

What Drives Protective Behaviors against Pesticide Exposure? A Study of Rice Farmers in Northern Iran

Mohammad Sharif Sharifzadeh

sharifzadeh@gau.ac.ir

Gorgan University of Agricultural Sciences and Natural Resources

Masoud Hashemi

University of Massachusetts

Gholamhossein Abdollahzadeh

Gorgan University of Agricultural Sciences and Natural Resources

Article

Keywords: Protective measures, enabling environment, information flow, social support, institutional incentives, behavior change

Posted Date: July 31st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10067797/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Scientific Reports on October 14th, 2026. See the published version at <https://doi.org/10.1038/s41598-026-72140-7>.

What Drives Protective Behaviors against Pesticide Exposure? A Study of Rice Farmers in Northern Iran

Mohammad Sharif Sharifzadeh^{*}, Masoud Hashemi[†] and Gholamhossein Abdollahzadeh[‡]

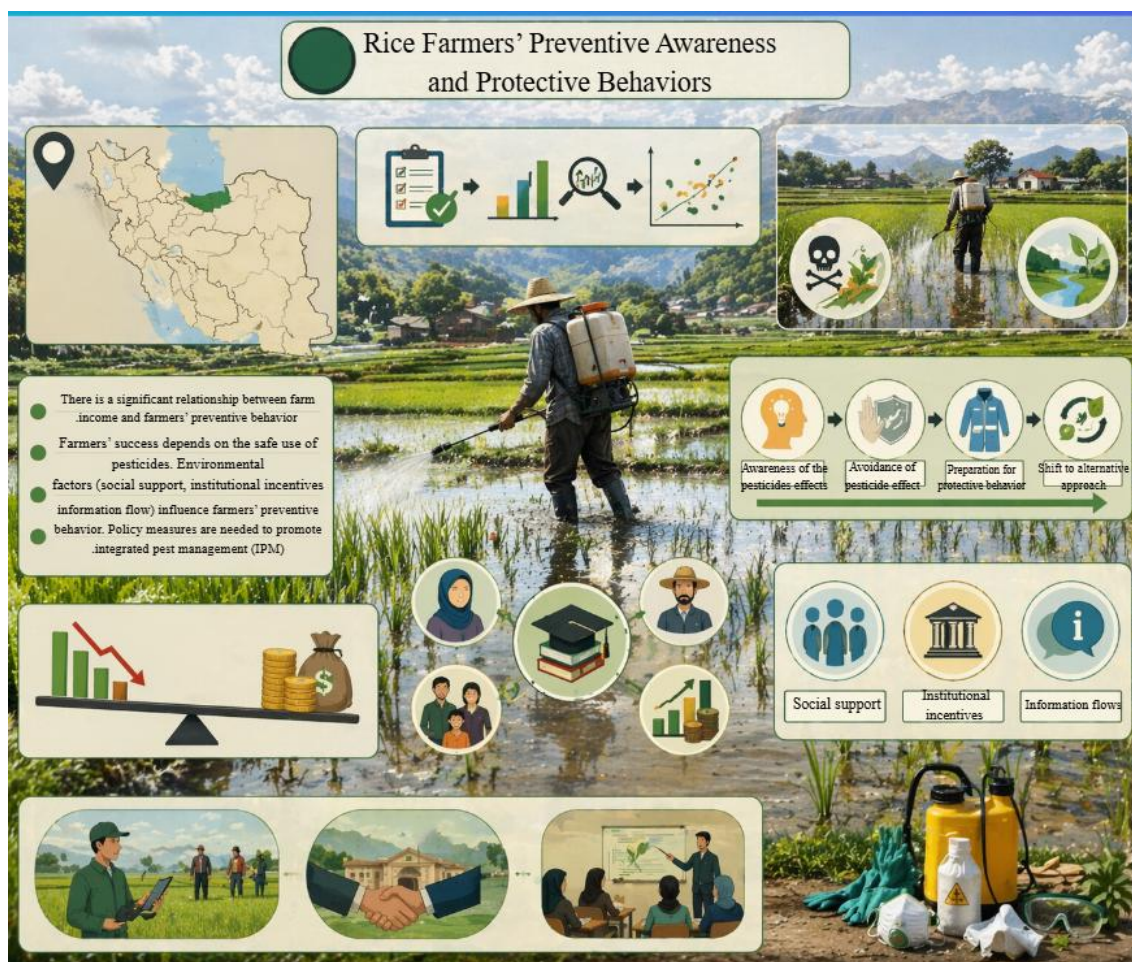
Highlights

- This study focuses on rice farming in Mazandaran Province, Iran, where heavy reliance on chemical pesticides poses significant health and environmental risks.
- Utilizes a cross-sectional survey involving 388 rice farmers, with data analyzed through exploratory factor analysis (EFA) and multiple linear regression (MLR) to uncover determinants of protective behaviors
- Introduces a multi-stage behavioral framework that identifies four key stages: awareness of pesticide effects, avoidance of pesticide poisoning, preparation for protective behavior, and recognition of the need for alternative pest management strategies.
- Key determinants influencing protective behavior include educational attainment, gender differences, household labor participation, and socio-economic factors with education emerging as the strongest predictor.
- Lower agricultural income and yield were associated with reduced protective actions, highlighting a paradox where economically successful farmers exhibited a reliance on chemical pesticides despite awareness of risks.
- Identifies critical enabling environment factors such as social support, institutional incentives, and information flow, which significantly influence farmers' decision-making and adoption of sustainable practices.
- Offers actionable recommendations for policymakers to enhance extension services, institutional support, and educational programs to facilitate behavioral transformation toward integrated pest management (IPM).

^{*} Department of Agricultural Extension and Education, Faculty of Agricultural Management, Gorgan University of Agricultural Sciences and Natural Resources - Golestan, Iran, sharifzadeh@gau.ac.ir

[†] Stockbridge School of Agriculture, University of Massachusetts, masoud@umass.edu

[‡] Department of Agricultural Extension and Education, Faculty of Agricultural Management, Gorgan University of Agricultural Sciences and Natural Resources - Golestan, Iran, abdollahzade1@gmail.com



Abstract

Background: Rice farming in Mazandaran Province, Iran, relies heavily on chemical pesticides, posing significant health and environmental risks. Despite efforts to promote pro-environmental practices, farmers' adoption of protective and sustainable behaviors remains limited. This study investigates the determinants of rice farmers' preventive awareness and protective behaviors, focusing on the sequential progression from awareness to preparation and eventual recognition of the need for alternative pest management strategies within an enabling environment framework.

Methods: A cross-sectional survey was conducted with 388 rice farmers across three major counties of Mazandaran Province. Data were collected through structured questionnaire and analyzed using exploratory factor analysis (EFA) and multiple linear regression (MLR).

Results:

Findings revealed generally low levels of preventive awareness and protective behavior. EFA identified four behavioral stages: awareness of pesticide impact, avoidance of pesticide poisoning effect, Preparation for protective behavior, and recognition of regent need for alternative pest management alongside three enabling environment factors: social support, institutional incentives, and information flows. Education, gender, and household labor participation significantly influenced behavioral outcomes, while higher income and yield were negatively associated with protective actions. Among enabling

environment variables, information flows exerted the strongest and most consistent influence across all behavioral stages, followed by institutional incentives and social support.

Conclusion: This study advances understanding of behavior change in pesticide use and pest management by conceptualizing protective behavior as a multi-stage process influenced by individual, economic, and institutional factors. The inclusion of enabling environment variables fills a key research gap and offers a comprehensive analytical framework. Policymakers should strengthen information networks, institutional support, and targeted training programs to facilitate gradual behavioral transformation toward sustainable pest management in Mazandaran's rice sector.

Keywords: Protective measures, enabling environment, information flow, social support, institutional incentives, behavior change

Introduction

Rice is recognized as the most vital cereal crop worldwide (Zeigler and Barclay, 2008). Its widespread cultivation has positioned it as the primary food source for humans (Gnanamanickam, 2009; Asma et al., 2023). Throughout history, rice farmers have played a more significant role in nourishing human societies than farmers of other staple grains, such as wheat, barley, and corn (Mohapatra and Sahu, 2021). In Iran, rice holds a significant place in the diet of the majority, ranking alongside wheat as a primary staple food (Sharifzadeh et al., 2021). The ecosystem of paddy fields creates an optimal environment for the proliferation of pests, weeds, and pathogens, posing a considerable threat to food security by reducing crop yields through any pest or disease outbreak (Zeigler and Barclay, 2008; Ghiasi et al., 2017). Approximately 50% of Iran's rice production occurs in Mazandaran province, situated in northern Iran along the southern shores of the Caspian Sea (Abdollahzadeh et al., 2016). Farmers in this region contend with a variety of pest challenges, including the Rice Stem Borer (*Scirpophaga incertulas*) and the Rice Leaf Folder (*Cnaphalocrocis medinalis*), as well as diseases such as Rice Blast (*Magnaporthe oryzae*) and Bacterial Blight (*Xanthomonas oryzae* pv. *oryzae*) (Ashoori et al., 2019).

Despite the availability of alternative pest and disease management strategies, local farmers predominantly rely on chemical control methods, utilizing various pesticides including Regent, Diazinon, Tricyclazole, and Tilt (Abdollahzadeh et al., 2025). This reliance has contributed to a marked increase in chemical product consumption in rice-growing regions throughout Iran (Tari et al., 2020). Although the average pesticide use per hectare in Iran is lower than the global average (approximately 2.2 kilograms per hectare), it has shown a concerning upward trend in recent years (MAJ, 2020). Statistical analyses of pesticide consumption from 2012 to 2020 indicate a more than twofold increase, with total use rising from about 14,000 tons to 35,000 tons (Morteza et al., 2017). Data pertaining to Mazandaran province indicate that approximately 60% of the 5,000 tons of pesticides consumed are allocated for rice cultivation (AJOM, 2022). Numerous studies have underscored the negative effects of this growing reliance on chemical substances among farmers in Mazandaran, highlighting implications for human health, biodiversity, and the pollution of water and soil resources (Abdollahzadeh et al., 2017; Amirahmadi et al., 2018). Despite various initiatives implemented under the titles of integrated pest management (IPM) and integrated crop management (ICM), which have been encouraged and supported by local agricultural authorities to control pesticide

consumption (Abdollahzadeh et al., 2025; Sharifzadeh et al., 2025), farmers remain insufficiently committed to adopting protective behaviors and preparing for a transition to alternative pest management methods due to a lack of awareness regarding the potential risks that pesticides pose to human health and the environment (Sharifzadeh et al., 2017). Numerous studies have confirmed that the adoption rates of biological control methods, pheromone traps, and other Integrated Pest Management (IPM) techniques remain consistently low with a high level of reliance on chemical control methods (Khan and Damalas, 2015; Abdollahzadeh et al., 2017; Sharifzadeh et al., 2021).

Preventive behaviors regarding pesticide risks encompass a wide range of activities such as awareness of pesticide consequences (Fan et al., 2015; Akter et al., 2018; Sabran and Abas, 2021; Imran et al., 2024), undertaking measures to avoid pesticide poisoning, especially refraining from eating and drinking while handling pesticides, and adhering to other health and safety protocols (Hashemi et al., 2012; Bondori et al., 2024; Kangavari et al., 2024). The transition to protective behaviors begins with awareness of pesticide-related consequences (Abdollahzadeh et al., 2015; Suprihanti et al., 2023; Kabir et al., 2024; Sharifzadeh and Abdollahzadeh, 2024), followed by the recognition of the need for specific protective actions, such as acquiring Personal Protective Equipment (PPE) (Davran et al., 2019; Sookhtanlou and Allahyari, 2021; Ansah and Skevas, 2024; Tsakiris et al., 2025), and ultimately results in preparation for adopting alternative pest management methods, particularly various IPM strategies (Alam et al., 2020; Sharifzadeh and Abdollahzadeh, 2024; Sharifzadeh et al., 2025). This behavioral change process is crucial for improving occupational safety and promoting sustainable farming practices (Abdollahzadeh et al., 2024).

Previous studies have clearly identified these actions as distinct protective behaviors, explaining the factors that influence their adoption. For instance, numerous studies have documented the acceptance and use of Personal Protective Equipment (PPE) (Damalas and Abdollahzadeh, 2016; Sookhtanlou and Allahyari, 2021; Ansah and Skevas, 2024; Tsakiris et al., 2025), the implementation of appropriate practices for pesticide application, avoidance of health risks, and hygiene practices following pesticide use (Hashemi et al., 2012; Fan et al., 2015; Houbraiken et al., 2016; Sharifzadeh et al., 2019). Additionally, extensive research has examined the adoption of IPM tactics, which including biological pest control methods (Abdollahzadeh et al., 2016; Mkenda et al., 2020), pheromone traps (Mehdizadeh et al., 2020; Ahmed, 2021; Kabir et al., 2023), botanical pesticide (Kabir et al., 2024), and agronomic pest control methods (Sharma et al., 2011) that aim to reduce long-term chemical dependence.

However, one of the most critical unanswered questions is how behavior change actually occurs during this process. Literature suggests that cognitive-informational deficits (such as low awareness of pesticide side effects) are identified as key barriers to transitioning to alternative pest management behaviors (Khan and Damalas, 2015; Abdollahzadeh et al., 2024). Without clear awareness of pesticide risks, farmers often remain dependent on conventional chemical controls, perceiving them as safer or more effective by default. This lack of awareness also reduces the perceived necessity of protective measures and safety behaviour (Damalas and Koutroubas, 2017; Bagheri et al., 2019; Lagili et al., 2020; Singh et al., 2024) and further delays the adoption of IPM (Abdollahzadeh et al., 2024). Nevertheless, a high level of knowledge regarding the pesticide use and safety behaviour alone does not necessarily lead to appropriate actions, such as replacing pesticides with safer alternatives like IPM methods (Yuantari et al., 2015; Krishnan et al., 2015; Slijper

et al., 2023; Bhujel et al., 2024). While knowledge is an important foundation, research shows that other factors such as preparedness and provision of resources, as well as the existence of an enabling environment (support from government and local institution, social norms, habits, resource access, and training and information), are necessary for achieving sustainable behavior change (Sharifzadeh et al., 2025).

Generally, much of the prior research has focused on demographic and farm management variables (Damalas and Abdollahzadeh, 2016; Sharifzadeh et al., 2019; Ansah and Skevas, 2024; Imran et al., 2024; Tsakiris et al., 2025; Ndirangu et al., 2025) influencing the transition to protective behaviors, while fewer studies have examined a comprehensive set of factors associated with the enabling environment. Factors associated with an enabling environment, such as government incentives, institutional pressure, access to extension and education services, and informational infrastructure, can play a crucial role in either facilitating or hindering farmers' transition to environmentally friendly behaviors (Barbosa, 2024; Sharifzadeh et al., 2025). Weaknesses in this enabling environment can undermine a farmer's actions, even in the presence of strong intentions. Therefore, the research gap lies in the absence of studies that investigate the components of behavior change, specifically the progression from mere awareness to preparation, and ultimately to sustained protective behavior. Additionally, there is a scarcity of studies that integrate the components of an enabling environment with demographic and farm structure variables, examining their influence on the elements of behavior change. The objective of this study is to investigate how the demographic characteristics of farmers, attributes of their farm structures, and their perceptions of the enabling environment relate to preventive awareness and protective behaviors concerning pesticide effects among a sample of rice farmers in Mazandaran province, northern Iran.

Literature review

Farmers' awareness of pesticide risks and their adoption of protective behaviors are influenced by a complex interplay of socio-demographic, educational, economic, and psychological factors, as well as access to information and training (Jones et al., 2008; Zhang et al., 2011; Yang et al., 2014; Fan et al., 2015; Wang et al., 2017; Jallow et al., 2017; Bhandari et al., 2018; Akter et al., 2018; Sharifzadeh et al., 2019; Shammi et al., 2020; Sabran and Abas, 2021; Thapa et al., 2021; Goeb and Lupi, 2021; Andersson and Isgren, 2021; Dinh and Miura, 2022; Keleb et al., 2024; Kangavari et al., 2024; Imran et al., 2024; Bondori et al., 2024; Adu, 2025; Aslam et al., 2025; Shah et al., 2026). These factors collectively determine how farmers perceive the dangers associated with pesticides and consequently, their willingness and ability to implement safety measures as well as moving towards alternative pest management methods (Jallow et al., 2017; Sharifzadeh et al., 2019; Sabran and Abas, 2021; Kangavari et al., 2024).

One of the primary determinants is the level of knowledge and awareness regarding pesticide risks (Fan et al., 2015; Akter et al., 2018; Bhandari et al., 2018; Sabran and Abas, 2021; Keleb et al., 2024). Studies have consistently shown that a lack of adequate knowledge about the harmful effects of pesticides on human health and the environment contributes to unsafe practices (Yang et al., 2014; Sabran and Abas, 2021). For instance, a study in Pulau Pinang, Malaysia, highlighted that obtaining information on pesticide risks is essential to mitigate adverse impacts (Sabran and Abas, 2021). Similarly, research in northern China indicated insufficient reports on farmers' knowledge and awareness regarding pesticide use (Fan et al., 2015). A study conducted among Iranian rice farmers revealed that those who possess a greater awareness of the negative impact of pesticide use are more inclined to support the adoption of alternative pest control methods, such as

biological control techniques (Abdollahzadeh et al., 2015). Sharifzadeh and Abdollahzadeh (2024) report that personal risk knowledge and environmental risk knowledge associate with high familiarity in integrated pest management. Fan et al. (2015) note that greater general knowledge and perception of pesticide consequences are significant factors in driving protective behaviors.

However, knowledge alone does not guarantee the adoption of environmentally friendly practices. Several studies indicate that while farmers may be aware of the negative consequences, the adoption rates of sustainable agricultural practices remain low due to various constraints (Krishnan et al., 2016; Slijper et al., 2023; Bhujel and Joshi, 2024). These constraints can include economic factors such as the high cost of alternative practices, lack of access to necessary technologies or inputs, inadequate market access for sustainably produced goods, and insufficient advisory or extension services (Slijper et al., 2023; Bhujel and Joshi, 2024; Ahmad et al., 2025). For instance, Dutch arable farmers continue to rely heavily on synthetic fertilizers and pesticides to secure high yields at low costs, despite the environmental degradation caused (Slijper et al., 2023). In Pakistan, farmers receiving public and private extension services showed varying likelihoods of adopting eco-friendly farming, suggesting the influence of the advisory system (Ahmad et al., 2025).

Socio-demographic characteristics play a crucial role (Wang et al., 2017; Wang et al., 2018; Sabran and Abas, 2021). Factors such as education level, age, and gender have been identified as significant influences (Wang et al., 2017; Aslam et al., 2025). Higher education levels often correlate with increased awareness and adoption of safer practices (Wang et al., 2018; Aslam et al., 2025). For example, studies in China showed that gender differences exist, with male farmers often having better knowledge of pesticide use and associated health risks compared to female farmers (Wang et al., 2017). In some contexts, older farmers may rely more on traditional, pesticide-based methods, while younger, more educated farmers might be more inclined to adopt newer, less pesticide-intensive technologies (Wang et al., 2018). Socio-economic factors significantly influence both the awareness and adoption of technologies related to alternative pest management strategies, such as biological control and pheromone trapping (Abdollahzadeh et al., 2015; Sharifzadeh et al., 2021). The finding of a study from Bangladesh revealed that background variables including education, age, farming experience, and farm ownership all contributed similarly to farmers' understanding of pesticide dangers to health and environment, regardless of rural or urban location (Shammi et al., 2020).

Access to information and training significantly impacts farmers' behavior (Wang et al., 2018; Goeb and Lupi, 2021; Aslam et al., 2025). Effective science communication frameworks are crucial for raising pesticide risk awareness and promoting the adoption of safe practices (Aslam et al., 2025). Farmer-to-farmer training programs have demonstrated effectiveness in improving pesticide knowledge (Goeb and Lupi, 2021). In many developing regions, farmers may receive information from unreliable sources or lack access to proper training, leading to inappropriate practices (Yang et al., 2014; Fan et al., 2015; Bhandari et al., 2018; Shammi et al., 2020; Andersson and Isgren, 2021).

Risk perception is another critical psychological factor influencing protective behaviors (Wang et al., 2017; Jallow et al., 2017; Sharifzadeh et al., 2019; Shammi et al., 2020; Bondori et al., 2024; Kangavari et al., 2024; Imran et al., 2024; Shah et al., 2026). Farmers' beliefs about the severity of pesticide-related health risks and their susceptibility to them directly affect their willingness to take protective measures (Kangavari et al., 2024; Shah et al., 2026). Studies in Pakistan found that risk perception and past pesticide-

related health problems experienced by farmers influence the adoption of protective pesticide behaviors (Imran et al., 2024). Farmers' perceptions of risks and the determinants of pesticide overuse are crucial for modifying their behavior towards reducing pesticide use and considering alternative pest control tactics (Jallow et al., 2017). Attitudes and cultural practices also shape farmers' decisions (Akter et al., 2018; Karasmanaki et al., 2021; Dinh & Miura, 2022; Imran et al., 2024; Adu, 2025). Positive attitudes towards safety and environmental protection are linked to safer pesticide handling (Akter et al., 2018; Karasmanaki et al., 2021; Dinh & Miura, 2022; Imran et al., 2024). Cultural background and eco-environmental awareness can significantly influence pesticide application behavior, including the choice of application intervals and preparation of pesticides (Jihong et al., 2016). However, some research suggests that pro-environmental behavior among farmers may not always directly translate into proper pesticide practices (Karasmanaki et al., 2021).

The availability and use of PPE is a direct measure of protective behavior (Jones et al., 2008; Davran et al., 2019; Thapa et al., 2021; Bondori et al., 2024). Factors affecting the adoption of PPE include knowledge of its importance, perceived effectiveness, cost, and comfort (Jones et al., 2008; Davran et al., 2019; Thapa et al., 2021). In many developing countries, the use of PPE is still low, leaving farmers directly exposed to harmful chemicals (Thapa et al., 2021). A study in Nepal identified various factors influencing the adoption of PPE, emphasizing the need for targeted interventions (Thapa et al., 2021). Farmers in Mozambique, for example, often lack knowledge of protective gear and health risks, leading to a lack of preventive measures (Jones et al., 2008).

Economic considerations significantly influence farmers' decisions regarding pesticide use and protective behaviors (Andersson and Isgren, 2021; Bjørnåvold et al., 2022). The desire for higher crop yields and market returns can drive intensive pesticide use (Wang et al., 2018; Andersson and Isgren, 2021). Farmers often face socio-economic trade-offs when considering the adoption of agro-ecological practices that reduce pesticide reliance (Bjørnåvold et al., 2022). The perceived impact on income after technological change and the time needed to change practices can create economic uncertainty, making farmers hesitant to invest in new, safer methods (Bjørnåvold et al., 2022). This is particularly relevant in contexts where farmers engage in risk-prone practices, increasing pesticide use to secure higher yields despite being aware of the associated risks (Andersson and Isgren, 2021).

Institutional pressures and regulatory frameworks also play a role (Wang et al., 2018; Bjørnåvold et al., 2022). Government regulations, environmental groups, and consumer preferences can influence pesticide application or their alternative method (Wang et al., 2018). However, governmental uncertainty, including technocratic decision-making, disconnect between governmental expectations and reality, and unreliable policy futures, can hinder the adoption of safer practices (Bjørnåvold et al., 2022). Delayed or unpaid subsidies can also create financial uncertainty for farmers and discourage them from making the switch to more sustainable practices (Bjørnåvold et al., 2022).

Finally, health experiences can profoundly influence protective behaviors (Zhang et al., 2011; Akter et al., 2018; Keleb et al., 2024; Imran et al., 2024). Farmers who have personally experienced or witnessed acute pesticide poisoning or other health problems related to pesticide exposure are more likely to adopt protective measures (Zhang et al., 2011; Akter et al., 2018; Keleb et al., 2024; Imran et al., 2024). A cross-sectional survey in Southern China, for example, investigated the prevalence and risk factors of acute work-related pesticide poisoning among farmers (Zhang et al., 2011). This direct

experience often serves as a powerful motivator for behavioral change, reinforcing the importance of safety practices (Imran et al., 2024).

In summary, improving farmers' preventive awareness and protective behaviors necessitates a multifaceted approach that addresses knowledge gaps, enhances training and information access, considers socio-economic realities, leverages positive risk perceptions, promotes the use of PPE, and fosters supportive regulatory and market environments (Wang et al., 2018; Goeb and Lupi, 2021; Bjørnåvold et al., 2022; Kangavari et al., 2024; Aslam et al., 2025; Shah et al., 2026).

Research method

Sampling and Procedure

This study was conducted in Mazandaran Province, recognized as Iran's leading rice-producing region. The research employed a cross-sectional survey design, with data collection taking place from February 2025 to September 2025. The target population comprised farmers actively engaged in rice production across the counties of Babol, Amol, and Sari in Mazandaran Province. These counties were purposefully selected due to their significance as major rice cultivation areas in Iran, where chemical use in rice production is notably high (Abdollahzadeh et al., 2015; Sharifzadeh et al., 2021). Moreover, the region has witnessed numerous extension and training initiatives aimed at encouraging farmers to adopt protective practices (Sharifzadeh et al., 2019) and alternative pest management methods (Abdollahzadeh et al., 2025).

To determine the sample size, the Krejcie-Morgan table (1970) indicated that a sample of 385 farmers would be sufficient. A comprehensive list of rice farmers was obtained from the Mazandaran Agricultural Jihad Organization, a provincial authority accountable for overseeing all agricultural activities. The sample was allocated proportionally across the three counties, with 10 to 12 villages randomly selected from each county, resulting in a total of 31 villages. Interviews were conducted in person at the participants' homes or farms, facilitated by six trained interviewers. Prior to the interviews, appointments were made via telephone to confirm the farmers' willingness to participate. Ultimately, following the exclusion of incomplete questionnaires, a total of 388 valid responses were included in the final analysis.

Questionnaire development

The questionnaire was developed through a thorough review of existing literature, focusing on the consequences and side effects of pesticide exposure on both farmers' health and the environment (Hashemi et al., 2012; Abdollahzadeh et al., 2015; Houbraken et al., 2016; Akter et al., 2018). Additionally, literature pertaining to protective behaviors aimed at preventing pesticide exposure (Fan et al., 2015; Houbraken et al., 2016; Damalas and Abdollahzadeh, 2016; Sharifzadeh et al., 2019) was examined, alongside strategies that farmers could adopt as alternatives to chemical pesticides (Sharifzadeh and Abdollahzadeh, 2024).

The initial questionnaire was created based on insights gained from these three areas of literature. To assess face validity, the questionnaire was reviewed by five local farmers, resulting in the incorporation of additional items that reflected their specific experiences within the study area. Following this, two subject matter experts include a specialist in agricultural extension and education and an expert in pest management and plant protection conducted further revisions, resulting in a refined version of the questionnaire. The final questionnaire was organized into three sections. The first section captured demographic information and farm-related characteristics. The second section comprised

21 items designed to measure farmers' awareness of preventive measures and protective behaviors concerning pesticide effects. The third section included 17 items assessing farmers' perceptions of their enabling environment. Responses in the second and third sections were measured on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). A pilot study was conducted with 15 rice farmers outside the study area to evaluate the coherence and clarity of the questionnaire items. Feedback from this pilot study resulted in minor revisions, leading to the final version of the questionnaire.

Statistical analysis

The data collected for this study were analyzed using SPSS software version 26. This study employed a combination of descriptive and inferential statistical methods to analyze the research variables comprehensively. Descriptive statistics, including mean, standard deviation, frequency, and percentage of frequency, were implemented to summarize the data. In addition, inferential statistical techniques were applied, specifically exploratory factor analysis (EFA), which involved principal component analysis with Varimax rotation. We established a criterion of eigenvalues greater than 1.0 and factor loadings of 0.50 or higher to determine factor retention. Given the multifaceted objectives of this study, we initially performed two EFA to effectively summarize the research data. The first analysis aimed to identify the underlying dimensions associated with preventive awareness and protective behavior in relation to the effects of pesticides. The second exploratory factor analysis focused on revealing the latent dimensions within the perceived enabling environment. To assess the reliability of the measures corresponding to the derived factor structures, we calculated Cronbach's alpha coefficients. Following the identification of the primary dimensions within the data structures of both scales, we computed composite scores for each factor, derived from the average of the mean scores of the items deemed significant for each factor. These composite scores were subsequently employed in the multiple linear regression (MLR) analysis to examine the effects of various independent variables on the dimensions of preventive awareness and protective behavior pertaining to pesticide impacts. In the MLR analysis, the four factors representing preventive behavior extracted from the EFA were treated as dependent variables. The independent variables were composed of three types of perceived enabling environments, which emerged from a secondary EFA, alongside selective demographic variables, including age, gender, education level, and the rate of self-consumption of output. Additionally, farm management variables such as agricultural income, area allocated to rice farming, percentage of household labor engaged in agriculture, and rice output per unit area were also included in the analysis.

4. Findings

4.1. Descriptive statistic of respondents

The descriptive statistics for the surveyed farmers are presented in Table 1. The average age of farmers is 45.18 years, indicating a mature demographic within the sector, while the mean years of formal education stands at 6.89, with notable variability suggesting differing educational backgrounds. The proportion of male farmers is significantly high at 87.11%, indicating a gender imbalance in the sample. Farmers report an average self-consumption rate of 40.20% of their total agricultural output, reflecting varied reliance on personal production for household consumption. The average monthly agricultural income is \$259.66, with a standard deviation of \$101.62, highlighting income disparities among farmers and indicating the low income of those in the study. On average, farmers

dedicate 3.78 hectares to rice farming, and the percentage of household labor involved in agriculture is 44.13%, indicating a strong reliance on family labor. Finally, the average rice output per hectare is 5.57 kg, with a high standard deviation of 3.07 kg, suggesting significant differences in productivity levels among farmers.

Table 1.
Descriptive statistics of variables for surveyed farmers

Variable description	Mean	SD*
Farmers' characteristics		
Age (years)	45.18	14.59
Proportion of male farmers (1 = male, 0 = female; total respondents = 388; percentage of male farmers = 87.11%)	0.87	0.34
Education (years formal education)	6.89	5.41
Self-consumption rate of output (Percentage of total agricultural output consumed by the household)	40.20	21.44
Farm management variables		
Average monthly agricultural income (US \$)	259.66	101.62
Area devoted to rice farming (hectares)	3.78	0.75
Percentage of household labor in agriculture (%)	44.13	18.43
Rice output per unit area (kilograms per hectare)	5.57	3.07

* Standard deviation

Factor analysis results of preventive awareness and protective behavior

Table 2 presents the findings of the factor analysis conducted to group items related to preventive awareness and protective behavior concerning pesticide effects. The total variance explained by the 17 factors was 64.747%, indicating an acceptable level of factor retention. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.791, indicating that the data structure is appropriate for factor analysis. Additionally, Bartlett's Test of Sphericity shows a significant p-value of 0.000 ($\chi^2 = 5074.911$; $df = 210$), confirming the presence of significant relationships among the 17 items related to preventive awareness and protective behavior concerning pesticide effects.

The results identify four distinct factors, as presented in Table 2. The first factor can be labeled 'awareness of pesticide effects', consisting of 6 items and explaining 18.413% of the variance. This factor reflects farmers' understanding of the impacts of pesticide use. The item that received the highest mean score, "understanding the effects of pesticides on the destruction of beneficial farm organisms and the reduction of biodiversity", attained a mean value of 2.855. This finding underscores the significant importance that farmers place on the protection of beneficial insects and highlights a critical need for informed pest management practices that prioritize biodiversity conservation. The second factor identified through factor analysis represents the need for transitioning to alternative pest control methods. This factor consists of 6 items and explains 16.663% of the variance, and is titled 'recognizing the urgent need to shift to alternative pest management strategies'. The item "establishing connections with producers and buyers of organic products to capture a share of the market for sustainably produced goods" has the highest mean in this group at 2.706, signaling optimism for developing sustainable practices. The third factor identified in the study was labeled as 'preparation for protective behavior', which encompasses five items and accounts for 15.974% of the explained variance. This factor underscores the importance of being prepared to implement protective measures

while handling pesticides. Among the items assessed, the statement, “ensuring the availability of a first aid kit in case of poisoning symptoms”, received the highest mean score of 2.472. The final factor identified in the study was labeled ‘avoidance of pesticide poisoning effects’, which includes four items and accounts for 13.696% of the explained variance. This factor focuses on actions aimed at minimizing exposure to pesticide-related risks. Notably, the item “avoid working with pesticides without personal protective equipment (PPE)” received the highest mean score in this category, measuring 2.259. This result underscores the critical importance of using PPE when handling pesticides to prevent adverse health effects. The data presented in Table 1 also reveal that the overall scores for the assessed items related to the four factors extracted from the factor analysis fall below the median score of the Likert scale, which is 3. Specifically, the average score in this analysis is 2.553. These findings indicate a troublingly low and inadequate level of preventive awareness and protective behavior concerning the effects of pesticides among farmers.

Table 2 shows that the internal consistency reliability coefficients in the Cronbach alpha for four factors were 0.771, 0.810, 0.732, and 0.714 respectively which indicate that these reliability coefficients were acceptable for next analysis (Hair et al., 2013).

Table 2.

Factor analysis for grouping items of preventive awareness and protective behavior related to pesticide effects

Items	Factor loadings	Mean (over 5)	Standard deviation
Awareness of the pesticides effects (Variance Explained: 18.413% Eigenvalue: 3.867, Cronbach's alpha: 0.771)			
Observing and understanding the effects of pesticides on personal health and farm labor force	0.722	2.941	0.947
Recognizing the long-term impact of pesticides on farm self-sufficiency due to dependency on external inputs	0.813	2.657	0.822
Understanding the relationship between pesticide use and diseases resulting from the consumption of unhealthy food produced for consumers	0.784	2.431	1.179
Observing and comprehending the destructive impact of pesticide use on water and soil quality	0.716	2.793	0.797
Understanding the effects of pesticides on the destruction of beneficial farm organisms (natural pest predators, parasites, and pathogens) and the reduction of biodiversity	0.866	2.855	0.981
Assessing the effectiveness of healthier alternatives for pest control	0.786	2.750	0.862
Overall score		2.738	1.065
Recognizing the urgent need to shift to alternative pest management strategies (Variance Explained: 16.663% Eigenvalue: 3.499, Cronbach's alpha: 0.810)			
Planning for the gradual replacement of integrated pest management methods	0.768	2.821	1.177
Engagement with local advisory centers for information on alternative pest control methods	0.620	2.696	1.215
Networking and partnership building through collaboration with neighboring farmers to eliminate pesticide use and facilitate the adoption of alternative methods”	0.783	2.553	1.191
Establishing communication with suppliers of predatory wasps, pheromone traps, and other alternative methods in place of pesticides	0.622	2.815	1.325

Establishing connections with producers and buyers of organic products to capture a share of the market for sustainably produced goods	0.864	2.706	0.987
Establishing communication with relevant authorities and agencies for obtaining permits, securing support, and gaining official recognition	0.840	2.526	1.131
Overall score		2.686	1.171
Preparation for protective behavior (Variance Explained: 15.974% Eigenvalue: 3.355, Cronbach's alpha: 0.732)			
Providing PPE during pesticide handling	0.831	2.552	1.080
Ensuring the availability of a first aid kit in case of symptoms of poisoning	0.863	2.472	0.974
Familiarity with first aid procedures and the resuscitation of individuals affected by poisoning	0.820	2.500	0.806
Care should be taken to prevent the reuse of pesticides that have previously caused poisoning incidents.	0.689	2.778	0.752
Informing neighboring farmers about the presence of hazardous pesticide particles and associated risks	0.716	2.057	0.865
Overall score		2.472	0.895
Avoidance of pesticide poisoning effect (Variance Explained: 13.696% Eigenvalue: 2.876, Cronbach's alpha: 0.714)			
Avoid working with pesticide without PPE	0.910	2.259	1.078
Avoid being in areas undergoing pesticide spraying	0.906	2.159	1.138
Stop working if you feel uncomfortable	0.720	2.488	1.103
Do not eat, drink, or smoke in environments that have previously been subjected to pesticide application.	0.770	2.348	0.972
Overall score		2.314	1.073
Total Variance 64.747%, Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy: KMO = 0.791, Bartlett's Test of Sphericity: p-value = 0.000 ($\chi^2 = 5074.911$; df = 210), Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization			

Factor analysis results of perceived enabling environment

Using the factor analysis, items of perceived enabling environment split into three distinct factors: social support, institutional incentives, and information flows (Table 3). The total variance explained by these factors is 61.057%, with a Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of 0.808 and Bartlett's Test of Sphericity indicating statistical significance ($p < 0.001$, $\chi^2 = 4465.243$; df = 136).

The first factor identified in the analysis is labeled 'social support', which comprises six items and accounts for 22.742% of the variance explained. This factor captures the community and familial support for adopting healthier production methods. A noteworthy item is the statement indicating that "consumers demonstrate a pronounced preference for products produced through healthier methods", which received a mean score of 3.812. This finding reflects a positive outlook among farmers regarding the market potential for organic products. The overall mean score for this factor was 3.083, suggesting a moderate perception of social support within the community for healthier agricultural practices. A key institutional incentive involves government backing for supply chain actors, ensuring the availability and accessibility of critical inputs and services that underpin the shift to healthier pest management practices. The second factor identified in the analysis is labeled 'institutional incentives', comprising six items and accounting for 19.817% of the explained variance. This dimension emphasizes the significance of government policies

and programs in promoting healthier agricultural practices. One particularly notable item is the statement, “local authorities have implemented targeted programs at the provincial and county levels to promote the cultivation of healthy products”, which received a mean score of 3.422. This finding emphasizes the local efforts aimed at encouraging farmers to adopt health-oriented production methods. The overall mean score for this factor was 2.953, indicating a relatively positive perception of institutional support among respondents. The third factor, designated as ‘information flows’, includes five items and accounts for 18.497% of the variance explained. This factor focuses on the accessibility and circulation of information pertaining to healthy agricultural practices. A key item in this category is, “farmers and suppliers exchange information related to healthy product production”, which received a mean score of 3.199. The overall mean score for this factor was 2.889, suggesting a relatively weak level of information accessibility among farmers. A key determinant of the transition toward environmentally friendly pest control methods is the accumulation of region-specific IPM knowledge. The localization of technical information and research findings reduces uncertainty among farmers by providing context-specific, field-validated alternatives to conventional chemical-intensive practices. Additionally, the reliability of the factors was assessed using Cronbach's alpha, as shown in Table 3. The internal consistency coefficients for the three factors were 0.755, 0.764, and 0.784, respectively. These values indicate acceptable reliability for the factors, making them suitable for use in subsequent analyses.

Table 3.

Factor analysis for grouping items of perceived enabling environment

Items	Factor loadings	Mean (over 5)	Standard deviation
Social support (Variance Explained: 22.742% Eigenvalue: 3.866, Cronbach's alpha: 0.755)			
Consumers show a heightened preference for products that are produced through healthier methods.	0.920	3.812	1.141
Suppliers prioritize the provision of production inputs conducive to healthier farming practices.	0.709	2.568	0.974
Neighboring farmers advocate for and are willing to collaborate on healthier production methods.	0.505	2.792	1.310
Farmworkers tend to favor employment in agricultural operations that adhere to good farming practices.	0.688	2.222	1.217
Family members encourage me to produce crops using healthier methods.	0.946	3.405	0.826
Farmers who adopt healthier production techniques actively interact with one another, providing mutual support.	0.880	3.698	1.411
Overall score		3.083	1.146
Institutional incentives (Variance Explained: 19.817% Eigenvalue: 3.369, Cronbach's alpha: 0.764)			
The government pursues specific policies aimed at supporting healthier production practices.	0.847	3.198	1.285
Local authorities have implemented targeted programs at the provincial and county levels to promote the cultivation of healthy products.	0.850	3.422	1.204
The government provides subsidies for essential inputs needed for the production of healthy products.	0.775	2.568	0.947
The government supports the promotion and advertisement of healthy product consumption through state-run radio and television programs, festivals, and other events.	0.694	2.928	1.139
There is government backing for specialized research initiatives focusing on good agricultural practices.	0.655	2.839	1.098
The government collaborates effectively with farmer associations and private investors to foster the development of value chains for healthy products.	0.612	2.766	1.116
Overall score		2.953	1.131
Information flows (Variance Explained: 18.497% Eigenvalue: 3.145, Cronbach's alpha: 0.784)			

Specialized experts are available in the region to offer guidance and advice on healthy product production.	0.803	2.648	0.983
Effective extension and training programs regarding healthy crop production are being implemented in the area.	0.796	2.743	1.008
Farmers and suppliers exchange information related to healthy product production.	0.779	3.199	0.918
Research institutions and universities engage with farmers in the region to facilitate the implementation of healthy production practices.	0.753	2.892	1.021
As result of integrated extension –research projects, information sources, such as booklets, brochures, and manuals concerning healthy farming practices, are readily available to farmers.	0.657	2.965	0.899
Overall score		2.889	0.966

Total Variance 61.057%, Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy: KMO = 0.808, Bartlett's Test of Sphericity: p-value = 0.000 ($\chi^2 = 4465.243$; df = 136), Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization

4.3. Determinants of protective behavior: Regression Analysis Results

Table 4 presents the results of the regression analysis conducted to assess the determinants of pesticide-related preventive awareness and protective behavior across four models, each with different dependent variables. It is noteworthy that the variable for agricultural work experience was not included in the analysis due to its collinearity with the age variable.

Model 1: awareness of the impact of pesticides

This model achieved acceptable fit indices, with an R value of 0.660 and an R² value of 0.436, indicating that approximately 43.6% of the variance in awareness can be explained by the independent variables. The adjusted R² of 0.419 further supports the model's validity. The F-statistic (26.377, $p < 0.01$) indicates that the model is statistically significant. The Durbin-Watson statistic is 2.243, which falls within the acceptable range of 1.5 to 2.5, suggesting no autocorrelation in the residuals. To control for multicollinearity, the Variance Inflation Factor (VIF) was evaluated; all VIF values were below 5, indicating no significant collinearity among the predictors. The Breusch-Pagan test results (3.356, $p > 0.05$) indicate no heteroskedasticity, confirming that the residuals are evenly distributed.

In this model, several independent variables showed significant effects on awareness. Specifically, age ($\beta = -0.226$, $p < 0.01$) and education ($\beta = 0.195$, $p < 0.01$) were significant predictors, suggesting that older farmers have less awareness, while higher education levels enhance awareness. Self-consumption rate ($\beta = 0.088$, $p < 0.05$) is another predictor of the dependent variable of awareness. Additionally, perceived social support ($\beta = 0.116$, $p < 0.01$), institutional incentives ($\beta = 0.138$, $p < 0.01$), and information flows ($\beta = 0.456$, $p < 0.01$) were positively associated with awareness, highlighting the importance of a supportive environment and access to information.

Model 2: avoidance of pesticide poisoning effects

This model exhibited strong fit indices, with an R value of 0.712 and an R² value of 0.506, indicating that over 50% of the variance in avoidance behaviors is explained by the model, supported by an adjusted R² of 0.492. The F-statistic (35.051, $p < 0.01$) reflects that the model is statistically significant, and the Durbin-Watson statistic of 2.207 indicates no autocorrelation. As with model 1, VIF values remained below 5, signifying no multicollinearity. The Breusch-Pagan test result (0.553, $p > 0.05$) further confirms homoscedasticity.

Significant predictors in this model included gender ($\beta = -0.182$, $p < 0.01$), indicating that male farmers are less likely to engage in behaviors aimed at avoiding pesticide poisoning compared to their female counterparts. Education ($\beta = 0.092$, $p < 0.05$), the rate of self-consumption of farm output ($\beta = 0.098$, $p < 0.01$), and the percentage of household labor employed in agriculture ($\beta = 0.254$, $p < 0.01$) were all positively correlated with avoidance behaviors, suggesting that higher levels of education and more significant involvement of household labor in agricultural activities contribute to increased awareness and protective actions against pesticide exposure. Conversely, agricultural income ($\beta = -0.353$, $p < 0.01$) and rice yield ($\beta = -0.079$, $p < 0.01$) were negatively associated with avoidance behaviors. These findings imply that farmers with greater income and higher farm yields may exhibit less concern regarding pesticide exposure. This phenomenon may stem from a perceived assurance of the benefits associated with pesticide usage, coupled with a reluctance to acknowledge its potential negative consequences. Additionally, three variables related to the perceived enabling environment, social support ($\beta = 0.085$, $p < 0.05$), institutional incentives ($\beta = 0.089$, $p < 0.01$), and information flows ($\beta = 0.286$, $p < 0.01$) showed positive associations with avoidance behaviors.

Model 3: preparation for protective behavior

The fit indices for this model are satisfactory, with an R value of 0.658 and an R^2 value of 0.433, indicating that approximately 43.3% of the variance in protective preparation can be explained by the independent variables. The adjusted R^2 of 0.416 supports its validity, and the F-statistic (26.086, $p < 0.01$) further confirms the model's significance. The Durbin-Watson statistic of 2.016 indicates no autocorrelation, while the VIF values remained below 5, signifying no multicollinearity. The Breusch-Pagan test result (3.141, $p > 0.05$) confirmed homoscedasticity.

Significant variables in this model included education ($\beta = 0.367$, $p < 0.01$), agricultural income ($\beta = 0.196$, $p < 0.01$) and percentage of household labor in agriculture ($\beta = 0.090$, $p < 0.05$). Gender ($\beta = -0.125$, $p < 0.01$) negatively impacted preparation, with male farmers being less likely to engage in protective behaviors. Social support ($\beta = 0.100$, $p < 0.05$), institutional incentives ($\beta = 0.290$, $p < 0.01$) and information flows ($\beta = 0.120$, $p < 0.01$) were also positively related to protective behavior preparation.

Model 4: recognizing the urgent need to shift to alternative pest management strategies

This model showed excellent fit indices, with an R value of 0.730 and an R^2 value of 0.533, indicating that over 53% of the variance in recognition for alternative strategies can be explained by the model, supported by an adjusted R^2 of 0.519. The F-statistic (40.774, $p < 0.01$) indicates significant model fit. The Durbin-Watson statistic of 2.130 confirms absence of autocorrelation. VIF values were again below 5, indicating no multicollinearity, while the Breusch-Pagan test (1.492, $p > 0.05$) indicated homoscedasticity.

In this model, significant predictors included gender ($\beta = -0.184$, $p < 0.01$), education ($\beta = 0.112$, $p < 0.01$), rate of self-consumption ($\beta = 0.084$, $p < 0.05$), agricultural income ($\beta = -0.0371$, $p < 0.01$), percentage of household labor in agriculture ($\beta = 0.192$, $p < 0.01$), and rice output per unit area ($\beta = -0.113$, $p < 0.01$). The findings indicate that social support ($\beta = 0.092$, $p < 0.05$) and institutional incentives ($\beta = 0.076$, $p < 0.05$) play supportive roles in recognizing this urgent need, while information flows ($\beta = 0.329$, $p < 0.01$) were critically important for encouraging a shift toward alternative strategies.

Table 4.

Regression analysis of determinants of pesticide-related preventive awareness and protective behavior

Independent Variables	B	SE	beta	t-ratio	VIF
Model 1: dependent variable: Awareness of the impact of pesticides					
Model statistics: $R = 0.660$, $R^2 = 0.436$, Adjusted $R^2 = 0.419$, $F = 26.377^{**}$, Durbin-Watson = 2.243, Breusch-Pagan Test for Heteroskedasticity = 3.356 ^{ns}					
Constant	-0.044	0.416		-0.105	
Farmers' characteristics					
Age (years)	-0.016	0.003	-0.226	-5.775 ^{**}	1.020
Gender (male)	-0.012	0.131	-0.004	-0.094	1.133
Education (years)	0.038	0.008	0.195	4.787 ^{**}	1.101
Rate of self-consumption of output (%)	0.004	0.002	0.088	2.194 [*]	1.066
Farm management variables					
Agricultural income	0.000	0.000	-0.043	-1.082	1.066
Area devoted to rice farming (ha)	0.048	0.055	0.034	0.870	1.013
Percentage of household labor in agriculture	0.000	0.002	0.004	0.107	1.102
Rice output per unit area	0.006	0.014	0.018	0.453	1.075
Perceived enabling environment					
Social support	0.140	0.048	0.116	2.901 ^{**}	1.067
Institutional incentives	0.160	0.047	0.138	3.425 ^{**}	1.074
Information flows	0.724	0.066	0.456	11.026 ^{**}	1.137

Model 2: dependent variable: Avoidance of pesticide poisoning effect					
Model statistics: $R = 0.712$, $R^2 = 0.506$, Adjusted $R^2 = 0.492$, $F = 35.051^{**}$, Durbin-Watson = 2.207, Breusch-Pagan Test for Heteroskedasticity = 0.553 ^{ns}					
Constant	1.832	0.212		8.633 ^{**}	1.020
Farmers' characteristics					
Age (years)	0.000	0.001	-0.012	-0.338	1.133
Gender (male)	-0.315	0.067	-0.182	-4.716 ^{**}	1.101
Education (years)	0.010	0.004	0.092	2.420 [*]	1.066
Rate of self-consumption of output (%)	0.003	0.001	0.098	2.608 ^{**}	1.066
Farm management variables					
Agricultural income	-0.002	0.000	-0.353	-9.444 ^{**}	1.013
Area devoted to rice farming (ha)	-0.050	0.028	-0.065	-1.791	1.102
Percentage of household labor in agriculture	0.008	0.001	0.254	6.680 ^{**}	1.075
Rice output per unit area	-0.015	0.007	-0.079	-2.109 [*]	1.067
Perceived enabling environment					
Social support	0.055	0.025	0.085	2.260 [*]	1.074
Institutional incentives	0.057	0.024	0.089	2.382 [*]	1.137
Information flows	0.247	0.033	0.286	7.390 ^{**}	1.020

Model 3: dependent variable: Preparation for protective behavior					
Model statistics: $R = 0.658$, $R^2 = 0.433$, Adjusted $R^2 = 0.416$, $F = 26.086^{**}$, Durbin-Watson = 2.016, Breusch-Pagan Test for Heteroskedasticity = 3.141 ^{ns}					
Constant	0.341	0.338		1.006	
Farmers' characteristics					
Age (years)	-0.004	0.002	-0.074	-1.874	1.020
Gender (male)	-0.322	0.106	-0.125	-3.024 ^{**}	1.133
Education (years)	0.058	0.007	0.367	8.995 ^{**}	1.101
Rate of self-consumption of output (%)	-0.002	0.002	-0.050	-1.250	1.066

Farm management variables					
Agricultural income	0.002	0.000	0.196	4.882**	1.066
Area devoted to rice farming (ha)	0.016	0.045	0.014	0.351	1.013
Percentage of household labor in agriculture	0.004	0.002	0.090	2.205*	1.102
Rice output per unit area	0.011	0.011	0.039	0.966	1.075
Perceived enabling environment					
Social support	0.098	0.039	0.100	2.502*	1.067
Institutional incentives	0.274	0.038	0.290	7.201**	1.074
Information flows	0.154	0.053	0.120	2.890**	1.137

Model 4: dependent variable: Recognizing the urgent need to shift to alternative pest management strategies.

Model statistics: $R = 0.730$, $R^2 = 0.533$, Adjusted $R^2 = 0.519$, $F = 40.774^{**}$, Durbin-Watson = 2.130, Breusch-Pagan Test for Heteroskedasticity = 1.492^{ns}

Constant	2.112	0.249		8.496	
Farmers' characteristics					
Age (years)	-0.001	0.002	-0.030	-0.830	1.020
Gender (male)	-0.383	0.078	-0.184	-4.908**	1.133
Education (years)	0.015	0.005	0.112	3.038**	1.101
Rate of self-consumption of output (%)	0.003	0.001	0.084	2.303*	1.066
Farm management variables					
Agricultural income	-0.003	0.000	-0.370	-10.180**	1.066
Area devoted to rice farming (ha)	-0.037	0.033	-0.040	-1.127	1.013
Percentage of household labor in agriculture	0.007	0.001	0.192	5.185**	1.102
Rice output per unit area	-0.026	0.008	-0.113	-3.079**	1.075
Perceived enabling environment					
Social support	0.073	0.029	0.092	2.535*	1.067
Institutional incentives	0.059	0.028	0.076	2.094*	1.074
Information flows	0.344	0.039	0.329	8.758**	1.137

SE: standard error; VIF: variance inflation factor.

* Significant at $P < 0.05$, ** Significant at $P < 0.01$, ns = not significant.

Discussion

This study investigated the determinants of rice farmers' preventive awareness and protective behaviors regarding pesticide use in Mazandaran Province, Iran, with a particular focus on the progression of behavioral change from awareness to preparedness and finally to the recognition of the need for alternative pest management strategies. The central contribution of this research lies in shaping a multi-stage behavioral trajectory for adopting safer pest control methods. Moving from self-persuasion (rooted in sensitization to pesticides) to strategic implementation, this study also investigated the contingent role of external factors. A key outcome is understanding how social support, institutional incentives, and information flows vary in effectiveness depending on the producer's specific stage of behavioral change.

The findings reveal a comprehensive behavioral pathway influenced by demographic, economic, and enabling environmental factors. The four identified behavioral dimensions include awareness of pesticide effects, avoidance of pesticide poisoning, preparation for protective behavior, and recognition of the need to adopt alternative pest management strategies collectively illustrate a sequential process through which farmers transition from passive knowledge to active behavioral change.

The findings represents a profound and strategic shift: the transition to safer pest control alternatives and integrated pest management (IPM) strategies, culminating in the farmer's

role as an agent of diffusion within their community. In essence, this phase marks an irreversible behavioral change toward sustainable farm management. It is characterized by significant investment, including the overhaul of farm infrastructure—such as upgrading storage facilities, establishing sanitary landfills, and acquiring standard equipment—and the adaptation of cultivation patterns to align with new, sustainable practices. This transition demands tangible investment in establishing the necessary infrastructure on the farm. It also requires a proactive search for ways to maintain or increase farm income and productivity under the new, often more stringent, conditions. Key indicators of having reached this stage include the farmer's efforts to scale these changes across their entire farming system and extend their impact to the surrounding agroecosystem by actively encouraging and persuading other farmers to adopt similar practices.

Education consistently emerged as one of the strongest predictors across all behavioral dimensions, confirming that improved educational attainment fosters greater understanding of pesticide risks, readiness to adopt protective measures, and openness to sustainable alternatives. The observed influence of education and information aligns with findings by Fan et al. (2015), Akter et al. (2018), and Sharifzadeh and Abdollahzadeh (2024), who emphasized the role of knowledge and risk awareness in shaping farm safety behaviors. Conversely, age exhibited a negative influence on awareness, suggesting that older farmers are less likely to update or adapt their knowledge. Gender differences were also significant, female farmers displayed higher levels of avoidance, preparation behaviors and alternative recognition behaviors, than males, reflecting gendered differences in risk perception and engagement in safety and pro-environmental practices. Similarly, the gendered pattern of protective behavior supports earlier evidence from Wang et al. (2017). This study further reveals that women's heightened engagement is linked to a range of activities, from avoidance behaviors to pesticide poisoning, assistance in preparing equipment, and ultimately, recognition of the need for alternative pest management strategies.

Farm management variables further clarified behavioral variability. Higher agricultural income and rice yields were negatively associated with avoidance and alternative recognition behaviors, implying that economic success may reinforce risk-taking or the habitual overuse of pesticides. Furthermore, agricultural income demonstrated a positive correlation with preparedness behavior, indicating that wealthier farmers are better equipped to invest in protective measures and equipment. Meanwhile, greater household labor participation in agriculture positively influenced avoidance, preparatory and alternative recognition behaviors, emphasizing the collective family involvement in ensuring safety. However, this study extends existing literature by demonstrating that economic affluence may paradoxically discourage protective and sustainable behavior, a nuance less explored in prior studies. The negative relationship between income and avoidance behaviors suggests that financially secure farmers may perceive reduced vulnerability to pesticide risks or prioritize productivity over safety echoing but deepening observations made by Andersson and Isgren (2021).

The enabling environment comprising social support, institutional incentives, and information flows proved decisive. Especially, information flows had the strongest and most consistent associations across three behavioral stages, underscoring the critical role of access to reliable information and extension services in fostering behavioral change. This finding reinforces the arguments by Goeb and Lupi (2021) and Aslam et al. (2025), who found that peer-to-peer learning and local extension services are among the most

effective catalysts of sustained behavioral change. The positive correlation between enabling environment factors and protective behaviors is also consistent with the institutional perspectives articulated by Wang et al. (2018) and Bjørnåvold et al. (2022), who argued that institutional trust and information access are essential to behavioral transformation.

In the Mazandaran rice production context where pest pressure from rice stem borers and other pests remains high the study's findings carry practical implications. First, extension and training programs should be redesigned to align with the four behavioral stages identified. For instance, early interventions should focus on raising awareness of pesticide effects, while subsequent programs should emphasize practical protective measures, provide PPE access, and facilitate IPM demonstration plots. Second, policymakers should strengthen institutional incentives such as subsidies for biological control agents, certification programs for safer production, and guaranteed markets for organic rice to make sustainable alternatives economically attractive. Third, information dissemination systems must be intensified. Local radio and television, virtual groups on mobile platforms, farmer field schools, and digital advisory networks can be utilized to enhance information flows among farmers, input suppliers, and research institutions. These interventions would not only mitigate the health and environmental hazards of pesticide overuse but also gradually build the behavioral foundation necessary for the mainstreaming of IPM practices in Mazandaran's rice sector, reducing ecological dependency on chemical inputs and improving long-term resilience.

Overall, this study makes a novel contribution by empirically tracing the behavioral progression from awareness to preparation and ultimately toward adoption of sustainable pest management alternatives, thus addressing the central research gap identified in the literature. Previous research tended to treat protective behavior as a singular outcome rather than as a multi-stage process (Damalas & Abdollahzadeh, 2016; Sharifzadeh et al., 2019). The current findings confirm that awareness alone, while foundational, is insufficient for behavioral transformation unless accompanied by preparatory capacity and institutional support. The results substantiate the assumption that behavioral adaptation follows a sequential model: awareness of pesticide impacts lays the cognitive foundation, avoidance behaviors signify precautionary adaptation, preparation reflects practical readiness, and recognition of the need for alternative pest management marks the transition toward sustainability. The statistical evidence especially the progressive increase in explanatory power (R^2 values ranging from 0.43 to 0.53) demonstrates that these stages are not isolated but cumulative and interdependent. Farmers who score higher in awareness and avoidance are significantly more likely to progress toward preparation and eventual recognition of IPM adoption needs. Furthermore, by integrating the enabling environment variables with demographic and farm structure characteristics, this study offers a systemic understanding of behavior change that has been largely absent from prior research. The strong effect of institutional incentives and information flows confirms that cognitive awareness must be reinforced through policy-driven and extension-based mechanisms. This integration bridges the micro-level (individual cognition and practice) and macro-level (institutional and informational structure) determinants of behavior, thereby filling a critical empirical void in the literature on sustainable pest management.

Finally, this study acknowledges several limitations, consistent with those identified in previous research. The primary limitation is the reliance on self-reported data, which may introduce response bias. Farmers may exaggerate constraints particularly regarding

access to PPE or institutional support to justify limited behavioral change. Moreover, while respondents cited a lack of facilities, the actual barrier to IPM implementation is often skill acquisition and continuous management, suggesting that behavioral inertia may stem more from capacity and motivation than from resource scarcity. A second limitation lies in the context-specific nature of the study. The findings are based on rice farmers in Mazandaran Province and may not be generalizable to other crops or regions with different socio-ecological conditions. Future studies should therefore test the staged behavioral framework across diverse agricultural contexts to assess its wider applicability.

Conclusion

This study advances the understanding of pesticide-related behavioral change among rice farmers by conceptualizing and empirically validating a multi-stage behavioral framework encompassing awareness, avoidance, preparation, and recognition of the need for alternative pest management. The results reveal that these stages are interdependent and sequential, each serving as a prerequisite for progression toward sustainable pest control practices such as IPM. The cornerstone of this transformation is pesticide sensitization. This growing awareness triggers a powerful process of self-persuasion, leading producers to embrace and internalize the identity of a healthy producer.

Education, gender, and household labor participation emerged as key demographic determinants, while income and yield exerted counterproductive effects on protective behavior. Critically, the enabling environment especially information flows and institutional incentives proved essential in facilitating movement through each behavioral stage. This highlights that sustainable behavioral transformation requires not only individual awareness but also a supportive socio-institutional ecosystem. By integrating enabling environmental factors with demographic and farm-level characteristics, this study fills a significant research gap in the literature, providing a comprehensive model that links micro-level behavior with macro-level institutional dynamics. The staged behavioral structure introduced here offers an important methodological innovation, serving as a guide for future research to examine each stage's specific drivers and barriers. Practically, the findings underscore the need for targeted extension strategies that mirror the behavioral stages of farmers. Awareness campaigns should precede hands-on safety training, followed by institutional support for IPM adoption. Agricultural authorities in Mazandaran province can apply these insights by enhancing communication infrastructure, incentivizing safer production systems, and embedding IPM training within existing extension programs. Future research should expand this model by incorporating longitudinal designs to trace behavioral evolution over time, explore psychological mediators such as risk perception and trust, and test the model across other crops and regions. In sum, this study not only explains the determinants of farmers' protective behaviors but also provides a behavioral roadmap for sustainable pest management, bridging the gap between awareness and action and contributing to the global discourse on agricultural safety and sustainability.

Acknowledgments

The authors sincerely thank the rice farmers of Mazandaran Province for their generous participation, time, and willingness to share their valuable experiences. Appreciation is also extended to the extension specialists and local agricultural authorities, with special recognition to the Agricultural Jihad Organizations of Golestan and Mazandaran

Provinces for their indispensable support and cooperation throughout the data collection process. The authors are most grateful to Gorgan University of Agricultural Sciences and Natural Resources for providing the financial and logistical support that made this research possible.

Funding Declaration

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions

Mohammad Sharif Sharifzadeh: Conceptualization, Methodology, Validation, Formal Analysis, Writing the Original Draft and Project Administration.

Masoud Hashemi: Conceptualization, Methodology, Validation, Review & Editing.

Gholamhossein Abdollahzadeh: Methodology, Instrument Development, Software and Formal Analysis.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethical Approval and Informed Consent (Human Subjects)

The study protocol was reviewed and approved by the Research and Technology Council of Gorgan University of Agricultural Sciences and Natural Resources, Iran (Approval No. 03-508-113) prior to the commencement of data collection. At the time the study was conducted, the Research and Technology Council served as the institutional body responsible for reviewing and approving all aspects of research proposals, including ethical considerations for non-interventional social science research involving human participants. Before participation, all respondents were informed about the objectives of the study, the voluntary nature of their participation, the confidentiality and anonymity of their responses, and their right to decline participation or withdraw at any time without consequence. Informed consent was obtained from all participants through their voluntary completion of the questionnaire. No personally identifiable information was collected. All procedures were conducted in accordance with the relevant institutional guidelines and regulations and the ethical principles of the Declaration of Helsinki, as applicable to research involving human participants.

References

1. Abdollahzadeh, G., Damalas, C. A., & Sharifzadeh, M. S. (2017). Understanding adoption, non-adoption, and discontinuance of biological control in rice fields of northern Iran. *Crop Protection*, 93, 60-68.
2. Abdollahzadeh, G., Damalas, C. A., & Sharifzadeh, M. S. (2024). Integrated pest management adoption among citrus growers in Iran: an application of the protection motivation theory. *Pest Management Science*, 80(12), 6287-6297.
3. Abdollahzadeh, G., Sharifzadeh, M. S., & Damalas, C. A. (2015). Perceptions of the beneficial and harmful effects of pesticides among Iranian rice farmers influence the adoption of biological control. *Crop Protection*, 75, 124-131.

4. Abdollahzadeh, G., Sharifzadeh, M. S., & Damalas, C. A. (2016). Motivations for adopting biological control among Iranian rice farmers. *Crop Protection*, 80, 42-50.
5. Abdollahzadeh, G., Sharifzadeh, M. S., Ahmadi-Gorgi, H., & Jahantigh, M. S. (2025). Transforming farmers' behavior: embracing reduced pesticide use under the integrated crop management program. *Journal of the Saudi Society of Agricultural Sciences*, 24(6), 1-15.
6. Adu, K. (2025). Knowledge, attitudes, and practices of mango farmers on the harmful effects of pesticide use in Southeast Ghana. *Cogent Food & Agriculture*, 11(1), 2538624.
7. Ahmad, M. I., Shen, Q., Song, C., & Ma, H. (2025). Beyond the pesticides: analysing the role of farm advisory services towards eco-friendly farming to reduce pesticide use in Pakistan. *International Journal of Agricultural Sustainability*, 23(1), 2497642.
8. Ahmed, N. (2021). *Determinants of adoption, discontinuation and rejection of pheromone trap: a case on vegetable growers of bogura district* (Doctoral dissertation, Department of Agricultural Extension and Information System, Sher-E-Bangla Agricultural University, Dhaka-1207).
9. AJOM (Agricultural Jihad Organization of Mazandaran). (2022). Agricultural Statistical Yearbook of Mazandaran Province 2022. Agricultural Jihad Organization of Mazandaran. Sari. Iran. (In Persian).
10. Akter, M., Fan, L., Rahman, M. M., Geissen, V., & Ritsema, C. J. (2018). Vegetable farmers' behaviour and knowledge related to pesticide use and related health problems: A case study from Bangladesh. *Journal of Cleaner Production*, 200, 122-133.
11. Alam, F., Saha, N. R., Islam, M. S., Ahmed, M. S., & Haque, M. S. (2020). Perception on environmental concern of pesticide use in relation to farmers' knowledge. *Journal of Environmental Science and Natural Resources*, 13(1-2), 94-99.
12. Amirahmadi, M., Yazdanpanah, H., Kobarfard, F., Shoeibi, S., Pirali-Hamedani, M., & Rastegar, H. (2018). Exposure assessment for some pesticides through rice consumption in Iran using a multiresidue analysis by GC-MS. *Iranian journal of pharmaceutical research: IJPR*, 17(1), 124.
13. Andersson, E., & Isgren, E. (2021). Gambling in the garden: Pesticide use and risk exposure in Ugandan smallholder farming. *Journal of Rural Studies*, 82, 76-86.
14. Ansah, M. O., & Skevas, T. (2024). Adoption and intensity of use of personal protective equipment by agricultural pesticide handlers: Empirical evidence from Peruvian agriculture. *Journal of Cleaner Production*, 446, 141433.
15. Ashoori, D., Allahyari, M. S., Bagheri, A., & Damalas, C. A. (2019). Adoption determinants of modern rice cultivars among smallholders of Northern Iran. *Agriculture*, 9(11), 232.
16. Aslam, S., Hussain, B., Riaz, S., Yousaf, M., Sohail, B., Ullah, F., & Hussain, S. (2025). Empowering farmers through science communication: a framework for pesticide risk awareness and adoption. *Social Sciences & Humanities Open*, 11, 101491.
17. Asma, J., Subrahmanyam, D., & Krishnaveni, D. (2023). The global lifeline: A staple crop sustaining two thirds of the world's population. *Agriculture Archives*, 2 (3), 15-18.
18. Bagheri, A., Emami, N., Damalas, C. A., & Allahyari, M. S. (2019). Farmers' knowledge, attitudes, and perceptions of pesticide use in apple farms of northern Iran: impact on safety behavior. *Environmental Science and Pollution Research*, 26(9), 9343-9351.

19. Barbosa, M. W. (2024). Government support mechanisms for sustainable agriculture: A systematic literature review and future research agenda. *Sustainability*, 16(5), 2185.
20. Bhandari, G., Atreya, K., Yang, X., Fan, L., & Geissen, V. (2018). Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers. *Science of the total environment*, 631, 1560-1571.
21. Bhujel, R. R., & Joshi, H. G. (2024). Factors influencing the adoption of sustainable agricultural practices in rural regions of developing countries: a review. *Food Research*, 8(4), 81-89.
22. Bjørnåvold, A., David, M., Bohan, D. A., Gibert, C., Rousselle, J. M., & Van Passel, S. (2022). Why does France not meet its pesticide reduction targets? Farmers' socio-economic trade-offs when adopting agro-ecological practices. *Ecological Economics*, 198, 107440.
23. Bondori, A., Bagheri, A., & Damalas, C. A. (2024). Protective behavior in chemical spraying among farmers of northern Iran. *Environment, Development and Sustainability*, 26(7), 17673-17685.
24. Damalas, C. A., & Abdollahzadeh, G. (2016). Farmers' use of personal protective equipment during handling of plant protection products: determinants of implementation. *Science of the Total Environment*, 571, 730-736.
25. Damalas, C. A., & Koutroubas, S. D. (2017). Farmers' training on pesticide use is associated with elevated safety behavior. *Toxics*, 5(3), 19.
26. Davran, M., Bozdogan, N. İ. G. A. R., Bozdoğan, A. L. İ., & Öztornacı, B. U. R. A. K. (2019). Determination of the level of awareness of farmers about the use of personal protective equipment in pesticide applications. *Fresenius Environmental Bulletin*, 28(10), 7621-7629.
27. Dinh, V. T., & Miura, K. (2022). Knowledge, Attitude, and Protective Behavior against Pesticide Health Risks: The Case of Vegetable Farmers in Northern Vietnam. *NRE Discussion Papers*, (2022-02). Division of Natural Resource Economics, Graduate School of Agriculture, Kyoto University, Japan.
28. Fan, L., Niu, H., Yang, X., Qin, W., Bento, C. P., Ritsema, C. J., & Geissen, V. (2015). Factors affecting farmers' behaviour in pesticide use: Insights from a field study in northern China. *Science of the Total Environment*, 537, 360-368.
29. Ghiasi, R., Allahyari, M. S., Damalas, C. A., Azizi, J., & Abedi, M. (2017). Crop protection services by Plant Clinics in Iran: An evaluation through rice farmers' satisfaction. *Crop Protection*, 98, 191-197.
30. Gnanamanickam, S. S. (2009). Rice and its importance to human life. In *Biological control of rice diseases* (pp. 1-11). Dordrecht: Springer Netherlands.
31. Goeb, J., & Lupi, F. (2021). Showing pesticides' true colors: The effects of a farmer-to-farmer training program on pesticide knowledge. *Journal of Environmental Management*, 279, 111821.
32. Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2013). *Multivariate data analysis: Pearson new international edition PDF eBook*. Pearson Higher Ed.
33. Hashemi, S. M., Rostami, R., Hashemi, M. K., & Damalas, C. A. (2012). Pesticide use and risk perceptions among farmers in southwest Iran. *Human and Ecological Risk Assessment: An International Journal*, 18(2), 456-470.
34. Houbraken, M., Bauweraerts, I., Fevery, D., Van Labeke, M. C., & Spanoghe, P. (2016). Pesticide knowledge and practice among horticultural workers in the Lâm Đồng region, Vietnam: A case study of chrysanthemum and strawberries. *Science of the Total Environment*, 550, 1001-1009.

35. Houbraken, M., Bauweraerts, I., Fevery, D., Van Labeke, M. C., & Spanoghe, P. (2016). Pesticide knowledge and practice among horticultural workers in the Lâm Đồng region, Vietnam: A case study of chrysanthemum and strawberries. *Science of the Total Environment*, 550, 1001-1009.
36. Imran, M., Mustafa, G., Rehman, S. U., & Yasri, Y. (2024). The interplay of safety knowledge, attitude and health experience in adoption of protective pesticide behavior: evidence from Pakistani fruit and vegetable farmers. *Journal of Agribusiness in Developing and Emerging Economies*.
37. Imran, M., Mustafa, G., Rehman, S. U., & Yasri, Y. (2024). The interplay of safety knowledge, attitude and health experience in adoption of protective pesticide behavior: evidence from Pakistani fruit and vegetable farmers. *Journal of Agribusiness in Developing and Emerging Economies*. Vol. ahead-of-print No. ahead-of-print. <https://doi.org/10.1108/JADEE-05-2024-0148>
38. Jallow, M. F., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Thomas, B. M. (2017). Pesticide risk behaviors and factors influencing pesticide use among farmers in Kuwait. *Science of the total environment*, 574, 490-498.
39. Jones, E., Mabota, A., & Larson, D. W. (2009). Farmers' knowledge of health risks and protective gear associated with pesticide use on cotton in Mozambique. *The Journal of Developing Areas*, 42(2), 267-282.
40. Kabir, M. H., Biswas, S., Rahman, M. S., Islam, M. S., & Tan, M. L. (2024). Determinants of vegetable growers' knowledge and willingness to adopt botanical pesticides. *International Journal of Pest Management*, 70(4), 1029-1038.
41. Kabir, M. H., Nur-e-Alam, S. M., Datta, A., Tan, M. L., & Rahman, M. S. (2023). Understanding vegetable farmers' adoption, dis-adoption, and non-adoption decisions of pest management by pheromone trapping. *Plos one*, 18(9), e0292254.
42. Kangavari, M., Sarvi, M., Afshari, M., & Maleki, S. (2024). Understanding determinants related to farmers' protective measures towards pesticide exposure: A systematic review. *PLoS one*, 19(2), e0298450.
43. Keleb, A., Ademas, A., Abebe, M., Berihun, G., Desye, B., & Bezie, A. E. (2024). Knowledge of health risks, safety practices, acute pesticide poisoning, and associated factors among farmers in rural irrigation areas of northeastern Ethiopia. *Frontiers in Public Health*, 12, 1474487.
44. Khan, M., & Damalas, C. A. (2015). Factors preventing the adoption of alternatives to chemical pest control among Pakistani cotton farmers. *International journal of pest management*, 61(1), 9-16.
45. Kim, K. H., Kabir, E., & Jahan, S. A. (2017). Exposure to pesticides and the associated human health effects. *Science of the total environment*, 575, 525-535.
46. Krishnan, L. M., Philip, H., Chinnadurai, M., & Ravichandran, V. (2015). Constraints in the adoption of eco-friendly conservation practices. *Journal of Extension Education*, 27(3), 5494-5498.
47. Lagili, H. S. A., Ayouz, H., Gunduz, S., Williams, N. E., Bamisile, O., & Kamalu, O. J. (2020). Farmers knowledge, practices and health problems associated with pesticides use in West Tripoli, Libya. *Archives of Current Research International*, 20(6), 42-57.
48. MAJ (Ministry of Agriculture-Jahad). (2021). Technical instructions for healthy rice production using Integrated Crop Management (ICM) method. Agricultural Research, Education and Extension Organization, Iran Rice Research Institute - Mazandaran Vice-Chancellor and Plant Protection Research Institute. Sari, Iran.

49. Mehdizadeh, S., Sharifzadeh, M. S., & Abdollahzadeh, G. H. (2020). Determinants of farmers' intention to use eco-friendly technologies: Pheromone trap to control of the rice pests in Simorgh county. *Quarterly Journal of Environmental Education and Sustainable Development*, 8(4), 133-144.
50. Mkenda, P. A., Ndakidemi, P. A., Stevenson, P. C., Arnold, S. E., Darbyshire, I., Belmain, S. R., ... & Gurr, G. M. (2020). Knowledge gaps among smallholder farmers hinder adoption of conservation biological control. *Biocontrol Science and Technology*, 30(3), 256-277.
51. Mohapatra, P. K., & Sahu, B. B. (2021). Importance of rice as human food. In *Panicle architecture of rice and its relationship with grain filling* (pp. 1-25). Cham: Springer International Publishing.
52. Ndirangu, Z. W., Zoltan, E., & Muhoro, A. M. (2025). Determinants of Pesticide Safety Adherence among Tomato Farmers in Kenya: Individual and Structural Factors for Sustainable Agriculture. *Journal of Sustainability Research*, 7(2).
53. Sabran, S. H., & Abas, A. (2021). Knowledge and awareness on the risks of pesticide use among farmers at Pulau Pinang, Malaysia. *Sage Open*, 11(4), 21582440211064894.
54. Shah, S. S., van Dam, J., Fan, L., Kumar, S., Singh, A., Bundela, D. S., ... & Ritsema, C. J. (2026). Understanding farmers' protective behavior towards pesticide use in Northern India: A health belief model approach using PLS-SEM and fsQCA. *Environmental Impact Assessment Review*, 117, 108193.
55. Shammi, M., Sultana, A., Hasan, N., Rahman, M. M., Islam, M. S., Bodrud-Doza, M., & Uddin, M. K. (2020). Pesticide exposures towards health and environmental hazard in Bangladesh: A case study on farmers' perception. *Journal of the Saudi Society of Agricultural Sciences*, 19(2), 161-173.
56. Sharifzadeh, M. S., & Abdollahzadeh, G. (2024). Do typologies of pesticide risk knowledge influence the adoption of IPM strategies? Evidence from rice farmers' behavior in northern Iran. *Pest Management Science*, 80(9), 4427-4436.
57. Sharifzadeh, M. S., Abdollahzadeh, G., & Damalas, C. A. (2025). Farmers' behaviour in the use of integrated pest management (IPM) practices: perspectives through the social practice theory. *International Journal of Pest Management*, 71(3), 406-419.
58. Sharifzadeh, M. S., Abdollahzadeh, G., & Rezaei, R. (2021). Use of Biological Pest Control among Rice Farmers in Simorgh County of Mazandaran Province: Assessing Behavior Change for Promoting Adoption. *Journal of Agricultural Science and Technology*, 23(3), 515-530.
59. Sharifzadeh, M. S., Damalas, C. A., Abdollahzadeh, G., & Ahmadi-Gorgi, H. (2017). Predicting adoption of biological control among Iranian rice farmers: An application of the extended technology acceptance model (TAM2). *Crop Protection*, 96, 88-96.
60. Sharma, A., Bailey, A., & Fraser, I. (2011). Technology adoption and pest control strategies among UK cereal farmers: evidence from parametric and nonparametric count data models. *Journal of agricultural economics*, 62(1), 73-92.
61. Singh, D. S., Tripathi, V., Ali, H., Rostant, L. V., Marshall, N., Jayaraman, J., ... & Mohammed, A. (2024). Perceptions on pesticides: Knowledge, attitudes and practices of residents in Trinidad and Tobago. *Archives of Environmental & Occupational Health*, 79(7-8), 247-261.
62. Slijper, T., Tensi, A. F., Ang, F., Ali, B. M., & Van Der Fels-Klerx, H. J. (2023). Investigating the relationship between knowledge and the adoption of sustainable

- agricultural practices: The case of Dutch arable farmers. *Journal of Cleaner Production*, 417, 138011.
63. Sookhtanlou, M., & Allahyari, M. S. (2021). Farmers' health risk and the use of personal protective equipment (PPE) during pesticide application. *Environmental Science and Pollution Research*, 28(22), 28168-28178.
 64. Suprihanti, A., Brotodjojo, R., & Wirawati, T. (2023). Interplay of Knowledge and Behavior in Environmentally Friendly Pest Control: A Study from Bantul, Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1242, No. 1, p. 012033). IOP Publishing.
 65. Tari, K., Samarghandi, M. R., Jaafarzadeh Haghighi Fard, N., Jorfi, S., Yari, A. R., & Panahi Fard, M. (2020). Pollution status of pesticide residues in food products in Iran: A mini-review within 2008-2018. *Archives of Hygiene Sciences*, 9(3), 214-223.
 66. Thapa, S., Thapa, B., Bhandari, R., Jamkatel, D., Acharya, P., Rawal, S., Bista, S., Singh, R., Prasai, A., Bharati, S., & Basnet, A. (2021). Knowledge on pesticide handling practices and factors affecting adoption of personal protective equipment: a case of farmers from Nepal. *Advances in Agriculture*, 2021(1), 5569835.
 67. Thapa, S., Thapa, B., Bhandari, R., Jamkatel, D., Acharya, P., Rawal, S., ... & Basnet, A. (2021). Knowledge on pesticide handling practices and factors affecting adoption of personal protective equipment: a case of farmers from Nepal. *Advances in Agriculture*, 2021(1), 5569835.
 68. Tsakiris, P., Damalas, C. A., & Koutroubas, S. D. (2025). Risk perception and use of personal protective equipment (PPE) in pesticide use: does risk shape farmers' safety behavior?. *International Journal of Environmental Health Research*, 35(2), 453-463.
 69. Wang, J., Deng, Y., & Diao, H. (2018). Market returns, external pressure, and safe pesticide practice—moderation role of information acquisition. *International Journal of Environmental Research and Public Health*, 15(9), 1829.
 70. Wang, W., Jin, J., He, R., & Gong, H. (2017). Gender differences in pesticide use knowledge, risk awareness and practices in Chinese farmers. *Science of the Total Environment*, 590, 22-28.
 71. Yang, X., Wang, F., Meng, L., Zhang, W., Fan, L., Geissen, V., & Ritsema, C. J. (2014). Farmer and retailer knowledge and awareness of the risks from pesticide use: A case study in the Wei River catchment, China. *Science of the Total Environment*, 497, 172-179.
 72. Yuantari, M. G., Van Gestel, C. A., Van Straalen, N. M., Widianarko, B., Sunoko, H. R., & Shobib, M. N. (2015). Knowledge, attitude, and practice of Indonesian farmers regarding the use of personal protective equipment against pesticide exposure. *Environmental monitoring and assessment*, 187(3), 142.
 73. Zeigler, R. S., & Barclay, A. (2008). The relevance of rice. *Rice*, 1(1), 3-10.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [graphicalabstract.png](#)