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Article

Determinants of Pesticide Safety Adherence among Tomato Farmers in Kenya: Individual and Structural Factors for Sustainable Agriculture

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ABSTRACT

Background: Hazardous pesticide practices among tomato farmers in Kirinyaga County, Kenya, pose significant risks to public health, environmental sustainability, and food safety. This study investigated whether these unsafe practices stem from farmers' ignorance to pesticide safety or systemic barriers. The study assessed the influence of knowledge and awareness, culture and social norms, cost and accessibility, regulatory control and demographic factors on safety adherence among tomato farmers in Kenya using the Health Belief Model as a framework for the study.

Methods: The study was conducted within four regions in Kirinyaga County, Kenya. Data was collected from 384 tomato farmers using structured questionnaires which was organized in a Likert scale. Analysis was done using descriptive and inferential statistics using IBM SPSS Statistics, Version 30.0 (IBM Corp., Armonk, NY, USA) and R software, Version 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results: The findings identify farmers as key actors in implementing safety measures. However, structural barriers, including the high cost of personal protective equipment, weak regulatory enforcement, and limited safety training opportunities, significantly hinder compliance. Older farmers exhibited lower compliance rates, while those with higher education and awareness demonstrated better adherence to safety practices.

Conclusions: Enhancing farmers' safety compliance requires empowering farmers through targeted education and addressing structural barriers by subsidizing PPE, enforcing stringent regulatory frameworks, and introducing culturally relevant safety interventions. These findings offer actionable recommendations for improving agricultural safety in Kenya and provide a roadmap for addressing similar challenges in other regions.

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KEYWORDS: pesticide safety practices; tomato farming; health belief model; adherence to safety; personal protective equipment; sustainable agriculture

ABBREVIATIONS

GDP, gross domestic product; HHP, highly hazardous products; HBM, health belief model; PPE, personal protective equipment; FIFRA, Federal Insecticide, Fungicide, and Rodenticide Act; APVMA, Australian Pesticides and Veterinary Medicines Authority; PCPB, Pest Control and Products Board

INTRODUCTION

Kenya's agricultural sector plays a major role in the economy, with 21% of GDP directly derived from agriculture and another 27% indirectly linked to the sector [1]. The industry employs over 40% of the national workforce, with more than 70% of these employment opportunities based in rural areas [1]. As a result, agriculture is central to food security, nutrition, and livelihoods in Kenya. However, despite its economic significance, the sector faces several ongoing challenges related to pesticide safety, safe environment and sustainability of food productivity in the long run.

Globally, approximately 40% of food crops are lost annually due to pests and diseases affecting them which poses a huge risk in world food security, productivity and nutrition [1]. To mitigate these risks majority of farmers, rely heavily on pesticide use to safeguard their crops against pests, diseases or weeds in a bid to enhance more yields and economic stability [2]. Many countries have recognized the relevance of pesticide safety and risk mitigation and have reacted by enacting and imposing laws and regulatory frameworks targeted to ensure their safe use. For example, Regulation (EC) No 1107/2009 in the European Union [3], FIFRA in the United States [4], and APVMA regulations in Australia [5] have been mandated to approve the pesticides which have the least effects on human health and the environment. These measures spread all over the world have significantly improved pesticide safety adherence.

However, Kenya offers a distinct and underexplored case in this regard. Despite the presence of regulatory frameworks through PCPB [6], widespread concerns surrounding weak enforcement, inadequate training of farmers, and accessibility of safe pesticides have emerged. For instance, it has been reported that nearly banned, pesticides sold and used by farmers in Kenya fall under the Highly Hazardous Product category, where almost 50% of these pesticides have been banned for example in the European Union due to their detrimental effects on human health and the environment [7]. Most pesticide users in Kenya are smallholder farmers, who often lack access to protective equipment, alternative pest management solutions, and regulatory guidance [8]. As a result, many farmers knowingly or unknowingly engage in unsafe pesticide practices, leading to acute and chronic health issues, environmental pollution, and loss of biodiversity.

Beyond individual health concerns, the long-term sustainability of Kenyan agricultural sector falls at serious risk from overuse and mismanagement of pesticides [7]. Sustainable agriculture has emphasized the need for responsibility in the use of chemically produced inputs, integrated pest management and organic farming as initiatives to provide green alternatives in agriculture to increase productivity while maintaining a safe environment [9–11]. In addition, addressing the safety of pesticides has been deemed critical to achieving sustainable development goals including Zero hunger, Good Health and Well-being and Climate Action SDGS [12–16]. Ensuring safe pesticides not only protects the health and safety of farmers but also has the potential to ensure environmental protection and promote climate-resilient agricultural practices [17]. Understanding reasons for farmers failure to adhere to pesticide safety practices and procedures is therefore essential in designing interventions aimed at ensuring health and safety of farmers and conservation of the environment.

Kirinyaga County is one of Kenya's leading tomato-producing regions and was therefore selected for this study. The region has reported a yearly production of over 60,000 tons of tomatoes with a revenue of 1.6 billion shillings [18], making it reflect the economic capacity, and the challenges associated with use of pesticides in tomato farming. Reports have indicated that adherence to pesticide safety measures remains low, with only one in six farmers using personal protective equipment when handling pesticides [7]. Additionally, small-scale farming, poor regulatory enforcement, and heavy reliance on pesticide-intensive crops further worsen risks associated with pesticide exposure. Studying Kirinyaga's unique context provides a valuable opportunity to understand pesticide safety behaviors and identify scalable interventions that can be applied to similar agricultural regions.

This study investigates whether non-adherence to pesticide safety measures among tomato farmers in Kirinyaga County is due ignorance or the absence of adequate support systems. Specifically, it examines how knowledge and awareness, cultural and social norms, financial constraints, and regulatory control influence tomato farmers' ability to adhere to safe pesticide practices. The study was therefore guided by the following hypotheses:

H1. *Knowledge and awareness do not significantly influence the adherence to pesticide safety measures among tomato farmers*.
H2. *Culture and social norms have no significant influence on adherence to pesticide safety among tomato farmers*.
H3. *Cost and accessibility are not major factors that influence adherence due to safety among tomato farmers*.

H4. *Regulatory control does not significantly influence pesticide safety adherence among tomato farmers*.

This study intends to identify actionable pathways that should be taken by the policymakers and stakeholders in informing decisions in line with the promotion of health and safety for tomato farmers in Kenya.

Theoretical Framework: The Health Belief Model and Relevant Literature

To analyze farmers' pesticide safety behaviors, this study was guided by Health Belief Model (HBM) [19,20]. This model helps explain people's behavior by measuring their motivations to the behavior, perceived risks and barriers to their behaviors and hence it was deemed appropriate for this study. While there exist alternative frameworks, such as the Theory of Planned Behavior [21], which equally provides information that could explain behavior, HBM emphasis on individual risk perceptions and motivations made it more applicable in understanding farmers pesticide safety adherence.

The major constructs in this model include perceived susceptibility, perceived severity, perceived benefits, perceived barriers, cues to action, and self-efficacy [22–24]. In pesticide safety, these constructs provided important information on the factors that could influence tomato farmers pesticide safety adherence.

Table 1 presents how each of the four hypotheses in this study was operationalized through specific HBM constructs that informed the key variables that were used to assess the factors leading to adherence to pesticide safety among tomato farmers in Kirinyaga County, Kenya.

Table 1. Operationalization of research hypothesis through HBM constructs.

Hypothesis	Relevant HBM Constructs
H1	Perceived Susceptibility, Perceived Severity, Cues to Action
H2	Cues to Action, Self-Efficacy
H3	Perceived Benefits, Perceived Barriers
H4	Perceived Barriers, Cues to Action, Self-Efficacy

Knowledge and Awareness: Perceived Susceptibility and Perceived Severity (H1)

Perceived susceptibility and perceived severity within the Health Belief Model play a critical role in understanding individual behavior based on individual perception of risk and their potential hazards [24]. Perceived susceptibility explains a person's belief on how likely they can experience harm from engaging in an activity, while perceived severity explains an individual's perception on the seriousness, they attach towards the consequences of the harm [24]. HBM tries to explain that individuals are likely to take up safety cautions and adhere to safety guidelines if they identify and perceive that an action may cause them serious harm.

Research conducted by Suphim & Songthap [25], in Northern Thailand concluded that pesticide safety adherence was highly determined by farmers safety vulnerability, self-efficacy and the social support of farmers. These findings revealed that farmers who perceived pesticide to be harmful to their health were more likely to adhere to safety procedures compared to those who didn't perceive pesticide as harmful. Similar results were identified by Anbazhagan et al. [26] who performed research in India and revealed that 68% of farmers did not perceive the harm caused by pesticide use despite 94.5% of them having experienced related health issues. Similarly, in Nigeria, research by Ogbomida et al. [27] showed that farmers possessed moderate understanding of the health risks associated with pesticide use, there existed critical knowledge gaps which hindered the farmers from complying with the set safety measures.

In Kenya, a report published by Route to Food Initiative highlighted a critical gap in farmers knowledge on the pesticide residual risks on their health, food and the environment [28]. Bollmohr [7] similarly reported that majority of farmers in the Country lacked adequate knowledge of the health risks associated with pesticide use and on the availability of organic pest control products that would be used as an alternative to pesticides. As reported by Pest Control Products Board [29] for crop production, there is a total of 3069 registered chemical pesticides and 156 biopesticides available for farmers in the Country. This highlights the critical gap in farmers awareness and accessibility of safer pest control products that would improve their safety in agriculture.

Cost and Accessibility: Perceived Benefits and Perceived Barriers (H2)

According to HBM, many people consider their perception of the benefits or barriers of an action to determine their behavior [24]. Research has shown that farmers tend to evaluate the advantages of using personal protective equipment such as gloves, masks or goggles while handling pesticides and other farm chemicals against potential barriers such as the cost of the PPE, accessibility or other internal or external factors. For example, in research conducted by Sapbamrer & Thammachai [30] the findings showed that the high cost of gloves and masks prevented farmers from buying the PPE even though they had experienced chronic health issues from the use of pesticides.

Similarly, in Iran, a study investigating the farmers health risks highlighted that the high cost of PPE prevented farmers from adopting safety measures [31]. Additionally, in Sub-Saharan Africa, although most farmers understood the need and usefulness of using PPE, availability, accessibility and affordability of the safety gears remained a critical issue with many farmers citing inadequate funds as a major barrier to adoption of the safety measures in farming [32,33]. These findings show how systemic challenges, like lack of resources and financial struggles, make it harder for farmers to stay safe, leaving them exposed to serious risks.

Culture and Social Norms: Cues to Action and Self-Efficacy (H3)

Cues to action are external factors that would prompt and influence an individual to adopt specific behaviors [22]. In farming, some factors that would influence an individual to adhere to pesticide safety rules may include influence from culture and social beliefs, advice from peers and legal sources, or campaigns to inform farmers about the risks associated with pesticide use. However, this influence depending on the source, may impact positively or negatively on farmers perception. Research has shown that influence from contradicting beliefs about safety in the community that contradicts government directives or formal information has the potential to negatively impact farmers therefore hindering adoption of safety measures [34]. In China, for example, Jackson et al., found that due to culture and norms, only 35% of farmers complied with the set modern safety rules while most farmers stuck with the traditional measures and techniques [35].

This was also observed in India where research by Mahyuni et al. [36] showed that 60% of farmers had failed to comply with modern safety practices due to societal stigma related to the use of personal protective equipment which made them feel embarrassed on the society. Similar findings were observed in Morocco where Zineb et al. [37] concluded that informal networks that guided the usage of pesticide were highly influential among farmers. Additionally, in Thailand, it was observed that peer influence greatly contributed to adoption of farming safety practices. These findings collectively show the impact of culture and societal norms in shaping farmers safety behavior.

In Kenya, a report by Kenya Organic Agriculture Network and Eco-trac Consulting showed that farmers overreliance on peer advice and influence from pesticide suppliers conflicted with the guidelines set aside by the government regarding pesticide safety use resulting with low safety adherence and confusion among farmers [38]. Similarly, in Kenya’s Mwea Irrigation Scheme, a key producer of rice in the Country, such peer-led initiatives proved to be highly effective and efficient in improving and motivating farmers to adhere to the safety precautions [39]. This highlighted the power of societal influence and community initiatives as drivers to positive change involving the use of safety gear in agriculture.

On the other hand, farmers belief in their own ability to execute certain tasks and behaviors (self-efficacy), plays a significant role in their safety compliance [22]. This could come from internal and external factors that improve farmers capability and confidence. Research has shown that training heavily focused on improving self-efficacy encourages safety adherence. Addressing barriers that could discourage farmers confidence such as cultural barriers could lead to improved compliance. McKim and Velez [40], proposed that to boost farmers confidence in their ability to adopt safety measures, there need to be targeted interventions and support programs customized to address such needs to build trust.

Regulatory Control: Perceived Barriers, Cues to Action, and Self-Efficacy (H4)

The role of the government in ensuring adherence to safe use of pesticides has been carefully evaluated in several studies. For example, Gong et al. [41] found out that the presence of effective regulations increased safety compliance by 25%. Similarly, in Nepal, Kharel et al. [42] found that presence of regulatory control was influential in maintaining good agricultural practices by ensuring a smooth certification process and setting safety standards. In contrast, farmers may possess the knowledge, capabilities and willingness to adopt safer methods but without implementation of strong regulations, this confidence may not always translate into adoption of safety procedures.

This issue is particularly evident in Kenya, where weak regulatory frameworks and insufficient enforcement have made pesticide-related problems worse. Bunei et al. [43] highlighted how the use of counterfeit pesticides, combined with weak regulatory systems, has undermined compliance and created serious health and environmental risks. Similarly, the Centre for Environment Justice and Development pointed out the prevalence of fake pesticides in Kenya and across other African nations, further eroding public trust in regulatory systems [44]. These challenges emphasize the pressing need to strengthen regulatory frameworks and enforcement to ensure the safe use of pesticides.

Research Gap and Study Rationale

One of the main concerns of sustainable agriculture projects is the protection and maintenance of farmers' health and safety, particularly in pesticide-intensive agricultural operations. The health risks that farmers face from pesticide exposure have been extensively studied and published, but comparatively few studies have examined the factors that affect farmers' adherence to pesticide safety regulations. Few studies examine why these practices continue despite the increased understanding of the health concerns connected with pesticide usage. Previous research has emphasized improper handling of pesticides, an excessive dependence on pesticides, or noncompliance with safety regulations. Additionally, although earlier research has looked at the consequences of pesticide exposure, they frequently ignore the ways in which system barriers and demographic variables like gender, age, education, and farming experience interact to affect pesticide safety adherence.

Beyond immediate health concerns, unsafe pesticide practices undermine sustainable agriculture by depleting soil health, reducing biodiversity, and contaminating water sources. However, research that explicitly connects pesticide safety behavior to sustainable farming practices remains limited, particularly among smallholder farmers in Kenya. With 75% of pesticides sold in Kenya classified as Highly Hazardous Pesticides and weak enforcement of pesticide regulations, there is an urgent need to understand the barriers to safe pesticide use and develop interventions that promote both farmer well-being and environmental sustainability. Addressing this research gap is essential to ensuring not only the long-term viability of Kenya's agricultural sector but also its alignment with global sustainability and climate action goals.

This study focuses on tomato farmers in Kirinyaga County, a region where pesticide-intensive farming is prevalent and concerns over health, safety, and environmental impact are pronounced. Given that Kenya's agricultural economy heavily relies on pesticide use, the Health Belief Model (HBM) provides a valuable framework for understanding how farmers' risk perceptions, motivations, and structural challenges influence pesticide safety behaviors.

MATERIALS AND METHODS

Kirinyaga County located in the Mount Kenya region covers an approximate size of 1478.1 square kilometers where 54% of this land is dedicated to agriculture [45]. This study investigated tomato farmers in Kirinyaga County, specifically in the areas of Mwea, Kutus, Kagio, and Makutano. Kirinyaga County was purposively selected because it is Kenya's leading tomato-producing region, contributing significantly to the national supply [46]. The farming community in Kirinyaga primarily consists of small-scale farmers engaged in mixed farming systems, where tomato cultivation is one of their primary agricultural activities [47]. Currently, there is no publicly available registry or dataset detailing the number, demographics, or socioeconomic characteristics of tomato farmers within the County. As a result, while the selected sample was a representative of Kirinyaga County, which is a key tomato producing region, caution should be exercised in generalization of the findings to other tomato producing regions where focus should be placed on the distinct differences in farming practices, demographics and specific factors that may affect adherence to pesticide safety practices. Nevertheless, Kirinyaga County's unique characteristics may reflect those of similar regions thus the study offers valuable insights that are likely to reflect broader trends in similar small-scale tomato farming regions.

Since comprehensive farmer registry was not available, the study employed purposive sampling method to select participants who could offer detailed and relevant insights [48]. Participants were identified through collaboration with agricultural extension officers, local farming cooperatives, and community leaders. Referrals from other farmers were also used to guarantee a wider reach, which assisted in including those who were actively involved in tomato farming but were not officially linked with cooperatives. Although there was a chance of bias when depending on referrals, this was carefully considered by cross-referencing participant data from other sources. This strategy decreased the possibility of a limited or homogeneous representation by guaranteeing a more inclusive and varied sample.

A sample size of 384 farmers was determined using Cochran's formula [49,50] ensuring adequate representation of the population for the study.

The formula is as follows: $n = \{Z^2 \cdot p \cdot (1 - p)\} / (e^2) = 384.16$

The formula included the Z-score (1.96), representing a 95% confidence level, p, the estimated proportion (0.5, assuming maximum variability), and e, the margin of error, to ensure accurate and reliable sampling.

96 respondents were chosen from each of the four regions, ensuring that the sample was evenly spread throughout them. This strategy was selected to preserve logistical equilibrium and guarantee equitable representation of farmers from around the County. Since these regions operate under the same administrative framework and share similar agricultural practices, the uniform allocation was deemed an appropriate method to capture the overall agricultural landscape of Kirinyaga County. Although equal distribution guarantees logistical practicality and proportional representation, subsequent research could integrate stratified sampling to address any regional disparities in agricultural practices.

Data was collected from August to November 2024 by self-administered questionnaires created in plain English and translated as needed. The questionnaire aimed to assess farmers' compliance with pesticide safety protocols and the primary factors affecting their conduct. The questionnaire was developed into a five-point Likert Scale which is effective in measuring participants opinions and attitudes [51]. The Likert Scale ranged from strongly agree, agree, neutral, disagree and strongly disagree and was coded from 5 to 1 where 5 represented strongly agree, 4 agree, 3 neutral, 2 disagree and 1 represented strongly disagree. The data was then analyzed through descriptive and inferential statistics using IBM SPSS Statistics, Version 30.0 (IBM Corp., Armonk, NY, USA) and R software, Version 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria).

The selected independent variables included: Awareness and Knowledge, Culture and Social Norms, Cost and Accessibility and Regulatory Control. Safety Adherence was our dependent variable. Demographic factors such as age, gender, education, and years of experience were included as control variables [52] to ensure the observed relationships between the independent variables and safety adherence were not confounded by these characteristics. Figure 1 shows the conceptual framework applied in the study.

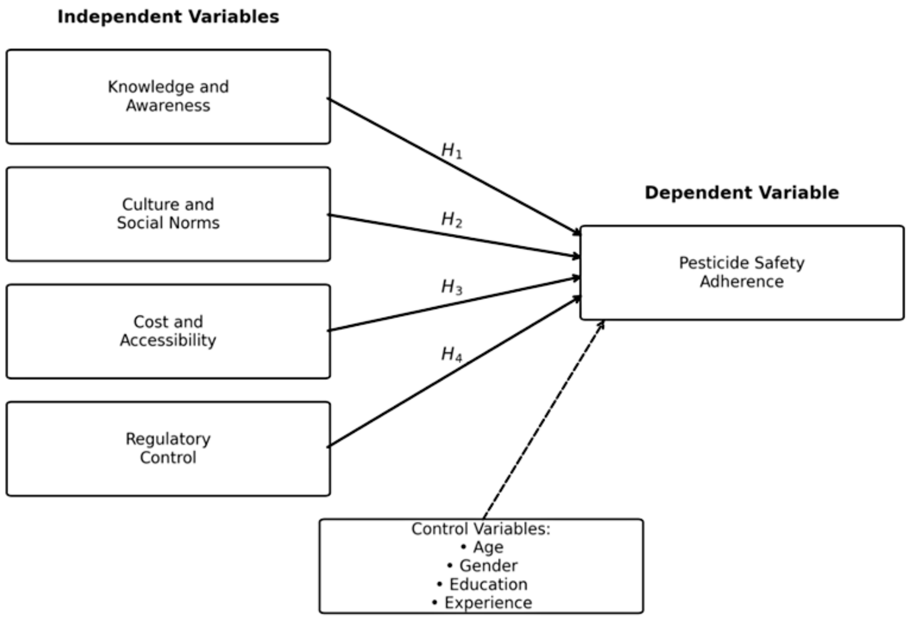

Figure 1. Conceptual Framework.

To ensure reliability and validity [53] the questionnaire was pretested with 20 tomato farmers from Embu County, a nearby region with similar agricultural practices to Kirinyaga. The pretest simulated study conditions to assess clarity, cultural relevance, and appropriateness of the questionnaire items. Farmers provided feedback on technical terminology, question phrasing, and Likert scale design. Adjustments included simplifying technical terms, refining translations, and rewording Likert scale labels. For example, farmers suggested that instead of using agrochemicals, we should simplify the term to farm chemicals. We employed Cronbach's alpha [54] to assess reliability by evaluating the consistency of the questionnaire items in measuring the same construct. The results showed the questions were clear and suitable for the farmers in the study.

Cronbach's Alpha was calculated using R statistical software to ensure accurate assessment of internal consistency across constructs. The results validated the reliability of the questionnaire as shown in Table 2.

Table 2. Test for reliability of questionnaire using Cronbach Alpha.

Variable Tested	Cronbach Alpha Value
Knowledge and Awareness	0.82
Culture and Social Norms	0.81
Cost and Accessibility	0.79
Regulatory Control	0.85

The reliability test confirmed that the questionnaire items for all constructs were internally consistent and suitable for the farmers in the study, with Cronbach's Alpha values ranging from 0.79 to 0.85 [54]. The results confirmed that the questionnaire was a reliable tool for exploring the factors influencing farmers' adherence to pesticide safety practices.

Given that the dependent variable, safety adherence, was measured using an ordinal Likert scale, ordinal regression was selected as the most appropriate analytical method [55,56]. This approach was chosen because it accounts for the ordinal nature of the response variable, recognizing that while adherence levels follow a meaningful order, the intervals between them may not be equal [56]. By employing ordinal regression, this study preserved the ordinal structure of the data while providing statistically robust insights into the factors influencing pesticide safety adherence among tomato farmers in Kirinyaga County.

Ethical Consideration

Since this research included human participants, ethical approval was secured from the Kenya National Commission for Science, Technology, and Innovation (NACOSTI) to ensure compliance with the Kenya's research standards. Farmers' consent (see Supplementary Material File S1) was also sought as they were informed about the study objectives, aim, procedures and their rights as participants to the study. Confidentiality of the participants was ensured by excluding all identifiable information from the analysis and using all the information given for academic purposes only.

RESULTS

This section has been formulated to present the findings from both descriptive and inferential statistical analyses. It also outlines the results of model evaluation and assumption checks that were conducted to validate the ordinal regression model, ensuring the reliability and robustness of the conclusions drawn.

Descriptive Statistics

Demographic findings

As indicated in Table 3, the study used percentages and frequencies to determine the participants' demographics.

Table 3. Demographic characteristics of the tomato farmers involved in the study.

Demographics	**Frequency**	**Percentage**
Gender	Male: 242	63%
	Female: 142	37%
Highest Level of Education	Primary School: 231	60%
	High school: 117	31%
	Post High school: 36	9%
Age Gap	<18: 7	2%
	19–35: 73	19%
	36–50: 118	31%
	>50: 186	48%
Years of Experience	0–10: 83	22%
	10–20: 135	35%
	>20: 166	43%

The results revealed that 63% of tomato growers were male while 37% of them were females. Additionally, 60% of farmers had only attained primary school education,31% had a high school diploma while only 9% had a post high school diploma. Under the age gap, 2% of the respondents were below 18 years of age, 19% were between 19–35 years while majority 48% were above 50 years of age. Similarly, 22% of the farmers had up to 10 years of experience, 35% had between 10 to 20 years of experience and most of the respondents 43% had over 20 years of experience. A further analysis on the health issues that farmers reported included: skin irritation (52%), eye irritation (37%), and nausea or vomiting (47%) while 38% of farmers identified they had experienced other related health issues.

Table 4 presents findings on key predictors, including knowledge and awareness, culture and social norms, cost and accessibility, regulatory control, and safety adherence. A median below 3 reflects disagreement or low adherence, while a median above 3 indicates agreement or higher adherence. The median was used instead of the means to account for the ordinal nature of Likert scale data, ensuring a more accurate representation of central tendency without assuming equal spacing between response categories [57].

Table 4. Descriptive findings on Knowledge and Awareness, Cultural and Social Norms, Cost and Accessibility, Regulatory Control and Safety Adherence.

Heading	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Median
Knowledge and Awareness						
I am aware that using farm chemicals in my tomato farm can pose risks for my health.	121	99	51	71	42	4
I am confident in my ability to safely handle farm chemicals on my farm.	40	50	109	105	80	2
I regularly check the labels and safety information on farm chemical products before use.	25	35	55	130	139	2
I am aware of the safety precautions I should take when applying farm chemicals.	31	43	121	93	96	3
I believe that PPE is essential when handling farm chemicals.	29	43	125	78	109	3
Culture and Social Norms						
Seeing my peers use or not use PPE influences my own decision to use it.	41	100	122	71	50	3
My farm chemical seller emphasizes the need for using PPE when applying farm chemicals.	32	49	88	126	89	2
Social gatherings among farmers in my area often include discussions about safety practices and PPE usage.	21	54	89	128	94	2
There are community programs or initiatives that promote safety in farm chemical usage among farmers.	15	41	126	112	89	2
My community leaders advocate for the use of protective equipment in farming.	22	57	136	109	60	3

Table 4. *Cont.*

Heading	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Median
Cost and Accessibility						
I find PPE to be affordable for my farming needs.	18	47	122	128	69	2
PPE is readily available in local markets or stores where I shop for farming supplies.	21	54	129	117	63	2.50
I often consider the cost of PPE before deciding whether to use it while farming.	76	131	105	52	20	4
I am aware of government initiatives that provide subsidized PPE for farmers.	37	58	125	115	49	3
The cost of PPE is a significant barrier for me in adopting safe farming practices.	76	116	130	42	20	3.50
Regulatory Control						
I am aware of the regulations regarding the use of farm chemicals and safety in farming.	15	30	50	130	159	2
My tomato farm is regularly monitored by an agricultural officer to assess safety compliance.	21	29	81	133	120	2
In case of contact with the farm chemicals, there is an office set aside where I can report the risks encountered from the use of the chemicals.	30	40	110	134	70	2
There should be a restriction on the advertisement and promotion of farm chemicals to farmers.	75	87	101	59	62	3
My government should subsidize farmers who adopt practices aimed at reducing over reliance on farm chemical.	95	115	73	53	48	4
I am willing to adopt alternative methods of pest and disease management other than the use of farm chemicals to increase my tomato production.	97	118	71	54	44	4

Table 4. *Cont.*

Heading	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Median
Safety Adherence						
I consistently wear protective equipment when handling farm chemicals on my tomato farm.	27	41	75	130	111	2
I buy farm chemicals together with the protective gear to use in applying the chemical in my tomato farm.	29	47	78	136	94	2
I consistently seek medical attention in case of exposure to the farm chemicals in my tomato farm.	27	41	66	140	110	2
I know the First Aid response to perform in case my fellow farmer or I become exposed to the farm chemicals.	29	37	78	143	97	2
I have medical insurance to safeguard me against all accidents regarding exposure to farm chemicals.	25	37	62	141	119	2
I report any safety incidents related to farm chemical use to the appropriate authorities.	21	37	55	130	141	2

Knowledge and awareness

Farmers showed varying levels of knowledge and awareness regarding pesticide safety. While most farmers acknowledged the health risks associated with farm chemical use (median = 4), their confidence in safely handling these chemicals was lower (median = 2). Checking labels and safety information before use had the lowest median score (median = 2), suggesting a widespread neglect of this important safety practice. Awareness of safety precautions when applying farm chemicals was neutral or mixed (median = 3), meaning farmers were divided on their level of awareness. Similarly, despite neutral to moderate agreement on the importance of PPE (median = 3), adherence to its use remained inconsistent.

Culture and social norms

Cultural and social influences on safety practices varied. Peer behavior had a neutral to moderate influence on farmers' decisions to use PPE (median = 3), indicating a mixed response. However, other cultural and community factors scored lower. For instance, discussions about safety practices and PPE usage at social gatherings were infrequent (median = 2), and community programs promoting agrochemical safety were limited (median = 2). Advocacy by community leaders for the use of protective equipment was somewhat neutral but leaned toward disagreement (median = 3), while farm chemical sellers' emphasis on PPE use was also low (median = 2), suggesting that formal safety encouragement from suppliers was minimal.

Cost and accessibility

Farmers reported significant barriers to accessing PPE due to cost and availability. Many considered the cost of PPE to be a significant barrier (median = 3.5). Affordability was a challenge (median = 2), while availability in local markets or stores was also limited (median = 2.5). Awareness of government initiatives to provide subsidized PPE was neutral to slightly positive (median = 3). Farmers often considered the cost of PPE before deciding whether to use it (median = 4), suggesting that financial constraints heavily influenced safety decisions.

Regulatory control

Findings revealed low awareness of regulatory controls and limited enforcement mechanisms. Awareness of regulations governing farm chemical use was the lowest across all categories (median = 2), indicating widespread lack of knowledge. Monitoring by agricultural officers to assess safety compliance was infrequent (median = 2). Farmers also reported few mechanisms for reporting risks from chemical exposure (median = 2). Despite these challenges, there was moderate support for stricter controls, such as restricting the advertisement of farm chemicals (median = 3) and providing subsidies for safer practices (median = 4). Additionally, farmers expressed a willingness to adopt alternative pest management methods (median = 4), suggesting openness to safer farming practices.

Safety adherence

Adherence to safety practices when handling agrochemicals was inconsistent among farmers. Consistent use of protective equipment was low (median = 2), and purchasing farm chemicals together with protective gear was uncommon (median = 2). Findings revealed the reluctance of farmers to seeking medical help following pesticide exposure (median = 2). Additionally, many farmers lacked knowledge of first aid responses for handling chemical exposure incidents (median = 2). Unfortunately, most farmers did not have medical insurance to protect against pesticide exposure (median = 2). The findings also showed that most farmers did not report pesticide exposure incidents to the relevant authorities (median = 2), highlighting a significant gap in safety reporting and regulatory engagement.

Adherence to safety measures: Patterns and key trends

Farmers' adherence to safety measures varied significantly across different behaviors, with some practices being more consistently followed than others. For example, descriptive analysis of median Likert scores revealed that the highest adherence was observed in farmers considering the cost of PPE before deciding whether to use it (median = 4), supporting subsidies for safer farming practices (median = 4) among others while in contrast, the lowest adherence was observed in consistently wearing PPE when handling farm chemicals (median = 2), purchasing farm chemicals together with protective gear (median = 2), seeking medical attention after exposure (median = 2) among others. This disparity warranted us to conduct a Kruskal-Wallis test [58,59] to examine whether pesticide safety adherence levels differed significantly across various safety behaviors. This was done with SPSS 30.0 software.

Table 5 shows the results of the Krukal-Wallis test.

Table 5. Kruskal-Wallis Test.

Test	**Statistic**	**df**	***p*-Value**
Kruskal-Wallis Test	H 51.561	6	<0.001

The test yielded a statistically significant result, H(6) = 51.561, $p < 0.001$, indicating that adherence to at least one safety behavior differed significantly from the others. Since the test compared adherence across seven key safety behaviors, the result suggests notable variations in how farmers engage in different protective measures.

To further explore the differences in adherence across safety behaviors, a post-hoc Dunn's test with Bonferroni correction [60,61] was conducted through R 4.33 software to identify which specific behaviors significantly differed from each other.

Due to the large number of pairwise comparisons in Dunn's test, only 10 key results are presented in Table 6 for clarity. The selected comparisons include both significant and non-significant findings to illustrate variation in adherence patterns across different safety behaviors.

Table 6. Dunn Test.

Safety Behavior 1	Safety Behavior 2	Mann-Whitney U	*p*-Value	Adjusted *p*-Value (Bonferroni)	Significant (Bonferroni)
Usage of PPE	Cost consideration before buying PPE	768.5	0.00039	0.0176	Yes
Reporting safety incidents	Alternative pest management methods	400.0	4.94×10^{-10}	2.22×10^{-8}	Yes
Reporting safety incidents	Cost consideration before buying PPE	560.0	5.41×10^{-7}	2.43×10^{-5}	Yes
Usage of PPE	Subsidy support for safer practices	714.5	8.56×10^{-5}	0.0039	Yes
Seeking medical attention	Alternative pest management methods	545.0	1.61×10^{-7}	7.25×10^{-6}	Yes
Usage of PPE	Seeking medical attention	1298.5	0.732	1.000	No
Usage of PPE	Reporting safety incidents	1459.5	0.136	1.000	No
Buying farm chemicals with PPE	Seeking medical attention	1330.0	0.571	1.000	No
First Aid Knowledge	Medical Insurance	1260.0	0.946	1.000	No
Seeking medical attention	Subsidy support for safer practices	1357.5	0.446	1.000	No

The test revealed significant differences in adherence when comparing safety adherence behaviors (e.g., PPE use, reporting incidents, seeking medical attention) to systemic factors (e.g., cost considerations, subsidy support, and alternative pest management methods).

For instance, adherence to reporting safety incidents significantly differed from adherence to alternative pest management methods (U = 400.0, $p < 4.94 \times 10^{-10}$, Bonferroni-adjusted $p < 2.22 \times 10^{-8}$), suggesting that engagement in reporting incidents is statistically distinct from adherence to alternative pest management. Similarly, adherence to seeking medical attention was significantly different from adherence to alternative pest management methods (U = 545.0, $p < 1.61 \times 10^{-7}$, Bonferroni-adjusted $p < 7.25 \times 10^{-6}$), indicating differences in prioritization between immediate safety actions and long-term pest control strategies.

Additionally, adherence to usage of PPE differed significantly from cost consideration before buying PPE (U = 768.5, $p = 0.00039$, Bonferroni-adjusted $p = 0.0176$), and adherence to PPE use was also significantly different from subsidy support for safer practices (U = 714.5, $p = 8.56 \times 10^{-5}$, Bonferroni-adjusted $p = 0.0039$). Similarly, adherence to reporting safety incidents was significantly different from cost consideration before buying PPE (U = 560.0, $p = 5.41 \times 10^{-7}$, Bonferroni-adjusted $p = 2.43 \times 10^{-5}$), reinforcing the role of financial concerns in safety reporting.

Conversely, several non-significant findings indicate that some adherence behaviors are followed at similar levels. For example, no significant difference was found between PPE use and seeking medical attention (U = 1298.5, $p = 0.732$, Bonferroni-adjusted $p = 1.000$), suggesting that farmers may prioritize both practices equally. Similarly, first aid knowledge and medical insurance did not significantly differ (U = 1260.0, p = 0.946, Bonferroni-adjusted p = 1.000), indicating that awareness of emergency responses and financial protection measures were followed at comparable levels.

Inferential Statistics

Model evaluation

Important model evaluation criteria were looked at to guarantee the ordinal regression model's validity: multicollinearity, test for parallel lines assumption, goodness of fit model, spearman's correlation, ordinal regression and pseudo r tests.

Multicollinearity test

Multicollinearity occurs when independent variables highly relate to each other; hence, it could lower the models reliability [62]. In testing predictor multicollinearity, Variance Inflation Factors (VIF) was applied as depicted in Table 7.

Table 7. Multicollinearity analysis.

Variable	GVIF	DF	GVIF^(1/(2 × Df))
knowledge_and_awareness	1.10	1	1.05
culture_and_norms	1.25	1	1.12
cost_and_accessibility	1.89	1	1.37
regulatory_control	1.34	1	1.16

In this analysis, the Generalized Variance Inflation Factor (GVIF) was calculated for each independent variable. The adjusted GVIF values for all variables were below 5 which indicated that multicollinearity was not a concern [62]. This implied that each predictor variable had a unique contribution to the regression model which added to the reliability of the model. Moreover, low multicollinearity indicated that the standard errors were stable, thus making the results interpretable and robust. Therefore, this model was deemed appropriate for further analysis and sustained valid inferences about the relationships between the predictor variables with safety adherence.

Test for parallel lines assumption

This assumption argues that the relationship between every independent variable and the dependent ordinal outcome is similar across all levels of the dependent variable [63]. The test compares the proportional odds model (which assumes parallel regression lines) with a general model (which estimates separate effects for each category of the outcome). If the difference is statistically significant ($p < 0.05$), the assumption is violated, meaning the relationship varies across categories. If $p > 0.05$, the assumption holds, meaning the model is appropriate [63].

Table 8 shows the results of the test for parallel lines.

Table 8. Test of Parallel Lines Output.

Model	−2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	295.456			
General	290.123	5.333	8	0.722

Since the $p > 0.05$, we failed to reject the null hypothesis, meaning there is no evidence that the proportional odds assumption was violated. This indicates that the relationship between the independent variables and the dependent variable is consistent across all ordinal levels, making ordinal regression appropriate for our data.

Goodness of fit model

This assumption states that the model adequately explains the observed data and that there is no significant discrepancy between the expected and observed values [64]. It is tested using the Pearson Chi-Square and Deviance Chi-Square tests, where non-significant *p*-values ($p > 0.05$) indicate a good model fit [64]. According to the findings in Table 7, (Pearson $p = 0.251$, Deviance $p = 0.510$), both tests show no significant difference between observed and predicted values, as all *p*-values are above 0.05 meaning the model fits well. Table 9 shows the findings on the test for goodness of fit.

Table 9. Goodness of fit assumption.

Statistic	Chi-Square	df	Sig. (*p*-Value)
Pearson	315.879	300	0.251
Deviance	298.768	300	0.510

Correlation findings

Correlation analysis is a statistical method used to explore the strength and direction of the relationship between variables [65]. In this study, Spearman's rank correlation was applied to examine the relationships between safety adherence and factors such as knowledge and awareness, cost and accessibility, cultural and social norms, regulatory control, and demographic indicators.

Spearman's rank correlation is a non-parametric test used for assessing the strength and direction of association between two ordinal variables or one ordinal and one continuous variable [66,67]. Unlike Pearson's correlation, which assumes linear relationships and interval data, Spearman's rank correlation evaluates the relationship based on the rank order of the data, making it suitable for ordinal variables where the intervals between values are not consistent [66,67].

Spearman's rank correlation coefficient (ρ) ranges from −1 to +1. A value of +1 indicates a perfect positive correlation, −1 indicates a perfect negative correlation, and 0 indicates no correlation. This method provides insights into the strength and direction of relationships between the variables, while accommodating the non-linear nature of ordinal data. The correlational findings are as seen in Table 10.

Table 10. Spearman's Correlational Findings.

Spearman's Rho	Safety Adherence	*p*-Value
Knowledge and Awareness	0.758 **	<0.001
Culture and Norms	0.587 **	<0.001
Cost and Accessibility	−0.623 **	<0.001
Regulatory Control	0.701 **	<0.009
Gender	0.716 **	<0.009
Level of Education	0.692 **	<0.007
Age Gap	−0.774 **	<0.001
Years of Experience	−0.715 **	<0.001

** Spearman's rho correlation is statistically significant ($p < 0.01$, 2-tailed).

The findings reveal several significant relationships between various factors and safety adherence. The strong positive correlation between knowledge and awareness (Rho = 0.758, $p < 0.001$) indicates that as farmers' awareness of farm chemical risks increases, their adherence to safety practices also improves.

Similarly, culture and norms (Rho = 0.587, $p < 0.001$) show a moderate positive correlation with safety adherence. This means that cultural and social factors such as peer influences positively affect farmers' safety behaviors.

Cost and accessibility present a moderate negative correlation (Rho = −0.623, $p < 0.001$) with safety adherence. This indicates that as financial barriers and accessibility issues increase, farmers are less likely to follow safety practices. The negative correlation is significant, showing that economic constraints are a critical barrier to safety adherence.

The correlation between regulatory control and safety adherence (Rho = 0.701, $p < 0.009$) is also strongly positive, suggesting that greater awareness and enforcement of regulations lead to better adherence to safety measures. Similarly, level of education (Rho = 0.692, $p < 0.007$) also shows a strong positive correlation with safety adherence, indicating that better educated farmers are more likely to follow safety guidelines.

Additionally, gender (Rho = 0.716, $p < 0.009$) showed a strong and statistically significant positive correlation with safety adherence. This shows that female farmers were more likely to adhere to pesticide safety standards as compared to male farmers.

Finally, age (Rho = −0.774, $p < 0.001$) and years of experience (Rho = −0.715, $p < 0.001$) both show strong negative correlations with safety adherence. This suggests that older farmers and those with more years of experience are less likely to follow safety practices.

Ordinal Regression Model

With an emphasis on the roles of knowledge and awareness, culture and norms, cost and accessibility, and regulatory control, ordinal regression was used to determine the factors impacting tomato producers' adherence to safety regulations. To account for any confounding effects, demographic characteristics such gender, age, education level, and years of experience were included as control variables and compared to these parameters. Previous research has suggested that demographic factors can influence safety behavior [68–70]. By controlling these demographic variables, this analysis ensured that the relationship between safety adherence and the main predictors was not confounded by individual characteristics.

The following ordinal regression model was specified to assess the effects of the predictors:

$$\text{logit}(P(Y \leq k)) = \beta_0 + \beta_1(\text{Knowledge}) + \beta_2(\text{Culture}) + \beta_3(\text{Cost}) + \beta_4(\text{Regulatory Control}) + \beta_5(\text{Gender}) + \beta_6(\text{Age}) + \beta_7(\text{Education}) + \beta_8(\text{Experience}) + e \quad (1)$$

Where:

Y represents safety adherence (ordinal dependent variable),

β_0 is the intercept,

β_1, β_2, β_3, β_4 are the coefficients for the main independent variables (knowledge, culture, cost, regulatory control),

β_5, β_6, β_7, β_8 are the coefficients for the demographic control variables (gender, age, education, experience),

ε represents the error term.

By incorporating these control variables, the model allowed for a more accurate estimation of the relationships between the independent variables and safety adherence, free from the influence of demographic factors. To examine these relationships, the ordinal regression model estimated threshold parameters and the effects of the predictor variables, as presented in Table 11.

Table 11. Ordinal regression.

Parameter	Estimate	Std. Error	Wald	df	Sig.	95% CI (Lower)	95% CI (Upper)	Odds Ratio
Threshold (Intercept)								
[Strongly disagree = 1]	−1.945	0.322	36.486	1	0.000	−2.577	−1.312	0.142
[Disagree = 2]	−0.897	0.314	8.149	1	0.004	−1.512	−0.281	0.409
[Neutral = 3]	0.428	0.310	1.908	1	0.167	−0.179	1.036	1.534
[Agree = 4]	1.583	0.318	24.760	1	0.000	0.960	2.206	4.873
Location (Predictors)								
Knowledge & Awareness	0.725	0.198	13.415	1	0.000	0.336	1.113	2.067
Culture & Norms	0.543	0.223	5.938	1	0.015	0.106	0.979	1.722
Cost & Accessibility	−0.361	0.187	3.728	1	0.004	−0.727	0.005	0.697
Regulatory Control	0.467	0.205	5.193	1	0.023	0.065	0.869	1.595
Gender	0.635	0.207	9.401	1	0.002	0.228	1.042	1.885
Age	−0.245	0.114	4.495	1	0.034	−0.468	−0.022	0.783
Level of Education	0.475	0.213	5.074	1	0.024	0.056	0.894	1.608
Years of Experience	−0.318	0.143	5.037	1	0.025	−0.599	−0.037	0.727

Threshold parameters

[Strongly Disagree = 1]: The estimate of −1.945 (p = 0.000) suggests that the predictors decrease the likelihood of strongly disagreeing with safety adherence to pesticide use. The odds ratio of 0.142 indicates that the likelihood of strongly disagreeing is reduced by approximately 0.142 for each unit increase in the predictors.

[Disagree = 2]: The estimate of −0.897 (p = 0.004) suggests that the predictors decrease the likelihood of disagreeing with safety adherence. The odds ratio of 0.409 shows a significant decrease in the likelihood of disagreement.

[Neutral = 3]: The estimate of 0.428 (p = 0.167) is positive, but not statistically significant. This suggests that the predictors do not significantly affect the likelihood of being neutral regarding safety adherence. This non-significance could indicate that there is no distinct pattern for how the predictors (e.g., knowledge, cost, regulatory control) influence farmers' responses when they are neutral about safety adherence.

[Agree = 4]: The estimate of 1.583 (p = 0.000) suggests that the predictors significantly increase the likelihood of agreeing with safety adherence. The odds ratio of 4.873 indicates that the likelihood of agreeing with safety adherence is nearly 5 times greater for each unit increase in the predictors.

Predictor variables

Knowledge & Awareness: Estimate = 0.725 (p = 0.000), odds ratio = 2.067. Knowledge and awareness significantly increase the likelihood of agreeing with safety adherence. For each unit increase in knowledge and awareness of farm chemical safety, the likelihood of agreeing with safety adherence increases by approximately 2.067 times.

Culture & Norms: Estimate = 0.543 (p = 0.015), odds ratio = 1.722. Cultural norms positively influence adherence to safety practices. For each unit increase in the influence of cultural and social norms regarding safety, the likelihood of agreeing with safety adherence increases by approximately 1.722 times.

Cost & Accessibility: Estimate = −0.361 (p = 0.004), odds ratio = 0.697. Higher costs and lower accessibility decrease the likelihood of agreeing with safety adherence. For each unit increase in the cost and accessibility barriers the likelihood of agreeing with safety adherence decreases by 0.697 times.

Regulatory Control: Estimate = 0.467 (p = 0.023), odds ratio = 1.595. Regulatory control significantly increases the likelihood of agreeing with safety adherence. For each unit increase in regulatory control the likelihood of agreeing with safety adherence increases by approximately 1.595 times

Gender: Estimate = 0.635 (p = 0.002), odds ratio = 1.885. Gender (female) significantly increases the likelihood of agreeing with safety adherence. For each unit increase in female farmers, the likelihood of agreeing with safety adherence increases by approximately 1.885 times

Age: Estimate = −0.245 (p = 0.034), odds ratio = 0.783. Older individuals are less likely to agree with safety adherence. For each unit increase in age, the likelihood of agreeing with safety adherence decreases by 0.783 times.

Level of Education: Estimate = 0.475 (p = 0.024), odds ratio = 1.608. Higher education levels are associated with an increased likelihood of agreeing with safety adherence. For each unit increase in the level of education, the likelihood of agreeing with safety adherence increases by approximately 1.608 times.

Years of Experience: Estimate = −0.318 (p = 0.025), odds ratio = 0.727. More years of experience are associated with a decreased likelihood of agreeing with safety adherence, with each additional year reducing the likelihood by 0.727 times.

The logistic regression equation used to model the factors influencing safety adherence to pesticide use is as follows:

$$\text{logit}(P(Y \leq k)) = \beta_0 + 0.725(\text{Knowledge}) + 0.543(\text{Culture}) - 0.361(\text{Cost}) + 0.467(\text{Regulatory Control}) + 0.635(\text{Gender}) - 0.245(\text{Age}) + 0.475(\text{Education}) - 0.318(\text{Experience}) + \varepsilon \quad (2)$$

Pseudo R Statistics

A further analysis was done to evaluate the goodness of fit of the regression model using the Pseudo R test [71,72]. This was done to evaluate how well the model explained the variability in the dependent variable through Cox &Snell, Nagelkerke and McFadden Statistics as seen in Table 12. Cox & Snell R-Square measures the proportion of variance explained by the model. However, it has an upper bound less than 1, so it can never reach 1, making it a conservative measure of model fit. A value closer to 0.8 or higher indicates a strong model fit [73]. On the other hand, Nagelkerke R-Square is an adjusted version of Cox & Snell that allows the statistics to reach 1. Higher values, like 0.8 or above, indicate that the model explains a large portion of the variance in the outcome variable [74]. Similarly, McFadden R-Square compares the likelihood of the model with the likelihood of a baseline (null) model. Typically, values between 0.2 and 0.4 indicate a good fit for logistic regression models [74]. This value tends to be lower than Cox & Snell and Nagelkerke, even in well-fitting models.

Table 12. Pseudo R.

Statistic	Value
Cox & Snell	0.710
Nagelkerke	0.830
McFadden	0.213

Based on the findings, Cox & Snell value of 0.710 suggested that approximately 71% of the variance in the outcome variable is explained by the predictors in the model. This indicates a strong model fit, but because the upper limit of Cox & Snell is less than 1, this value is a reasonable reflection of the model's explanatory power without reaching the ideal maximum. On the other hand, the Nagelkerke value of 0.830 means the model explains 83% of the variance in the outcome variable. This is a strong fit and indicates that the predictors are doing an excellent job of explaining the variance in the dependent variable. Since Nagelkerke is adjusted to allow for an upper limit of 1, this value suggests a very good fit, with the model capturing most of the variance. Finally, the McFadden value of 0.213 suggested that the model improves the likelihood of predicting the outcome by 21.3% compared to the null model (a model with no predictors). McFadden values between 0.2 and 0.4 are generally considered indicative of a good model fit in logistic regression. Although it's lower than Cox & Snell and Nagelkerke, this value is still acceptable and suggests that the model is a good fit overall.

DISCUSSION OF FINDINGS

Demographics

The findings reveal significant demographic and health-related trends among tomato farmers. A higher proportion of male farmers (63%) compared to female farmers (37%) suggests the need for targeted safety programs addressing male risk perceptions, while also ensuring sufficient support for women. The low levels of educational attainment (60% with only primary education) highlight the importance of accessible training programs to bridge the knowledge gap, while the age distribution, with 48% of farmers over 50 years old, signals potential sustainability concerns and the need to attract younger generations to farming. Additionally, the diverse experience levels (43% with over 20 years) call for tailored educational initiatives that cater to both seasoned farmers and newer entrants. Health issues such as skin irritation (52%), eye irritation (37%), and nausea/vomiting (47%) suggest inadequate safety measures and the need for improved protective equipment and practices. Similar health risks were identified by Afshari et al. [69] proving the detrimental effects associated with pesticide use. To address the difficulties experienced by tomato growers and eventually advance a healthier and more sustainable farming community, these findings highlight the urgent need for comprehensive safety, health, and educational programs.

Independent Variables

The results show a substantial discrepancy between farmers' actual adherence to safety procedures and their understanding of agricultural chemical safety. Although most farmers are aware of the health dangers that come with using chemicals, they lack confidence in their ability to handle chemicals safely, and they don't always follow procedures like label reading and wearing PPE. This emphasizes the necessity of focused interventions that close the knowledge gap and enable real-world implementation. Financial limitations, such as the price and scarcity of PPE, make this problem even worse, indicating that it is imperative to make safety gear more accessible and inexpensive. Farmers' inadequate knowledge of current regulations suggests a vacuum in enforcement and education that needs to be addressed, even while they show a moderate support for regulatory measures like subsidies and stronger controls.

Although they seem to have little influence, cultural and social factors also shape safety procedures. There was little evidence of peer behavior, community conversations, or community leaders' support for safety procedures, which suggests that farming communities lack a strong social support network for chemical safety. This implies that increasing adherence to safety procedures may be facilitated by strengthening community involvement and cultivating a culture of safety through peer-led projects and leadership advocacy. The need for greater community involvement and education in promoting agricultural chemical safety is further highlighted by the low levels of safety-related conversation at social events and the vendors' limited advocacy of farm chemical safety.

Significant differences in adherence to various safety behaviors were found by the statistical analysis, which included the Kruskal-Wallis and Dunn's post-hoc tests. Individual behaviors such as PPE use or incident reporting were less important in influencing safety practices than systemic factors and financial considerations. The results, for example, demonstrate that farmers place a higher priority on cost than on the use of PPE and that reporting safety incidents is substantially less common than using other pest management techniques. These differences imply that although farmers could be open to implementing systemic reforms, their individual safety measures frequently fall short because of lack of funding or weak enforcement of regulations.

The multicollinearity test, using the Generalized Variance Inflation Factor (GVIF), showed that all predictor variables had low levels of multicollinearity (with GVIF values well below 5). This confirmed that all the predictor variables were not correlated with each other and that each variable had a unique contribution to the ordinal regression model.

Additionally, the test for parallel lines confirmed that the assumption of proportional odds holds for the model. The p-value of 0.722 (which is greater than 0.05) suggests that there is no statistical evidence to reject the null hypothesis, meaning that the relationship between the independent variables and the dependent variable (safety adherence) was consistent across all levels of the outcome variable.

The goodness of fit model analysis, conducted through the Pearson and Deviance Chi-Square tests, further supports the adequacy of the model. Both p-values (0.251 for Pearson and 0.510 for Deviance) were greater than 0.05, indicating that there is no significant discrepancy between the observed and expected values. This implied that the model was a good fit as it explained the variations of the dependent variable without significant error.

The Spearman's rank correlation revealed a strong positive correlation between knowledge and awareness (Rho = 0.758, $p < 0.001$). This implied that as farmers' awareness of farm chemical risks increases, their adherence to safety practices also improves. To support these findings, a systematic review by Kangavari et al. [75] showed that farmers' knowledge and education significantly influence their attitudes toward adhering to safety practices. This finding suggests that interventions focusing on educating farmers about the risks of farm chemicals could have a significant impact on safety behaviors. Similarly, culture and norms (Rho = 0.587, $p < 0.001$) show that cultural and social factors play an important role in shaping safety behaviors, with peer influence and community norms encouraging safer practices. Similar findings were identified by Wongta et al. and Zineb et al. [37,76] who concluded that peer influence had an impact on safety adherence. The findings emphasize the importance of fostering a safety culture within farming communities, where safety practices are normalized and reinforced.

On the other hand, the negative correlation between cost and accessibility (Rho = −0.623, $p < 0.001$) with safety adherence highlights a critical barrier: as financial constraints and difficulties accessing safety resources increase, adherence to safety practices decreases. Similar findings were also found by Sapbamrer et al. and Sookhtanlou et al. [31,70] who found the cost of personal protective equipment as a huge barrier towards safety adherence. This underscores the need for policy interventions, such as subsidies or better access to safety equipment, to alleviate these financial and logistical barriers. Regulatory control (Rho = 0.701, $p < 0.009$) also showed a strong positive relationship with safety adherence, indicating that greater awareness and enforcement of safety regulations are associated with better adherence to safety measures. This suggests that regulatory frameworks play a significant role in promoting safer practices, and strengthening enforcement could further improve safety adherence. Similar to these findings, Zikankuba et al. [77] highlighted that in retrospect, weak regulatory framework only worsened the misuse of pesticides in agriculture which in return adversely affected the farmers and the environment at large. In this regard, Kiambi et al. [78] suggested that enhancing regulatory enforcement methods and establishing standardized monitoring systems could greatly improve adherence to safety practices.

Demographic factors including age (Rho = −0.774, $p < 0.001$), and years of experience (Rho = −0.715, $p < 0.001$) showed negative correlations with safety adherence while gender (Rho = 0.716, $p < 0.009$) showed a positive correlation, suggesting that older and more experienced farmers, as well as male farmers, were less likely to follow safety practices. This discrepancy may reflect differences in risk perception and attitude towards safety and PPE in pesticide handling. Similar findings were found by Wang and Jiang [79] who found that female farmers were more willing to adopt safety precautions as compared to male farmers. Overcoming these inequalities will need gender-sensitive solutions that appropriately respond to the unique barriers male farmers face. Similarly, the findings denoted a generational resistance to change with overreliance by farmers on traditional safety practices or a deep perception that safety measures are unnecessary. These trends are consistent with previous research by Conway et al. and Damalas et al. [80,81] who highlighted the need to address cultural and behavioral opposition among elderly farmers.

The ordinal regression model and the Pseudo R-Square statistics provide further confirmation of the model's strength. The Cox & Snell value of 0.710 suggests that approximately 71% of the variance in safety adherence is explained by the predictors, while the Nagelkerke value of 0.830 indicates an 83% explanation of the variance. Both values indicate a strong model fit, demonstrating that the selected predictors (such as knowledge, culture, cost, and regulatory control) significantly explain pesticide safety adherence. The McFadden value of 0.213 suggests a moderate improvement in likelihood over the null model, which is also considered a good fit for logistic regression models. These results suggest that the predictors (knowledge and awareness, culture and norms, cost and accessibility and regulatory control) explain a large variability in farmers safety adherence.

Based on these findings, we were able to make conclusions about our hypotheses. We rejected all four null hypotheses, as each predictor was found to have a significant influence on safety adherence. These findings indicate that improving knowledge and awareness, fostering supportive social norms, reducing cost barriers, and strengthening regulatory control are crucial in enhancing pesticide safety practices among tomato farmers.

CONCLUSIONS

The study major aim was to find out whether nonadherence of pesticide safety practices among tomato farmers in Kirinyaga County was due to farmers ignorance or the unavailability of support systems. Inspired by the Health Belief Model, this study identified key predictors of farmers pesticide safety adherence. The findings showed that knowledge and awareness (r = 0.725, p = 0.000), culture and social norms (r = 0.543, p = 0.015) and regulatory control (r = 0.467, p = 0.065) positively influenced safety adherence while high cost and lack of accessibility of adequate personal protective equipment negatively influenced safety adherence (r = −0.361, p = 0.004). The model provided strong evidence that these variables significantly shaped safety adherence behaviors among tomato farmers.

The findings also highlighted the role of the demographics of the tomato farmers as older and more experienced farmers showed reluctance to adhere to safety (r = −0.245, p = 0.034). Gender showed a moderate positive relationship with safety adherence indicating that female farmers were more open to adopt the safety precautions as opposed to the male tomato farmers (r = 0.635, p = 0.002). The findings also highlighted that education had a positive relationship with safety adherence (r = 0.475, p = 0.024) which shows the critical role of education to equip farmers with knowledge and training relevant to safe pesticide use precautions.

The study also highlighted that adherence to safety practices when handling agrochemicals was inconsistent among tomato farmers who failed to use protective equipment consistently. The study also concludes that tomato farmers lack medical insurance to cover the accidents from pesticide exposure. This emphasized the individual, systemic and structural barriers that often-hindered adherence to safety in agrochemical handling.

Farmers lack of adequate resources, education, and support, aligns with argument in “Stop Blaming the Farmer” [82] that emphasizes that weak regulations and inadequate systems limit farmers ability to act safely.

From this perspective, it is critical to tackle the systemic inequalities that support harmful behaviors, rather than reassigning blame solely to farmers.

While farmers hold some responsibility to adopt safer practices, the findings stress the need for external support, such as government-subsidized safety equipment, accessible training tailored to literacy levels, and stricter regulatory enforcement. Community-driven cultural initiatives can also help reinforce safety norms. Addressing these issues requires collaboration among farmers, policymakers, and stakeholders. A shared commitment to fostering a culture of safety will lead to more sustainable agricultural practices and better health outcomes for farming communities. This study therefore answered our research question that farmers ignorance plays a role in lack of pesticide safety adherence, but they shouldn't be blamed entirely as systemic support also plays a critical role in reinforcing safety adherence.

RECOMMENDATIONS

This study accentuates the urgent need for targeted short and long-term interventions aimed at improving safety among tomato growers in Kirinyaga County that would be relevant across agricultural systems in other low- and middle-income countries as well. For decision-makers or stakeholders interested in improving safety adherence among farmers, this model acts as a guideline on understanding the motivations of farmers towards adhering to pesticide safety measures. The strong explanatory power (as indicated by the R-squares) means that targeted interventions can be designed around these key factors, such as enhancing knowledge or reducing barriers related to cost and accessibility.

The study recommends boosting awareness and education at close quarters with localized training on agrochemical safety, responsible use of pesticides, as well as first aid. Visual representation of the information through charts and graphs, frequent workshops in school, and telecast alerts such as SMS alerts, community radio, and mobile apps can further strengthen these measures. Awareness and Compliance need periodic refresher campaigns to keep the wave going.

The study recommends the government to work closely with the private sector, the farmers, the vendors and suppliers to ensure access to affordable personal protective equipment. The study also suggests stronger regulations on pesticide usage including periodic monitoring by agricultural officers, to ensure involvement of farmers in policymaking, and to ensure balance between advocacy and stricter enforcement to improve compliance.

These focused efforts are essential for creating a more inclusive approach, such as mentorship programs for older farmers, gender-sensitive policies that address the needs of both women and men, and practical teaching tools to help less-educated tomato farmers gain knowledge and awareness. Stakeholders can use these recommendations to reduce safety risks, foster inclusivity, and encourage sustainable farming practices, not just in Kirinyaga County but also in similar agricultural settings in low- and middle-income countries.

PROSPECTIVE RESEARCH

The study proposes more research to be done to understand the factors that influence farmers to comply with safety practices both in pesticide use or other ergonomic practices. Since the findings revealed farmers education as a direct contributor towards safety adherence, immediate studies should be conducted to leverage on educational programs and training. This being a digital era and technology being on the rise, more research could explore the role of technology in safety adherence by using the internet, mobile phones and advanced technologies to equip farmers with the necessary knowledge and hands-on experience on how they can use technologies to advance their safety.

The study revealed the disparity in gender in response to adherence to safety rules. Both men and female farmers face unique problems in terms of their safety in agriculture. The study proposes that studies be conducted on how to safeguard women and men farmers based on their perception of risk. It is also important for research to be done as community based, to identify specific problems encountered and how to leverage community leadership to train farmers and impose rules guarding specific community needs. Further research should be done to evaluate the current regulations and frameworks on safety guidelines, to understand which ones are outdated and which ones could work and be improved more to improve adherence to agricultural safety standards.

STUDY LIMITATIONS

While the study has provided very valuable insights on the factors that affect farmers adherence to pesticide safety measures, several limitations of this study were identified.

First, self-reported data and response bias may have influenced the findings of this study. Farmers may have reported socially desirable responses particularly regarding safety practices rather than exactly reporting their behaviors accurately. This introduced the risk of farmer biases. To overcome this, future studies should incorporate observations or mixed data collection methods to overcome the risk of bias.

Secondly, the study encountered the risk of representation of the sample. Although efforts were made to ensure that the sample was diverse and inclusive, the findings may not be generalizable to all farming communities, especially those with different conditions such as a stronger regulatory framework than that of the study group. Therefore, generalization of these study findings beyond Kirinyaga County should be approached with caution. Future research could also explore other types of agriculture such as animal farming and other crops as well.

Lastly, while this study focused on multiple variables that could influence pesticide safety adherence among tomato farmers, there exists also very many unmeasured variables such as: quality of training programs, enforcement of rules and regulation. Future research could expand more on these factors to have a comprehensive analysis on the factors that affect pesticide safety adherence.

SUPPLEMENTARY MATERIALS

The following supplementary materials are available online at https:/doi.org/10.20900/jsr20250028, Supplementary Material File S1: Questionnaire: "Farmers' Safety Ignorance or Lack of Support? A Case Study of Tomato Farmers in Kenya".

ETHICAL STATEMENT

Ethics Approval

Ethical approval for this research was obtained from the National Commission for Science, Technology, and Innovation (NACOSTI), Kenya. License Number: NACOSTI/P/24/414357, Date: 29th November 2024.

Informed Consent

Informed consent was obtained from all respondents involved in the study.

DATA AVAILABILITY

The literature data provided in this study can be accessed via Google Scholar/Research Gate/Google Search.

AUTHORS CONTRIBUTION

Conceptualization: ZWN; Methodology: ZWN, EZ; Data Collection: AMM, ZWN; Data Analysis: ZWN, EZ; Writing—Original Draft Preparation: ZWN, AMM; Writing—Review and Editing: ZWN, EZ; Supervision: EZ; Funds Acquisition: EZ. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

All the authors of this research have declared no conflict of interest.

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