Journal of Food Protection 88 (2025) 100646

Contents lists available at ScienceDirect

Journal of Food Protection

journal homepage: www.elsevier.com/locate/jfp

Research Paper

What Drives the Use of Highly Hazardous Pesticides and Farmers' Beliefs About Crop Contamination in Punjab, Pakistan? Implications for Sustainable Agriculture and Public Health

Yasir Mehmood [1], Muhammad Arshad [2,*], Stefan Sieber [2,3]

[1] Department of Humanities and Sciences, National University of Medical Sciences (NUMS), Rawalpindi, Pakistan
[2] Leibniz Centre for Agricultural Landscape Research (ZALF), Sustainable Land Use in Developing Countries, Müncheberg, Germany
[3] Department of Agricultural Economics, Faculty of Life Sciences, Humboldt Universität zu Berlin, Berlin, Germany

A R T I C L E I N F O

Keywords:
Pesticides
Health risks
Crop contamination
Environmental pollution
Farmer awareness
Public health

A B S T R A C T

Pesticides are extensively used in agriculture to improve crop yields and protect against pests. However, the excessive and indiscriminate application of highly hazardous pesticides (HHPs) poses serious threats to farmers, the environment, and consumer health—risks that are particularly acute in developing countries where awareness of pesticide hazards is limited. Using farm household-level survey data, this study investigates the factors that drive the use of HHP and farmers' beliefs about crop contamination in Punjab, Pakistan. Ordered logistic regression models were applied for analysis. Results show that media exposure, participation in Farmer Field Schools (FFS), perceived effectiveness, and yield-maximization intent significantly increase the likelihood of HHP use. Retailer recommendations also have a positive influence ($\beta = 0.495, p < 0.05$), while farmers' awareness of pesticide risks reduces usage ($\beta = -0.432, p < 0.05$). Beliefs about crop contamination are positively influenced by education level, media exposure, FFS participation, and label reading, whereas retailer advice exerted a strong negative influence ($\beta = -0.850, p < 0.01$). Overall, farmers demonstrated limited knowledge of pesticide hazards, with 76% and 71% of farmers citing yield gains and economic necessity, respectively, as their primary motivations for HHP use. These findings highlight the need for targeted policy interventions and institutional support to raise awareness of pesticide-related health risks and to promote safer, more sustainable agricultural practices.

Farmers' use of hazardous pesticides has been a long-standing concern, due to negative impacts on human health, biodiversity, and the environment (Ahmad et al., 2024; Asefa et al., 2024; Arshad et al., 2025). Excessive pesticide use can pose serious health risks to the farmers who directly apply them, to communities living near agricultural farms, and to consumers who ingest pesticide-contaminated food. Over recent decades, pesticide use has significantly increased worldwide (Shattuck et al., 2023). The Food and Agricultural Organization (FAO) documented that approximately 3.70 million tons of pesticides were used globally in 2022—constituting a 4% increase from 2021, and a nearly 94% increase in pesticide use per cropland area since 1990 (FAO, 2025). In Asian countries, the problem is not limited to increased pesticide use per cropland area but also includes the use of highly hazardous pesticides (HHPs)[‡] (Saeed et al., 2017; Karunarathne et al., 2021; Liang et al., 2022). The Pesticide Action Network (PAN) reported that in the Asia Pacific region—including Bangladesh, India, Laos, and Vietnam—close to 75% of responding farmers apply HHP or pesticide that are banned in one or more countries (PAN, 2023). Most farmers, particularly in resource-constrained countries, have poor knowledge of pesticide hazards and apply HHP without regard for their negative repercussions (Boateng et al., 2023). Farmers heavily rely on potent agrochemicals because their use is associated with economic benefits, including reduced crop loss due to insect pests, which contribute to higher income levels. However, the consequences of hazardous pesticide use outweigh the immediate economic gains.

Pesticide residues can remain in grains, fruits, vegetables, and other crops, entering the human body through consumption and posing potential significant toxicity risks to consumer health (Syed et al., 2014). Washing, cleaning, and peeling may reduce exposure to pesticide residues but cannot eliminate their risk. Numerous studies

* Corresponding author at: Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Straße 84, 15374 Müncheberg, Germany.
E-mail address: muhammad.arshad@zalf.de (M. Arshad).

‡ As per World Health Organization (WHO), HHP are pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or the environment.

https://doi.org/10.1016/j.jfp.2025.100646
Received 10 May 2025; Accepted 12 October 2025
Available online 22 October 2025

have noted that prolonged exposure to even low levels of hazardous pesticides can cause severe health complications, including endocrine disruption, carcinogenic effects, neurotoxicity, and reproductive health disorders, etc., (Pan et al., 2021; Parra-Arroyo et al., 2022; Li et al., 2023; Priyadarshanee et al., 2022). Elderly individuals, pregnant women, and children are particularly vulnerable to pesticide exposure as their immune systems are highly sensitive (Lee et al. 2018; Ramírez-Guerrero et al. 2025; Furlong et al., 2024; Liu et al., 2024). The residue level in crops depends upon the category of pesticides applied, farmers' overuse behavior, their knowledge of pesticide hazards, and their adherence to safety guidelines (Mehmood et al., 2021a). These risks are further exacerbated in regions with limited monitoring capabilities, particularly in low- and middle-income countries. There is growing recognition that heavy reliance on HHP, particularly those categorized in IA and IB (According to the WHO, IA indicates extremely hazardous and IB highly hazardous pesticides), is unsustainable. National and international nongovernment organizations advocate for a shift towards safer and more sustainable alternatives, but the scope of these efforts and programs remains limited.

Agriculture is regarded as the backbone of Pakistan's economy, contributing approximately 19% to the country's national gross domestic product (GDP) and serving as the primary source of income for nearly 38% of the country's total labor force (Government of Pakistan, 2024). This sector also provides raw materials for industries, contributes to the national GDP through a significant share of exports (Mehmood et al., 2023). Punjab Province is also known as the breadbasket of the country, producing varieties of crops, such as rice, wheat, cotton, sugarcane, and maize (Mehmood et al., 2012). The province's agriculture is primarily irrigated by a system connected to the Indus River, considered one of the best and largest in the world. This irrigation infrastructure has transformed the semi-arid areas of Punjab into fertile farmlands, irrigating millions of hectares of agricultural land. Agriculture in the province also provides significant employment opportunities for millions of people and ensures national and regional food security.

Enhancing crop production using modern and sustainable practices is critical to improving farmers' livelihoods, reducing poverty, and boosting economic growth in the country. The use of HHP in the country is an exigent issue due to their widespread application in agriculture without regard for their health and environmental consequences (Tariq et al., 2007; Rashid et al., 2022). To combat pest infestations and increase crop yields, farmers in Pakistan heavily rely on hazardous pesticides, even to the point of applying counterfeit and unregistered pesticides, which exacerbates the problems associated with them (Saeed et al., 2017). Farmers, especially in resource-constrained countries such as Pakistan, often use HHP due to their high effectiveness and easy access at low costs compared to safer alternatives (Khan et al., 2015). Intensive agricultural practices in the Punjab province have also led to farmers heavily relying on insecticides, pesticides, and herbicides to boost crop yields, posing a potential hazard. The province accounts for approximately 88.3% of the country's pesticide applications (Khan et al., 2020). Unregistered pesticides sometimes enter the market illegally undermining the regulatory frameworks (Mehmood et al., 2021b). Poor implementation of pesticide regulations and farmers' lack of awareness have contributed to the continued use of illegal pesticides in the country. Although farmers can implement alternative pest control strategies, adoption rates remain low due to financial constraints and lack of government support (Akter et al., 2018; Sharafi et al., 2018). Addressing this issue requires a multifaceted approach that involves promoting awareness campaigns, guiding farmers about affordable alternatives and – most importantly – strengthening regulatory authorities.

While a large number of studies have been conducted on this issue, they have predominantly focused on the impacts of pesticide exposure on farmers' health, knowledge of pesticide hazardousness, and overuse behavior. Thus, significant gaps still remain in understanding the factors driving farmers to continue using HHP (Akter et al., 2018; Sharafi et al., 2018). Specifically, studies that investigate farmer beliefs about crop toxicity–related risks and analyze the factors driving them to continue using HHP are limited in number. Studies on similar topics have various methodological shortcomings and lack rigorous empirical examination. For instance, Wang et al. (2015) investigated the determinants of farmers' choices of restricted pesticides in China using the Poisson regression model but ignored some important explanatory factors, including farmers' participation in FFS[§], government-sponsored training on integrated pest management (IPM) practices, and access to institutional credit. Kapeleka (2024) used a dataset of Tanzanian households to investigate the factors influencing farmers' increased pesticide use; however, drivers of farmers' use of HHP were not explored. Addressing these gaps is essential for drafting suitable policies and designing targeted interventions that help reduce farmers' use of HHP. Two policy questions are addressed in this study: (1) What factors affect farmers' use of HHP? (2) What drives farmers' beliefs about food toxicity–related risks arising from the use of HHP? By addressing these concerns, this study contributes to existing studies by guiding farmers and policymakers on safe and sustainable agricultural practices, such as by minimizing farmers' heavy reliance on harmful chemicals and by promoting organic farming and IPM practices.

Materials and methods

Study area and population. This study was conducted in three randomly selected districts of Punjab, Pakistan: Jhelum, Sheikhupura, and Vehari. These districts provide diverse agro-ecological and cropping patterns within the province. District Jhelum, located in the northern part of the province, is a semi-arid zone with mixed farming practices. District Sheikhupura, situated in central Punjab, is known for its intensive agriculture and nearness to industrial areas. Vehari, in southern Punjab, located in the cotton-wheat zone is characterized by extensive pesticide application due to intensive cotton production. The population of the study comprised smallholder and medium-scale farmers actively engaged in farming practices. The study population provides valuable insight into types of pesticide use by the farmers, their handling practices, and the risk of phytotoxicity[**].

Sampling and data collection. In 2024, a primary survey was conducted using data collected from farmers in rural areas of Punjab, Pakistan employing a multistage sampling technique. This sampling method was used to ensure representation from all over the province based on harvesting patterns, different farm sizes, and pesticide use and application. Data collected using a multistage sampling technique are considered more appropriate and representative of a larger population than analysis derived from a single sampling technique (Taherdoost, 2016). Thus, taking cost-effectiveness and precision into account, a multistage sampling technique was adopted. Initially, Punjab province was divided into three strata, and then, one district from each stratum was chosen randomly; the three randomly selected districts were Jhelum, Shiekhupura, and Vehari. Next, respondents were recruited for the collection of desired information using the systematic random sampling technique. A list of 5,743 registered vegetable growers was obtained from the local agricultural offices of each district, then, using an online sample size calculator; a sample size of 361 respondents was calculated. The percentage of farmers who responded

[§] The FFS is an interactive, season-long training program that provides participants with hands-on experience and opportunities to share knowledge with farmers. It primarily focuses on promoting safer agricultural practices such as integrated pest management, judicious use of chemicals, and sustainable production methods. The sessions are conducted at regular intervals throughout the cropping season to help prevent major crop failures, reduce costs, and enhance farm efficiency and productivity.

[**] Phytotoxicity refers to the harmful effects that chemical substances, such as pesticides, can have on plant growth and development (Hasanuzzaman et al., 2020).

was 84.76%, and the remaining 15.24% were either unavailable or provided insufficient information. Thus, the actual sample size was 306. To address the issue of nonresponse bias, a follow-up survey was also conducted to approach those respondents who were initially not available at their farm or home. The inclusion criteria comprised farmers who were actively engaged in vegetable production during the survey period, whereas the exclusion criteria included farmers not directly involved in farming, those practicing organic farming methods, or those unwilling to participate.

Face-to-face information was collected from respondents using a well-structured questionnaire. The questionnaire was categorized into three main sections, including demographics and farming characteristics (e.g., age, formal education, household size, monthly income, number of workers, farm size, and farming experience, among others), determinants of use of HHP together with determinants of farmers' belief of crop contamination (for instance, media influence, role of institutions, retailer recommendations, and perceived effectiveness). The questions included in the questionnaires were based on somewhat similar studies conducted in Bangladesh, China, Iran, India, and Pakistan (Ali et al., 2020; Hashemi et al., 2012; Sharifzadeh et al., 2019; Wang et al., 2015). To refine the questionnaire, pretesting was done on 10 farmers (their information was not included in the main sample). For relevance and comprehensiveness, the content validity of the questionnaire was also assessed by experts in agricultural economics, health economics, and environmental science. Internal consistency was measured using Cronbach's alpha, and a coefficient value greater than 0.7 was accepted. The original questionnaire was initially developed in English, but an Urdu translation was also performed for respondents' ease of understanding in order to ensure data quality. Prior to collecting the information, a verbal consent was obtained from participants after explaining the purpose, methods, and benefits of the study. The participants were assured of confidentiality of the information they provided, and those who declined to take part were not interviewed. The institutional review board of the university oversaw the protocol and ethics and gave consent to conduct the study.

Theoretical framework and empirical model. To understand the concept of the farmers' decision to use HHP despite risks of crop contamination and environmental harm, Kurt Lewin's Field Theory (Lewin, 1943) was utilized. The framework of this theory explains human behavior as a function of an individual's environment and behavior (B) which is determined by the interaction between a person (P) and their environment (E). This can be expressed as:

$$\mathrm{B} = f(\mathrm{P}, \mathrm{E})$$

This theory operates under the following four principles: (1) life-space, (2) force field analysis (includes driving forces and restraining forces), (3) equilibrium and change, and (4) situational influence. Life-space explains farmers' decision-making as being operated by a complex system that includes social, economic, and regulatory pressures. Force field analysis includes driving forces that encourage the use of HHP with the intention to maximize crop yield, the influence of agrochemical companies or pressure from suppliers, market demand, lack of awareness or limited access to safer alternatives, and related socioeconomic factors, on the other hand restraining forces discourage the use of HHP due to, variables such as consumer demand for organic products, environmental regulations, farmers' experience with pesticide-related harm. Equilibrium and change explain that farmers may continue using HHP if the driving forces outweigh the restraining forces. To promote safer practices, interventions must reduce driving forces (e.g., stricter regulations, incentives for organic farming) and strengthen restraining forces (e.g., education, subsidies for biopesticides). Situational influences explain that instead of blaming farmers themselves, some systemic factors that influence farmers' choices such as lack of availability or farmer's financial constraints that affect farmers' affordability to purchase alternatives should also be considered. List of commonly used pesticides by vegetable farmers in Pakistan, per active ingredient, chemical group, WHO classification, and their impact on crop is presented in Table 1.

For empirical estimation, two separate Ordered logistic regression models were used. The first model was used to examine factors determining farmers' use of HHP. According to internationally accepted classification systems introduced by the WHO, hazardous pesticides are acknowledged as presenting high levels of acute or chronic hazards to the environment as well as to human health. For this study, farmers' uses of pesticides were categorized into four ordered levels. This model considers the ordinal nature of the dataset or the intervals between the different hazardousness levels, as categorized by the WHO (2019).

Table 1
List of commonly used pesticides by vegetable farmers in Pakistan, per active ingredient, chemical group, WHO classification, and their impact on crop

Active ingredient	Chemical group	WHO class	Crop impact
Parathion (ethyl)	Organophosphate	Ia	Phytotoxicity risk with misapplication; residues pose an acute dietary risk.
Methyl parathion	Organophosphate	Ia	Crop injury at high rates; residues easily exceed MRLs if misused.
Phorate	Organophosphate	Ia	Primarily soil-applied; misuse can cause crop injury and residues.
Carbofuran	Carbamate	Ib	Phytotoxicity at high rates; residue and preharvest interval violations are dangerous.
Methomyl	Carbamate	Ib	Can injure foliage if overdosed; strong selection pressure for resistance.
Dichlorvos (DDVP)	Organophosphate	Ib	Potential phytotoxicity in enclosed environments; rapid residues dissipate but misuse risky.
Methamidophos	Organophosphate	Ib	Crop injury is possible at high concentrations; residue persistence concerns.
Omethoate	Organophosphate	Ib	Phytotoxic at high doses; residues in leafy vegetables if PHI is ignored.
Monocrotophos	Organophosphate	Ib	Can cause phytotoxicity; residues are problematic; banned/restricted in many countries.
Triazophos	Organophosphate	Ib	Reports of phytotoxicity on some vegetables if misused; residue issues are possible.
Imidacloprid	Neonicotinoid	II	Systemic residues can appear in edible parts; resistance in sucking pests.
Cypermethrin	Pyrethroid	II	Can cause mite/pest resurgence and resistance; possible leaf burn if misused.
Dimethoate	Organophosphate	II	Can cause leaf burn on tender crops if overdosed; residues are common if PHI is ignored.
Deltamethrin	Pyrethroid	II	Misuse may scorch tender foliage; resistance selection pressure.
Profenofos	Organophosphate	II	Overuse is linked with residues on produce and reduced natural enemies.
Emamectin benzoate	Avermectin (macrocyclic lactone)	II	Generally safe to crops at label rates, but overdosing can cause leaf scorch; resistance risk in lepidopterans.
Diazinon	Organophosphate	II	Can flare secondary pests; residue concerns if PHI not observed.
Lambda-cyhalothrin	Pyrethroid	II	Can disrupt biological control and induce resistance.
Chlorpyrifos	Organophosphate	II	At high doses can cause phytotoxicity; residue exceedances are reported; it can trigger secondary pest outbreaks.
Bifenthrin	Pyrethroid	II	Potential residue issues on leafy vegetables; resistance risk.
Endosulfan	Organochlorine cyclodiene	II	Can cause phytotoxic symptoms in sensitive crops; long-term residues in soils.

Ia: Extremely hazardous; Ib: Highly hazardous; II: Moderately hazardous, according to WHO hazard classification.

$$k_i^* = X_i\beta_i + Y_i \quad (1)$$

$$K_i = \begin{cases} 1 \ whenever \ k_i^* \leq \alpha 1 \\ 2 \ whenever \ \alpha 1 \leq k_i^* \leq \alpha 2 \\ 3 \ whenever \ \alpha 2 \leq k_i^* \leq \alpha 3 \\ 4 \ whenever \ k_i^* \leq \alpha 3 \end{cases} \quad (2)$$

Let K_i be a categorical variable representing pesticides' hazardousness levels. $K_i = 1$ represents "not hazardous,"$K_i = 2$ represents "slightly hazardous," $K_i = 3$ represents "moderately hazardous," and $K_i = 4$ represents "extremely and highly hazardous." The parameter αi indicates the threshold points for pesticides' hazardousness levels, and X_i is a vector of explanatory factors, e.g., farmers' socioeconomic characteristics, farming characteristics, etc., included in the model. In Eq. (1), β_i denotes the vector of coefficients to be estimated and Y_i shows the error term.

The second Ordered Logistic Regression model was used to estimate farmers' beliefs about the crop contamination due to pesticide use. Farmers' beliefs were also categorized into four ordered levels. This model considers the ordinal nature of the dataset or the intervals that provide a clear understanding of farmers' beliefs.

$$k_i^* = X_i\beta_i + Y_i \quad (3)$$

$$K_i = \begin{cases} 1 \ whenever \ k_i^* \leq \alpha 1 \\ 2 \ whenever \ \alpha 1 \leq k_i^* \leq \alpha 2 \\ 3 \ whenever \ \alpha 2 \leq k_i^* \leq \alpha 3 \\ 4 \ whenever \ k_i^* \leq \alpha 3 \end{cases} \quad (4)$$

Let K_i be a categorical variable representing farmers' beliefs of crop contamination due to pesticide use. $K_i = 1$ represents "not hazardous," $K_i = 2$ represents "slightly hazardous," $K_i = 3$ represents "moderately hazardous," $K_i = 4$ represents, and "extremely and highly hazardous". The parameter α_i indicates the threshold points for farmers' belief response categories, while X_i is a vector of explanatory factors included in the model. In Eq. (3), β_i denotes the vector of coefficients to be estimated and Y_i shows the error term. Table 2 presents the description and measurement of variables used for quantitative analysis.

Other statistical analysis. Descriptive statistics was used to summarize farmers' socioeconomic and farming characteristics, understanding about pesticide hazardousness, and the explanatory variables. Additional test of the variance inflation factor (VIF) was also used to investigate the multicollinearity in the regression analysis. All statistical analyses were performed using Stata version 13.

Results

Socio-economic and farming characteristics. Table 3 presents the socio-demographic and farming characteristics of farmers. The surveyed farmers had a mean age of 45 years and an average of 4.78 years of formal schooling. The mean of gender of respondent farmers was 0.96 indicating that the majority of the farmers were male. A greater percentage of respondent farmers were married (70%), with an average 3.98 number of children, while the mean household size was 7.37 family members. The mean monthly income (household) was US$ 239 (PKR 66,681), and the mean earning hands per household were 2.16 family members, with a majority of them engaged in

Table 2
Description and measurement of variables used for quantitative analysis

Variables	Description and measurement	Mean	SD
Use of HHPs	Farmers' use of hazardous pesticides as per the WHO classification measured in a four points Likert scale i.e., 1 for the use of unhazardous pesticide (WHO class-U), 2 for slightly hazardous (WHO class-II), 3 for moderately hazardous (WHO class-III), and 4 of highly hazardous (WHO class-IA and-IB)	2.83	0.90
Farmers' beliefs	Farmer's belief about crop contamination – related risk was measured in a four – points Likert scale i.e., unhazardous to highly hazardous	2.09	1.04
Farmer age	Measured in years	44.93	10.74
Education	Farmer's education (formal years of schooling) measured in years	4.78	5.02
Monthly income[a]	Farmer's monthly income measured in US$	239	119
Farming experience	Measured in years	12.83	5.55
Farm size	Measured in hectare	6.80	4.59
Use of hybrid seed	If a farmer applied hybrid seed for crop prediction, the value is set to be one; else, zero	0.32	0.46
Use of PPE[b]	If a farmer uses PPE, the value is set to 1; else, 0	0.45	0.49
Owned land	If a farmer grows a crop on their own field, the value is set to be one; else zero	0.75	0.43
Media influence	If a farmer receives information about pesticide hazardousness, the value is set to 1; else, 0	0.30	0.46
Health effects[c]	If a farmer experienced short-term health effects due to exposure to pesticides, the value is set to 1; else, 0	0.29	0.31
Participation in FFS[d]	If a farmer participated in the FFS, the value is set to 1; else, 0	0.27	0.44
Member of a farming society	If a farmer was a member of farming society, the value is set to 1; else, 0	0.33	0.47
Access to extension	If a farmer is guided by the agricultural field officers about agricultural practices, the value is set to 1; else, 0	0.29	0.45
Access to credit	If a farmer received a loan from a formal financial institution, the value is set to 1; else, 0	0.24	0.43
Access to market	A farmer's access to the market was measured in kilometers	15.28	5.32
IPM training	The value is set to 1 if a farmer adopts IPM practices, else 0	0.20	0.40
Yield maximization intent	The value is set to 1 if a farmer applies pesticides with an intention to maximize crop yield, else 0	0.53	0.49
Easy availability	If hazardous pesticides are easily available in the market, the value is set to 1, else 0	0.52	0.50
Cost-effectiveness	If a farmer perceives that a hazardous pesticide achieves a desired outcome at the lowest cost, the value is set to 1, else 0	0.30	0.45
Perceived effectiveness	If a farmer perceives that a highly hazardous pesticide is highly effective to control insects or pests, the value is set to 1, else 0	0.50	0.50
Label reading	If a farmer reads the bottle label before applying the pesticide, the value is set to 1, else 0	0.39	0.49
Retailer recommendations	If a farmer applied a hazardous pesticide as per the advice of retailers, the value is set to 1, else 0	0.46	0.49

SD: Standard deviation.
Average exchange rate in February 2024: 1 US$ = 279/- PKR.
[a] For smooth estimation, Farmer's monthly income was analyzed in the log form in the Ordered Logistic Regression model.
[b] PPE includes the use facemask, respirator, protective glasses, gloves, rubber shoes, etc.
[c] Short-term health effects include dizziness, skin irritation, nausea, headache, etc., reported by the respondent farmers within 24 h after exposure to pesticides.
[d] A FFS is a participatory, group-based approach to agricultural education in which farmers learn by doing, experimenting, and observing in their own fields.

Table 3
Socio-demographic and farming characteristics of respondent farmers

Variable	Unit/Description	Mean	SD
Farmer age	Years	44.93	10.74
Education	Years	4.78	5.04
Gender	Dummy (1 = male, 0 = female)	0.96	0.19
Marital status	Dummy (1 = married, 0 = else)	0.70	0.45
Number of children	Number	3.98	1.86
Household size	Number	7.37	3.61
Monthly income	US Dollars (USD)	239	119
Off-farm employment	Dummy (1 = yes, 0 = no)	0.31	0.46
Earning hands	Number	2.16	1.34
Farm size	Hectares	6.80	4.59
Family labor	Number	1.46	0.70
Land ownership	Dummy (1 = owner, 0 = else)	0.75	0.43
Livestock holding	Dummy (1 = yes, 0 = no)	0.33	0.47
Farming experience	Years	12.83	5.55

SD: Standard deviation.

agricultural activities. The mean farm size was 6.80 ha, and the majority of them were small landholders, whereas a greater percentage (about 75%) of farmers were landowners. About one−third of the respondent farmers held livestock at their farm. Considering farming experience, the respondent farmers had 12.83 average years of experience.

Determinants of farmer's use of hazardous pesticides. A small percentage of farmers (9.15%) in the area surveyed applied nonhazardous pesticides, while 23.52% of the farmers used slightly hazardous pesticides. A greater percentage (42.15%) reported the use of moderately hazardous pesticides, whereas about one quarter (25.16%) of the farmers applied highly hazardous pesticides. Figure 1 presents the categories of pesticides applied by farmers as per the WHO classification.

The results of the Ordered Logistic Regression model employed to analyze the determinants of farmers' use of HHP are presented in Table 4. The coefficients of the negative and significant association were found between farmers' use of HHP and the independent factors

Table 4
Estimated coefficients of the Ordered Logistic Regression model for the use of HHPs

Variable	Coefficient	*z*-score	VIF
Farmer age	0.016	1.45	1.12
Education	-0.062^{**}	−2.60	1.12
Monthly income	0.817	1.36	1.10
Farming experience	0.009	0.48	1.07
Farm size	0.015	0.59	1.09
Use of hybrid seed	0.207	0.79	1.18
Use of PPE	-0.538^{**}	−2.18	1.19
Owned land	0.254	0.94	1.06
Media influence	-0.730^{**}	−2.86	1.12
Health effects	-0.537^{**}	−2.13	1.11
Participation in FFS	-0.782^{**}	−2.70	1.28
Member of a farming society	−0.002	−0.01	1.17
Access to extension	−0.220	−0.85	1.14
Access to credit	-1.08^{**}	−3.04	1.77
Access to market	0.001	0.09	1.06
IPM training	0.098	0.33	1.15
Yield maximization intent	1.261^{***}	4.40	1.48
Easy availability	0.730^{**}	2.84	1.27
Cost-effectiveness	0.871^{**}	2.63	1.77
Perceived effectiveness	0.670^{**}	0.28	1.14
Label reading	−0.150	−0.53	1.55
Retailer recommendations	0.495^{**}	2.09	1.10
Farmer's belief	-0.432^{**}	−3.85	1.08
Log-likelihood	–322	–	—
Pseudo R^2	0.171	–	—
LR χ^2	133	–	—

$^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

are farmer's education ($\beta = -0.062$), use of PPE ($\beta = -0.538$), media influence ($\beta = -0.730$), health effects ($\beta = -0.537$), participation in FFS ($\beta = -0.782$), and access to credit ($\beta = -1.083$). Most importantly, the prime variable of this study- farmers' belief- was also found to be negative and significant. The coefficients of the positive and significant relationships between farmers' use of HHP and the independent factors are yield maximization intent ($\beta = 1.261$), easy

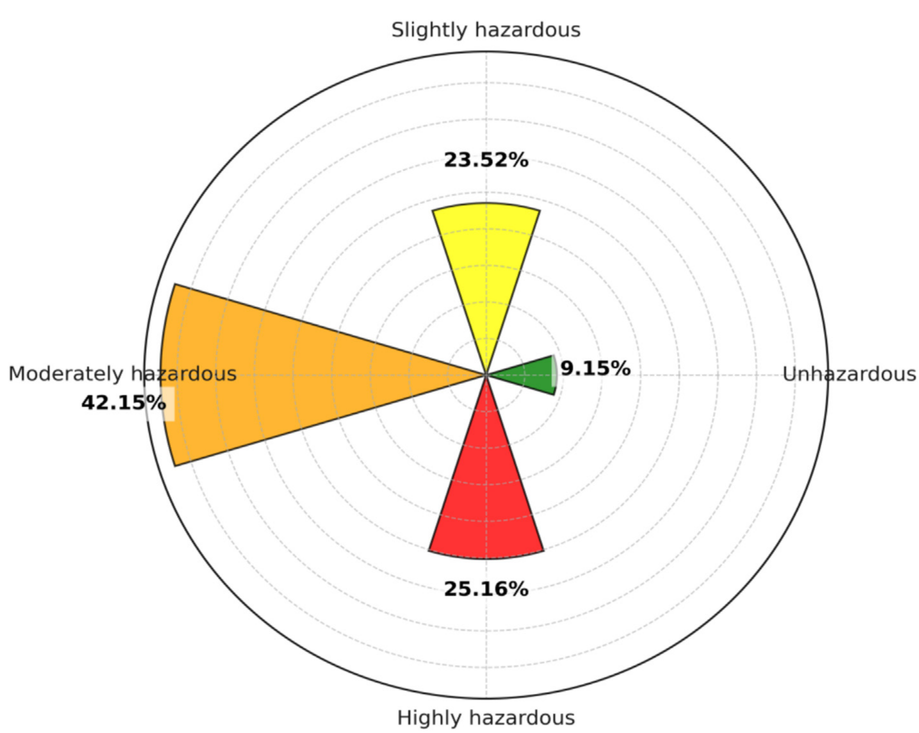

Figure 1. Categories of pesticides applied by farmers as per the WHO classification.

availability (β = 0.042), cost-effectiveness (β = 0.871), perceived effectiveness (β = 0.670), and retailer recommendations (β = 0.495). Farmer age, monthly income, farming experience, farm size, owned land, member of a farming society, access to extension services, access to market, IPM training, and label reading did not have any significant influence on farmers' use of HHP. Other statistics, including Pseudo R^2 (0.166), the Log-likelihood (–323), and the LR χ^2 (129) show goodness-of-fit statistics for the Ordered Logistic Regression model. The mean of VIF was 1.22, and the lowest value of VIF was estimated for the coefficient of owned land, i.e., 1.06.

Determinants of farmers' beliefs about crop contamination. Table 5 presents the farmers' knowledge about the use of HHP and crop contamination. The findings show that 38.56% of the respondent farmers maintained that they knew the potential risks of using HHP on crops. Almost 29% of the respondents stated that pesticide residues remain on crops after application. A lower percentage of the farmers, namely 15.68%, stated that they were aware of the chemical composition of the pesticides they used. Around 34% of the respondents reported that they were aware of the waiting period (preharvest interval) before harvesting crops after pesticide use. Almost 39% of the respondents observed changes in pest resistance due to repeated pesticide use on crops.

Around 37% of farmers believe that the use of pesticides is nonphytotoxic for crops, while 28.76% say it is slightly phytotoxic for crops. About 21% of the farmers stated that pesticides are moderately phytotoxic for crops, and 12.75% said pesticides are highly phytotoxic for crops. Figure 2 presents farmers' beliefs about the use of HHP and crop contamination.

The results of the Ordered Logistic Regression model employed to analyze the determinants of farmers' belief about the use of HHP and crop contamination are presented in Table 6. The coefficient of the negative and significant relationships between farmers' beliefs and the independent factor is retailer recommendations ($\beta = -0.850$). The coefficients of the positive and significant association were found between farmers' beliefs and the independent factors are farmer's education (β = 0.053), farming experience (β = 0.042), use of PPE (β = 0.603), media influence (β = 0.632), health effects (β = 1.081), participation in FFS (β = 0.606), IPM training (β = 0.783), yield maximization intent (β = 0.654), and perceived effectiveness (β = 0.705). Farmer age, monthly income, farm size, use of hybrid seed, owned land, member of a farming society, access to extension services, access to credit, access to market, easy availability, and cost-effectiveness did not have any significant influence on farmers' beliefs. Other statistics, including Pseudo R^2 (0.186), the Log-likelihood (-328), and the LR χ^2 (150), show goodness-of-fit statistics for the Ordered Logistic Regression model.

Reasons for applying highly hazardous pesticides. The respondents were also asked about the reasons for applying HHP beyond the main reason of killing insects/pests (Table 7). Around 76% reported that yield maximization intent was one of the main reasons for applying HHP. Almost 71% of the respondents stated that applying HHP is an economic necessity as pest-related losses can be financially devastating. About 64% of the respondents stated that the reason was a lack of effective alternatives. Three out of ten highlighted climate and environmental factors; for example, warm, humid, or rainy conditions often promote rapid pest reproduction, making hazardous pesticide application necessary. A significant percentage, namely 59.15%, stated that agro-chemical companies influenced them to use HHP, while 39.54% stated that buyers often demand high-quality crops i.e., free from pest damage; hence, they applied HHP. Furthermore, 21.89% and 17.97% of respondents respectively reported monoculture farming and pest resistance management as reasons for applying HHP. Limited knowledge and a lack of training about pesticide use were highlighted by almost 66.99% of the respondents. The question "Are government policies and subsidies on pesticides promoting the usage of HHP?" was also posed to the respondents, and a low percentage, 5.55% of the respondents, answered yes.

Table 5
Farmers' knowledge about the use of HHPs and crop contamination

Sr. No.	Questions	Yes	%
1	Do you know the potential risks of using hazardous pesticides on crops?	118	38.56
2	Do you know pesticide residues remain on crops after application?	89	29.08
3	Do you know the chemical composition of the pesticides you used?	48	15.68
4	Do you know the waiting period (preharvest interval) before harvesting crops after pesticide use?	105	34.31
5	Have you observed changes in pest resistance due to repeated pesticide use on crops?	122	39.86

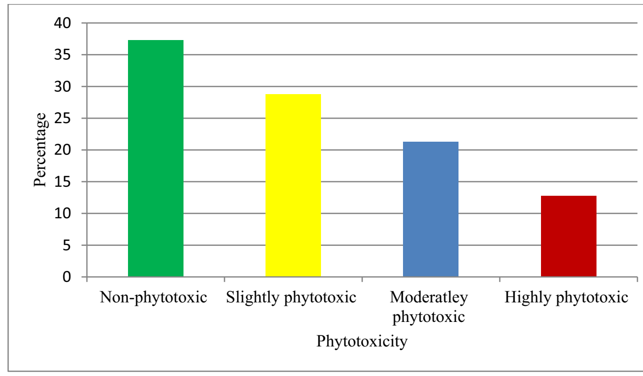

Figure 2. Farmers' beliefs about the use of hazardous pesticides and crop contamination (%).

Table 6
Estimated coefficients of the Ordered Logistic Regression model for farmer's belief about the use of HHPs and crop contamination

Variables	Coefficient	z-score
Farmer age	0.006	0.61
Education	0.053**	2.23
Monthly income	−0.278	−0.46
Farming experience	0.042**	1.95
Farm size	−0.001	−0.06
Use of hybrid seed	−0.336	−1.31
Use of PPE	0.603**	2.45
Owned land	0.100	0.37
Media influence	0.632**	2.33
Health effects	1.081**	4.12
Participation in FFS	0.606**	2.01
Member of a farming society	−0.388	−1.51
Access to extension	0.273	1.04
Access to credit	−0.417	−1.29
Access to market	0.012	0.58
IPM training	0.783**	2.52
Yield maximization intent	0.654**	2.55
Easy availability	−0.288	−1.15
Cost-effectiveness	−0.259	−0.90
Perceived effectiveness	0.705**	2.99
Label reading	0.694**	2.61
Retailer recommendations	−0.850***	−3.57
Log-likelihood	−328	–
Pseudo R^2	0.186	–
LR χ^2	150	–

*$p < 0.10$, **$p < 0.05$, and ***$p < 0.01$.

Table 7
Reasons for applying HHPs

Sr. No.	Reasons	Yes	%
1	Yield maximization intent	233	76.14
2	Economic necessity	218	71.24
3	Lack of effective alternatives	197	64.37
4	Climate and environmental factors	106	34.64
5	Influence of agro-chemical companies	181	59.15
6	Regulatory and market pressures	121	39.54
7	Monoculture farming	67	21.89
8	Resistance management	55	17.97
9	Limited knowledge or training	205	66.99
10	Government policies and subsidies	17	5.55

Discussion

Rapid urbanization, rising food demand, poor knowledge about hazardous pesticides, lack of effective alternatives, and farmers' intention to increase yield, among other factors, influence farmers' injudicious use of pesticides. Many countries have set standards for maximum residue limits of pesticides in crops and imposed strict regulations on applying certain hazardous pesticides, but these limits are not always harmonized globally (Gunnell et al. 2017). Especially in developing countries, regulatory authorities and testing infrastructure are inadequate and farmers frequently apply HHP disregarding the regulations (Matthews et al., 2011; Kubiak-Hardiman et al., 2023). The findings of this study show that farmers in the area surveyed had poor knowledge about the use of pesticides and its negative repercussions. Only 38% of the farmers were aware of the potential risks of using hazardous pesticides, while 29.08% knew that pesticide residues remain in crops after application. Farmers' poor knowledge about pesticide use and related risks has also been reported by several studies from developing countries such as Bangladesh (Akter et al., 2018), China (Fan et al., 2015), Indonesia (Dewi et al., 2022), Iran (Abadi, 2018; Sharafi et al., 2018), and Tanzania (Lekei et al., 2014).

The results of the first Ordered Logistic Regression model showed that the coefficient of farmers' education had a significant negative impact on the use of HHP (Table 4). This signifies that educated farmers are more likely to understand the risks associated with harmful agrochemicals, are determined to adopt alternative pest control practices, and are likely to apply less hazardous pesticides. This finding is concurrent with the study by Miyittah et al. (2022), who stated that enhancing farmers' education through training programs and awareness campaigns can promote the adoption of safer practices and reduce farmers' reliance on hazardous chemicals. The coefficient of the use of PPE was also found to be significant at a 5% level. This demonstrates that those farmers who use PPE are more responsible in handling hazardous pesticides, are aware of associated risks, and try to avoid their exposure. This finding is in line with that of Iranian farmers studied by Abdollahzadeh and Sharifzadeh (2021). In contrast, Oyekale (2018) state that each unit increases in pesticide contact corresponded to a 0.0942 decrease in the log number of PPE items used by farmers. As expected, the coefficient of media influence was found to be negative and significant. Media shapes farmers' perceptions and influences the use of less hazardous pesticides (Bondori et al., 2021). Evidence provided by Qiao et al. (2023) stated that each additional point in social learning of farmers corresponds to a 3.41% increase in the probability of farmers practicing six safe pesticide use behaviors. Sometimes, advertisements and promotional campaigns by pesticide companies emphasize pesticide effectiveness and encourage farmers to apply hazardous pesticides, disregarding negative externalities. Balanced awareness campaigns educate farmers about proper handling, disposal of pesticide residues, and promotion of safer alternatives. Another important variable, farmers' participation in FFS, was found to be significant, indicating that FFS motivates the reduced use of hazardous pesticides; emphasizes natural pest control, IPM techniques, and safe pesticide practices; and reduces farmers' dependency on highly toxic chemicals, safeguarding farmers' health and the environment, improving farming practices, and promoting long-term agricultural productivity. Using a dataset of cotton growers in Mali, Settle et al. (2014) reported that farmers trained through FFS reduced their use of HHP by 92.5%.

Farmers' yield maximization intent had a significant positive impact on the use of HHP. The coefficient value indicates that a 1% increase in farmers' intention to maximize crop yield increases the use of highly hazardous pesticides by 0.031%. This result is concurrent with the previous studies by Bagheri et al., 2019; Damalas, 2021. Moreover, the coefficients of the easy availability of hazardous pesticides and the coefficient of cost-effectiveness significantly contribute to their widespread use by farmers. Khan and Damalas (2015) stated that when hazardous chemicals are readily accessible and affordable, farmers may choose them over safer but costlier alternatives, prioritizing short-term pest control over long-term safety. The coefficient of retailer recommendations was significant at a 5% level of significance, indicating that retailers significantly influence farmers' decisions and encourage them to use hazardous chemicals. The findings are backing up the earlier studies by Yang et al. (2014); Jin et al. (2015). The coefficient of perceived effectiveness had a significant positive effect on the use of HHP, signifying that those farmers who believe that hazardous pesticides have quick and effective control over insects or pests prioritize their usage despite potential health and environmental risks. The coefficient of retailer recommendations was found to be positive and significant, indicating that farmers' decisions to use HHP are significantly influenced by retailers' advice, who, often driven by profit motives, promote these products as immediate and effective solutions. Sun et al. (2023) find that retailers' recommendations significantly increase the probability of farmers overusing pesticides. Farmers tend to trust these recommendations and follow retailers' advice without considering safer alternatives (Wang et al., 2015; Rother, 2018). Importantly, the prime variable included in this study—farmers' beliefs—was also found to be negative and significant. Mehmood et al. (2021b) reported that when farmers understand health and environmental risks, they are more likely to use these chemicals carefully. Conversely, limited knowledge or visible short-term benefits may overshadow concerns about toxicity.

The second Ordered logistic regression model, which aimed to determine farmers' beliefs about crop contamination due to the use of HHP, showed that education had a significant positive effect on farmers' beliefs (Table 6). Farmer education appears to play a crucial role in shaping farmers' beliefs and recognizing potential risks of HHP. The coefficient of farming experiences was also significant at a 5% level, which suggests that experienced farmers develop strong beliefs in crop protection and thereby reduce reliance on hazardous chemicals. Farmers' use of PPE explains their perception, attitude, and action towards risk prevention. Farmers who adequately use PPE perceive pesticides as hazardous for crops, human health, and biodiversity Arshad et al. (2025).

As expected, the coefficient of media influence helps in shaping farmers' beliefs about crop contamination. Although pesticide – formulating companies invest much in advertisement and promotion for product sales, balanced and accurate reporting improves farmers' beliefs. The coefficient of health effects was found to be positive and significant at a 5% level, which indicates that farmers who faced health issues from exposure to pesticides avoid using hazardous pesticides. The coefficient of participation in FFS and the coefficient of IPM training had significant positive impacts on farmers' beliefs about crop contamination. Farmers with better access to these services are more likely to understand the dangers of pesticide residues on crops and adopt safer practices. Waddington et al. (2014) reported that participation in FFS changed farmers' beliefs and led to a 23% reduction in pesticide use. This is also concurrent with the studies by Abdollahzadeh and Sharifzadeh (2024); Asante et al. (2025). The coefficient of a farmer's yield maximization intent was found to be positive and significant. Although some farmers perceive hazardous pesticides as harmful for their crops, their yield maximization intent pressures them to apply these chemicals anyway. The findings further show the significant and positive impact of a farmer's label reading of pesticide bottles. This explains that those farmers who read pesticide labels are better informed about the safe use of hazardous chemicals, leading to a heightened awareness of potential crop contamination. Another important variable—retailer recommendations—had a significant negative effect on farmers' beliefs. This signifies that pesticide retailers influence farmers' decisions, ultimately leading to excessive or inappropriate application, increasing crop contamination risks.

Addressing the issue of the use of HHP through changing farmers' beliefs requires a multifaceted approach, including better pest management practices, promotion of safer alternatives, improving farmer education, and implementing stricter regulation. Augmenting farmers' knowledge and improving awareness through media campaigns and conducting seminars at a village level is essential to educate farmers about the risks associated with HHP and crop contamination. Besides developing farmers' training and capacity building about the judicious use of pesticides, awareness sessions for pesticide retailers should also be conducted by those who are considered the most trustworthy sources to advise farming practices in rural areas. Concerned government departments may consider designing mechanisms to strictly monitor the use of unregistered or banned pesticides. This could be done by rigorous food safety testing and imposing heavy penalties on farmers who use HHP. HHPs also pose significant ecological challenges, including contamination of soil, water, and nontarget organisms, which can disrupt ecosystems, and reduce biodiversity. Ensuring stricter controls, promoting eco-friendly alternatives, and educating farmers and pesticide retailers about human health and environmental risks are crucial to reduce dependency on toxic pesticides.

This study has some limitations to be considered when interpreting the findings. First, recall bias or social desirability bias may have occurred as the study relied on self-reported data from farmers. Farmers might have underreported the use of HHP to align with regulatory requirements. Second, the generalizability of the findings may be limited, as the study was conducted only in one province. The results may not fully represent farmers' beliefs in other regions or countries with different socioeconomic and environmental contexts. Third, the prime focus of the study was to analyze the determinants of HHP usage, potentially overlooking the role of external factors such as the availability of safer pesticide alternatives, regulatory enforcement, and growing food demand. Future studies could delve deeper into how external factors could influence farmers to use HHP despite their known risks. Finally, while the study estimated farmers' beliefs about crop contamination, laboratory testing of the use of pesticide residues on crops was not explored. Moreover, the long-term health or environmental consequences of pesticide use were not analyzed. Such data could provide further valuable insights into the actual consequences of these practices and inform targeted interventions. Addressing these limitations in future research would strengthen the understanding of the complex dynamics between pesticide use and farmers' beliefs, ultimately contributing to safer and more sustainable agricultural practices.

Conclusion

The injudicious use of HHP is commonly practiced in farming communities, particularly in countries whose economies are significantly dependent on agriculture. Farmers in such countries are often unaware of the negative repercussions of using HHP pesticides due to a lack of knowledge. The estimation of the first Ordered Logistic Regression model shows that a significant percentage of farmers in the study area rely on the use of HHP pesticides as a primary means of pest control. Such reliance on the HHP use is influenced by education, media influence, participation in FFS, the yield maximization intent, easy availability, retailer recommendations, cost-effectiveness, perceived effectiveness, and farmers' beliefs. The findings further show that farmers have a low knowledge level about pesticide hazards and crop contamination, as only 38.56% of them indicated that they knew about the potential risks of using HHP pesticides on crops, while a mere 29% stated that pesticide residues remain on crops after application. This lack of knowledge may be attributed to inadequate access to training, lack of information about alternatives, and weak enforcement of safety regulations. Importantly, farmers in the area surveyed are significantly influenced by pesticide retailers, which affects their decision-making and often leads to over-reliance on chemicals or the use of HHP. Thus, in addition to educating farmers about pesticide use, the study finds that pesticide retailers should be informed about the negative repercussions of pesticide use so that they can guide farmers toward judicious use. Strengthening regulatory frameworks and ensuring the accountability of pesticide retailers are also crucial steps toward promoting safe and sustainable farming practices. The findings of the second Ordered logistic regression model further show that farmer education, media influence, participation in FFS, access to extension services, and IPM training significantly influence farmers' beliefs about crop contamination due to pesticide use. Expanding access to agricultural extension services and encouraging their participation in FFS and IPM training programs can shape farmers' beliefs and equip them with the knowledge and tools to reduce their dependence on pesticides. Balanced, informative media can also reduce farmer's reliance on harmful pesticides while promoting sustainable practices. Furthermore, public awareness campaigns about the toxicity risks of pesticide use can help bridge the gap between farmers' beliefs and actions, ultimately safeguarding food safety and public health.

CRediT authorship contribution statement

Yasir Mehmood: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Muhammad Arshad:** Writing – review & editing, Conceptualization. **Stefan Sieber:** Writing – review & editing.

Declaration of competing interest

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.

References

Abadi, B. (2018). The determinants of cucumber farmers' pesticide use behavior in central Iran: Implications for the pesticide use management. *Journal of Cleaner Production, 205*, 1069–1081. https://doi.org/10.1016/j.jclepro.2018.09.156.

Abdollahzadeh, G., & Sharifzadeh, M. S. (2021). Predicting farmers' intention to use PPE to prevent pesticide adverse effects: An examination of the health belief model (HBM). *Journal of the Saudi Society of Agricultural Sciences, 20*(1), 40–47. https://doi.org/10.1016/j.jssas.2020.10.001.

Abdollahzadeh, G., & Sharifzadeh, M. S. (2024). Perceived advantages and disadvantages of IPM practices among Iranian rice farmers. *International Journal of Pest Management, 1–14*. https://doi.org/10.1080/09670874.2024.2308929.

Ahmad, M. F., Ahmad, F. A., Alsayegh, A. A., Zeyaullah, M., AlShahrani, A. M., Muzammil, K., Saati, A. A., Wahab, S., Elbendary, E. Y., Kambal, N., & Abdelrahman, M. H. (2024). Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. *Heliyon, 10*(3)e25623. https://doi.org/10.1016/j.heliyon.2024.e25623.

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. https://doi.org/10.1016/j.jclepro.2018.07.252.

Ali, M. P., Kabir, M. M. M., Haque, S. S., Qin, X., Nasrin, S., Landis, D., Holmquist, B., & Ahmed, N. (2020). Farmer's behavior in pesticide use: Insights study from smallholder and intensive agricultural farms in Bangladesh. *Science of the Total Environment, 747*, 141160. https://doi.org/10.1016/j.scitotenv.2020.141160.

Arshad, M., Mehmood, Y., Aravindakshan, S., Ullah, A., Sieber, S., & Krupnik, T. J. (2025). Pesticide exposure, health impacts, predeterminism, and health insurance demand among Pakistani farmers: Implications for policy. *Journal of Agriculture and Food Research, 21*, 101905. https://doi.org/10.1016/j.jafr.2025.101905.

Asante, I. K., Inkoom, E. W., Ocran, J. K., Kyeremateng, E., Sabari, G., & Odamtten, F. T. (2025). Intention of smallholder maize farmers to adopt integrated pest management practices for fall armyworm control in the Upper East region of Ghana. *International Journal of Pest Management, 71*(2), 265–282. https://doi.org/10.1080/09670874.2023.2199331.

Asefa, E. M., Damtew, Y. T., & Ober, J. (2024). Pesticide water pollution, human health risks, and regulatory evaluation: A nationwide analysis in Ethiopia. *Journal of Hazardous Materials, 459*, 135326. https://doi.org/10.1016/j.jhazmat.2023.135326.

Bagheri, A., Bondori, A., Allahyari, M. S., & Damalas, C. A. (2019). Modeling farmers' intention to use pesticides: An expanded version of the theory of planned behavior. *Journal of Environmental Management, 248*, 109291. https://doi.org/10.1016/j.jenvman.2019.07.003.

Boateng, K. O., Dankyi, E., Amponsah, I. K., Awudzi, G. K., Amponsah, E., & Darko, G. (2023). Knowledge, perception, and pesticide application practices among smallholder cocoa farmers in four Ghanaian cocoa-growing regions. *Toxicology Reports, 10*, 46–55. https://doi.org/10.1016/j.toxrep.2022.12.022.

Bondori, A., Bagheri, A., Sookhtanlou, M., & Damalas, C. A. (2021). Modeling farmers' intention for safe pesticide use: The role of risk perception and use of information sources. *Environmental Science and Pollution Research, 28*, 66677–66686. https://doi.org/10.1007/s11356-021-14624-4.

Damalas, C. A. (2021). Farmers' intention to reduce pesticide use: The role of perceived risk of loss in the model of the planned behavior theory. *Environmental Science and Pollution Research, 28*(26), 35278–35285. https://doi.org/10.1007/s11356-021-13150-5.

Dewi, Y. A., Yulianti, A., Hanifah, V. W., Jamal, E., Sarwani, M., Mardiharini, M., Anugrah, I. S., Darwis, V., Suib, E., Herteddy, D., & Sutriadi, M. T. (2022). Farmers' knowledge and practice regarding good agricultural practices (GAP) on safe pesticide usage in Indonesia. *Heliyon, 8*(1)e08730. https://doi.org/10.1016/j.heliyon.2021.e08730.

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. https://doi.org/10.1016/j.scitotenv.2015.07.150.

Food and Agricultural Organization. (2025). Pesticides use and trade. 1990–2022. https://www.fao.org/statistics/highlights-archive/highlights-detail/pesticides-use-and-trade-1990-2022/en (Accessed date April 01, 2025).

Furlong, M. A., Yang, W., Guo, T., Wu, C., & Ritz, B. (2024). Residential proximity to agricultural pesticide applications and stillbirth in California. *American Journal of Epidemiology, 193*(10), 874–885. https://doi.org/10.1093/aje/kwae182.

Government of Pakistan (2024). *Economic Survey of Pakistan 2023–24*. Ministry of Finance, Government of Pakistan.

Gunnell, D., Knipe, D., Chang, S. S., Pearson, M., Konradsen, F., Lee, W. J., & Eddleston, M. (2017). Prevention of suicide with regulations aimed at restricting access to highly hazardous pesticides: A systematic review of the international evidence. *The Lancet Global Health, 5*(10), e1026–e1037. https://doi.org/10.1016/S2214-109X(17)30396-5.

Hasanuzzaman, M., Mohsin, S. M., Bhuyan, M. B., Bhuiyan, T. F., Anee, T. I., Masud, A. A. C., & Nahar, K. (2020). Phytotoxicity, environmental and health hazards of herbicides: Challenges and ways forward. In *Agrochemicals detection, treatment and remediation* (pp. 55–99). Butterworth-Heinemann.

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. https://doi.org/10.1080/10807039.2012.672901.

Jin, S., Bluemling, B., & Mol, A. P. J. (2015). Information, trust and pesticide overuse: Interactions between retailers and cotton farmers in China. *NJAS: Wageningen Journal of Life Sciences, 72–73*, 23–32. https://doi.org/10.1016/j.njas.2014.12.001.

Kapeleka, J. A. (2024). Quantification of pesticide dosage and determinants of excessive pesticide use in smallholder vegetable production systems in Tanzania. *Heliyon, 10*(24)e26259. https://doi.org/10.1016/j.heliyon.2024.e26259.

Karunarathne, A., Bhalla, A., Sethi, A., Perera, U., & Eddleston, M. (2021). Importance of pesticides for lethal poisoning in India during 1999 to 2018: A systematic review. *BMC Public Health, 21*, 1441. https://doi.org/10.1186/s12889-021-11156-2.

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. https://doi.org/10.1080/09670874.2014.984260.

Khan, M., Mahmood, H. Z., & Damalas, C. A. (2015). Pesticide use and risk perceptions among farmers in the cotton belt of Punjab, Pakistan. *Crop Protection, 67*, 184–190. https://doi.org/10.1016/j.cropro.2014.10.013.

Khan, M. I., Shoukat, M. A., Cheema, S. A., Arif, H. N., Niazi, N. K., Azam, M., Bashir, S., Ashraf, I., & Qadri, R. (2020). Use, contamination and exposure of pesticides in Pakistan: A review. *Pakistan Journal of Agricultural Sciences, 57*(1), 1–10. https://doi.org/10.21162/PAKJAS/20.9338.

Kubiak-Hardiman, P., Haughey, S. A., Meneely, J., Miller, S., Banerjee, K., & Elliott, C. T. (2023). Identifying gaps and challenges in global pesticide legislation that impact the protection of consumer health: Rice as a case study. *Exposure and Health, 15*(3), 597–618. https://doi.org/10.1007/s12403-022-00508-x.

Lee, D. H., Steffes, M. W., & Jacobs, D. R. (2018). Association between serum concentrations of persistent organic pollutants and T-cell immunosenescence in the U.S. general population. *Environmental Research, 160*, 452–458. https://doi.org/10.1016/j.envres.2017.10.038.

Lekei, E. E., Ngowi, A. V., & London, L. (2014). Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania. *BMC Public Health, 14*, 389. https://doi.org/10.1186/1471-2458-14-389.

Lewin, K. (1943). Defining the field at a given time. *Psychological Review, 50*(3), 292–310. https://doi.org/10.1037/h0062738.

Li, H., Wang, C., Chang, W. Y., & Liu, H. (2023). Factors affecting Chinese farmers' environment-friendly pesticide application behavior: A meta-analysis. *Journal of Cleaner Production, 409*, 137277. https://doi.org/10.1016/j.jclepro.2023.137277.

Liang, S. X., Li, H., Chang, Q., Bai, R., Zhao, Z., & Pang, G. F. (2022). Residual levels and dietary exposure risk assessment of banned pesticides in fruits and vegetables from Chinese market based on long-term nontargeted screening by HPLC-Q-TOF/MS. *Ecotoxicology and Environmental Safety, 248*, 114280. https://doi.org/10.1016/j.ecoenv.2022.114280.

Liu, L., Zhang, H., Wang, Q., Chen, Y., & Zhao, J. (2024). Maternal periconceptional pesticide exposure and birth defects: A population-based cross-sectional study in Shaanxi Province, China. *Frontiers in Public Health, 12*, 1489365. https://doi.org/10.3389/fpubh.2024.1489365.

Matthews, G., Zaim, M., Yadav, R. S., Soares, A., Hii, J., Ameneshewa, B., Mnzava, A., Dash, A. P., Ejov, M., Tan, S. H., & van den Berg, H. (2011). Status of legislation and regulatory control of public health pesticides in countries endemic with or at risk of major vector-borne diseases. *Environmental Health Perspectives, 119*(11), 1517–1522. https://doi.org/10.1289/ehp.1103637.

Mehmood, Y., Arshad, M., & Bashir, M. K. (2023). Household income and food security during the COVID-19 pandemic in the urban slums of Punjab, Pakistan. *Local Environment, 28*(12), 1573–1589. https://doi.org/10.1080/13549839.2023.2296517.

Mehmood, Y., Arshad, M., Kächele, H., Mahmood, N., & Kong, R. (2021a). Pesticide residues, health risks, and vegetable farmers' risk perceptions in Punjab, Pakistan. *Human and Ecological Risk Assessment: An International Journal, 27*(3), 846–864. https://doi.org/10.1080/10807039.2020.1776591.

Mehmood, Y., Arshad, M., Mahmood, N., Kächele, H., & Kong, R. (2021b). Occupational hazards, health costs, and pesticide handling practices among vegetable growers in Pakistan. *Environmental Research, 200*, 111340. https://doi.org/10.1016/j.envres.2021.111340.

Mehmood, Y., Farooqi, Z., Bakhsh, K., Anjum, M. B., & Ahmad, M. (2012). Impact of Bt cotton varieties on productivity: Evidence from district Vehari, Pakistan. *Journal Agriculture and Social Sciences, 8*, 109–111.

Miyittah, M. K., Kosivi, R. K., Tulashie, S. K., Addi, M. N., & Tawiah, J. Y. (2022). The need for alternative pest management methods to mitigate risks among cocoa farmers in the Volta region, Ghana. *Heliyon, 8*(12). https://doi.org/10.1016/j.heliyon.2022.e12345.

Oyekale, A. S. (2018). Cocoa farmers' compliance with safety precautions in spraying agrochemicals and use of personal protective equipment (PPE) in Cameroon. *International Journal of Environmental Research and Public Health, 15*(2), 327. https://doi.org/10.3390/ijerph15020327.

Pan, Y., Ren, Y., & Luning, P. A. (2021). Factors influencing Chinese farmers' proper pesticide application in agricultural products–a review. *Food Control, 122*, 107788. https://doi.org/10.1016/j.foodcont.2020.107788.

PAN (2023). *Majority of pesticides used in farming communities in 4 Asian countries are highly hazardous or banned in EU. Pesticide Action Network Asia Pacific*. https://panap.net/2023/02/new-report-majority-of-pesticides-used-in-farming-communities-in-4-asian-countries-are-highly-hazardous-or-banned-in-eu/.

Parra-Arroyo, L., González-González, R. B., Castillo-Zacarías, C., Martínez, E. M. M., Sosa-Hernández, J. E., Bilal, M., Iqbal, H. M., Barceló, D., & Parra-Saldívar, R. (2022). Highly hazardous pesticides and related pollutants: Toxicological, regulatory, and analytical aspects. *Science of The Total Environment, 807*, 151879. https://doi.org/10.1016/j.scitotenv.2021.151879.

Priyadarshanee, M., Mahto, U., & Das, S. (2022). Mechanism of toxicity and adverse health effects of environmental pollutants. In *Microbial Biodegradation and Bioremediation* (pp. 33–53). Elsevier. https://doi.org/10.1016/B978-0-323-85780-2.00003-3.

Qiao, D., Luo, L., Chen, C., Qiu, L., & Fu, X. (2023). How does social learning influence Chinese farmers' safe pesticide use behavior? An analysis based on a moderated mediation effect. *Journal of Cleaner Production, 430*, 139722. https://doi.org/10.1016/j.jclepro.2023.139722.

Ramírez-Guerrero, M. C., Mena-Valenzuela, C. F., Lizarazo-Forero, C. A., Sánchez-Rodríguez, M., & Pérez-Medina, J. (2025). Environmental exposure to pesticides and immune-inflammatory indices in school-aged children from agricultural areas of Mexico. *Environmental Research, 245*, 118009. https://doi.org/10.1016/j.envres.2024.118009.

Rashid, S., Rashid, W., Tulcan, R. X. S., & Huang, H. (2022). Use, exposure, and environmental impacts of pesticides in Pakistan: A critical review. *Environmental Science and Pollution Research, 29*(29), 43675–43689. https://doi.org/10.1007/s11356-022-19153-1.

Rother, H. A. (2018). Pesticide labels: Protecting liability or health?–Unpacking "misuse" of pesticides. *Current Opinion in Environmental Science & Health, 4*, 10–15. https://doi.org/10.1016/j.coesh.2018.03.005.

Saeed, M. F., Shaheen, M., Ahmad, I., Zakir, A., Nadeem, M., Chishti, A. A., Shahid, M., Bakhsh, K., & Damalas, C. A. (2017). Pesticide exposure in the local community of Vehari District in Pakistan: An assessment of knowledge and residues in human blood. *Science of the Total Environment, 587*, 137–144. https://doi.org/10.1016/j.scitotenv.2017.02.123.

Settle, W., Soumaré, M., Sarr, M., Garba, M. H., & Poisot, A. S. (2014). Reducing pesticide risks to farming communities: Cotton farmer field schools in Mali. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1639) 20120277. https://doi.org/10.1098/rstb.2012.0277.

Sharafi, K., Pirsaheb, M., Maleki, S., Arfaeinia, H., Karimyan, K., Moradi, M., & Safari, Y. (2018). Knowledge, attitude and practices of farmers about pesticide use, risks, and wastes: A cross-sectional study (Kermanshah, Iran). *Science of the Total Environment, 645*, 509–517. https://doi.org/10.1016/j.scitotenv.2018.07.064.

Sharifzadeh, M. S., Abdollahzadeh, G., Damalas, C. A., Rezaei, R., & Ahmadyousefi, M. (2019). Determinants of pesticide safety behavior among Iranian rice farmers. *Science of the Total Environment, 651*, 2953–2960. https://doi.org/10.1016/j.scitotenv.2018.10.176.

Shattuck, A., Werner, M., Mempel, F., Dunivin, Z., & Galt, R. (2023). Global pesticide use and trade database (GloPUT): New estimates show pesticide use trends in low-income countries substantially underestimated. *Global Environmental Change, 81*, 102693. https://doi.org/10.1016/j.gloenvcha.2023.102693.

Sun, S., Zhang, C., Hu, R., & Liu, J. (2023). Do pesticide retailers' recommendations aggravate pesticide overuse? Evidence from rural China. *Agriculture, 13*(7), 1442. https://doi.org/10.3390/agriculture13071442.

Syed, J. H., Alamdar, A., Mohammad, A., Ahad, K., Shabir, Z., Ahmed, H., Ali, S. M., Sani, S. G. A. S., Bokhari, H., Gallagher, K. D., & Ahmad, I. (2014). Pesticide residues in fruits and vegetables from Pakistan: A review of the occurrence and associated human health risks. *Environmental Science and Pollution Research, 21*, 13367–13393. https://doi.org/10.1007/s11356-014-3023-5.

Taherdoost, H. (2016). Sampling methods in research methodology: How to choose a sampling technique for research. *International Journal of Academic Research in Management (IJARM), 5*. https://doi.org/10.2139/ssrn.2812096.

Tariq, M. I., Afzal, S., Hussain, I., & Sultana, N. (2007). Pesticides exposure in Pakistan: A review. *Environment International, 33*(8), 1107–1122. https://doi.org/10.1016/j.envint.2007.06.006.

Waddington, H., Snilstveit, B., Hombrados, J., Vojtkova, M., Phillips, D., Davies, P., & White, H. (2014). Farmer field schools for improving farming practices and farmer outcomes: A systematic review. *Campbell Systematic Reviews, 10*(1), i–335. https://doi.org/10.4073/csr.2014.6.

Wang, Y., Wang, Y., Huo, X., & Zhu, Y. (2015). Why some restricted pesticides are still chosen by some farmers in China? Empirical evidence from a survey of vegetable and apple growers. *Food Control, 51*, 417–424. https://doi.org/10.1016/j.foodcont.2014.10.027.

WHO (2019). *The WHO recommended classification of pesticides by hazard and guidelines to classification (2019 edition)*. https://www.who.int/publications/i/item/9789240005662.

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. https://doi.org/10.1016/j.scitotenv.2014.08.042.