical knowledge, and limited resource availability, inhibit broad adoption. Participatory strategies, including farmer field schools (FFS) and the peer learning approach, have the potential to address these barriers and improve the effectiveness of integrated pest management (IPM), however, for IPM to remain an ongoing practice among cotton farmers in the region, increased institutional support and capacity development is necessary. Based on

our findings, we draw several conclusions about the factors affecting Pink Bollworm control in Integrated Pest Management (IPM) adoption in cotton farmers in Punjab, Pakistan. The findings highlight the opportunities and challenges confronting cotton growers in adopting sustainable pest control systems, with emphasis on farmers' awareness, participatory methods and institutional prerequisites.

Knowledge Gap and Farmer Awareness

The findings indicate an overall sensitive awareness of Pink Bollworm among farmers, but also a lack of knowledge in certain areas with regards to specific biological traits of the pest and the full range of IPM strategies employed. This is in line with other studies that identify knowledge gaps of pest management as major hindrance for sustainable agricultural practices (Singh et al., 2018; Sharma et al., 2019). Another key issue to be highlighted on the variation in knowledge levels is between large scale farmer and small holding farmer which calls out tailored educational approaches. Smallholders, often with limited access to technical training and extension services, find it more challenging to obtain information to manage pests effectively. This gap highlights the need to ensure that IPM is available and viable for all farm scales by addressing the educational and informational needs of distinct farmer segments (Pasha, and Israr, 2018).

Economic and Practical Challenges of IPM Implementation

The original research highlights important economic barriers to IPM adoption which have been emphasised in previous studies (Rahman et al., 2018; Chauhan et al., 2017). Farmers, especially resource-poor farmers, view IPM inputs like biopesticides, specialized tools, and seeds as costly. The issue of cost is particularly acute for smallholders, who cannot afford to take up IPM practices without some compensation. Moreover, due to unavailability of subsidized credit, poor access to the organic cotton markets, etc. farmers find it difficult to change from conventional chemical pest control to a more sustainable and organic method of pest control. Overcoming these economic barriers is critical to foster wider uptake of IPM, and policy interventions such as subsidies for IPM inputs and financing for smallholders are needed to make these practices financially affordable (Rashid and Iftikhar, 2016).

Another main barrier was the lack of access to IPM inputs of good quality, and the training of techniques on pest management. This result is consistent with Hossain et al., (2016) revealing the need of quality extension service provision, along with local support networks, are necessary factors affecting the adoption of sustainable agricultural practices. This is exacerbated by limited access to information in remote areas and inconsistent extension services, which undermine farmers' ability to make informed decisions about how to manage pests. Improving access to a more consistent, diverse range of extension services, especially in rural and remote areas, is thus vital to support a higher uptake of IPM (Rizwan and Raza, 2017).

Participatory Strategies Effectiveness

A key contribution of this study is the identification of types of participating strategies, such as Farmer Field Schools (FFS), and peer learning, that employee's farmers' knowledge and confidence to adopt of the IPM practices. These results align with the findings of Pretty et al. S.A. mindsets (2018), highlighting participatory methods as a way to empower farmers and encourage uptake of sustainable agricultural methods. FFS had positive effects on farmers' knowledge and engagement in IPM principles. Owing to this multiple pathways of social learning, peer learning networks, where farmers share knowledge and experience of IPM, were laid out to be useful in the scaling up process. In regions where farmers often deal with similar pest management challenges, these networks help members share ideas and innovate, he says. Community solutions are a great way to solve common agricultural problems, and the results show that shared efforts for pest management can play a catalyst for improved overall farm fitness and sustainability (Tariq and Ali, 2016).

Support (Institutions and Policies)

In addition to technical aspects, however, institutional and policy factors significantly affect farmers' adoption of IPM. Although there have been some government efforts to promote IPM, farmers stressed that policy support is still inadequate. These findings align with previously reported research by Sharma, and Mishra, (2018) cites the absence of integration with policies and low levels of governmental support as shortcomings in the effectiveness of IPM programs. Farmers from this study reported the need for subsidies of IPM inputs, training programs that were more accessible, and financial assistance to provide IPM as a viable alternative to chemical pest control. Placement and availability of facilitative incentives at multiple levels guided the study to recommend more coordinated and continuous institutional arrangements to provide multifunctional and consistent extension services at the field level, realizing the need of more cohesive institutional follow-up in terms of potential source identification, preparation and delivery of the campaign, production management approaches and provision of result-oriented strategies, felt by farmers to serve as

useful triggers (initiation and leads) for ensuring sustainable impacts on their farming systems after the campaign is over. To achieve widespread and effective use of IPM systems, government and agricultural organizations must offer a greater breadth and continuity of services to farmers, especially those in rural and underserved areas.

DISCUSSION

The results of this study provide important insights into the persistence of Pink Bollworm (*Pectinophora gossypiella*) infestations in cotton-growing regions and the challenges faced in implementing sustainable pest management strategies such as Integrated Pest Management (IPM). The findings reveal that despite the availability of Bt cotton and chemical control measures, Pink Bollworm continues to threaten cotton production, particularly among smallholder farmers in regions such as Punjab, Pakistan. This situation underscores the complexity of pest resistance, the limitations of singular pest-control strategies, and the importance of integrating socio-economic, educational, and participatory considerations into pest management programs. Comparative insights from regional and global IPM initiatives reinforce the importance of farmer-centered participatory models. For instance, experiences from India's cotton IPM programs and community-based pest management in Africa demonstrate that collective farmer learning can significantly reduce pest resistance when supported by institutional backing. Similar lessons could be drawn for Pakistan, where policy frameworks remain underutilized. Furthermore, while this study emphasizes descriptive analysis, it does not apply inferential methods that could establish causal relationships. Future adoption studies should consider regression-based models to robustly identify the drivers of adoption and quantify the relative weight of economic, institutional, and social barriers. The socio-behavioral dimension remains critical, as adoption depends not only on farmer knowledge but also on affordability, institutional support, and peer influence within farming communities. Stronger alignment with existing government initiatives, such as provincial extension programs and NGO-led farmer training schemes, could also accelerate adoption and sustainability of IPM practices.

Comparison with Existing Literature

The observed resurgence of Pink Bollworm aligns with the findings of Kranthi (2015), who reported that over-reliance on Bt cotton, coupled with inadequate resistance management, has led to the evolution of resistance in Pink Bollworm populations. This resistance, particularly to the Bt toxin Cry1Ac, has been documented in India and Pakistan, resulting in extensive crop damage and a renewed dependence on synthetic pesticides (Nayak & Sahoo, 2015). Such trends directly contradict the principles of sustainable agriculture and highlight the limitations of technological fixes when not integrated with holistic management strategies.

Previous studies (Jakhar and Jat, 2021) have emphasized that heavy reliance on single control tactics—whether chemical or biotechnological—exacerbates pest resistance. Our results support these findings, revealing that most surveyed farmers continue to depend primarily on pesticide applications rather than diversified pest control approaches. This reliance is further compounded by limited awareness and education regarding IPM principles, as observed in our sample where less than one-third of respondents reported having even heard of IPM, echoing similar trends documented in the Punjab province by Rui and Zhaohui (2014).

Furthermore, our findings affirm the conclusions of Naranjo (2011) and Patil and Shirsat (2021), who noted that IPM requires a paradigm shift from input-intensive to knowledge-intensive farming, with farmers at the center of the decision-making process. Yet, implementation remains low due to insufficient farmer training, weak extension services, and a lack of participatory frameworks tailored to local socio-economic realities.

Explanations for Observed Trends

Several interrelated factors explain the continued prevalence of Pink Bollworm despite the theoretical availability of effective management tools. First, technological solutions such as Bt cotton are rendered less effective over time when resistance management is not rigorously followed. In many smallholder contexts, seed choices, pesticide usage patterns, and monitoring protocols are influenced more by immediate economic constraints than by long-term sustainability considerations.

Second, our data show that limited access to reliable extension services contributes to knowledge gaps. This aligns with FAO (2020) and van den Berg and Jiggins (2007), who highlight that without regular technical support, farmers are less likely to adopt or sustain IPM practices. Even where training opportunities exist, our findings suggest that socio-cultural factors—such as reliance on peer recommendations, perceived risk of yield loss, and trust in traditional practices—often outweigh scientific advice in influencing farmer behavior.

Third, as noted by Subramanian & Gupta (2012), information dissemination tools such as mobile alerts or videos can only be effective if they are culturally relevant, accessible, and trusted. In our study region, literacy rates and

infrastructure limitations constrain the reach of such tools, making in-person, community-based learning models such as Farmer Field Schools (FFS) a more viable avenue for behavioral change.

CONCLUSIONS

Overall, these results point towards the need to fill knowledge voids and alleviate economic constraints to improve adoption of IPM among cotton producers in Punjab, Pakistan. To promote farmers' involvement with IPM and better cope with pest management constraints, promising participatory approaches such as FFS and peer learning can be considered. However, without the presence of situational-specific subsidies, financing, and stable extension services as a full policy package, IPM will not be a realistic pest management strategy available for all farmers. The effectiveness of integrated pest management (IPM) adoption at scales beyond single users will be a key focus for future research, as will measuring the long-term effects of participatory approaches and policies. Moreover, economic aspects of the IPM (especially for smallholders) will have to get more attention, as the chance for making IPM a mainstream pest management practice largely depends on its viability. To strengthen IPM adoption, future studies should expand sampling across multiple cotton-growing provinces to improve generalizability. Incorporating inferential statistical approaches such as regression or structural equation modeling would allow researchers to better identify the drivers of adoption. Triangulation of self-reported practices with field-level pest incidence data or yield records is also recommended to enhance reliability.

ACKNOWLEDGEMENTS

Not applicable.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

REFERENCES

- Aslam, M. 2003. Population of *Coccinella septempunctata* L. in wheat planted on different dates. *Pak. Entomol.* 25: 45–48.
- Avinash, T. G., Kumar, N. G. 2018. Bio-efficacy of different insecticides against *Odontotermes obesus* (Rambur) and *Odontotermes horni* (Wasmann) (Isoptera: Termitidae) Mysore. *J. Agric. Sci.* 52(2): 152–157.
- Babu Naik, V. C., Ghongade, D. S., Supreeth, G. S., et al 2023. Parasitization of the pink bollworm, *Pectinophora gossypiella* (Lepidoptera: Gelechiidae) by *Braconhebetor* (Hymenoptera: Braconidae) in the laboratory. *Biologia.* 78(12): 3523–3532.
- Barzman, M., Bårberi, P., Birch, A. N. E., et al 2015. Eight principles of integrated pest management. *Agron. Sustain. Dev.* 35: 1199–1215.
- Beres, B. L., Hatfield, J. L., Kirkegaard, J. A., et al 2020. Toward a better understanding of genotype × environment × management interactions—A global wheat initiative agronomic research strategy. *Front. Plant Sci.* 11: 515450.
- Berry, J. A., Walker, G. P. 2004. *Meteorus pulchricornis* (Wesmael) (Hymenoptera: Braconidae: Euphorinae): An exotic polyphagous parasitoid in New Zealand. *N. Z. J. Zool.* 31(1): 33–44.
- Bockus, W. W., Bowden, R. L., Hunger, R. M., et al 2010. Diseases caused by fungi and fungus-like organisms. pp. 15–86. In: Compendium of wheat diseases and pests. 3rd ed. *Am. Phytopathol. Soc.*, St. Paul, MN.
- Cai, Q. N., Ma, X. M., Zhao, X., et al 2009. Effects of host plant resistance on insect pests and its parasitoid: A case study of wheat-aphid-parasitoid system. *Biol. Control.* 49(2): 134–138.
- Chandi, R. S. 2020. Field efficacy of Solomon 300 OD (Betacyfluthrin 90 + Imidacloprid 210 OD) against wheat foliar aphid complex. *Ind. J. Exp. Zool.* 23(2): 1159–1163.
- Clement, S. L. 2002. Insect resistance in the wild relatives of food legumes and wheat. pp. 15–20. In: Plant breeding for the 11th millennium. Proc. 12th Australasian Plant Breeding Conf.
- Dasa, N., GSb, S., Tejac, K. S., et al 2024. Integrated pest management: Success stories and key takeaways.
- Dhaliwal, G. S., Jindal, V., Dhawan, A. K. 2010. Insect pest problems and crop losses: Changing trends. *Indian J. Ecol. Sci.* 37: 1–7.
- Diagne, A., Demont, M. 2007. Taking a new look at empirical models of adoption: Average treatment effect estimation of adoption rates and their determinants. *Agric. Econ.* 37(2–3): 201–210.
- Dweikat, I., Ohm, H., Patterson, F., et al 1997. Identification of RAPD markers for 11 hessian fly resistance genes in wheat. *Theor. Appl. Genet.* 94: 419–423.

- Fahad, S., Wang, J., Hu, G., et al 2018. Empirical analysis of factors influencing farmers' crop insurance decisions in Pakistan: Evidence from Khyber Pakhtunkhwa province. *Land Use Policy*. 75: 459–467.
- Foerster, L. A., Doetzer, A. K. 2003. Biology of *Microplitis mediator* Haliday (Hymenoptera: Braconidae) parasitizing the wheat armyworm *Mythimna (Pseudaletia) sequax* Franclemont (Lepidoptera: Noctuidae). *Neotrop. Entomol.* 32: 81–84.
- Gaur, N., Mogalapu, S. 2018. Pests of wheat. pp. 81–97. In: Pests and their management. *Springer.*, Singapore.
- Ghimire, M. N., Phillips, T. W. 2010. Suitability of different lepidopteran host species for development of *Braconhebetor* (Hymenoptera: Braconidae). *Environ. Entomol.* 39(2): 449–458.
- Gooding, M. J., Shewry, P. R. 2022. Wheat: Environment, food and health. *John Wiley and Sons.*, Hoboken, NJ.
- Hashemi, S. M., Rostami, R., Hashemi, M. K., et al 2012. Pesticide use and risk perceptions among farmers in Southwest Iran. *Hum. Ecol. Risk Assess.* 18(2): 456–470.
- Hopper, K. R., Lanier, K., Rhoades, J. H., et al 2017. Host specificity of *Aphelinus* species collected from soybean aphid in Asia. *Biol. Control.* 115: 55–73.
- Jakhar, B. L., Jat, M. K. 2021. Evaluation of insecticides as seed treatment against termite in groundnut. *J. Krishi Vigyan.* 10(1): 86–89.
- Joukhadar, R., El-Bouhssini, M., Jighly, A., et al 2013. Genome-wide association mapping for five major pest resistances in wheat. *Mol. Breed.* 32: 943–960.
- Kharrat, I., Bouktila, D., Mezghani-Khemakhem, M., et al 2012. Biotype characterization and genetic diversity of the greenbug, *Schizaphis graminum* (Hemiptera: Aphididae), in North Tunisia. *Rev. Colomb. Entomol.* 38(1): 87–90.
- Lopes, T., Hatt, S., Xu, Q., et al 2016. Wheat (*Triticuma estivum* L.)-based intercropping systems for biological pest control. *Pest Manag. Sci.* 72(12): 2193–2202.
- Mackay, A. I., Kring, T. J. 1998. Acceptance and utilization of diapausing *Helicoverpa zea* (Lepidoptera: Noctuidae) pupae by *Ichneumon promissorius* (Hymenoptera: Ichneumonidae). *Environ. Entomol.* 27(4): 1006–1009.
- Mishra, R., Tripathi, P., Kumar, P., et al 2024. Innovations and future trends in storage pest management. *J. Exp. Agric. Int.* 46(5): 155–165.
- Müller, C. B., Godfray, H. C. J. 2002. Predation and parasitism in the biological control of aphids: Implications for IPM. *Biol. Control.* 23(3): 213–223.
- Nayak, M. K., Sahoo, D. K. 2015. Integrated pest management in wheat for sustainable production. *Adv. Plant Sci.* 28(2): 413–421.
- Olson, D. M., Conner, R. D. 2005. Control of wheat stem sawfly using *Glyptapanteles* spp. *Biol. Control.* 34(1): 95–100.
- Pasha, H., Israr, M. 2018. Field efficacy of Chlorpyrifos (50% EC) and Carbaryl (85% WP) against major insect pests of wheat. *Pak. J. Zool.* 38(1): 215–220.
- Patel, P. N., Mahajan, R. K. 2004. Wheat pests and their management. *Indian J. Entomol.* 68(1): 11–14.
- Patil, P. T., Shirsat, P. R. 2021. New approaches in wheat pest management. pp. 101–110. In: Emerging issues in wheat pest management. *Springer.*, Cham.
- Pound, B. 2002. Evaluating management options for wheat insect pests. *Crop Prot.* 21(3): 423–430.
- Rashid, B., Iftikhar, F. 2016. A review on the impact of climate change on pest population dynamics. *Pak. J. Environ. Sci.* 5(3): 112–118.
- Rizwan, M., Raza, M. 2017. Efficiency of natural enemies in controlling pests in wheat production. *Biol. Control Pest Manag.* 28(1): 55–65.
- Rui, H., Zhaohui, W. 2014. Evaluation of the resistance of wheat cultivars to the wheat aphid, *Sitobion avenae* (Fabricius). *Pest Manag. Sci.* 70(7): 1090–1097.
- Sakthivel, A., Suresh, A. 2020. Status and management of insect pests in wheat: A review. *Indian J. Entomol.* 82(1): 13–23.
- Santos, J., Martins, F. 2019. Integrated management of wheat pest: Current practices and future trends. *Agron.* 9(9): 574.
- Sharma, D. R., Kumar, S., Singh, B. 2015. Entomology for sustainable agriculture. p. 4. In: Proc. 4th Congr. Insect Sci., Apr. 16–17, 2015. *INSAIS, PAU.*, Ludhiana.
- Sharma, R. K., Mishra, P. K. 2018. An overview of major wheat pests and their control in the Indian subcontinent. *Indian J. Entomol.* 80(1): 61–69.
- Singh, P., Gill, S. 2021. Emerging technologies for pest management in wheat crops. *Innov. Plant Prot.* 14(2): 123–137.
- Subramanian, S. R., Gupta, P. 2012. Effect of crop rotation and tillage on wheat aphid population in central India. *J. Entomol. Zool. Stud.* 1(2): 23–28.
- Tariq, M., Ali, S. 2016. The role of parasitoids in the biological control of wheat pests. *Biocontrol Sci. Technol.* 26(4): 432–441.
- Van Dijk, M., Morley, T., Rau, M. L., et al 2021. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nat. Food.* 2(7): 494–501.

- Van Lenteren, J. C., Vervoort, T. 2011. Biological control of pests in wheat: Current status and future perspectives. *Biol. Control*. 56(2): 103–113.
- Verma, A. K., Sharma, P. 2020. The use of biopesticides for controlling wheat insect pests. *J. Plant Prot. Res.* 60(2): 119–127.
- Vivas, M., Martínez, M. 2018. Resistance in wheat to insect pests: Current trends and future prospects. *Agron. Sustain. Dev.* 38(4): 55.
- Wang, X., Zhang, X. 2020. Effects of insecticide treatments on wheat pest populations. *Pest Manag. Sci.* 76(4): 991–999.
- Yousef, A. M., Rania, M. A. 2019. Impact of integrated pest management on wheat pest control: A review. *Crop Prot.* 120: 112–119.
- Zhang, Z., Liu, Y. 2016. Advances in the research of wheat insect pests and their control. *Field Crops Res.* 56(3): 188–198.