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Fuzzy multicriteria analysis of "Better Cotton" farmers' adoption and experts' recommendation on cotton pest and disease management practices

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Fuzzy multicriteria analysis of "Better Cotton" farmers' adoption and experts' recommendation on cotton pest and disease management practices

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Abstract

Aim of study: The Better Cotton Initiative is the largest cotton sustainability programme in the world because of the problems with conventional cotton farming and its impact on the environment. It aims to assist cotton communities in surviving and thriving while protecting and restoring the environment. Pakistan needs to make sure that local farmers are adopting these improved crop management practices in order to increase cotton production over the long term. Therefore, our work was to: (i) identify the cotton pests and disease management practices (CPDM) in Pakistan; (ii) evaluate the BC farmers' level of adoption of CPDM; (iii) compare the experts' recommendation on CPDM, and (iv) propose a suitable method to evaluate the adoption level.

Area of study: BC farmers from Tando Allahyar district areas (Pakistan) were selected to investigate the adoptability to CPDM practices.

Material and methods: The method first identified evaluation criteria based on a literature review and the recommendations of ten experts in crop protection. Then, the Fuzzy Analytic Hierarchy Process was used to weigh all the criteria according to two aspects, BC farmers' adoption level and experts' recommendations.

Main results: Crop rotation, resistant cultivars, planting Bt with non-Bt cotton and border crops, recommended by experts, were all highly adopted by farmers. However, the adoption rate of other technologies and practices (NEFR technology, botanical spray, and pheromone traps) was low.

Research highlights: It was found that BC farmers were more likely to adopt CPDM practices recommended by experts. The above modern concepts and technologies must be adopted to promote sustainable cotton production, pest and disease management, and environmental quality.

Additional key words: AHP; farming; framework; Pakistan; sustainability

Abbreviations used: AHP (analytical hierarchy process); BCI (Better Cotton Initiative); BNP (best non-fuzzy performance); CABI (Centre for Agriculture and Bioscience International); CPDM (Cotton pest and disease management); CR (consistency ratio); IPM (Integrated Pest Management); MCDM (multiple-criteria decision-making); NEFR (Natural enemies field reservoir); TFNs (triangular fuzzy numbers).

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Introduction

Cotton (*Gossypium hirsutum* L.) is the world's leading natural fiber crop and one of the world's largest industries (textile industry), with an annual global economic impact of about $500 billion (Rahman *et al.*, 2012). Punjab province is the largest cotton producer in Pakistan, followed by Sindh and Balochistan (Siyal *et al.*, 2021).

In Pakistan, about 70-80% of pesticides are used against cotton pests (Anonymous, 2008). As a result, pesticide residues have been detected both in surface and ground drinking water in the cotton belt of Punjab and Sindh provinces, respectively (Kaur *et al.*, 2021). High dependence on chemicals has led to higher production costs, environmental degradation, biodiversity loss, and poverty in many countries, as well as a decrease in soil fertility (Zulfiquar *et al.*, 2019). Seeds, irrigation water, fertilizers, pesticides and natural resources, as well as the environment, have been found to have a significant impact on cotton productivity (Page & Ritchie, 2009). As a result of traditional agricultural techniques, Pakistan's cotton output has been endangered, and the country's food security and poverty alleviation have been compromised (Jamil *et al.*, 2021). Managing agricultural pests without destroying the environment is a major challenge (Shah & Razaq, 2020).

For reasons of socioeconomic and environmental harm, the Better Cotton Initiative (BCI) was launched in Pakistan in 2009 through the Centre for Agriculture and Bioscience International (CABI) according to the BCI's guiding principles and criteria (Bhutto *et al.*, 2022). BCI is an eco-friendlier alternative to traditional cotton due to its efficient resource utilization and lower environmental externalities, but the level of adoption of Better Cotton in Pakistan is in its early stages. To improve any strategy or put into practice any initiative, scholars around the world have argued that evaluation is necessary which directs to the implementation of a certain initiative. For example, Shenge (2014) argued that before implementing training programs and fostering organizational growth and development, it is necessary to first evaluate the degree of competence required for effective management.

The core of the research on the performance of initiatives is the effective use of analysis, data and evaluation. Evaluation is often used as a tool for monitoring and promoting adoption and performance. Many researchers identified the risk (Singh *et al.*, 2007) and harmful impact of pesticide use in cotton (Kannan *et al.*, 2004; Yasin *et al.*, 2021). Other issues that have been investigated are: farmers' understanding and perception of pest incidence and management practice (Arshad *et al.*, 2009); the adoption of sustainable residue management practices (Raza *et al.*, 2019); general overview of cotton pest issues and management practices in China (Wu & Guo, 2005); the impact of cover crops on natural enemy and pest communities (Bowers *et al.*, 2020); adoption status of crop production practices in Bt cotton (Sharma *et al.*, 2021); the future of organic insect pest management (Headrick, 2021); developing and implementing integrated pest management (IPM) strategies for broadacre farming in Victoria, Australia (Horne *et al.*, 2008); directions to improve economic evaluations and impacts of the IPM-FFS approach (Rejesus & Jones, 2020), etc. These investigations have been mostly done in India, Pakistan, China, Georgia and USA. In spite of a great deal of academic debate, some research questions still remain unexplored in the literature, especially in developing countries like Pakistan. Then, the aims of our work were to: (i) identify the cotton pests and disease management practices (CPDM) in Pakistan; (ii) evaluate the BC farmers level of adoption of CPDM; (iii) compare the experts' recommendation on CPDM, and (iv) propose a suitable method to evaluate the adoption level.

Evaluation is a powerful tool for determining which technologies and interventions work and which do not. It is the driving development and adoption of effective strategies, the enhancement of current programs, and the demonstration of implementation outcomes in the field and through other ways. It also helps in determining if the work being done is worthwhile in terms of crop output. To this end, acquiring field knowledge from experts and farmers can guide the selection of CPDM practices. Moreover, applying the appropriate multiple-criteria decision-making (MCDM) method to evaluate most recommended practices thoroughly is essential in realistic recommendation situations. Therefore, these two knowledge gaps must be considered to provide a solid foundation for more efficient analysis.

Material and methods

The purpose of this study was to provide technical support for implementing cotton pest and disease management practices. Fig. 1 depicts the entire methodological process used to complete this study. First, multiple criteria for CPDM practices were identified (Fig. S1 [suppl]). Then, for weighting the relative importance of various options, an initial index for comparison matrices analysis was created. The tool provides a framework for comparing each option to all others and assists in demonstrating the importance of various factors and cotton pest and disease management practices.

Next, we organized a panel of experts for the decision-making process, who: i) were questioned about the relative importance of 10 practices selected for CPDM; ii) discussed the study's research questions and objectives. Their input helped to classify the best CPDM approaches, which were then used for taking their subjective judgments. Ten crop protection specialists (academics, practitioners or both) with at least five years of experience in sustainable development and crop protection in Pakistan were chosen. Cotton crop protection was well-known among the members of the decision-making team.

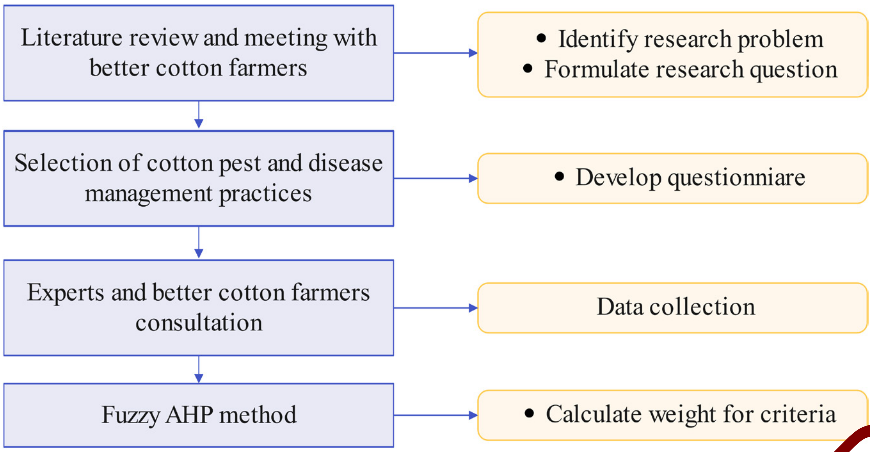

Figure 1. Research framework. AHP: analytical hierarchy process.

In addition, 20 CABI's registered BC farmers from Tando Allahyar district areas (including Nasarpur, Usman Shah Hurri, Dhigano Bozdar, Tando Soomro and Pak Singhar) were selected for the current study and the survey was conducted in the 2021 season to investigate the adoptability of BC farmers to CPDM practices. During the onsite face-to-face interview, each questionnaire took 15-20 minutes to complete. Finally, fuzzy AHP was applied to analyze BC farmers' adoption and experts' recommendation on CPDM practices.

Evaluation model

The first step in this research was to develop an evaluation model according to the set goals. For this, an extensive review of the existing literature from the sources of WOS, Google scholar and Scopus on CPDM and BC was performed in order to identify the multiple criteria for CPDM practices. Subsequently, the evaluation model was established based on the basic conditions of CPDM and BC. The evaluation model is shown in Fig. 2, comprising two layers of hierarchical structure. The first layer is the target layer that outlines the goal of evaluation. The second one is criterion layers consisting of specific indicators to be evaluated.

The evaluation was carried out based on two aspects: 1) BC farmers' adoption level and 2) experts' recommendations.

Evaluation method

Literature suggests that the analytical hierarchy process (AHP) is the most widely used multiple-criteria decision-making (MCDM) model for real-world decision-making problems (Jiskani *et al.*, 2021). It simplifies a complicated MCDM issue into a hierarchical structure to incorporate expert opinion and judgment (Jiskani *et al.*, 2020; Mohammed *et al.*, 2021). AHP was developed by Saaty (1989).

The framework's leading indicators and sub-indicators were compared. In Fuzzy AHP, the step is to perform pairwise comparisons of the criteria as described by Sun (2010). Each team member compared each criterion with the others in the evaluation model using pairwise comparison matrices. Experts used the nine linguistic terms for the evaluation. These linguistic terms represent the triangular fuzzy numbers (TFNs) used to construct a pairwise matrix of decision-makers' preferences. These linguistic terms and their respective TFNs for comparison were: "Extremely important (8,9,10)", "Absolutely strongly important (7,8,9)", "Very strongly important (6,7,8)", "Strongly important (5,6,7)", "Not too important (4,5,6)", "Moderately plus important (3,4,5)", "Moderately important (2,3,4)", "Weakly important (1,2,3)" and "Equally important (1,1,1)" (Jiskani *et al.*, 2021). Each expert, as a decision-maker, individually conducted pairwise comparison by using this scale. A sample of the questionnaire for data collection is provided in the Appendix [suppl]. The comparison matrix $\tilde{A}$ is represented in Eq. (1):

$$\tilde{A}=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1\end{bmatrix}=\begin{bmatrix}1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ \frac{1}{\tilde{a}_{21}} & 1 & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \frac{1}{\tilde{a}_{n1}} & \frac{1}{\tilde{a}_{n2}} & \cdots & 1\end{bmatrix} \qquad (1)$$

where $\tilde{a}_{ij}=1$ if indicator *i* and indicator *j* are equally important; $\tilde{a}_{ij}=\tilde{1},\tilde{2},\tilde{3},\tilde{4},\tilde{5},\tilde{6},\tilde{7},\tilde{8},\tilde{9}$ if indicator *i* has importance over indicator *j*; $\tilde{a}_{ij}=\tilde{9}^{-1},\tilde{8}^{-1},\tilde{7}^{-1},\tilde{6}^{-1},\tilde{5}^{-1},\tilde{4}^{-1},\tilde{3}^{-1},\tilde{2}^{-1},\tilde{1}^{-1}$ if indicator *j* is more important than indicator *i*.

Eq. (2) gives the geometric mean technique for computing fuzzy weights, which is used to compute the matrix in Eq. (3):

$$\tilde{r}_i=\left(\tilde{a}_{ij}^{1}\times\tilde{a}_{ij}^{2}\cdots\tilde{a}_{ij}^{n}\right)^{\frac{1}{n}} \qquad (2)$$

$$\tilde{w}_i=\tilde{r}_i\left(\tilde{r}_1+\tilde{r}_2\cdots\tilde{r}_n\right)^{-1} \qquad (3)$$

where $\tilde{a}_{ij}$ is the fuzzy comparison value of indicator i to indicator j and $\tilde{r}_i$ the geometric mean of the fuzzy comparison value of indicator i The fuzzy weight of indicator i is $\widetilde{w}_i$, which is indicated by TFNs as $lw_i + mw_i + uw_i$.

The fuzzy weights are defuzzied by locating the best non-fuzzy performance (BNP) value because the output is in the form of fuzzy weights. BNP is calculated using Eq. (4):

$$BNP_i = \frac{(lw_i + mw_i + uw_i)}{3} \quad (4)$$

BNP values that have been normalized are considered as relative weights. To get a weighted total of 1, the BNP value of indicator i is divided by the sum of BNP values of all indicators.

Lastly, using Eq. (5), the consistency ratio (CR) of each matrix was calculated to determine the results' reliability:

$$CR = \frac{CI}{RI} \quad (5)$$

where $CI = \frac{\lambda_{max} - n}{n - 1}$ is the consistency index, in which λ_{max} is the principal eigenvalue of the matrix $\tilde{A}$ (Saaty, 1977) and n is the number of indicators in the matrix. RI is the random index whose values for matrices of various sizes are pre-defined (Saaty, 1977; Gogus & Boucher, 1998). If the value of CR is less than 0.1, the results are consistent.

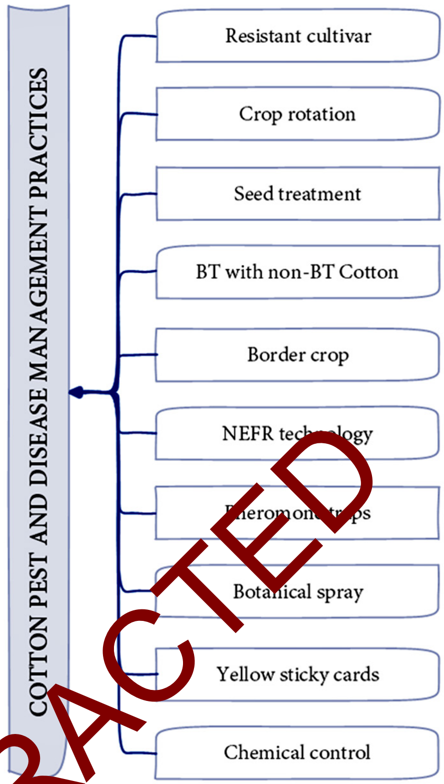

Figure 2. Evaluation model. NEFR: natural enemies field reservoir.

Results and discussion

Ranking of the recommended and adopted practices for cotton pests and disease management

According to the evaluation in terms of experts' recommendation (Fig. 3), the use of resistant cultivars, Bt with non-Bt cotton and crop rotation were the most-recommended practices, followed by seed treatment, border crop, yellow sticky cards, natural enemies field reservoir (NEFR) technology, botanical spray, pheromone traps and chemical control. The weights of these practices from high to low were 0.16, 0.14, 0.12, 0.10, 0.10, 0.08, 0.08, 0.08, 0.08 and 0.06, respectively.

From the viewpoint of the BC farmers' adaptation (Fig. 3), the ranking of these practices according to computed weights was (from highest to lowest): crop rotation (0.14), resistant cultivar (0.13), Bt with non-Bt cotton (0.12), border crop (0.11), chemical control (0.11), seed treatment (0.09), yellow sticky cards (0.09), pheromone traps (0.08), botanical spray (0.07) and NEFR technology (0.06).

Discussion of the cotton pest and disease management practices rankings

According to the result of experts' responses, the use of resistant cultivars is the most recommended practice for the CPDM. This recommendation was based on several field trials conducted using integrated disease management strategies (Hillocks, 1998; Allen, 2007; Singh *et al.*, 2008). On the other hand, farmer adoption results (Fig. 3) showed that this is the second most adopted practice after crop rotation. Thus, the use of resistant cultivars is considered the most crucial factor and obtained the highest weight in experts' recommendations and BC farmers' level of adoption. It implies that resistant cultivar is adopted by BC farmers according to experts' recommendations.

According to experts, Bt with non-Bt cotton is ranked as the second most recommended practice for the CPDM (Fig. 3), as cotton bollworm has developed resistance against Bt cotton. Our results are in accordance with the results of Ho *et al.* (2009), who recommended planting non-Bt cotton varieties on 20% of the Bt cotton planting area in order to avoid resistance to Bt cotton. It is because the cotton bollworm population resistant to Bt cotton will continue to cross with the non-resistant cotton bollworm population feeding on non-Bt cotton (so there is no chance of resistance). These results are also supported by Tabashnik *et al.* (2012) and Wan *et al.* (2012), who recommended the co-planting of Bt and non-Bt cotton crops to control the buildup of resistance in the pest population. According to the results of BC farmers' adoption, this is the third most adopted practice. However, based on the expert recommendations and BC farmers' adoption level, the level of adoption by BC farmers is closer to the expert recommendations.

The rotation of crops is one of the most efficient ways of keeping the plant environment unfavorable for crop pests and disease-causing pathogens, and it is the third most recommended practice for the CPDM, according to expert responses. Tariq *et al.* (2019) stated that crop rotation is not only the principle of a strategy toward higher yields but also a weapon for controlling diseases, pests and weeds. Hurd (1994) and Ahmad *et al.* (2020) also suggested that rotation of crops be implemented to interrupt the life cycle of insects, weed pests and diseases. It is ranked as the first and most adopted practice by BC farmers from the set of evaluated CPDMs. In order to minimize pests in the soil and maintain soil productivity, Better Cotton producers are using crop rotation and growing other field crops.

The seed treatment practice ranked fourth for the CPDM. It has also been recommended by other researchers (Prasanna *et al.,* 2002; Negalur *et al.,* 2017). Bessi *et al.* (2010) and Zhang *et al.* (2011) emphasized that seed treatment is gaining popularity in agriculture over traditional foliar application because it is less expensive, poses a substantially reduced hazard to the environment, and is less toxic to humans. When it comes to BC farmer adoption, the results show that it comes into the sixth rank of the adopted practices. The majority of the BC farmers are applying less seed treatments than the recommended quantity. Our results contradict those of Sable & Kadam (2012), who stated that farmers do not use seed treatment because they believe that Bt cotton seeds can control all diseases and pests. In our analysis, the BC farmers in the study had a good knowledge of seed treatments and used them in their fields.

The use of border crops is ranked as the fifth recommended practice. It is also recommended by other researchers; the cotton crop bordered by sorghum has revealed significantly lower whitefly populations (Blaise & Kranthi, 2019). However, BC farmers' adoption results showed that it is the fourth most adopted practice before chemical control. According to Zulfiqar *et al.* (2017)'s research in the Bahawalpur, Ahmadpur, and Yazman sub-districts, the adoption of border crops and biological pest management was quite low. However, the adoption of border crops was closer to experts' recommendations in the present research region of BC farmers from Tando Allahyar.

Yellow sticky cards ranked as the sixth recommended practice according to experts' responses. The use of yellow sticky cards, especially for whitefly and jassid, has also been recommended by Abdel-Megeed *et al.* (1998) and Atakan & Canhilal (2004). According to the results of BC farmers' adoption, it ranked as the seventh adopted practice. showing that yellow sticky cards are adopted by BC farmers as recommended by experts.

The NEFR technology ranked seventh in recommended practices. It has also been recommended by other researchers for the management of the cotton mealybug (Bhutto *et al.*, 2018; Mahmood *et al.*, 2018). As a result of BC farmer adoption, it ranked eighth in terms of adoption. Further research is needed to better understand the low level of adoption.

The botanical spray ranked as eighth recommended practice. Insecticidal qualities are found in many plants and minerals, which means they are toxic to insects. Natural compounds (insect poisons) collected or derived from plants or minerals are known as plant insecticides (botanical spray), and they are also recommended by other researchers mainly for the management of cotton sucking insect pests (Sultana *et al.*, 2012; Prishanthini & Vinobaba, 2014). According to BC farmers' adoption, it was the least adopted practice for the CPDM. However, in many studies,

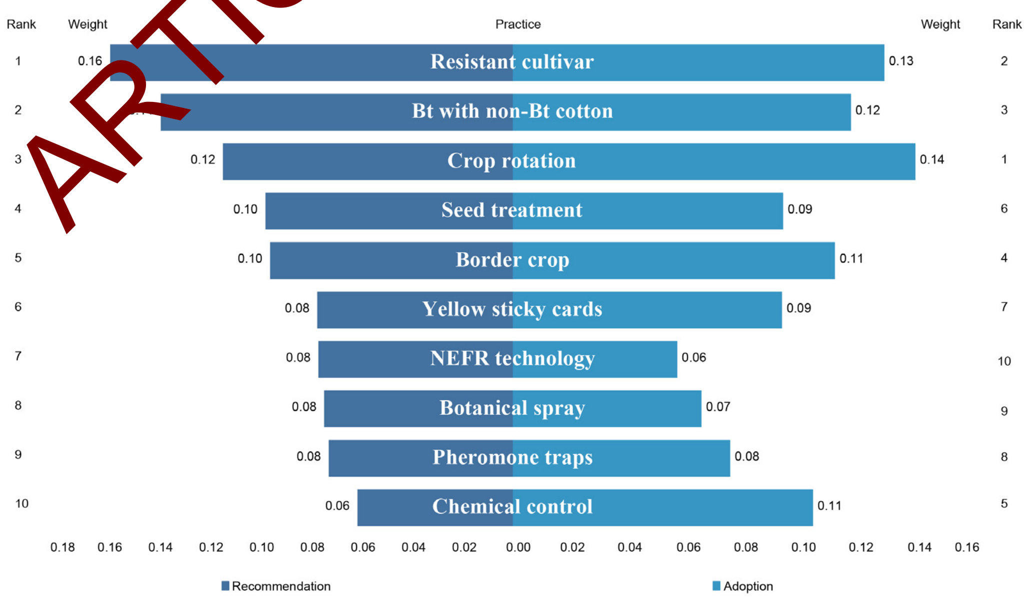

Figure 3. Experts' recommendation and Better Cotton farmers' adoption against cotton pests and disease management. NEFR: natural enemies field reservoir.

Neem spray is mentioned as the most effective method for the management of cotton sucking pests and diseases.

Pheromone traps ranked ninth. Pheromone traps have also been recommended in other studies (Murtaza *et al.*, 2019; Sehto *et al.*, 2020). Our results confirm the necessity to raise attention to the low adoption level of pheromone traps in the cultivation of cotton, as pointed out by Ashok *et al.* (2010).

The chemical control method should only be used as the last option for the CPDM, as recommended by experts and the IPM approach and argued by many experts around the world (Lewis *et al.*, 1997; Walter, 2005; Deguine *et al.*, 2008; Ahmad *et al.*, 2011). According to the results of BC farmer adoption level, it is the fifth most adopted practice for CPDM. However, experts recommended it as a last choice. This practice should be employed as a less frequent and last choice for the CPDM to achieve sustainable development goals. Many researchers also argued for the excessive use of pesticides in cotton. However, BC farmers use fewer pesticides than traditional cotton farmers (Zulfiquar *et al.,* 2019).

All of the above recommendations are closely related to economic and environmental benefits at the farm level. The adoption of less polluting and efficient practices can reduce harmful impacts on health, the environment and biodiversity, thereby reducing production costs. Radhakrishnan (2017) suggested that IPM, intercropping and companion planting, mulching, ground cover, and manual control and release of beneficial insects and organisms could be used instead of pesticides.

The adoption rate of some technologies and practices (NEFR technology, botanical spray and pheromone traps) was low. Some technologies may not have easily observable impacts, for example, through direct yield gains. In our analysis, technologies with lower levels of adoption fell into this category. This emphasizes the necessity to educate farmers on the benefits of these practices (Pathak *et al., 2019)*. More research is needed to improve our understanding of the diversity of factors involved in adoption decisions.

Conclusion

The BCI aims to improve global cotton production for the benefit of the people who grow it, the environment in which it grows, and the sector's long-term viability. This can be accomplished through environmentally friendly technologies and effective management. This research proposed an indicator framework comprising ten classified CPDM practices for analyzing the current situation and providing recommendations against crop protection for the future. Our results, derived from fuzzy AHP-based methodological approach, imply that the farmer participation in BC training led to a closer adherence of their practices to experts' recommendations. It was observed that BC farmers who received training were more likely to follow experts' recommendations for sustainable practices throughout the cotton production cycle. Farmers' participation in Better Cotton training programmes was a common factor in the higher adoption of sustainable practices across all production stages, highlighting the need for non-adopters to be trained to improve eco-innovation adoption.

Crop rotation, resistant cultivars, planting Bt with non-Bt cotton, border crop, and chemical control were highly adopted by BC farmers. We identified a discrepancy between the ranking for the level of adoption of chemical control by BC farmers and the recommended ranking of this strategy by experts. The difference suggests that chemical control may be over-adopted, and farmers should begin to view this practice more as a last resort for managing pests and diseases in cotton. It may be concluded that adopting recommended practices may pave the way for devising the optimal path for promoting sustainable cotton production and pest and disease management. To this end, efforts must be directed toward embracing modern concepts and technologies, and to achieve a higher level of BC production. All stakeholders need to make pledges to reduce production costs while increasing yield and income.

The present analysis has been conducted through the recommendation of ten experts and adoption of twenty BC farmers from Tando Allahyar district. In future work, the adoption of BC farmers can also be analyzed across all other remaining districts. Future studies can compare the views from different countries on the adoption of CPDM practices to observe differences. To make the adoption of CPDM easier, it should also be done to provide input support for farmers, such as the provision of crop varieties and other materials that can be used in place of pesticides against CPDM with easy availability at low prices.

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Authors' contributions

Conceptualization: A. M. Jiskani
Data curation: A. M. Jiskani
Formal analysis: A. M. Jiskani
Funding acquisition: Not applicable.
Investigation: A. M. Jiskani
Methodology: A. M. Jiskani
Project administration: Not applicable.
Resources: A. M. Jiskani
Software: Not applicable.
Supervision: M. A. Abro, M. I. Khaskheli and K. H. Wagan
Validation: A. M. Jiskani
Visualization: A. M. Jiskani

Writing – original draft: A. M. Jiskani
Writing – review & editing: A. M. Jiskani

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