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Pesticide exposure, health impacts, predeterminism, and health insurance demand among Pakistani farmers: Implications for policy

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A R T I C L E I N F O

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A B S T R A C T

The indiscriminate use of chemical pesticides, regardless of pest infestation, is widespread in the developing world to mitigate agricultural losses. Farmers face significant health risks from pesticides, yet indemnity provision is often neglected in policy discussions. Socio-cultural factors, including religion and trust in governments, can influence indemnity demand, especially among religious communities. However, little to no attention has been given to religious predeterminism and public trust in indemnity service design. We employed a novel approach integrating count data models with contingent valuation to analyze the health impacts of pesticide use and influence of socioeconomic factors, particularly religious predeterminism and public trust, on health insurance demand among farmers in rural Pakistan. Results reveal critical health risks posed by pesticide use among farmers and highlight the limited willingness to pay for health insurance to mitigate these risks. Findings from the Negative Binomial (NB) regression model showed significant positive effects of pesticide quantity ($\beta = 0.607$, $p < 0.05$), WHO Class IA-and-IB pesticides ($\beta = 0.420$, $p < 0.05$), and WHO Class II pesticides ($\beta = 0.277$, $p < 0.05$) on farmers' health. Religious predeterminism and public trust significantly influence farmers' willingness to pay, with only about 27 % of farmers expressing readiness to pay an average of US$4.02 per annum for health insurance. These findings emphasize the importance of tailored health insurance designs that accommodate religious beliefs. Policy initiatives should focus on educating farmers about safe pesticide use and health insurance benefits. Governments can build public trust through subsidized insurance schemes to reduce farmers' out-of-pocket health expenses. The findings emphasize the role of socio-cultural factors, in shaping insurance uptake, suggesting that health insurance policies must be tailored to align with farmers' belief systems. Government-led initiatives, including subsidized insurance schemes, are essential to enhance public trust, foster safe farming practices, and support sustainable agriculture.

1. Introduction

The intensification of agriculture, stemming from the legacy policies of the Green Revolution era, has led to a significant increase in the use of agro-chemicals, including pesticides, insecticides, and herbicides. Synthetic chemical usage in agricultural production is widespread in the developing world, serving either for pest control or as a preventative measure against yield losses from pest infestations [1]. Farmers and farm laborers bear a high risk of pesticide exposure, resulting in elevated rates of pesticide toxicity in their everyday activities [2,3]. The vulnerability of health to pesticides is influenced by several factors, such as improper application techniques, lack of personal protective equipment (PPE), farmers' knowledge regarding pesticide selection, and toxicity levels, among others. Despite advancements in pesticide

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application technology and handling practices, effective transfer of these advancements to the farming community, particularly in developing countries, remains inadequate [4]. Globally, pesticide poisoning incidents lead to numerous deaths annually [5], with approximately 385 million cases of acute poisoning reported each year [6]. On average, around 200,000 people succumb to toxic pesticide exposure annually worldwide, indicating that approximately 44 % of the global population working in agriculture—comprising farmers and agricultural workers—suffers poisoning each year [6]. A significant proportion (99 %) of these deaths occurs in developing countries [7–9].

The health impacts of pesticides on farmers depend on the types and levels of pesticides used, which span various chemical classes. Toxic compounds like organophosphates and carbamates can induce acute muscarinic symptoms such as lacrimation, urination, vomiting, and bronchospasm [10] and disrupt the central nervous system (CNS) [11,12]. Some pesticides may also affect the endocrine system and contribute to various types of cancer, including hematopoietic cancer [13]. Chemicals like *1,2-Dibromo-3-chloropropane* and *Chlordecone* are reproductive toxicants, reducing sperm motility in male farm workers [14]. Pesticide exposure has been linked to a range of health issues, including shingles [15], Hodgkin and Non-Hodgkin Lymphoma diseases [16]. Studies by Refs. [17,18] highlight the association between pesticide exposure and short-term acute respiratory diseases, nausea, blurred vision, eye irritation, and other health problems.

Despite perceived benefits, pesticide use in developing countries poses significant hazards [4,18,19]. Comprehensive assessments must consider broader human health and environmental impacts [20,21]. Indiscriminate pesticide use escalates medical expenses, reduces productivity, and lowers daily wages [3,19,22]. Pesticides also harm natural ecosystems, air, soil, water, and contribute to greenhouse gas emissions [23–25], resulting in environmental costs like land degradation and groundwater depletion [26,27]. Moreover, pesticides decrease agricultural production and farmers' net income [1]. Health costs from pesticide poisoning can consume a significant portion of pesticide returns [28], potentially outweighing benefits over time unless preventive measures are implemented.

In Pakistan, approximately 64 % of the population resides in rural areas, with 39 % of the labor force directly engaged in agriculture [29]. Despite agriculture's economic significance, the per capita gross domestic product (GDP) remains low at $1482.40 USD, and healthcare spending accounts for only 1.1 % of total GDP [29]. This limited allocation restricts access to healthcare, particularly in rural areas, where political instability and competing government priorities further exacerbate challenges [30]. As a result, many farming communities rely on out-of-pocket medical expenses, making them particularly vulnerable to financial shocks from health risks associated with occupational hazards, including pesticide exposure.

Given these constraints, there is a pressing need to assess the health risks faced by farmers, quantify the economic burden of pesticide-related illnesses, and explore sustainable mechanisms such as health insurance to enhance healthcare access in rural Pakistan. Understanding farmers' willingness to pay (WTP) for health insurance is crucial in determining the feasibility of such schemes. However, beyond financial considerations, socio-cultural factors such as religious predeterminism—the belief that health outcomes are predetermined by divine will—may influence farmers' decisions on healthcare investments, including insurance uptake. Any economic evaluation of insurance demand must therefore account for both market and non-market influences.

This study provides empirical evidence to guide policymakers and private insurers in designing health insurance schemes that align with the needs and preferences of rural farmers. We employ the contingent valuation method (CVM), a widely used approach for estimating individuals' WTP for health insurance in developing countries [1,31]. By creating a hypothetical market for non-market goods and services, CVM facilitates structured discussions and preference elicitation, enabling a better understanding of how farmers perceive and value health insurance.

Farmers' decisions regarding pesticide use and health insurance uptake are shaped by both sociopsychological and socio-economic factors. Studies on Tunisian and Sicilian farmers have demonstrated that attitudes, social norms, and perceived behavioral control play a significant role in shaping adoption behavior [32,33]. While previous research has examined the health effects of pesticide exposure and farmers' willingness to pay (WTP) for health insurance in developing countries [4,34,35,36], few studies have simultaneously assessed both the short-term health impacts of pesticide use and the demand for health insurance. In Pakistan, studies such as [37,36] have explored pesticide-related health risks but have not accounted for key socio-cultural factors that may influence health outcomes and insurance adoption. By integrating religious predeterminism and public trust—two factors largely overlooked in existing literature—our study provides a more comprehensive understanding of the behavioral and structural determinants influencing farmers' decision-making.

Punjab, home to nearly 60 % of Pakistan's population, is a region where 99 % of residents identify as Muslims [38]. In this context, socio-cultural beliefs and trust in government play a critical role in shaping demand for indemnity services. However, the influence of religious predeterminism on pesticide use and health insurance demand has not been explored in Pakistan. Previous research suggests that fatalistic beliefs affect individuals' adoption of climate-smart agricultural practices [39,40] and influence decisions regarding business and weather index insurance [41,42]. Despite these findings, no study has specifically examined the role of religious predeterminism in health insurance decisions among farmers.

Additionally, existing research indicates that farmers often distrust government-led agricultural and environmental programs and exhibit skepticism toward public healthcare initiatives [43]. However, little attention has been given to how public distrust affects participation in government-facilitated health insurance schemes. Our study addresses these gaps by incorporating both religious predeterminism and public trust into our demand models. By doing so, we provide a more comprehensive understanding of the factors influencing farmers' willingness to invest in health insurance, offering valuable insights for policymakers and insurance providers.

2. Material and methods

2.1. Study area and population

The study area is Punjab Province in Pakistan, widely known as the country's breadbasket and a significant contributor to its GDP. With a population of approximately 110 million as of 2017, Punjab boasts a vast cropped area of 16.68 million hectares, supporting a variety of crops like wheat, rice, cotton, sugarcane, maize, oilseeds, fruits, and vegetables. Among these crops, Pakistan cultivates over 35 varieties of vegetables across different climatic zones, ensuring their availability in markets year-round. Punjab leads in vegetable production, occupying 63.11 % of the total area dedicated to vegetables. This prominence is driven by the economic potential of vegetable cultivation for poverty alleviation and its suitability for smallholders. Despite Punjab's advanced irrigation system, water shortages impact agriculture. To mitigate production risks, farmers rely heavily on pesticides, with Punjab accounting for over 80 % of Pakistan's total pesticide use. The use of pesticides in Pakistan has been steadily increasing, yet the control over their usage remains inadequate due to weak legislation and monitoring [18]. For example, in 2010, the total annual pesticide consumption was 73,632 metric tons, but by 2017, it had tripled [44]. However, this indiscriminate pesticide use poses severe health risks to farmers and environmental concerns.

Despite bans on toxic pesticides like Ethylene Dichloride (ED), Organo Chlorine pesticide (OCP), and Dichlorodiphenyltrichloroethane

(DDT) in many countries, including Pakistan, they are still utilized in crop production. This unregulated pesticide use has resulted in health issues such as acute respiratory diseases, asthma, skin allergies, nausea, and disruptions in female reproductive hormones. Given these challenges and the absence of occupational hygiene, legislation, and regulations, it is imperative to assess the health effects of pesticides in Punjab's farming systems and explore the market potential of health insurance schemes. To address these concerns, three districts of Punjab—Sahiwal, Kasur, and Gujrat—were selected due to their significant vegetable production volume and a history of widespread pesticide use.

2.2. Sampling and assessment tools

A multistage random sampling technique was employed for a cross-sectional survey conducted in two phases. Initially, the Punjab Province was stratified into three segments, from which one district – Sahiwal, Kasur, and Gujrat – was randomly chosen. Subsequently, two tehsils were randomly selected from each chosen district. Tehsils, sub-divisions of a district, were further divided into union councils, from which 18 were randomly chosen – 3 from each tehsil and 6 from each district. The sampling frame consisted of 8764 vegetable growers, from which a sample size of 369 farmers was generated using an automatic random number generator. The study addressed three main inquiries: (i) the impact of pesticide exposure on farmers' health, (ii) farmers' willingness to purchase health insurance, and (iii) factors influencing farmers' willingness to pay (WTP) for health insurance. Data were collected from major vegetable-producing rural areas of Punjab, Pakistan. The total response rate was 83.19 %, with 307 vegetable growers participating in the survey; the remaining 16.81 % either could not be reached or declined participation.

The questionnaire was developed based on the researchers' field experience and insights from existing literature. It covered various aspects, including socioeconomic characteristics, farming practices, short-term health effects of pesticide exposure, use of personal protective equipment, and farmers' WTP for health insurance premiums. The questionnaire underwent content validation by a panel of experts in health economics, health education, and environmental economics. Additionally, face validity was assessed through pre-testing interviews with 20 farmers to evaluate question complexity and comprehension. The questionnaire was initially drafted in English and then translated into Urdu for ease of understanding by the farmers.

Experienced research surveyors, proficient in health economics and skilled in field surveys and data collection, were tasked with gathering information from respondents. Prior to the interviews informed consent was obtained from each participant, and those who declined participation were not included in the survey.

2.3. Model specification

To investigate the health implications of pesticide exposure among farmers, we employed the Negative Binomial (NB) regression model, a widely validated approach in epidemiology, agriculture, and social sciences. This model was chosen due to its ability to account for non-linearity in model parameters and handle overdispersion in count data, which are common characteristics in health outcome datasets influenced by pesticide exposure [45]. Additionally, the NB regression model assumed independence among individual observations, making it a statistically robust choice for analyzing health-related count data.

We considered alternative models before finalizing our choice. Linear regression was ruled out due to the non-normal distribution of the outcome variable, which violated the assumptions of ordinary least squares (OLS) estimation [46,47]. Similarly, Logit and Probit models were deemed unsuitable because the dependent variable was count-based rather than dichotomous.

To ensure methodological rigor, we tested four different models for count data analysis:

1. Poisson regression model
2. Negative Binomial (NB) regression model
3. Zero-Inflated Negative Binomial (ZINB) regression model
4. Zero-Inflated Poisson (ZIP) regression model

The final model selection was based on the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Among all models, the NB regression model exhibited the lowest BIC value, indicating the best fit for the data (see Table 1). This selection ensured a more reliable and accurate analysis of the relationship between pesticide exposure and health effects.

The analysis of health effects resulting from pesticide exposure reveals a prevalence of zero counts in the dataset alongside a pronounced right-skewed distribution, as depicted in Fig. 1.

This observation reinforces our choice of the Negative Binomial regression model. The employed Negative Binomial (NB) regression model is as follows:

$$Pr(Y_i = y_i) = \frac{\Gamma(y_i + \alpha_i)}{\Gamma(\alpha_i) \cdot y_i!} \cdot \left(\frac{\alpha_i}{\alpha_i + \mu_i}\right)^{\alpha_i} \cdot \left(\frac{\mu_i}{\alpha_i + \mu_i}\right)^{y_i} \quad \text{(Eq.1)}$$

Here, (Y_i) denotes the probability of farmers experiencing short-term health effects due to pesticide use within a specific time frame, where (μ_i) signifies the mean number of short-term health effects experienced by farmers. The count of such health effects is represented by (y_i), with potential values ranging from 0 to any positive integer. We focused solely on short-term health effects, such as skin irritation, eye irritation, blurred vision, respiratory diseases, coughing, headache, sweating, salivation, and muscle fatigue, typically manifesting within 24 h of pesticide exposure. This can be rewritten as:

$$Pr(Y_i - y_i) = \frac{\mu_i^{y_i} \cdot e^{-\mu_i}}{y_i!} \quad \text{(Eq.2)}$$

In Eq. (2), the relationship between the mean (μ_i) and the explanatory variables (X_i) is delineated as:

$$\ln(\mu_i) = X_i^T \beta \quad \text{(Eq.3)}$$

Here, the number of short-term health effects experienced by farmers is modeled as a function of the vector of explanatory variables (X_i), with (β) representing the coefficient of these variables. The estimation of (β) is achieved through maximizing the logarithm of the likelihood function, as depicted in Eq. (4):

$$\ln L(\beta) = \sum_i \left[-e^{X_i^T \beta} + (X_i^T \beta) y_i - ln(y_i!) \right] \quad \text{(Eq.4)}$$

The decision to eschew the Poisson regression model stems from the discrepancy between its mean and variance (mean = 1.64, variance = 3.07), indicative of overdispersion within the dataset. This overdispersion, often resulting from variability between observations, can be mitigated by the Negative Binomial (NB) regression model. To account for the variance of the NB regression distribution, expressed as $\mu_i + \alpha\,\mu_i^2$, where (α) denotes the overdispersion parameter, an error term $(\in_{i)}$ of gamma distribution is introduced (Eq. (5)):

$$\ln(\mu_i) = X_i^T \beta + \in_i \quad \text{(Eq.5)}$$

NB regression model is widely considered as the best model to

Table 1
Comparison of count data regression models using Akaike and Bayesian information criteria.

Model Performance	Poisson Regression	NB Regression	ZIP Regression	ZINB Regression
AIC	1057	1036	1014	1016
BIC	1117	1099	1133	1139

Note: Lower AIC and BIC values indicate a better model fit.

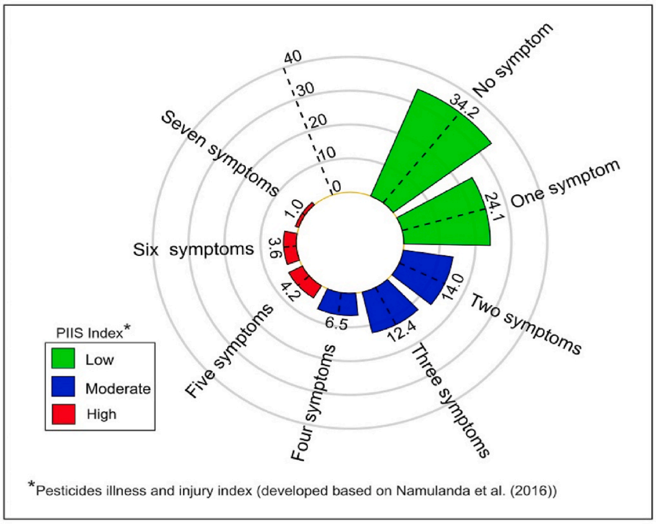

Fig. 1. Polar bar chart illustrating distribution of health effects from pesticide exposure.

estimate health impacts [48]. The model used for investigating changes in dependent variables related to health effects is formulated as:

$$\text{Health Effects} = \beta_0 + \beta_1(\text{Farmer age}) + \beta_2(\text{Education level}) + \beta_3(\text{Monthly income}) + \beta_4(\text{Farming expereince})\ldots\ldots\beta_{15}(\text{WHO} - \text{III}) \quad \text{(Eq. 6)}$$

For eliciting farmers' Willingness-To-Pay (WTP) for health insurance premiums, Contingent Valuation Method (CVM) was employed. This approach, widely utilized in both academic research and governmental assessments, facilitates the market valuation of goods and services. The WTP reflects individual preferences and is determined by factors such as the contentment benefits derived from distinctive natural environments and adjustments in environmental quality prior to policy implementation, such as health insurance coverage for pesticide handlers. To mitigate hypothetical bias, the CVM incorporated three modules in WTP questions: (1) resource explanation, (2) means of payment, and (3) the elicitation process.

A Logistic regression model, akin to that employed in previous studies [49], was utilized to analyze farmers' WTP for health insurance premiums:

$$P_i(Yes) = \frac{1}{1 + \exp\left[-(\alpha - \beta A)\right]} \quad \text{(Eq.7)}$$

Here, the coefficients (α) and (β) in equation (Eq. (7)) are estimated through the maximum likelihood (ML) estimation method, where (A) represents the response of farmers' WTP for insurance purchase. The WTP can then be estimated as:

$$\text{WTP} = -\alpha/_{\beta} \quad \text{(Eq.8)}$$

The description and measurement of variables used in the negative binomial (NB) regression model and logistic regression model are provided in Table 2. All analyses in this paper were conducted using STATA 18 and R version 4.3.1.

3. Results

3.1. Socioeconomic characteristics of farmers and sickness episodes

Table 3 presents the socioeconomic characteristics of the respondents. The sampled farmers had a mean age of 42.34 years, with the majority falling within the 35–45 age bracket (data not shown). On

Table 2
Description and measurement of variables in the Negative Binomial (NB) and Logistic regression models.

Variables	Description and measurement	Mean	SD
Health effects	Health effects indicates the number of perceived health effects (short-term symptoms) of households	1.64	1.75
WTP	Farmers' willingness to pay health premium for medical care, which is a dichotomous.	0.26	0.44
Farmer age	Analyzed in years	42.34	10.43
Education level	Formal years of schooling estimated in years	3.48	4.21
Family size	Measured in numbers	5.37	3.14
Earners	Total number of earning hands in a household, measured in numbers		
Children	Measured in numbers	3.31	1.87
Farming experience	Measured in years	10.65	6.43
Farm size	Area under cultivation measured in hectares	5.51	4.33
Monthly income	Farmers monthly income from all sources measured in US$	224	107
Media influence	If farmers had received information about health effect of pesticide use from media, then one; otherwise, zero	0.37	0.48
Integrated pest management (IPM)	If farmers use IPM practices to control insect pests then one; otherwise, zero	0.16	0.37
Read label	If farmers carefully read pesticide bottle label before applying then value is set to one; otherwise, zero	0.30	0.46
Access to extension services	If farmers receive information from agriculture field officer about pesticide handling and agriculture practices then value is set to one; otherwise, zero	0.28	0.45
Access to healthcare services	If farmers access to healthcare facility is less than 20 km, then value is considered to one; otherwise, zero	0.26	0.44
Personal protective equipment	If farmers use PPE while applying the pesticide then value is considered one; otherwise, zero	0.66	1.07
Quantity of pesticide use	Total quantity of pesticides applied by the farmers on area under cultivation, measured in liters	9.46	2.98
WHO Ia and Ib	If farmers applied WHO Ia and Ib categorized pesticide then value is considered one; otherwise, zero	0.22	0.41
WHO-II	If farmers applied WHO-II categorized pesticide then value is considered one; otherwise, zero	0.58	0.49
WHO-III	If farmers applied WHO-III categorized pesticide then value is considered one; otherwise, zero	0.54	0.49
Religious predeterminism	If a sampled farmer holds the belief that past, present, and future human actions have already been predetermined by a higher power, the variable is set a value of one; otherwise, zero.	0.77	0.42
Distrust in government	If farmers had trust in government the value is set to zero; otherwise, one	0.27	0.44
Awareness of health insurance	If farmers had information about health insurance the value is set to one; otherwise, zero	0.21	0.42
Access to institutional credit	If farmers obtained loan from the financial institution the value is set to one; otherwise, zero	0.23	0.42
Distance from the market	If distance from the market to farm is less than 20 km the value is set to one; otherwise, zero	0.58	0.49
Health cost	Health cost incurred by farmers due to exposure to pesticides measured in US$	2.10	5.92

SD: Standard deviation.
1 US$ = 279/- PKR.

Table 3
Socioeconomic characteristics and incidence of sickness episodes among sampled farmers.

Variable	Minimum	Maximum	Mean	SD
Farmer age	19	68	42.34	10.43
Education level	0	16	3.45	4.21
Marital status	0	1	0.74	0.43
Family size	2	15	5.37	3.14
Children	0	8	3.31	1.87
Crop farming	0	1	0.83	0.37
Monthly income	72	609	224	107
Farming experience	2	35	10.65	6.43
Farm size	2	23	5.51	4.33
Livestock holding	0	1	0.36	0.48
[a]***Sickness episode # (%)***				
No symptom	105	34.20		
One time sickness	97	31.59		
Two times sickness	63	20.52		
Three times or above	42	13.68		

SD: Standard deviation.
[a] Episodes of sickness reported within the past two months based on respondents' recall.

average, farmers had 3.45 years of formal education, which is below the national and universal education standards. Notably, all surveyed farmers in the study area were male, as pesticide handling practices are predominantly undertaken by male farmers in Pakistan. Among the surveyed population, over 74 % were married, with an average of 3.31 children. Approximately 83 % of the sampled farmers derived their main income from farming, with an average monthly income of US $224 (PKR 62496/-). The average farm size was 5.51 ha, and all farmers cultivated vegetable crops. The surveyed farmers had an average farming experience of 10.65 years, and three out of ten farmers kept livestock on their farms.

Table 3 also provides insights into the sickness episodes experienced by farmers in the surveyed area. Around 35 % of respondents reported no sickness symptoms during the two months preceding data collection, while 31.59 % experienced illness once. Additionally, 20.52 % suffered from sickness twice, and 13.68 % reported three or more instances of illness.

3.2. Exposure to pesticide and short-term health effects

Table 4 presents an overview of exposure to pesticides and the perceived health effects reported by farmers. Among the most commonly reported symptoms were skin irritation, headache or dizziness, sweating and salivation, vomiting, eye irritation, and difficulty in breathing. Notably, a significant proportion of surveyed farmers, approximately 40 %, reported experiencing sweating and salivation, which may indicate systemic effects of pesticide exposure. Additionally, 31.92 % of respondents reported experiencing headache and dizziness, possibly indicative of neurological effects. Skin irritation, identified as dermatitis, was reported by 27.68 % of farmers, suggesting direct contact effects of pesticide exposure on the skin.

Table 4
Exposure to pesticides and short-term health effects experienced by farmers.

Health effects	*f*	(%)
Sweating and salivation	123	40.06
Headache or dizziness	98	31.92
Vomiting sensation	28	9.12
Muscle twitching	55	17.91
Skin irritation or skin rashes	85	27.68
Difficulty in breathing	17	5.53
Eye irritation or blurred vision	56	18.24
Others	44	14.33

The percentage is not equal to 100 as some farmers stated more than one health effect.

In addition to these commonly reported symptoms, other health effects were also observed among the surveyed farmers. Around 18.24 % reported experiencing eye irritation, which could be attributed to ocular exposure to pesticides. Similarly, 9.12 % of respondents reported experiencing a sensation of vomiting, indicating potential gastrointestinal effects. Furthermore, 5.53 % reported difficulty in breathing, suggesting respiratory effects associated with pesticide exposure. These findings highlight a range of health effects experienced by farmers due to pesticide exposure, highlighting the need for effective mitigation strategies and health interventions in agricultural communities.

The estimated coefficients of farmers' perceived health effects, obtained through the NB regression model, are detailed in Table 5. Notably, several variables exhibited significant positive effects at the 5 % level of significance. These include farmer age ($\beta = 0.013$), farm size ($\beta = 0.027$), quantity of pesticide use ($\beta = 0.607$), WHO-Ia and-Ib ($\beta = 0.420$), and WHO-II ($\beta = 0.270$). Conversely, certain variables demonstrated significant negative effects on farmers' perceived health outcomes, such as education ($\beta = -0.031$), farming experience ($\beta = -0.020$), integrated pest management (IPM) ($\beta = -0.389$), and personal protective equipment ($\beta = -0.224$).

Furthermore, key statistics derived from the analysis are also reported. These include the log-likelihood statistics (−501), *Pseudo* R^2 (0.064), and $LR\ \chi^2$ (69.59), serving as indicators of the goodness of fit of the NB regression model. Notably, the maximum value of VIF was observed for the coefficient of WHO-III, calculated at 1.47, while the mean VIF across all variables considered in the analysis stood at 1.17. Additionally, Table 6 presents determinants of short-term health effects of farmers using alternative econometric models other than the NB regression model, which serve to complement the latter.

3.3. Willingness to pay for insurance for medical care among pesticide-exposed farmers

Farmers' willingness to pay for health insurance premiums for medical care is illustrated in Fig. 2. The analysis reveals that approximately 27 % of respondents, totaling 82 farmers, expressed their willingness to pay, while the remaining 73 % declined, citing various reasons, despite frequently encountering pesticide risks during their routine crop management operations. Among the 27 % who agreed to pay, a nuanced breakdown emerged: 17.07 % were inclined to contribute less than US$7, roughly 26 % were open to paying between US$8 and US$11, while another 17.07 % expressed a willingness to

Table 5
Determinants of farmers' perceived health effects using the negative binomial regression model.

Variable	Coefficient	*z*-score	VIF
Farmer age	0.013**	2.43	1.04
Education	−0.031**	−2.13	1.10
Monthly income	−0.034	−0.12	1.04
Farming experience	−0.020**	−2.12	1.05
Farm size	0.027**	2.31	1.04
Media influence	−0.118	−0.99	1.05
Integrated pest management (IPM)	−0.389**	−2.17	1.33
Read label	−0.172	−1.30	1.14
Access to extension services	−0.090	−0.60	1.40
Access to healthcare services	−0.047	−0.34	1.16
Personal protective equipment	−0.224**	−3.25	1.11
Quantity of pesticide use	0.607**	3.13	1.03
WHO Class IA and IB	0.420**	2.80	1.40
WHO Class II	0.277**	2.16	1.19
WHO Class III	0.157	1.12	1.47
Constant	−0.497	−0.63	–
$LR\ \chi^2$	69.59***	–	–
Pseudo R^2	0.064	–	–
Log-likelihood	−501	–	–

The values of monthly income were considered in the log form.
$^*p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

Table 6
Determinants of short-term health effects of farmers using alternative econometric models.

Variable	Poisson Regression model		ZIP Regression model		ZINB Regression model	
	Coefficient	Z-score	Coefficient	Z-score	Coefficient	Z-score
Farmer age	0.013**	3.00	0.006	1.25	0.006	1.21
Education	−0.028**	−2.37	−0.024*	−1.76	−0.024*	−1.71
Monthly income	−0.020	−0.09	−0.327	−1.18	−0.319	−1.12
Farming experience	−0.021**	−2.56	−0.009	−1.00	−0.009	−0.91
Farm size	0.027**	3.03	0.044***	4.27	0.043***	3.77
Media influence	−0.138	−1.45	−0.067	−0.64	−0.066	−0.61
Integrated pest management (IPM)	−0.381	−2.71	−0.420	−2.34	−0.439	−2.01
Read label	−0.178*	−1.70	−0.215*	−1.86	−0.218*	−1.84
Access to extension services	−0.116	−0.98	0.160	1.18	0.166	1.17
Access to healthcare services	−0.048	−0.44	0.207	1.68	0.209	1.65
Personal protective equipment	0.226***	−3.84	0.080	1.09	0.076	1.01
Quantity of pesticide use	0.062***	4.00	0.061***	3.36	0.059**	3.03
WHO Class IA-and-IB	0.408***	3.60	0.497***	3.37	0.507**	3.05
WHO Class II	0.271**	2.62	0.301**	2.44	0.295**	2.21
WHO Class III	0.152	1.39	0.009	0.07	0.002	0.02
Constant	−0.514	−0.84	0.244	0.36	0.225	0.32
LR χ^2	124***	–	69.43***		54.70***	–
Pseudo R^2	0.107	–	–		–	–
Log likelihood	−512	–	−475		−475	–

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

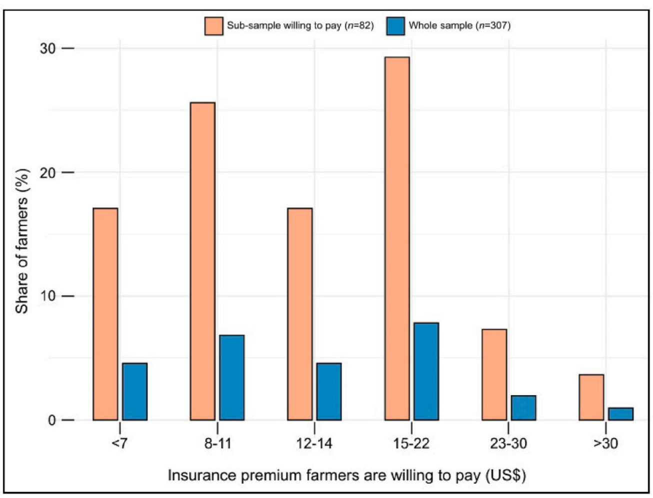

Fig. 2. Farmers' willingness to pay for health insurance.

contribute between US$12 and US$14. Furthermore, approximately 29 % were prepared to pay between US$15 and US$22, 7.31 % showed interest in contributing between US$23 and US$30, and a smaller percentage (3.65 %) indicated a willingness to pay more than US$30. However, it is noteworthy that the mean willingness to pay for medical care among farmers was estimated at a relatively low US$4.03 per individual per annum.

The logistic regression model employed to discern the factors influencing farmers' demand and willingness to pay for health insurance provides robust statistical insights (Table 7). Key metrics such as log-likelihood (−125), *Pseudo* R^2 (0.295), and *LR* χ^2 (105) offer important indications of model fit and explanatory power. Moreover, the assessment of multicollinearity using Variance Inflation Factor (VIF) reveals pertinent findings, with the highest VIF observed for access to institutional credit (1.67) and a mean VIF of 1.18 across all coefficients. The model estimates detailed in Table 6 shows that out of the eighteen variables examined, eleven exhibit noteworthy impacts on farmers' WTP for medical care coverage. Particularly distinctive are the findings related to religious predeterminism and distrust in government, which emerge as key factors significantly decreasing farmers' WTP.

Specifically, religious predeterminism ($\beta = -0.927$) and distrust in government ($\beta = -1.748$) wield substantial adverse effects on farmers' propensity to invest in health insurance coverage. This underscores the profound sway of cultural and political factors in shaping farmers' perceptions and behaviors concerning health-related risk management. On the flip side, positive influences are discerned from factors such as education level ($\beta = 0.095$), household income ($\beta = 1.942$), farm size ($\beta = 0.153$), awareness of health insurance ($\beta = 1.010$), and access to institutional credit ($\beta = 1.785$). Additionally, variables reflecting health-related concerns, including health effects ($\beta = 0.207$) and health costs ($\beta = 0.068$), significantly bolster WTP at a 5 % significance level, highlighting the complex interplay of factors shaping farmers' decisions to purchase health insurance.

Table 7
Determinants of farmers' willingness to pay (WTP) for health insurance premiums for medical care employing the logistic regression model.

Variable	Coefficient	z-score	VIF
Farmer age	−0.020	−1.28	1.07
Education	0.095**	2.49	1.09
Marital status	0.196	0.51	1.05
Children	−0.235**	−2.62	1.10
Family size	−0.027	−0.51	1.06
Earners	0.646**	3.02	1.05
Monthly income	1.942**	2.24	1.04
Farm size	0.153***	4.15	1.12
Religious predetermination	−0.927**	−2.46	1.05
Distrust in government	−1.748***	−3.40	1.52
Awareness of health insurance	1.010**	2.38	1.40
Access to institutional credit	1.785***	3.76	1.67
Access to extension services	0.051	0.14	1.10
Integrated pest management (IPM)	0.701	1.56	1.21
Distance from the healthcare services	0.104	0.29	1.08
Distance from the market	−0.207	−0.60	1.10
Health effects	0.207**	2.06	1.33
Health cost	0.068**	2.47	1.20
Constant	−6.28	−2.65	–
LR χ^2	105***	–	–
Pseudo R^2	0.295	–	–
Log-likelihood	−125	–	–

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

4. Discussion

Since the introduction of a new agricultural policy and the granting of legal rights to the private sector for pesticide sales in 1980, the farming community in Pakistan has become heavily reliant on synthetic pesticides. Simultaneously [1], noted a disregard for alternative methods of insect or pest control. Several factors contribute to the widespread use of pesticides in Pakistan. Firstly, farmers' expectations regarding future crop yields and pest control play a significant role. Secondly, sales promotion targets and financial incentives for field officers of pesticide companies encourage farmers to use these chemicals. Consequently, pesticide promotion strategies over the past two decades have resulted in the indiscriminate use of pesticides and the neglect of alternative pest control methods in Pakistan. Conversely, farmers appear unconcerned about the potential health and ecological risks posed by these hazardous chemicals [18]. As long as farmers perceive pesticides as essential for pest control and achieving higher yields, they will continue to use toxic chemicals despite their adverse effects on health and the environment.

The estimated results of the NB regression model indicate several noteworthy relationships. Firstly, the coefficient of farmer age is positively significant at a 5 % level (Table 5), implying that with each additional year in age, the probability of experiencing health effects increases by 0.013 %. Additionally, farmers' education, serving as a proxy for their management abilities, exhibits a significant negative relationship in our analysis. Similarly, the coefficient of farming experience is significant at a 5 % level, aligning with findings by Ref. [1], suggesting that increased farming experience may mitigate health risks associated with pesticide exposure. Experienced farmers are likely to adopt better preventive measures, reducing their exposure to pesticides and subsequent health risks. Furthermore, participation in Integrated Pest Management (IPM) training programs is associated with a negative and significant coefficient, indicating a reduction in the frequency of health effects related to pesticide poisoning. This underscores the importance of farmer training programs in equipping individuals with advanced knowledge, as noted by Refs. [47,49]. Effective training should cover detailed information on pesticide health effects, proper Personal Protective Equipment (PPE) usage, and safe handling practices. Consistent with expectations, the variable representing the use of PPE exhibits a positive and significant coefficient. This suggests that adopting protective measures, such as wearing masks, goggles, gloves, and other gear while handling pesticides, can significantly mitigate the health effects of pesticide exposure. These findings corroborate with previous research by Refs. [50,51].

The coefficient analysis reveals several significant associations regarding pesticide usage and health effects among the studied farmers. Firstly, the coefficient of pesticide quantity exhibits a significant negative effect on farmers' health status, indicating that the likelihood of experiencing health effects increases with higher pesticide quantities. This finding is consistent with previous research by Refs. [1,34,37]. Moreover, the coefficients associated with pesticide toxicity classes, specifically WHO categories IA, IB, and II, are significantly positive at a 5 % level of significance. This suggests that increased usage of highly toxic chemicals, classified under these categories, is linked to a rise in the occurrence of adverse health effects by 0.42 % and 0.27 %, respectively. The prevalence of these highly toxic pesticides among farmers is concerning and warrants immediate attention from policymakers and state pesticide management agencies, given their potential serious health implications. However, no significant relationship was observed between health effects and farmers' use of WHO-III pesticide categories.

Our logistic regression model estimates revealed several significant predictors for farmers' willingness to pay (WTP) for health insurance premiums (Table 7). Firstly, farmers' education level exhibited a positive association with WTP, suggesting that more educated farmers are more inclined to invest in health insurance, recognizing the health risks associated with pesticide use. This finding aligns with previous research [1,46] and is further supported by studies on Tunisian and Sicilian farmers, which demonstrated that education positively influences the adoption of sustainable pest management and risk-mitigation strategies [32,33].

Similarly, the number of earners and monthly income showed a positive correlation with WTP, indicating that higher-income farmers are more willing to pay for health insurance. This result is consistent with previous studies emphasizing the role of income in determining WTP [52,53]. Farm size also emerged as a significant factor, likely due to increased pesticide exposure risks associated with larger cultivation areas, as noted by Ref. [1]. Conversely, religious beliefs and trust in government exhibited significant negative relationships with WTP, reinforcing the role of socio-cultural factors in shaping insurance adoption decisions.

Furthermore, awareness of health insurance premiums positively influenced WTP, underscoring the need for farmer education on the benefits of health insurance, as highlighted by Ref. [54]. Access to institutional credit was also a key determinant, indicating that credit facilities can enhance farmers' financial flexibility and willingness to invest in risk-mitigation mechanisms, a pattern observed in prior research [31]. Lastly, perceived health effects and health costs significantly impacted WTP, reflecting farmers' recognition of insurance coverage as a safeguard against pesticide-related health risks.

Despite the belief in predeterminism, farmers in Pakistan may still be motivated to apply pesticides indiscriminately due to religious and cultural factors. Islamic teachings permit the killing of harmful pests that threaten crops, with scholars such as *Imam Qurtubi* and *Ibn Rajab* justifying pest control based on its economic necessity and role in preventing crop damage [55]. However, religious restrictions on conventional insurance—linked to its association with uncertainty (*Al-Gharar*), interest-based transactions, and gambling-like structures—create barriers to insurance adoption [56,57]. In contrast, Islamic insurance (*Takaful*), which operates on the principle of *Tabarru* (mutual donation), offers an alternative aligned with Sharia principles. The cooperative nature of *Takaful*, where policyholders act as participants rather than insured individuals, could provide a culturally acceptable model for expanding health insurance coverage among farmers.

By integrating sociopsychological factors such as attitudes, social norms, and perceived behavioral control, as highlighted in studies on Tunisian and Sicilian farmers [32,33], future policy interventions can better address the behavioral barriers to health insurance adoption. Strengthening awareness campaigns and institutional trust, alongside offering *Sharia*-compliant insurance options, may enhance participation in health insurance schemes, ensuring better health protection for farming communities.

This study has several limitations that should be addressed in future research. Firstly, we only examined the short-term health effects of pesticide exposure among farmers, neglecting potential long-term health implications and associated costs. Moreover, reliance on farmers' recall for sickness status and health costs data may introduce information bias. Additionally, the short-term health effects analyzed may overlap with symptoms of common diseases or seasonal factors, warranting caution in interpreting the results.

5. Conclusion and policy recommendations

This study examined the health effects of pesticides and farmers' willingness to pay (WTP) for health insurance premiums to mitigate associated health risks utilizing data collected from 307 vegetable growers in Punjab, Pakistan, in 2023. Our empirical analysis showed significant associations between different factors and farmers' health outcomes. The negative binomial regression model illuminated the impact of factors such as farmers' age, education level, use of personal protective equipment (PPE), integrated pest management (IPM) training, quantity, and toxicity level of pesticides on farmers' short-term health. Additionally, our contingent valuation method revealed that only 27 % of farmers were willing to pay a premium for health insurance to address pesticide-related health risks. Results from the logistic regression model underscored the significance of key variables, including farmers' awareness of health insurance premiums, health effects, and health costs, in determining WTP for a health insurance program. Given the escalating demand for vegetables and widespread pesticide use in Pakistan, urgent policy interventions are imperative to mitigate health risks associated with pesticide handling. Encouraging the adoption of PPE and safe pesticide-handling practices among farming communities is paramount. Furthermore, updating farmers' knowledge on risk reduction strategies is crucial. Government initiatives, such as subsidized health insurance schemes, can significantly contribute to promoting clean and sustainable vegetable production practices. Importantly, this research sheds light on the influence of socio-cultural factors, such as religious predeterminism, on the purchase of health insurance. It underscores the necessity of identifying societies prone to pesticide exposure and tailoring insurance policy designs to align with religious norms. Governments must work to increase public trust in healthcare systems and enhance organizational capabilities to deliver healthcare services and products, including subsidized insurance schemes that align with community belief systems. Our findings provide important insights for policymakers and private insurance agencies aiming to introduce health insurance schemes in rural areas, thereby bolstering access to healthcare and fostering sustainable crop production in Pakistan and similar country and socio-cultural contexts.

CRediT authorship contribution statement

Muhammad Arshad: Writing – review & editing, Writing – original draft, Validation, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Yasir Mehmood:** Visualization, Software, Formal analysis, Data curation. **Sreejith Aravindakshan:** Writing – review & editing, Visualization, Validation, Funding acquisition. **Ayat Ullah:** Writing – review & editing, Validation. **Stefan Sieber:** Writing – review & editing, Validation. **Timothy Joseph Krupnik:** Writing – review & editing, Validation.

Availability of supporting data

The datasets used in this study are readily available from the corresponding author upon request.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Muhammad Arshad reports financial support was provided by Alexander von Humboldt Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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