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Abstract

Health consequences of harmful pesticide use are a growing concern in developing countries. As an analytical framework for farmers' protective behavior, the literature has long proposed the knowledge, attitude, and behavior (KAB) model in which knowledge translates to perceptions, leading to behavioral changes. However, there are mixed results on the role of knowledge and perceptions in farmers' self-protection against pesticide-related health risks. This study tests the KAB model using survey data from 138 vegetable farmers in northern Vietnam, in a regression framework. The empirical results show that knowledge affects general protection practices (e.g., handwashing after spraying) in the direct and indirect pathways via risk perceptions. In contrast, knowledge affects personal protective equipment use through attitudes relevant to risk perceptions, consistent with the classical linear progression in the KAB model. Thus, risk perceptions mediate the link between risk awareness and protection against pesticide-related health risks. Overall, the KAB model's goodness-of-fit to the data depends on protective actions, offering a possible explanation for the mixed results in the literature. We also identify poisoning experiences and advice from peers, retailers, and media, rather than governmental training, as significant sources of knowledge formation processes. Finally, we offer policy recommendations to facilitate safe pesticide use by small-scale Vietnamese farmers.

Keywords: *knowledge, attitude, and behavior model*; *safe pesticide use*; *personal protective equipment; small-scale farmers; Vietnam.*

1. Introduction

Despite their undeniable contributions to global agricultural production, synthetic agrochemicals have affected the environment and human health, particularly among direct applicators, owing to their prolonged exposure to products (Antle & Pingali, 1994; Fan et al., 2015; PAN Germany, 2012). There are 860 million annual cases of acute unintended poisoning, or 44% of the global farming population (Boedeker et al., 2020), and farming is regarded as one of the occupations with the highest health burdens. In response to health concerns, multiple developed countries have attempted to curb their reliance on chemical pesticides and limit associated accidents among agricultural workers (Ecobichon, 2001).

However, safe agricultural pesticide usage remains a significant challenge in developing countries. The prevalence of harmful farming is due to the wide presence of highly hazardous pesticides, a large at-risk population, and because of small-scale farmers' vulnerability in terms of poor access to precise information, misperceptions, and a lack of protective tools (Matthews, 2008; Schreinemachers et al., 2015; Yuantari et al., 2015). Consequently, most pesticide-related severe poisoning and mortality are prevalent in low-income countries (Ecobichon, 2001; Sapbamrer & Thammachai, 2020), although they are highly preventable with proper personal protective equipment (PPE) (Dasgupta et al., 2007). Thus, a holistic understanding of the constraints behind safe pesticide use is necessary to design policies to mitigate the health hazards of smallholders in developing countries.

The workhorse model for this purpose is the knowledge, attitude, and behavior (KAB) model. The original model from the 1950s proposed a linear progression: knowledge updates beliefs regarding the issue, leading

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to behavioral changes. This idea suggests that information provision through education and training is a policy recommendation to promote averting behavior. However, the key observation is that improved knowledge (and hence better risk awareness) is a necessary but insufficient condition for personal protection. For instance, institutional constraints (e.g., inadequate supply) may prevent informed farmers from protecting their health and that of their families. This speculation aligns with the reported insignificant impact of enhanced knowledge and skills gained through technical training on pesticide applications and unintentional accidents (Schreinemachers et al., 2015; Sellare et al., 2020). Moreover, knowledge can directly lead to safety behaviors, particularly when perceptions are easy to manipulate. Thus, whether knowledge improvement alone is sufficient for behavioral change and how risk awareness drives averting behavior require empirical scrutiny.

This study tested the KAB model using survey data from farm households in northern Vietnam in a regression framework. Investigating factors influencing protective behavior regarding pesticide use among Vietnamese farmers is an appealing addition to the literature on this theme for the following reasons. First, accompanied by rapid economic growth, Vietnam experienced a sharp increase in synthetic pesticides both in quantity and diversity, and approved 4153 trading names by 2020, equivalent to approximately 182 new products entering the market annually between 2009 and 2020 (Figure 1). Accordingly, medical tests on farmers have confirmed a high prevalence of acute and chronic poisoning symptoms, although the use of protective tools can reduce health risks approximately 50% (Dasgupta et al., 2007). Second, while previous studies have analyzed large-scale commercial agricultural systems, governmental regulations, and technical assessments in Vietnam (Dasgupta et al., 2007; Thuy et al., 2012; Van Hoi et al., 2009), little attention has been paid to the issues from small-scale farmers' perspectives and the interconnection between agencies informing their decisions on preventive measures. An alternative approach from a micro perspective would produce improved policy implications to promote safe pesticide use in agriculture.

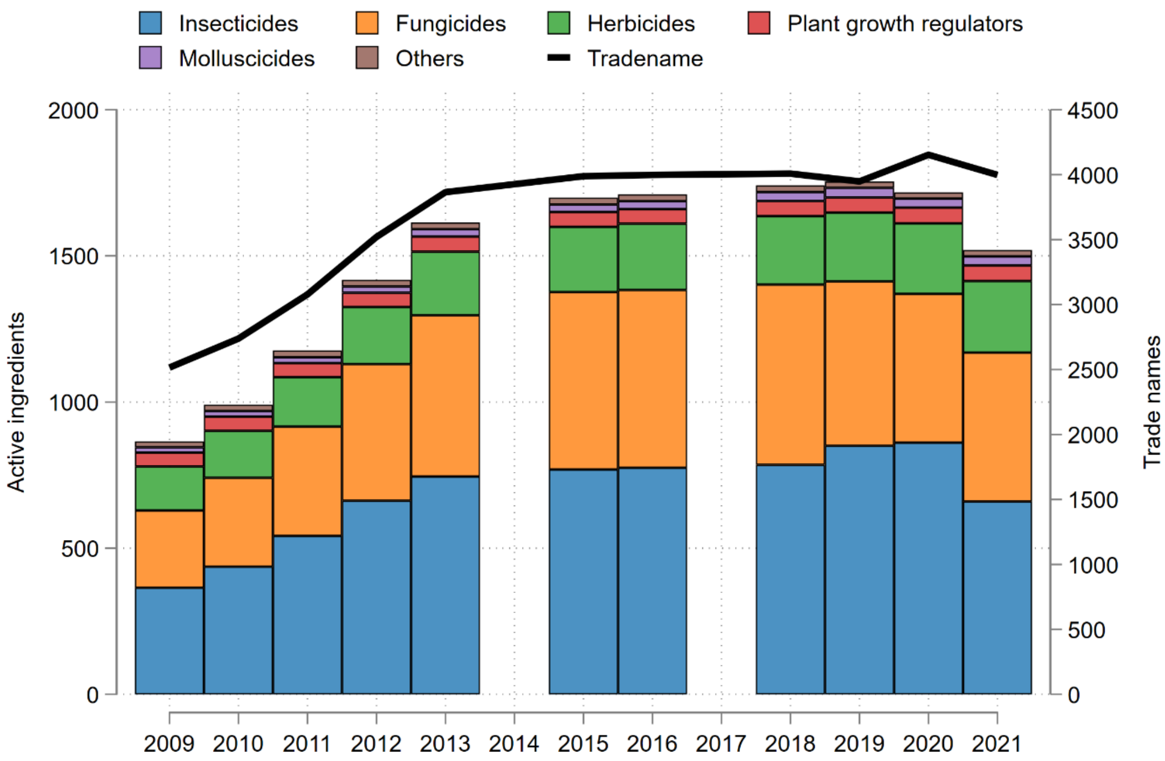


Figure 1. Permitted pesticides by type in Vietnam, 2009–2021
Note: The left (right) y-axis measures the number of active ingredients (trade names). No circular was issued in 2014 and 2017.
Source: Circulars of the Ministry of Agriculture and Rural Development

Given this motivation, the role of knowledge and attitudes toward pesticide-related health risks in shaping safety practices among small-scale farmers in Vietnam was investigated. The regression results show that knowledge affects farmers' general safety practices (e.g., handwashing after spraying) in the direct and indirect pathways via risk perceptions. By contrast, knowledge affects PPE use through risk perceptions, which is consistent with the classical linear progression proposed by the KAB model. Thus, the explanatory power of the KAB model depends on its protective action. While these findings provide empirical grounds for policy interventions to commit to information provisions to upgrade knowledge levels, the dissemination of PPE adoption warrants an improvement in risk perception among small-scale Vietnamese farmers.

Further analyses identified previous poisoning experiences and advice from peers, retailers, and the media, rather than governmental organizations and their training, as essential information sources in farmers' learning processes. We also find that information from retailers and the media has an independent pathway to risk perceptions, calling for careful policy designs with their involvement to avoid manipulating misperceptions. Overall, this study underscores the need to re-design governmental training to be sufficiently effective to alter farmers' risk beliefs. Our empirical evidence suggests policy recommendations, such as (1) leveraging existing social networks among fellow farmers in the community and (2) exploiting mass media and retailers as information diffusion channels with monitoring systems to decrease the risk of manipulating perceptions in the wrong direction.

This study contributes to the literature on pesticide use among small-scale farmers in three ways (Sapbamrer & Thammachai, 2020). First, it adds to the body of empirical scholarship on the contribution of knowledge and perceptions to behavioral formation by providing a general framework for statistically testing the KAB model. The model fitness of the KAB framework depends on protective practices, offering a possible explanation for the reported mixed results in the literature on pesticide safety. This is important because the policy implications differ depending on the role of risk perception. Another finding of insignificant influence from governmental training complements previous studies (Palis et al., 2006; Sellare et al., 2020; Yuantari et al., 2015) in Asian and African contexts, highlighting the incorporation of participatory approaches into training design to facilitate farmers' learning processes. Finally, this study is one of the first attempts to unpack the decision-making process of pesticide-related protective behavior among farmers in northern Vietnam, where pesticides are mostly applied to vegetable production. Another unique feature of this study is that most respondents in our survey were female. Therefore, this study provides an interesting case to contribute to future comparative studies to generalize farmers' safety behaviors.

The remainder of this paper is organized as follows. Section 2 outlines the KAB model as a theoretical framework. The background of the research context and survey data is described in Section 3. Section 4 presents the econometric framework and main results of the empirical test of the KAB model. The knowledge- and belief-formation processes were also investigated. Section 5 contrasts our main findings with the literature on farmers' safe pesticide applications in order to derive lessons for policymaking. Section 6 concludes.

2. Conceptual framework

The theoretical framework of this study builds on the KAB model widely applied in health-related environmental fields (FAO, 2014; Kollmuss & Agyeman, 2002; Oreg & Katz-Gerro, 2006). Knowledge refers to possessed information on a given topic, attitude (or perception) denotes the emotional beliefs that can influence positive or negative responses, and behaviors are actual personal actions responding to a particular set of conditions (Schrader & Lawless, 2004). The original model, developed in the 1950s, was founded on the basic premise of rational individual responses, proposing a linear progression that supports specific behavior patterns. It starts by improving individual knowledge through training and experiences, fostering informed attitudes toward the issue being examined, and later progresses to targeted behavioral change (Bettinghaus, 1986; Kollmuss & Agyeman, 2002). Numerous scholars have attempted to modify the model by adding other factors (e.g., intention and personal beliefs) and argued for backward causation between behavior and attitude (Olson & Jeff Stone, 2005; Oreg & Katz-Gerro, 2006) while retaining the original model's core structure.

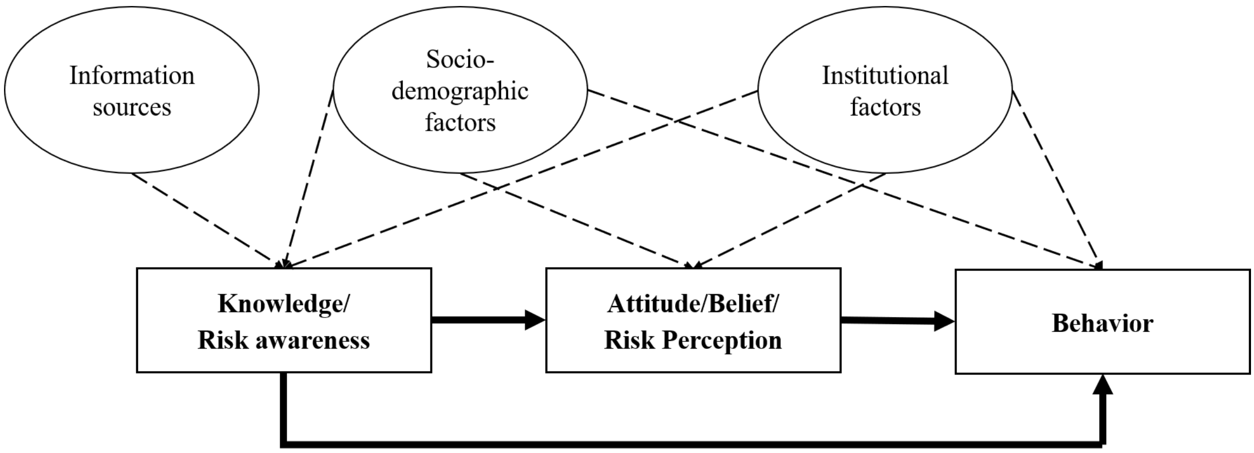


Figure 2. Conceptual framework of the study

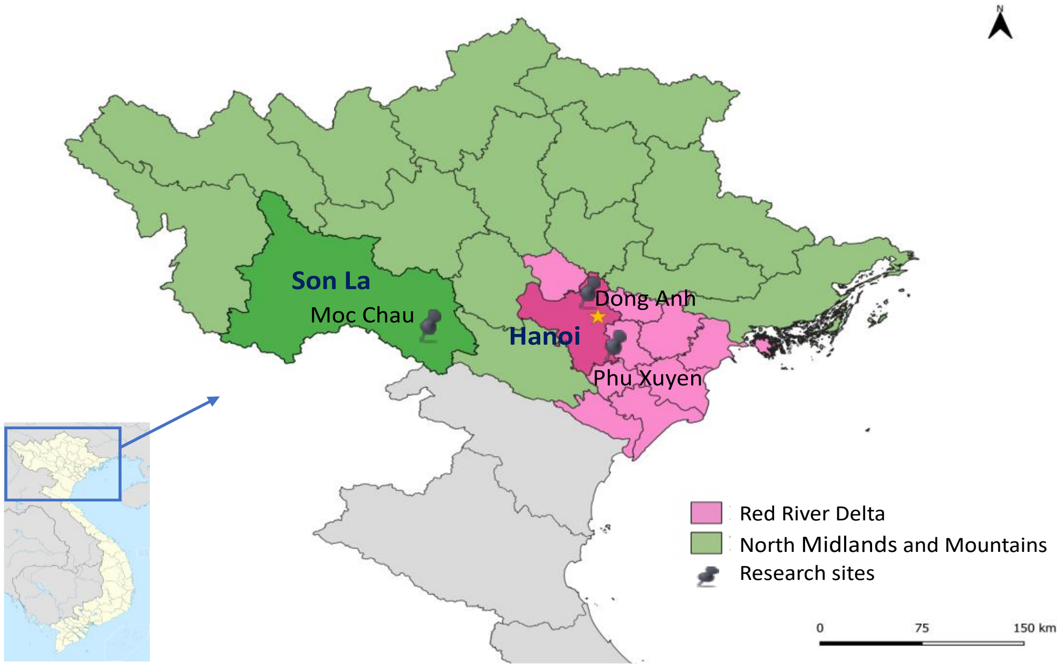
Figure 2 summarizes the conceptual framework of the subsequent empirical analysis. While empirical tests have been conducted for the KAB model in various settings (Sapbamrer & Thammachai, 2020), evidence for the role of knowledge and attitude in shaping preventive behavior is nuanced and specific to the research context. Furthermore, given the complicated interrelation between elements, evaluations using a binary option or treating different components independently (Jones et al., 2009; Schreinemachers et al., 2017; Yuantari et al., 2015) may overlook essential points and draw a partial picture. This study advances the empirical literature by appraising the multidimensional association between factors in a regression framework using a five-point Likert scale for farmers' responses. Another challenge of the previous KAB survey was the lack of a standard questionnaire, making the comparison between different contexts incompatible. By asking multiple questions with a unified measuring scale and aggregating them into scores through the principal component analysis, this study neutralizes KAB outcomes to their regional features to better understand variations in protective behavior across farmers within specific contexts.

In addition to the core internal factors of KAB theory, socio-demographic and institutional factors that influence the KAB components are incorporated into the regression framework. Examples of demographic factors include sex and age. Although women are more susceptible to chemical exposure (RCRD et al., 2015) and are likely to comply with mitigation measures, several studies have excluded female farmers from the analysis because of their limited involvement in decision-making within the family (Sharifzadeh et al., 2019). The literature also suggests that young farmers with better risk awareness will show greater openness than their older counterparts to adopt PPE and new protective behaviors (Akter et al., 2018; Fan et al., 2015). Training attendance, as an example of institutional factors, can increase the chance of reading product labels, but may not improve compliance with instructions on pesticide and PPE usage (Nguyen et al., 2018). By collecting empirical counterparts for each component of the framework in household surveys, this study tests whether the KAB model explains health-risk preventive behavior in pesticide application contexts, and if so, elucidates information sources of knowledge and driving forces of beliefs among small-scale farmers in northern Vietnam.

3. Settings and data

3.1. Study sites

Vietnam has witnessed a slow transformation from pesticide-based agriculture to safer crop production. Indeed, approved synthetic pesticides grew rapidly during the early 2010s after the private sector's involvement in product imports, formulation, and distribution (Hoi et al., 2016; V. H. Pham et al., 2009). The government approved 4153 trading names by 2020 (Figure 1). In response to public pressure on food safety and environmental concerns, the state has issued several regulations to manage the domestic pesticide business and usage, but could not achieve proper enforcement (Van Hoi et al., 2013). Pesticide contamination and poisoning, as side effects of long-term use, have become serious public health issues (Dasgupta et al., 2007; M. H. Pham et al., 2011). For instance, medical tests found that 35% and 21% of rice farmers in the Mekong River Delta of Vietnam have acute and chronic poisoning symptoms, respectively, due to organophosphates and carbamates. Although PPE can mitigate substantial health risks when working with pesticides, their adoption remains limited among smallholders (Dasgupta et al., 2007; Sapbamrer & Thammachai, 2020).



Source: Provided by the authors.

Figure 3. Research sites in northern Vietnam

Two geographic regions in northern Vietnam, the Red River Delta (RRD) and Northern Midlands and Mountains (NMM), were selected as research sites for the following reasons (Figure 3). First, local agriculture features small, economically insecure, and fragile farm plots, with >90% of households categorized as small-scale farmers (World Bank, 2016). Second, regional contrasts in cultivation practices and geographical and ethnic features make research sites attractive for comparative studies. RRD is the region with the longest farming and civilization history (van den Berg et al., 2003). Commercial production within populated areas and devastated soils have motivated delta farmers to rely heavily on chemical interventions to maintain expected yields. Alternatively, NMM features an underdeveloped infrastructure, geographical disconnections, and ethnic complexity. These unfavorable conditions are conducive to the prevalence of poverty, illiteracy, and culturally determined behavioral restrictions (Minot et al., 2006). Consequently, these farmers are prone to using hazardous and cheap chemicals and have poor access to proper PPE and the knowledge thereof (Matthews, 2008; Palis et al., 2006).

This study selected three northern Vietnamese areas: Dong Anh (semi-urban) and Phu Xuyen (rural) districts of Hanoi, RRD, and Moc Chau (rural mountainous) district of Son La Province, NMM (Figure 3). We determined representative farming patterns based on preliminary reports (Raneri et al., 2019) and consultations with key local informants during a visit to the International Center for Tropical Agriculture–Asia Regional Office in Hanoi. This study focuses on vegetables because of their significant consumption in Vietnamese diets (Huong et al., 2013) and the high frequency and quantity of agrochemical use associated with vegetable production (V. H. Pham et al., 2009). In Dong Anh, local farmers engage in commercial vegetable production. As certified by the Department of Agricultural and Rural Development, farming is characterized by low pesticide application with permitted chemicals and non-polluted water sources. In contrast, rural farmers in the Phu Xuyen and Moc Chau districts grow vegetables using conventional and mixed agricultural systems. In addition, only a few agricultural households in these two areas join the local agricultural cooperative/groups (AC/AG) that promote safe production with strict requirements to control chemical residues but intermittently sell their vegetable products through the cooperative.

3.2. Survey

To understand farmers' pesticide application holistically and relevant protective practices, household interviews were conducted at the survey sites using a prepared questionnaire between October and December 2019. The household questionnaire was designed with the following structure: it started with some background of the participants and their household farming conditions, followed by general pesticide usage practices and their agreement on various KAB statements related to pesticides. Before finalizing the questionnaire design, one of the authors conducted a pilot test with a small number of farmers in the Hanoi area and consulted with officials of the Farmers' Union (FU) in the Moc Chau district to evaluate the clarity of the questions and their suitability for the local culture. The interview began by explaining the study's purpose and contents, and requesting written or verbal consent, and lasted for approximately 20–30 mins.

Farmer interviewees were recruited based on these criteria: ≥16 years of age, currently growing vegetables for commercial purposes, and having worked with synthetic pesticides. The sample size for each site was determined using stratified random sampling based on national statistics on the demographic characteristics of the area. Because there are no available data on the number of commercial farmers by sub-region, the General Statistics Office of Vietnam's database on the working-age population in 2018 was utilized separately for typical RRD and NMM regions. We also referred to statistics on urban and rural Hanoi's working population to approximate the population of farmers in the semi-urban areas. Based on the sampling design, data were collected from 49, 44, and 45 households in Dong Anh, Phu Xuyen, and Moc Chau, respectively, totaling 138 households from five communes. For this dataset, the chi-square goodness-of-fit test of the sample size found that the test statistic was $4.55<5.99$ (the critical value at the 5% significance level), indicating no significant difference between the sampling and expected frequencies. Thus, we consider the selected sample to be a good representation of the entire northern Vietnamese population.

In addition to household interviews, qualitative information was obtained from local farmers through focus group discussions in the two villages. Furthermore, interviews were conducted with representatives of the district Plant Protection Station (PPS), FU, AC/AG, pesticide retailers, and village leaders. The interview protocol included questions on general information on research sites, general agricultural development and pesticide use in the district, respondents' viewpoints on farmers' pesticide use and protection practices, and specific questions tailored to each respondent group. This qualitative information complements discussions based on quantitative data from the household surveys.

3.3. Summary statistics

Table 1 summarizes the respondent and household characteristics from the survey. If the value is missing, it is replaced with the sample average throughout the study to maintain sample size. While this replacement may slightly underestimate the standard deviations, the averages remain intact. For example, Table 1 reports the average respondent age as 53.8 years, and most respondents were female, accounting for 85% of the total sample. Given the popularity of the one-person knapsack sprayer, female family members purchase pesticides and apply the products independently when men and young people are absent due to non-agricultural employment in cities and industrial zones. Thus, females may be more knowledgeable and suitable for surveying than their male counterparts. Furthermore, NMM respondents had a lower rate of completing at least secondary education (62%) than their RDD counterparts (87%) did.

Table 1. Descriptive statistics for survey households by research site

	Dong Anh	Phu Xuyen	Moc Chau	Total
Respondent characteristics				
Age	54.78	55.77	50.78	53.79
	(8.37)	(8.26)	(11.50)	(9.64)
Female (dummy)	0.90	0.75	0.91	0.85
	(0.31)	(0.44)	(0.29)	(0.35)
Completed secondary school (dummy)	0.70	0.64	0.44	0.59
	(0.45)	(0.49)	(0.50)	(0.49)
Completed high school or higher (dummy)	0.17	0.23	0.18	0.19
	(0.37)	(0.42)	(0.39)	(0.39)
Experience of agriculture (year)	35.87	38.61	32.09	35.51
	(9.08)	(12.32)	(12.57)	(11.58)
Experience of synthetic pesticide use (year)	29.62	26.93	26.18	27.64
	(6.35)	(8.82)	(8.34)	(7.95)
Household characteristics				
HH size (person/s)	4.20	3.07	3.60	3.64
	(1.41)	(1.40)	(1.29)	(1.44)
Members working in agriculture (person/s)	1.82	1.98	2.02	1.93
	(0.39)	(0.55)	(0.69)	(0.56)
Total farm size (ha)	0.22	0.38	0.81	0.46
	(0.11)	(0.70)	(0.77)	(0.64)
Number of plots (plot)	4.79	3.80	4.12	4.25
	(1.68)	(1.41)	(1.57)	(1.61)
% of farm income to HH income	72.98	76.14	84.22	77.65
	(24.40)	(28.11)	(18.15)	(24.19)
% of pesticide cost to total production cost	20.33	20.39	20.36	20.36
	(5.14)	(10.80)	(6.69)	(7.76)
Information sources				
Experienced pesticide poisonings (dummy)	0.20	0.36	0.40	0.32
	(0.41)	(0.49)	(0.50)	(0.47)
Attended training about pesticide safety (dummy)	0.76	0.41	0.62	0.60
	(0.43)	(0.50)	(0.49)	(0.49)
Learn through self-study (dummy)	0.18	0.16	0.02	0.12
	(0.39)	(0.37)	(0.15)	(0.33)
Seek advice from neighbors and friends (dummy)	0.57	0.30	0.67	0.51
	(0.50)	(0.46)	(0.48)	(0.50)
Seek advice from PPS/FU (dummy)	0.12	0.09	0.80	0.33
	(0.33)	(0.29)	(0.40)	(0.47)
Seek advice from retailers (dummy)	0.47	0.25	0.20	0.31
	(0.50)	(0.44)	(0.40)	(0.46)
Seek advice from media (dummy)	0.14	0.27	0.31	0.24
	(0.35)	(0.45)	(0.47)	(0.43)
Observations	49	44	45	138

Notes: Means are presented with standard deviations (SD) in parentheses. Observations with missing values were replaced by the sample average.

Table 1 also shows that the survey households are small-scale farmers with an average cultivated land size of 0.46 hectares. Moreover, small-scale farming has become more extreme due to plot fragmentation, particularly in peri-urban Dong Anh, where average households have their farmland divided into five plots. Nevertheless, farm households in northern Vietnam rely heavily on agricultural activities, with almost two people involved in farming per an average family size of 3.64, accounting for >80% of the household income. On average, local farmers have worked with artificial agrochemicals for almost 28 years, indicating their long-term dependence on pesticides for commercial vegetable production. In addition, pesticide costs account for approximately one-fifth of the total agricultural production expenditure, irrespective of region.

3.4. Pesticide use and health consequences in the study area

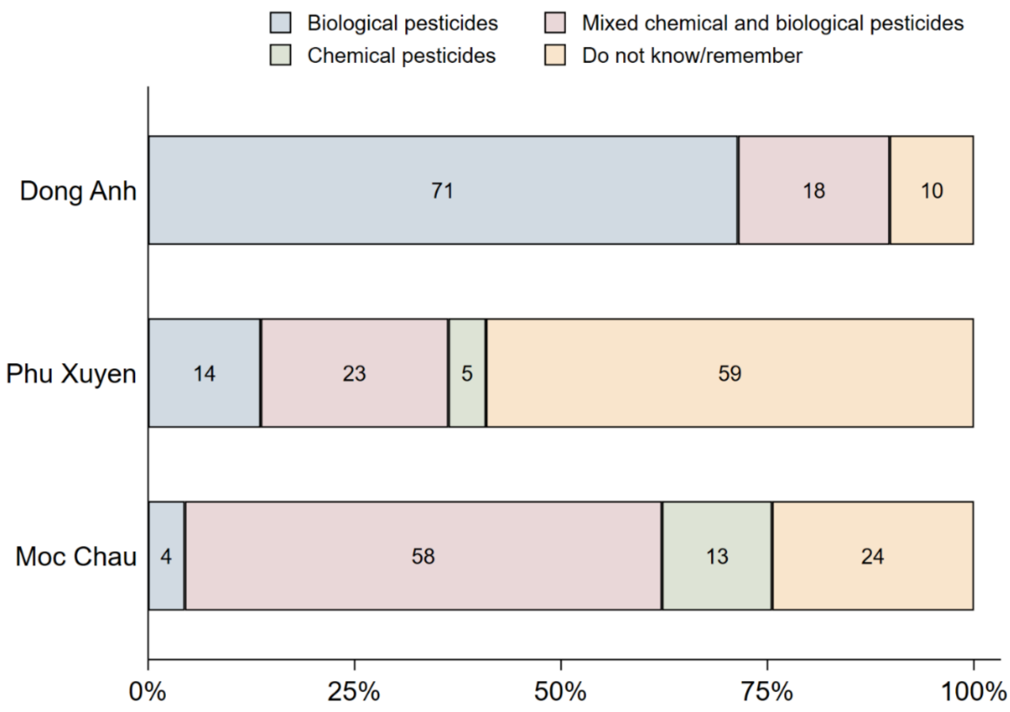


Figure 4. Pesticide types among the respondents by research site

Notes: The number of observations is 138.

Figure 4 shows the types of pesticides used by respondents to understand the status-quo of pesticide application in local agriculture. The results revealed significant variations in pesticide types across the study sites. The majority (71%) of peri-urban RRD farmers use biological pesticides, particularly in certified safe production areas. However, the use of biological pesticides is limited among farmers in the rural RRD and NMM regions. Qualitative interviews and field observations showed that these farmers prefer chemical products to biological pesticides because of their strong and long-lasting effects. Additionally, higher financial and labor costs due to more frequent applications required for biological pest control (5–7 days vs. 14 days) is another reason for the limited use of bio-pesticides, despite inconsiderable price differences with chemical pesticides.

The overuse and misuse of synthetic pesticides are also prevalent in research sites. For instance, 60% of rural farmers in the Phu Xuyen district do not know or remember pesticide types, accelerating the severity of pesticide misuse. In-depth interviews found that local farmers frequently apply double the recommended dosage on product labels, following retailers' advice. Another common reason for overuse is farmers' coping mechanisms, due to concerns about pesticide resistance and counterfeit products. Additionally, farmers regularly spray pesticides every 5–7 days, even in unnecessary cases such as the absence of insects and diseases on crops, or repeat the spraying if pest elimination is unclear after application. As the most common misuse, farmers randomly combine at least three types of pesticides based on their habits.

> *"Each farmer has their own secret mixing style based on their personal knowledge and experience."* (Pesticide retailer, Dong Anh District).

This mixed practice is prevalent among farmers, particularly in the NMM (Figure 4).

Pesticide misuse can lead to serious health consequences. The survey asked respondents about their prior experience with poisoning symptoms. Results showed that approximately a third of the respondents had experienced at least one pesticide poisoning symptom. The most common symptoms were weakness, headache, and excessive sweating after mixing and spraying of these chemicals. The data also show that elderly farmers have more experience with pesticide poisoning: three-quarters of poisoning cases occurred among farmers >55 years of age—those who worked with first-generation highly hazardous chemicals (e.g., Vofatoc, Metaphot, and Bi58) when synthetic pesticides were first introduced in Vietnam (Duc Vien & Van Hoi, 2009). Notably, numerous respondents mentioned unintentional poisoning and death resulting from improper disposal and re-entry of treated fields among their neighbors and acquaintances. Additionally, local farmers judge symptoms as the usual side effects of working long hours in a hot climate and thus acknowledge only insignificant causal links between pesticide contact and illness (Dasgupta et al., 2007; Matthews, 2008).

3.5. Farmers' knowledge, perception, and behavior concerning pesticide application

This subsection discusses farmers' knowledge and perceptions of pesticide health risks and protection behaviors while using chemicals. To verify the respondents' cognitive patterns, the survey elicited their agreement with various KAB statements related to pesticides using a five-point Likert scale (FAO, 2014; Schrader & Lawless, 2004). Specifically, knowledge questions reflect information on common exposure routes (e.g., dermal, inhalation, and ingestion) and the protective functions of PPE. The attitude and perception sections include statements on willingness to adopt PPE and the perceived health impacts of pesticide use on general agricultural workers and their families. Finally, the protective behavior portion consisted of general prevention practices and the usage of common PPE.

Table 2. KAB factors relating to pesticide safety among the respondents

	Mean	SD
*Knowledge**		
K1. Pesticides used in the field cause harmful effects on workers.	3.93	0.52
K2. Children and pregnant women are more vulnerable to pesticide exposure.	4.34	0.66
K3. Pesticides can enter the body through the skin.	3.43	0.68
K4. Ingested pesticides can `harm the health of farmers.	3.05	0.71
K5. Inhaled pesticides can harm the health of farmers.	4.09	0.60
K6. The use of PPE can prevent poisoning when spraying pesticides.	3.87	0.50
Knowledge score	0.00	1.52
*Attitude**		
Am1. I do not have to use a full set of PPE (reversed).	2.97	0.81
Am2. I think that PPE is expensive (reversed).	3.14	0.58
Am3. I do not want to spend money on health care relating to pesticide effects (reversed).	1.86	0.70
Ap1. Pesticide poisoning is common for farmers.	3.68	0.77
Ap2. Pesticides have negative impacts on family health.	4.20	0.67
Ap3. I worry about cancer associated with pesticide use.	4.23	0.59
Ap4. Wearing PPE is comfortable.	2.80	0.73
Ap5. Pesticides only affect pests and insects (reversed).	2.99	0.69
Ap6. It is important to use PPE while contacting with pesticides.	4.05	0.53
Attitude score	-0.00	1.52
*Protective practices***		
B1. I have a habit of recording pesticide use.	2.21	0.76
B2. Actively search for information on pesticide use and protective measures.	2.82	0.90
B3. Read pesticide label carefully before use.	3.65	0.67
B4. Have the first-aid kit ready.	2.32	0.69
B5. Keep children away from pesticide storage.	3.88	0.69
B6. Inform my family where I applied the pesticide.	3.81	0.62
B7. Avoid eating/drinking/smoking while spraying.	3.93	0.62
B8. Shower or wash with soaps right after spraying.	4.00	0.51
B9. Wash work clothes separately from home laundry.	3.79	0.72
Protection score	-0.00	1.88
*PPE use***		
PPE1. Use of thick and long trousers	4.55	0.50
PPE2. Use of thick and long sleeves shirt	4.55	0.50
PPE3. Wear face mask/shield	3.49	1.09
PPE4. Wear raincoat	3.20	0.69
PPE5. Use of long rubber gloves	3.58	0.70
PPE6. Use of protective glasses/goggles	1.93	0.94
PPE7. Use of long rubber boots	3.96	0.66
PPE8. Cover the head with a suitable hat	4.36	0.52
PPE use score	-0.00	1.75

Notes: PPE, personal protective equipment. All responses are measured on a five-point Likert scale. * 1-Strongly disagree to 5- Strongly agree. ** 1-Never to 5-Always.

Table 2 presents the average scores of the KAB statements, ranging from one to five points. The results show that average farmers have adequate knowledge of the potential impacts of pesticides on human health. Additionally, respondents understood the exposure route inhalation rather than oral and dermal exposure. Finally, most farmers recognized that PPE is effective against poisoning. To elucidate the process of knowledge formation, respondents were asked about their learning sources regarding pesticide safety. This survey question allowed for multiple answers, and Table 1 lists the selection percentage for each information source. The results showed that respondents perceived peer pressure from other farmers and neighbors (51%) as the most common safety information source, followed by governmental agencies such as PPS and FU (33%), and pesticide businesses (31%).

Turning to attitudes toward pesticide-associated risks, we discuss the perceptions of monetary and psychological costs relevant to protection against chemical exposure separately. The first questions Am1–Am3 in the attitude section of Table 2 ask about attitudes toward a willingness to pay for prevention practices. The results from these questions do not show a high willingness to pay for protection against pesticide-related health damage among survey respondents in northern Vietnam. The remaining six questions, Ap1–Ap6, are more about risk perceptions and attitudes toward mental costs to adopt prevention practices. The results show that respondent farmers worry about detrimental effects on their health (Ap2). Nevertheless, many respondents consider pesticide poisoning a common risk embedded in general agricultural practices, despite the perceived usefulness of protective tools (Ap1). Psychological barriers also appear high, since farmers acknowledge the inconvenience of using PPE while working with pesticides (Ap4).

Northern Vietnamese farmers self-reported inappropriate and uncompliant protective behavior despite their awareness of pesticide exposure severity and the preventive effectiveness of PPE. First, farmers rarely prepare records of agrochemical applications (B1) or first-aid sets for emergent cases (B4). Second, significant variations were observed in PPE use among respondents. Respondents' common PPE is long working clothes, rubber boots, and hats because of outdoor working conditions rather than pesticide application. In practice, farmers' self-protection varies depending on available materials and conventional customs. For example, female respondents prevent chemical inhalation by tying a piece of fabric cloth around the face to cover the mouth, despite the possibility of secondary exposure to pesticide droplets from saturated fabric. In contrast, few respondents used protective glasses while working with pesticides (PPE6). Furthermore, farmer focus group discussions revealed several barriers to safety compliance.

> "*There is no specialized shop for personal protection tools. Local farmers use only the available equipment. For instance, I usually wear sunglasses when applying pesticides.*"

> "*We only wear the upper part of the raincoat because wearing an overall [raincoat] in hot weather might lead to heat shock.*"

> "*Farmers prefer plastic single-use gloves [to the recommended rubber gloves], as they can easily tease the product's package off. Even with gloves, sometimes we might pull them off when opening the package.*"

In short, the significant constraints raised by the qualitative interviews are the unavailability of standard PPE, inconvenience while working in tropical weather, and reduced physical flexibility.

To test the role of knowledge and awareness as drivers of preventive behavior in the following section, principal component analysis was applied to aggregate responses to each statement for each KAB component. Next, the first principal component was used as the standardized score representing each KAB factor in the regression analysis. For instance, questions K1–K6 were aggregated to create a knowledge score. Table 2 shows the observed variations in the representative scores for each KAB component.

4. Results

4.1. Empirical specifications

We tested whether the KAB framework explains general protection actions (e.g., handwashing after spraying) and specific safety practices (e.g., PPE use) by running the following OLS regression:

$$Y_{ij} = \beta_K Kscore_{ij} + X_{ij}\beta_X + \alpha_j + \varepsilon_{ij} \quad (1)$$

where Y_{ij} is the outcome variable of household i in commune j. We used the protection behavior and PPE use scores as our outcome. $Kscore_i$ represents the aggregated knowledge score of household i in commune j. X_{ij} is a vector of household i's socio-demographic factors, such as the respondent's age and household size, which independently determine the outcome. In addition, because previous studies have highlighted the inaccessibility to proper protection as a key constraint for PPE adoption in developing countries (Palis et al., 2006; RCRD et al., 2015; Stadlinger et al., 2011), commune fixed effects α_j are added to account for contextual supply side constraints. Finally, ε_{ij} is an error term.

In Equation (1), β_K captures the overall impact of knowledge on safety behavior. Building on the KAB framework, we expect a positive and significant coefficient β_K. Additionally, the KAB model suggests that attitudes toward pesticide-related health risks are crucial for translating knowledge into behavior. To examine the role of attitude as a mediator, the aggregated attitude score ($Ascore_{ij}$) is added to the right-hand side of Equation (1):

$$Y_{ij} = \gamma_K Kscore_{ij} + \gamma_H Ascore_{ij} + X_{ij}\gamma_X + \alpha_j + u_{ij} \quad (2)$$

In this specification, γ_K captures the direct link between knowledge and outcomes after closing the channel via attitude. Hence, significant β_K and insignificant γ_K indicate that knowledge affects behavior only through risk perceptions, which is consistent with the classical linear progression proposed by the KAB model. Alternatively, the significance of γ_K suggests that knowledge plays an independent role. Finally, the insignificant coefficients γ_K and γ_H imply that neither knowledge nor attitude may lead to preventive behavior, suggesting other constraints hindering protection against pesticide-related health damage in this research context. The role of specific attitudes in protective behavior was further investigated by separately adding the attitude score based on questions regarding the willingness to pay for prevention practices (i.e., Am1–Am3) and the other attitude score based on questions regarding risk perceptions and mental costs of using protective gear (i.e., Ap1–Ap6). This auxiliary exercise can provide insights into which dimensions of attitudes are more influential in shaping protective behavior.

We acknowledge that the estimated coefficients in Equations (1) and (2) do not have causal interpretations because of unobserved omitted factors that invite endogeneity bias in the estimated coefficients of interest. Instead, our focus was limited to describing the statistical interconnections between the core components in the KAB framework.

4.2. Testing the KAB model

Table 3. OLS regressions of protective behavior on knowledge and attitude scores

	(1) Protection	(2) Protection	(3) Protection	(4) PPE use	(5) PPE use	(6) PPE use
Knowledge score	0.437***	0.273**	0.246**	0.260***	0.043	0.042
	(0.094)	(0.105)	(0.109)	(0.080)	(0.108)	(0.112)
Attitude score		0.284***			0.377***	
		(0.107)			(0.097)	
Attitude score (monetary)			-0.071			-0.069
			(0.136)			(0.128)
Attitude score (perceived)			0.330***			0.378***
			(0.112)			(0.113)
Age	0.017	0.014	0.013	0.035***	0.031**	0.029**
	(0.015)	(0.014)	(0.014)	(0.012)	(0.012)	(0.012)
Female (dummy)	0.494	0.551	0.553	-0.006	0.070	0.059
	(0.366)	(0.348)	(0.350)	(0.318)	(0.319)	(0.318)
Completed secondary school	-0.056	-0.153	-0.132	0.295	0.166	0.211
(dummy)	(0.347)	(0.342)	(0.341)	(0.329)	(0.326)	(0.335)
Completed high school or higher	1.499***	1.220***	1.193**	0.744*	0.373	0.394
(dummy)	(0.445)	(0.446)	(0.457)	(0.436)	(0.429)	(0.454)
HH size (person/s)	0.217**	0.201**	0.194**	0.092	0.071	0.067
	(0.085)	(0.081)	(0.077)	(0.086)	(0.080)	(0.082)
Total farm size (ha)	0.201	0.242	0.252	-0.056	-0.001	-0.002
	(0.176)	(0.160)	(0.177)	(0.420)	(0.384)	(0.419)
Commune dummies	YES	YES	YES	YES	YES	YES
R squared	0.42	0.44	0.45	0.38	0.43	0.43
N	138	138	138	138	138	138

Notes: Robust standard errors are in parentheses. The reference category for the education dummies was completed in primary school or lower. PPE, personal protective equipment. BP, biological pesticide. ***p<0.01, **p<0.05, *p<0.1.

Table 3 shows regression results for general protection behavior in columns (1)–(3) and PPE use in columns (4)–(6). Estimation results for Equation (1) in columns (1) and (4) find that the overall associations of knowledge with behavior are statistically significant for farmers' protection behavior and protective gear use while applying pesticides on farms. The estimated coefficient on knowledge scores is also economically significant: a 1 SD increase in knowledge score (1.52) would boost the protection score by 0.663, equal to 0.352 SD. The same numerical experiment implies an increase in the PPE use score by 0.395, equal to 0.226 SD. Therefore, knowledge is pivotal in motivating general protection actions and safety practices specific to chemical exposure from statistical and economic significance perspectives, consistent with our prior expectations.

The specifications in columns (2) and (5) shut down the pathway via the attitude component by adding the attitude score to the variables on the right-hand side. The regression results for Equation (2) show stark contrasts in the role of knowledge between general protection and PPE use. First, the coefficient of the knowledge score is still significant, even after conditioning on the aggregated attitude score in column 2. This result implies that knowledge has an independent association with general protective behavior, while attitude also plays a mediating role, since its coefficient is significant and the knowledge coefficient shrunk to approximately 62% (=0.273/0.437) in magnitude compared to the counterpart in column (1). Additionally, the attitude coefficient is comparable in magnitude to the knowledge coefficient. Thus, while the regression results for general protective behavior support the KAB model with the independent role of knowledge, linear progression does not fully explain the empirical regularity.

Second, the regression results in column (5) show that the estimated knowledge coefficient is no longer significant after shutting down the attitude channel. Since the attitude coefficient is statistically significant, the empirical patterns in PPE use support the linear progression model. Thus, risk perceptions completely mediate the relationship between knowledge and PPE adoption. This important finding suggests that policy interventions aimed at disseminating PPE use through knowledge improvement require altering risk perceptions among participants, as changes in risk perceptions are the only pathway through which knowledge induces behavioral changes.

Therefore, the role of attitude in shaping protective behavior is further considered. To address this, we disaggregate the attitude score into the part attributed to the willingness to pay for protection and the part attributed to risk perceptions and mental costs of using protective gear and add them as separate regressor. Columns (3) and (6) present the regression results for this additional regression exercise. Irrespective of outcomes, the regression results highlight significant roles in farmers' risk perceptions rather than their willingness to pay for protection against pesticide-related health risks. Thus, policy interventions to drive behavioral changes when working with pesticides should improve pesticide risk perception among local farmers.

Coefficients on respondent characteristics also provide informative patterns for understanding farmers' efforts to prevent pesticide-related health risks. For example, even after controlling for the knowledge score, high school graduates had a higher score for general protection practices than other education categories, consistent with previous studies underscoring the contribution of formal education (Akter et al., 2018; Sam et al., 2008; Stadlinger et al., 2011). In addition, female farmers comply more with recommended general protection actions than male farmers do, although the coefficients are never significant at the conventional level across specifications. Finally, the results show that older generations are more likely to adopt PPE than are young farmers. A possible explanation is that older farmers are more cautious because they have a higher chance of experiencing severe poisoning themselves or from other farmers than young farmers. Pesticide types may provide an alternative explanation: the pesticides that older generations are familiar with are chemicals with strong odors perceived as the primary exposure route. This pesticide feature may work as a persuading factor for older generations to wear PPE as a coping mechanism for chemical pesticides. In contrast, new biological pesticides which young farmers would be familiar with do not have chemical smells and thus have less chance of severe poisoning, accounting for their lower compliance with safety measures.

4.3. What shapes knowledge and risk perceptions?

Our estimation results highlight the importance of knowledge in protection against pesticide-related health risks. Irrespective of contextual differences, informed individuals are more likely to follow recommended protective practices against pesticide-related health risks. For general protection actions, knowledge has an independent path and an indirect channel via attitudes toward the behavior of interest. Regarding protective gear use, knowledge affects adoption only through risk perception. The natural question is in what way do local farmers learn about pesticide safety. Furthermore, we found that beliefs about health risks lead to general self-protective behavior and PPE use. While farmers' knowledge is expected to be the primary determinant, as indicated by the KAB model, other factors may have independent contributions to belief formation.

Given these motivations, knowledge and attitude scores were regressed on personal experiences and information sources. Experiences include past pesticide poisoning and training attendance regarding pesticide use and safety. While the latter is indirect, the former is an example of direct experience expected to have a strong correlation. By adding information sources about pesticide safety as a regressor, the relative importance of outside stakeholders (e.g., fellow farmers, governmental organizations, pesticide retailers, and media) and learning-by-doing in the knowledge acquisition process were also examined.

Table 4. OLS regressions of knowledge and attitude scores on experiences and information sources

	(1) Knowledge score	(2) Attitude score	(3) Attitude score
Experiences			
Pesticide poisonings (dummy)	0.874***	0.459*	0.030
	(0.262)	(0.246)	(0.206)
Pesticide safety training (dummy)	0.296	0.405	0.259
	(0.294)	(0.262)	(0.234)
Information sources			
Self-study (dummy)	-0.527	-0.006	0.253
	(0.394)	(0.318)	(0.261)
Neighbors and friends (dummy)	0.515*	0.537**	0.284
	(0.267)	(0.252)	(0.207)
PPS/FU (dummy)	0.121	0.385	0.325
	(0.400)	(0.341)	(0.275)
Retailers (dummy)	0.685**	0.762***	0.426**
	(0.284)	(0.261)	(0.190)
Media (dummy)	1.003***	1.008***	0.515**
	(0.328)	(0.294)	(0.218)
Knowledge score			0.491***
			(0.098)
Commune dummies	YES	YES	YES
R squared	0.33	0.45	0.61
N	138	138	138

Notes: Robust standard errors are in parentheses. The same set of household and respondent controls, as shown in Table 3, are included but not reported. ***p<0.01, **p<0.05, *p<0.1.

Table 4 displays regression results. Results in columns (1) and (2) find that previous pesticide poisonings boost both knowledge and attitude scores. However, the coefficient on pesticide poisoning experiences is no longer significant after conditioning the knowledge score (Column 3). Thus, direct health shocks make farmers aware of health risks mainly through improving relevant knowledge to prevent further shocks. In contrast, no significant association between pest management training attendances and knowledge and attitude scores was found.

Regarding the role of various stakeholders, columns (1) and (2) illustrate similar patterns between knowledge and attitude factors. In particular, information and advice from peers, retailers, and the media affect farmers' safety knowledge and pesticide-related health risk perceptions. Because the coefficients of the latter two sources are still statistically significant even after controlling for the knowledge score, these information sources have an independent pathway to the attitude score (column 3). Such direct effects imply that these channels may easily manipulate farmers' beliefs, calling for careful policy design with their involvement. In contrast, advice from governmental organizations (e.g., PPS/FU) contributes neither knowledge nor belief formation. Thus, government agencies have little influence on farmers' preferences for personal protection when working with agrochemicals.

Table 4 also demonstrates that interpersonal agents outweigh internal sources since the coefficients on self-study are not significant. Finally, we found no significant relevance of demographic factors such as sex and age in knowledge and belief formation processes, except that high school graduates showed better risk perceptions (not reported).

5. Discussions

Our empirical analysis showed that the linear progression proposed by the KAB model explains farmers' PPE use. In addition to the linear progression via risk perceptions, we found an independent role for knowledge in general safety practices against the adverse health effects of pesticides. Furthermore, we identify previous poisoning experiences and advice from peers, retailers, and the media as essential for farmers' learning processes. This discussion relates our empirical findings to the previous literature to hint at practical policy implications.

5.1. Knowledge as a driver for improved protective practices

In theory, knowledge improvement alone may be insufficient to facilitate behavioral changes among farmers. Previous studies have provided supporting evidence for this (Akter et al., 2018; Berni et al., 2021; Govindharaj et al., 2021). For instance, Akter et al. (2018) showed that insufficient protective behaviors when using pesticides were attributed to inadequate knowledge and poor access to safety training among vegetable farmers in Bangladesh. Nevertheless, this was not the case in our research context in northern Vietnam. Our empirical test of the KAB model confirmed the vital role of knowledge in determining farmers' perceptions and actual safety practices. This result also implies that access to PPE is not a significant constraint, in contrast to previous reports (Sharifzadeh et al., 2019; Walton et al., 2016). Using conventional clothing and items as substitute for PPE among our survey farmers would partially explain this contrast. Instead, the provision of PPE may not ensure accurate and regular compliance. Thus, policy interventions should target the demand side, rather than the supply side, by providing accurate information on pesticide safety that leads to sufficient improvement in risk perceptions, and thus, their PPE adoption.

5.2. Governmental training as a channel to improve knowledge

However, our estimation results suggest the ineffectiveness of current government training in farmers' knowledge formation processes. These discouraging results are consistent with the unclear influence of pesticide-related training on actual practices among participants reported in previous literature on their impact evaluations. For example, Sam et al. (2008) found that the effects of training and educational campaigns on safe practices in South Africa rapidly faded one month after the course. Similarly, Schreinemachers et al. (2015) showed that IPM training in farmer field schools for Vietnamese rice farmers improved farmers' knowledge but did not reduce insecticide application. Finally, Sharifzadeh et al. (2019) argued that attending training on safe pesticide management did not influence farmers' safety behavior, indicating impractical content and ineffective training design. Another important finding from our regression analysis is that risk perceptions always mediate the link between risk awareness and behavior.

Given our empirical evidence for linear progression, the training design should have a learner-centered approach to persuade farmers to alter risk perceptions and encourage their motivation to apply knowledge to practice.

In our research context, the government's agricultural training is through FUs in rural and mountainous sites and PPSs in peri-urban safe vegetable production sites in the RRD. However, considering their significant contributions to belief formation, it would be more effective for governmental organizations to leverage mass media and the Internet as information channels to update information and upgrade knowledge among farmers. Because our results also imply the risk of belief manipulation by the media, what to deliver through these channels requires careful consideration.

5.3. Peers and retailers as knowledge diffusion channels

Our results identify advice from peers as a significant source of information that contributes to knowledge formation. In the research context, farmer groups (ACs/AGs) are a common channel for exchanging information and experiences related to pesticide safety among fellow farmers. This finding is in line with previous studies that emphasized the positive impact of being a member of a farming group on improving knowledge of health risks and usage of personal protection (Feola & Binder, 2010; Jones et al., 2009; Perry et al., 2000; Sellare et al., 2020). Therefore, policy interventions should leverage ACs/AGs as a channel for diffusing information to protect agricultural workers' health and well-being.

The regression analyses found that retailers also play a critical role in knowledge diffusion and risk perception improvement among local farmers. The significant influence of retailers is consistent with previous studies in developing countries (Bhandari et al., 2018; Hoi et al., 2016; Schreinemachers et al., 2015). Moreover, our results found an independent influence on risk beliefs, not via knowledge channels. This finding suggests the risk of easy manipulation of beliefs, as Van Hoi et al. (2009) suggested, and retailers' policy involvement may backfire on farmers' health. For example, qualitative interviews report pesticide companies' exaggeration of biopesticides' safety for human health (e.g., eating biopesticides directly in front of customers), facilitating farmers' misunderstandings about products' safety and preventive needs. Since retailers have incentives to boost their sales without informing users of necessary protection, policies designed with retailers' active involvement warrant governmental regulations and monitoring systems to harness their market behavior.

6. Conclusions

Safe pesticide use is the product of a complex set of cognitive and contextual predictors. This study investigates complicated safety decisions among vegetable farmers in northern Vietnam by testing the linear progression of knowledge into actions via perceptions as an explanatory model. We find that knowledge plays significant role in general safety actions and specific protection against pesticide-related health risks (i.e., PPE use). More importantly, knowledge affects PPE use only through risk perceptions. Thus, attitudes played a mediating role in the nexus between risk awareness and protective but uncomfortable protection. This empirical finding suggests that policy interventions aimed at disseminating PPE use through knowledge improvement require altering participants' risk perceptions. Overall, the model fitness of the KAB framework depends on the safety practices of interest, offering a potential explanation for the reported mixed results in the pesticide safety literature. Our main contribution to the literature is the provision of a general framework for empirically testing the KAB model.

Governments worldwide often emphasize protecting consumer safety and health (Chèze et al., 2020; FAO & WHO, 2020) while directly placing the primary responsibility of safe and healthy agrochemical use on agricultural producers. However, small-scale farmers in developing countries have inadequate knowledge and perception of pesticide-associated risks. Indeed, our survey illustrates the vulnerability of small-scale farmers in northern Vietnam to pesticide exposure due to the overuse and misuse of hazardous agrochemicals, particularly at rural sites. Governmental interventions may help farmers facilitate safe pesticide use. However, our results indicate that current training programs do not effectively achieve this purpose. Alternatively, media and retailers can play a role in diffusing knowledge to local farmers, while the observed significant influence on belief formations from agrochemical retailers and media underlines the risk of easily manipulated perceptions. Combining these results, as a policy implication of the current study, interventions to improve farmers' self-protection should incorporate participatory approaches that influence risk beliefs and the active involvement of business sectors and media with monitoring systems to harness their market behavior and unintended consequences into training design. This study also highlights the potential of grassroots farmer groups and cooperatives as promising information distribution channels.

While this study offers far-reaching implications concerning safe pesticide use based on a field survey designed for specific research purposes, there are several limitations. First, the results presented in this study were based on a small sample from certain areas in northern Vietnam. Despite its representativeness for the region, the external validity of the results may be insufficient to generalize them to other research contexts. Further data collection that allows us to compare protective behaviors across various settings is required. In addition, the empirical assessment of the KAB model rests on farmers' self-reported responses, which unobserved confounders (e.g., cultural factors) may affect, instead of objective measures such as pesticide use amounts (Schreinemachers et al., 2015, 2017; Walton et al., 2016). Additionally, pesticide usage and poisoning among farmers may be sensitive topics to discuss with local farmers, pesticide retailers, and governmental agencies because of their concern about the problematic pesticide-intensive image of their crops. Hence, an attempt to collect subjective and objective measures and compare the results is a promising avenue for future studies.

Declaration of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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