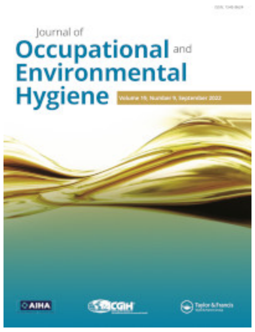

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Assessment of pesticide safety knowledge and practices in Vietnam: A cross-sectional study of smallholder farmers in the Mekong Delta

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ABSTRACT

Over the past three decades, the Vietnamese Mekong Delta has experienced a significant increase in agricultural productivity, partly achieved through increased agrochemical use. To abate negative effects on human and environmental health, several national programs were launched to enhance safer pesticide use. This study aimed to assess the patterns and relationships of official sustainable agriculture educational programs, pesticide safety knowledge, and practices of smallholder farmers in the Mekong Delta. A cross-sectional survey was conducted with 400 smallholder farmers from three communes in Thoi Lai district (Can Tho province) from March to May 2020. Twenty-four questions on pesticide safety knowledge and practices were used to identify traits using latent class analysis. Adjusted generalized linear regression was used to assess determinants of pesticide safety knowledge and estimate associations of pesticide safety knowledge with pesticide practices. 96.2% of participants have used at least one WHO class II pesticide during the past year while the use of specific personal protective equipment was limited mainly due to unavailability (37.0%) or discomfort (83.0%). High education (Odds Ratio (OR), 95% Confidence Interval; 3.84, 1.70–9.45), exposure to official educational programs (1.87, 1.13–3.12), peer-to-peer knowledge exchange (3.58, 2.18–6.00), and learning from governmental extension services (2.31, 1.14–4.98) were positively associated with increased pesticide safety knowledge. Compared to poor practices, pesticide safety knowledge was increasingly positively associated with intermediate (1.65, 1.02–2.66) and good pesticide practices (8.96, 2.58–31.12). These findings highlight the importance of school education and educational programs, access to PPE, and addressing discomforts of PPE to improve the protection of farmers from pesticide exposures. Simultaneously, pesticide market authorization processes should be reconsidered to promote the authorization of less toxic products. Further in-depth studies on the nature of pesticides used, nonuse of personal protective equipment, and effectiveness of educational programs will further define leverage points for safer pesticide use.

KEYWORDS
Agriculture; occupational health; personal protective equipment; pesticide knowledge; pesticide practice; pesticide safety

Introduction

Over the past three decades, Vietnam has undergone a remarkable transformation from a country suffering from food insecurity to becoming one of the world's leading agricultural export countries (World Bank 2016; Nguyen 2020). This change was supported by the opening of the Vietnamese market to the import of pesticides and fertilizers during the Green Revolution in the 1980s (Hoi et al. 2016). Nowadays, agriculture constitutes the livelihood of almost half of Vietnam's population and almost 40% of the country's land area is utilized for agricultural production (Nguyen 2020). Despite the positive impacts of higher agro-chemical use, the increase of agro-inputs contributed to environmental pollution, soil infertility, and a decrease in biodiversity (Nguyen 2017; Berg and Tam 2018). Ground- and drinking water were found to be

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polluted and high levels of pesticide residues were identified in food products (Lamers et al. 2011; Toan et al. 2013; Chau et al. 2015). This persistent exposure resulted in detectable pesticide residues in human blood, breast milk, and urine, which is known to result in a range of negative health effects (Dasgupta et al. 2007; Nguyen et al. 2010; Phung et al. 2012; Richter et al. 2015; Lam et al. 2017). To reduce pesticide exposure and make export products more attractive to the Western market, the Vietnamese government introduced more sustainable agricultural practices (Van Hoi et al. 2010). Thus, during the past decade, the government implemented several initiatives for promoting sustainable agricultural practice (Dien 2019; Hoi et al. 2016; Nguyen 2017; Pham and Smith 2013; Phong 2011). This included educational programs aimed at reducing pesticide and fertilizer use, optimizing water use, and preventing harvest losses, along with promoting certified seeds and increasing productivity (Nguyen 2017). However, studies on the impact of such educational programs on good agricultural practices were mostly observational in nature and inconclusive (DeRoo and Rautiainen 2000; Daam et al. 2019; Coman et al. 2020). Studies involving peers in knowledge transfer and community-based approaches showed beneficial behavioral changes, whereas studies focusing on information transfer only could not demonstrate such changes (Salvatore et al. 2009; Coman et al. 2020).

Understanding farmers' pesticide-related knowledge, attitudes, and practices (KAP) is crucial to assessing health and environmental risks, and setting the basis to promote policy changes for the mitigation of the risks identified (Schreinemachers et al. 2017). Previous studies have investigated pesticide practices and perceptions of Vietnamese farmers (Van Mele et al. 2001, 2002; Hoai et al. 2011; Phung et al. 2013; Nguyen et al. 2018). Inaccessibility to personal protective equipment (PPE) and a lack of pesticide-related knowledge were identified the as main reasons for farmers' insufficient occupational safety (Phung et al. 2013). Pesticide-related knowledge was usually acquired through the farmer's own experience with pests and diseases (Houbraken et al. 2016). But despite educational efforts targeting farmers, poor practices of pesticide use and pesticide handling continued to be documented (Van Mele et al. 2001, 2002; Hoai et al. 2011; Phung et al. 2013; Schreinemachers et al. 2017; Nguyen et al. 2018). This includes poor pesticide storage, pesticide application methods that differed from the product label, and improper container disposal (Lamers et al. 2011; Thuy et al. 2012; Toan et al. 2013; Hoi et al. 2016; Nguyen 2017).

There are only a few studies investigating pesticide practices related to KAP of smallholder farmers in the Mekong Delta since the Vietnamese government started to promote sustainable farming in the early 2000s (Van Mele et al. 2001, 2002). To our knowledge, the impact of agricultural educational programs has so far not been researched in this setting. The present study pursued two main research objectives: (i) to describe pesticide-related knowledge and practices (K&P) of smallholder farmers in the Mekong Delta; and (ii) to assess determinants of pesticide safety knowledge and estimate associations of pesticide safety knowledge with pesticide practices.

Methods

Study area and population

This study included three communes (Trường Xuân, Trường Xuân B, and Thới Tân) located in the Thới Lai district in Cần Thơ province of the Mekong Delta, southern Vietnam (Figure 1). The district covers an area of 267 km^2 with 108,605 inhabitants in 2020 (Can Tho Statistics Office 2021). Farming is the main source of income for 34.9% of the population, whereas farmers predominantly cultivate rice (189.7 km^2) and fruits (20.6 km^2) (Can Tho Statistics Office 2021). The study population consisted of farm owners and farm workers who were at least 18 years old. Additionally, study participants must have planted crops, applied pesticides, and lived and worked in one of the study communes for 12 months previous to data collection.

Study design and sample size

This study was a cross-sectional questionnaire survey that took place from March 13th to May 5th, 2020 (including a 1-month break due to Vietnamese COVID-19 restrictions). Half of the study participants were expected to fall into more favorable categories of the main variables of interest (i.e., high pesticide safety knowledge or at least intermediate pesticide use practices) estimating the appropriate sample size of N = 400 with a precision of 5.0% (Naing and Winn 2006).

Recruitment and field procedures

The questions of this K&P survey were previously used in low- and middle-income countries (LMICs) with smallholder farmers and were adapted to the context of Vietnam (Schreinemachers et al. 2017; Fuhrimann et al.

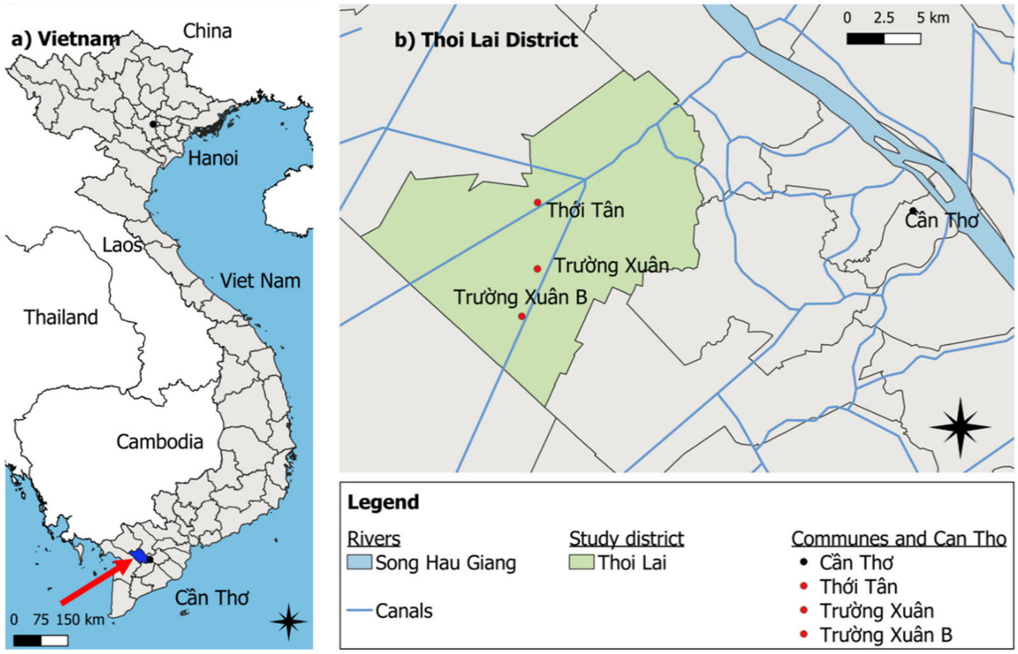

Figure 1. Map of Vietnam with the Can Tho province marked in dark blue (left) Thoi Lai District, with the three study communes Trường Xuân, Trường Xuân B, and Thới Tân (right).

2019; Staudacher et al. 2020). Before piloting, the questions were translated from English to Vietnamese with back translation to English and reviewed by three Vietnamese native speakers. The survey was programmed with the software Open Data Kit (Get ODK Inc., http://opendatakit.org) and uploaded to tablet PCs. The survey was piloted for cultural and language acceptability before data collection with 22 smallholder farmers from the study communes. The local field staff spoke English. However, to ensure understanding during the training and the data collection, a translator accompanied the team throughout the study period.

Due to difficulties in obtaining access to the respective registries, the number of farming households per commune was retrieved from the respective commune representatives. The number of farmers per commune was sampled proportionally to the number of farming households per commune (Trường Xuân = 2,077, Trường Xuân B = 1,703, Thới Tân = 1,225). For each day of data collection within a commune, one household was chosen randomly. The trained local field assistant responsible for recruiting participants started by visiting the selected household and inquiring about eligibility. If the household was eligible, it was included in the survey. Upon completion of the first household, the field assistant continued with the neighboring households in a transect walk. In case the household was not eligible, the field assistant continued directly with the neighboring households to assess eligibility and recruit one self-selected person per household.

Variables

Standard demographic and socioeconomic information of all participants were collected in the K&P survey (Supplementary Table 1). This included gender, age, marriage status, average monthly income, and education. The latter was classified into three levels, named after the highest educational attainment reached: (i) primary school (no schooling or completion of primary school), (ii) secondary school (completion of secondary school), and (iii) minimum of high school (completion of high school or higher education).

Farm characteristics

Farming experience was defined as the duration from the first year of farming up to the time of the survey. Farm size was included in hectares (ha). Having completed any educational program in farming was defined as having received at least one training from someone else except family members and peers. This initial overview question was used to determine how many farmers have ever received any agricultural education. Whether a respondent ever attended an official educational program in agriculture was defined as having taken part in any previous educational program within official Vietnamese initiatives (Table 1) (VietGAP 2014; Nguyen 2017). In addition, exposures to the following sources of pesticide information were determined: government extension workers; radio; television; newspapers; agricultural input (agro-input) dealers; peers and family; personal experience; non-

Table 1. Agricultural educational interventions identified as official educational programs in this study.

Abbreviation	Name	Organization
1M5R	One Must Do—Five Reductions	International Rice Research Institute (IRRI) and the World Bank
3I3R	Three Reductions—Three Increases	Vietnamese Ministry of Agriculture and Rural Development (MARD)
GAP	Global Good Agricultural Practice	Food and Agriculture Organization of the United Nations (FAO)
VietGAP	Vietnamese Good Agricultural Practice	MARD
IPM	Integrated Pest Management	Not applicable

governmental organization (NGO) representatives; researchers; or information on the pesticide container.

The place of pesticide acquisition and reasons for not using PPE were multi-item questions (Supplementary Table 2). A list of the 16 most frequently used pesticide products identified by the farmers union and local agro-input dealers was provided to assess specific pesticides used by the participants. The list detailed the commercial names, active ingredients, and pictures of the product during the survey. To complement the list, participants were asked to state any other products which they have used frequently during the past year.

Pesticide safety knowledge and practices

Pesticide-related safety knowledge, henceforth called knowledge, was assessed based on six dichotomous general knowledge questions about pesticides and three questions on the identification of pesticide safety pictograms (Supplementary Figure 1) based on the questionnaires used by Schreinemachers et al. (2017), Fuhrimann et al. (2019), and Staudacher et al. (2020). The general knowledge questions enquired whether: (i) pesticides can enter the body through the skin; (ii) herbicides are toxic for humans; (iii) drinking alcohol after spraying helps to eliminate side effects of pesticides; (iv) empty pesticide containers can be reused; (v) washing pesticide equipment in ponds or rivers negatively affects water quality; and (vi) whether good pesticides kill insects immediately. The pictograms used were "Lock away and keep out of reach of children," "Dangerous/harmful to fish" and "Toxic," with the response options being wrong, partially correct, or correct. Participants' answers were rated partially correct if they stated elements of the fully correct answer.

Pesticide-related farming practices were assessed using multi-item questions on access to and frequency of use of agricultural PPE (Supplementary Table 2) (Staudacher et al. 2020). Contextualized PPE options included in the study were gumboots, long gumboots (reaching over the knee), rubber apron, poncho, overall, surgical mask, respirator, cloth face covering, gloves, and helmet with face shield. In this study, any type of air-purifying respirator, removing aerosols, vapors, or gases from the air, was labeled as a respirator. PPE related to sun protection, such as the use of long pants and long-sleeved shirts, were excluded from the analysis. Availability of PPE was a general inquiry, not differentiating different types of PPE, or whether a farmer could access the available PPE (e.g., financially, spatially). Hygiene practices variables included: (i) practicing hand washing; (ii) changing clothes; or (iii) bathing or showering immediately after pesticide application. Storage of pesticides was defined as the farmer storing pesticides in a separate storage room inside their house or a separate storage room outside their house.

Statistical analysis

For descriptive analysis, variables were reported as proportions and means with standard deviations (SDs). Comparisons between communes were tested with χ^2 or Kruskal–Wallis-test where appropriate. Using the large set of multi-item questions on pesticide safety knowledge (nine questions) and pesticide-related practices (10 farming, 3 hygienic, 2 storage questions), Latent class analyses (LCA) were run using generalized structural equation modeling to identify latent traits of (i) knowledge and (ii) pesticide practices using the respective sets of variables. Dummy variables were used for the presence or absence of practices (use vs. no access or no use) and similarly for general knowledge items (correctly answered vs. not). Pictogram knowledge items were entered categorically to include information on partially answered questions. To identify the most appropriate class solution (number of unobserved groups), testing continued up to the class solution where model non-convergence occurred. Then, the model with the best fit based on the Bayesian Information Criterion was selected, which was deemed most appropriate (Nylund et al. 2007).

Associations of farmers' characteristics with knowledge and knowledge of pesticide practices were estimated using generalized linear regression modeling. Covariates were selected according to a Directed Acyclic Graph (DAG) describing the variable dependencies (Supplementary Figures 2 and 3) of all variables identified as relevant. To estimate the association of official educational programs/additional sources of information (received training and knowledge from peers and governmental extension services) with knowledge, the model was adjusted for education (primary school, secondary school, minimum of high school), age (years), gender (male/female), and farm size (hectares). Due to information on a variety of additional sources of pesticide information, a forward stepwise approach was used to select relevant variables to be included in the final model to avoid multi-collinearity issues. To estimate the unbiased association of knowledge with pesticide practices, the minimal adjustment set identified with the DAG used in the multinomial model was age, farm size, gender, and socio-economic status (monthly income per person per household). All models were additionally adjusted for the commune to account for geographical differences, even though the communes were located in very close proximity to each other. Models were clustered per day of data collection to assess the potential impact of the sampling strategy; clustered models did not deviate from the unclustered models (data not shown).

To explore whether the impact of official educational programs on knowledge was dependent on school education, the main model of farmers' characteristics on knowledge was run (i) stratified by a primary school, secondary school, and a minimum of high school education or (ii) with a multiplicative interaction term of primary school vs. secondary school or a minimum of high school education and official educational programs. All statistical analyses were computed with the software R (version 4.0.1, R Core Team, Vienna) and the latent class analysis was computed using the generalized structural equation package in Stata 16 SE (StataCorp LLC, College Station, TX). DAGs were computed using the software DAGitty (J. Textor, Tumor Immunology Lab, and Institute for Computing and Information Sciences, Redboud University Nijmegen) (Textor et al. 2016). Statistical significance was measured at a 0.05 level.

Results

Participant characteristics

Four hundred farmers from three communes in the Thới Lai district participated in the survey and all of them completed it. With our sampling strategy, 8% of the farming community in each commune participated in the survey (Table 2).

The socio-demographic characteristics across the three communes were similar among the survey participants (Table 2). The smallest municipality (Thới Tân) differed significantly from the other two communes in four survey participant characteristics: The mean age (53.2 years) was significantly higher and farming experience was longer compared to the two other communes. More women from this commune participated in the survey (11.5%) compared to Trường Xuân (7.1%) and Trường Xuân B (2.9%). In addition, the mean farm size in Thới Tân (1.3 ha) was significantly smaller compared to the mean farm size in Trường Xuân B (2.0 ha).

Table 2. Study population overview depicting mean with the standard deviation (SD) and percentage of participants.

Characteristic		Trường Xuân (n = 168)	Trường Xuân B (n = 136)	Thới Tân (n = 96)	*p*-value	Total (n = 400)
Age (years)	Mean (SD)	48.8 (12.2)	47.6 (12.2)	53.2 (12.6)	0.003	49.5
Men	Percent	92.9	97.1	88.5	0.038	93.3
Married or cohabitation	Percent	96.4	96.3	97.9	0.760	96.8
Years in commune	Mean (SD)	41.0 (15.2)	44.7 (13.2)	45.8 (15.4)	0.066	43.4
Able to read and write	Percent	98.8	98.5	94.8	0.217	98.0
Completed no or primary school	Percent	45.3	33.8	42.7	0.001	40.8
Completed secondary school	Percent	41.0	47.8	45.8	0.048	44.5
Completed high school or higher	Percent	13.7	18.4	11.5	0.054	14.8
Farm size (ha)	Mean (SD)	1.7 (1.4)	2.0 (1.6)	1.3 (0.8)	0.003	1.7
Years of farming experience	Mean (SD)	23.2 (11.0)	22.4 (14.4)	27.8 (14.4)	0.005	24.0
Any educational program in farming	Percent	64.9	67.7	67.7	0.843	66.5
Type of official educational program:	Percent					
IPM		39.3	42.6	29.2	0.103	38.0
1M5R		27.4	22.1	17.7	0.186	23.3
Global GAP		3.0	0.0	2.2	0.139	1.8
VietGAP		7.1	5.1	6.3	0.775	6.3
3R3I		34.5	45.6	43.8	0.112	40.1
Average income per month per person in a household (in Mio. VND)	Mean (SD)	2.2 (1.4)	2.8 (3.1)	2.6 (2.4)	0.459	2.5

The majority of farmers (83.8%) purchased pesticides from an agro-input dealer in the area, while 22.0% of the farmers visited agro-input dealers in the nearby larger city, Cần Thơ City. Some farmers (7.5%) bought pesticides from both dealers in the area and Cần Thơ City. The farmers spent an average of 34% of total agricultural expenditures for pesticides. Almost all of the farmers (96.2%) had used at least one WHO class II pesticide during the past year (Table 3) (WHO 2020). Further, at least two pesticides of WHO class Ib were identifiable from pesticide names the participants remembered using during the past year. These pesticides were Dichlorvos, reported by 5.0%, and Triazophos reported by 3.0% of the 400 participants. A total of 21.0% of the farmers reported using organic or biological pesticides in large amounts. However, none of these farmers used exclusively non-synthetic pesticides. For every pesticide presented to farmers using the commercial name, active ingredient, and showing a picture of the commercial product, there were always farmers who were unsure whether they have used them, with an average of 24.2% of farmers in doubt (see Table 3). The number of participants not recognizing pesticides differed greatly between the different pesticides.

The use of specific PPE was generally very limited except surgical masks or cloth face coverings (62.0%) and gloves (36.8%) (Figure 2). The least used items were rubber aprons and respirators, which only 0.3% and 1.0% of participants stated to utilize, respectively. When asked why they do not wear PPE, 83.0% of the farmers responded that it is not comfortable. Other reasons were that the PPE is not available (37.0%) or that the participants did not care about wearing PPE (10.8%). Access to PPE was assessed separately for each PPE used in the survey and indicated the possibility to use the PPE if a farmer wanted to. Access to PPE varied from 1.3% for rubber aprons to 97% for surgical masks. Only 10.0% of the farmers reported to drink during application, whereas even less (1.5%) ate during this time. After the use of pesticides, 22.2% of the participants bathed and 17.2% changed their clothes immediately. Pesticides were stored in a separate room inside the house by 8.3% and in a separate room outside the house by 66.8% of the participants. More than half of the participants burned their empty containers (Supplementary Figure 4). About a fifth of participants reported selling or recycling their empty containers. The remaining participants either left containers in the field or garden, buried them, or disposed of them in a landfill.

Knowledge and pesticide practice classes

The latent class approach to derive unobserved or latent subgroups of pesticide-related knowledge revealed that two qualitatively different classes described our sample most appropriately. They were labeled (i) low knowledge and (ii) high knowledge (Table 4, Supplementary Tables 3 and 4). The latter was largely characterized by a substantially better performance in pictogram identification, specifically well for pictograms "Dangerous/harmful to fish" and "Toxic" while low knowledge performed particularly poor in pictogram "Lock away and keep out of reach of children," and some better performance regarding general knowledge compared to the low knowledge class. The knowledge was most pronounced in the questions: "Herbicides are not dangerous to humans," "Empty pesticide containers can be reused," and "Good pesticides kill insects immediately" (for detailed marginal means and probabilities see Supplementary Table 4). The marginal probability to be in the high knowledge class was 65.2%.

For the quality of pesticide practices, the LCA approach identified 3 distinct classes. They were labeled (i) poor practices, (ii) intermediate practices, and (iii) good practices (Table 4, Supplementary Tables 5 and 6) according to the following group characteristics. For all practices, more favorable behaviors (i.e., use of PPE, outside storage, more personal hygiene) were similar or more likely to occur in the intermediate practices compared to the poor practices group and were similar or more likely in the good practices compared to intermediate practices group. The good practices group was most strongly differentiated by high probabilities of using gumboots, ponchos, and gloves and quickly taking a bath or changing clothes after pesticide application vs. the other groups. Farmers of that group were also more likely to use overalls, respirators, and helmets, albeit at much lower levels. While the intermediate group was generally more likely to use any type of mask and practiced more hygiene, they most strongly differed from the poor practices group in the storage of pesticides (i.e., storing them outside the house). In fact, a key difference between poor practices and the two other groups was that the group stored pesticides inside the house. Despite these differences across practice subgroups, wearing surgical masks and cloth face coverings, and especially hand washing after pesticides were relatively common among all farmers. The marginal probability to be in the poor practice group was 32.2%, the intermediate group was 56.9% and the good practice group was 11.0%.

Table 3. Pesticides investigated by the survey*.

Type of pesticide	Active ingredient	Commercial names asked for	WHO classification	% used it	% do not know	% farmers mixing it of farmers using it	Popularity 1 = rarely to 5 = highly popular)
Insecticide	Emamectin Benzoate	Angun 5WG, EMA Gold	Class II	16.5	42.0	37.9	3
Insecticide	Fenobucarb	Virtako 40 WG, Bassa, Jetan	Class II	45.8	21.0	41.0	3
Insecticide	Hexaconazole	Anvil 5SC	Class III	66.5	9.8	33.5	4
Insecticide	Pymetrocine	Chess 15WG	Class III	30.0	26.5	19.2	3
Insecticide	Spinetoram	Radiant 60SC	Unlikely hazard	15.3	41.0	45.9	2
Insecticide	Spirotetramat	Movento	Class III	4.3	37.8	17.6	2
Insecticide	Triflumezopyrim	DuPont (Pexena) 106 SC	Class III	29.0	24.0	25.9	5
Insecticide + small pests	Chlorpyrifos Ethyl + Cypermethrin	Dragon 585EC, Tungcydan	(Class II)+ Class II	22.3	35.0	29.2	4
Insecticide + small pests	Fipronil	Regent 800 WP, AnPyral 800 WG	Class II	43.8	21.3	24.0	1
Fungicide	Azoxystrobin Difenoconazole	Help	Unlikely hazard + Class II	37.3	24.5	29.5	4
Fungicide	Mancozeb + Metalaxyl-M	Mancozeb, Ridomil Gold, Dithane	Unlikely hazard + Class II	14.8	37.0	20.3	3
Fungicide	Propinerb	Antracol	Unlikely hazard	64.3	12.5	46.7	4
Fungicide	Tricyclazole + Propiconazole	Filia 252SE	Class II + Class II	47.3	16.8	26.5	5
Fungicide	Trifloxystrobin + Tebuconazole	Nativo 750 WG	Unlikely hazard + Class II	34.8	23.3	35.3	4
Herbicide	Butachor + Propanil	Cantanil	Class III + Class II	61.8	9.5	10.5	5
Herbicide	Pretilachlor	Sofit	Unlikely hazard	74.3	4.8	6.7	5

*With information on the type of pesticide, the active ingredient, the commercial name used in the survey, the WHO hazard classification, the percentage of participants who have used it during the past year, the percentage of participants who did not know if they have used it during the past year, the percentage of participants who have mixed it with other pesticides, and the popularity of the product according to the local authorities.

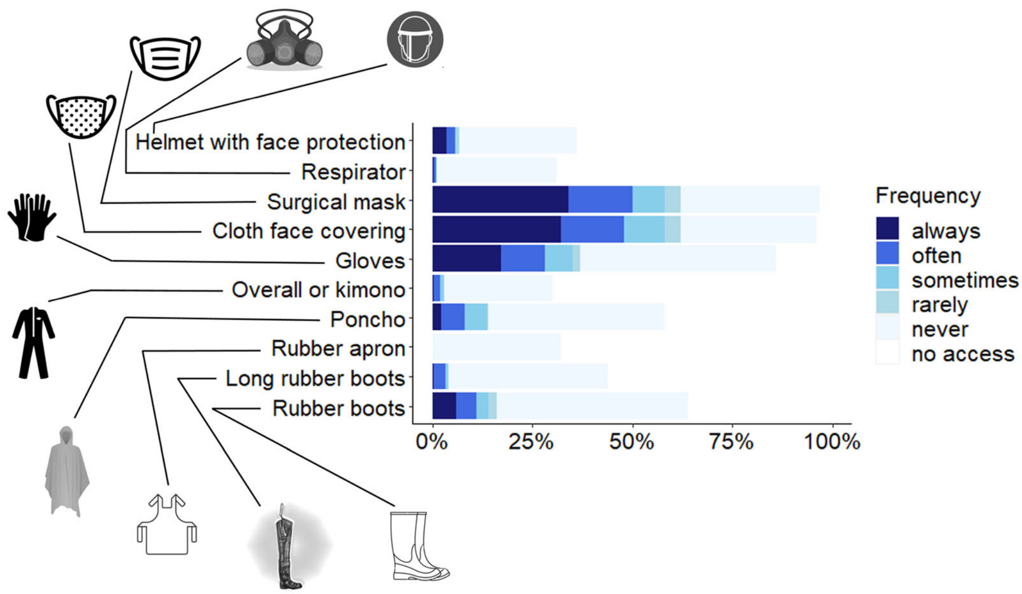

Figure 2. Access and use of specific PPE not related to sun protection.

Table 4. Latent classes derived from the latent class analysis for knowledge and practices.

Class	Number of participants	%
High knowledge	273	68.4
Low knowledge	126	31.6
Poor practices	129	32.3
Intermediate practices	230	57.7
Good practices	40	10.0

Table 5. Mutually adjusted associations of demographics and farming specific factors with pesticide safety knowledge (high vs. low)*.

	Knowledge high vs. low		
	OR	95% CI	*p*-value
Official educational programs:			
No	1.00		
Yes	1.87	1.13–3.12	0.015
Education:			
Primary school	1.00		
Secondary school	2.17	1.30–3.64	0.003
Minimum of high school	3.84	1.70–9.45	0.002
Source of pesticide safety knowledge:			
Not learn from govt. extension workers	1.00		
Learn from govt. extension workers	2.31	1.14–4.98	0.025
Not learn from peers	1.00		
Learn from peers	3.58	2.18–6.00	<0.001
Farm size, Ha:	1.22	1.01–1.50	0.052
Gender:			
Female	1.00		
Male	2.53	1.04–6.35	0.042
Age, years:	1.00	0.98–1.02	0.762

*Logistic regression analysis of pesticide safety knowledge based on the adjustment set identified with the DAG and additional adjustment for the commune cluster.

Factors associated with knowledge

Respondents within the group of high pesticide-specific knowledge were significantly more likely to have attended official educational programs in sustainable agriculture (Odds Ratio, 95% Confidence Interval) (1.87, 1.13–3.12) (Table 5). Similarly, increasingly higher education (highest vs. lowest: 3.84, 1.70–9.45) and having learned about pesticides from government extension workers (2.31, 1.14–4.98) or peers (3.58, 2.18–6.00), as well as being male (2.53, 1.04–6.35) were significantly and positively associated with higher knowledge.

Exploring whether the official educational program association was modified by general education suggested that official educational programs affected farmers in the three strata differently. Farmers with the lowest school education level benefited the most from official educational programs (3.2, 1.5–7.1), while this was not found in farmers with a secondary school education level (1.3, 0.6–2.8) and a minimum of high school education level (1.1, 0.1–19.5). Entering a multiplicative interaction term of school education and official educational programs in the final model was, however, not statistically significant (p-value $= 0.13$).

Association of knowledge with pesticide practices

High knowledge was significantly positively associated with intermediate pesticide practices (vs. poor practices) (1.65, 1.02–2.66) and strongly associated with good pesticide practices (vs. poor practices) (8.96, 2.58–31.12) (Table 6). Farm size was also positively associated with being in the intermediate (1.39, 1.11–1.74) or the good (1.55, 1.14–2.10) pesticide practice group. Participants living in Trường Xuân B (2.50, 1.45–4.32) and Thới Tân (2.39, 1.33–4.27) were both more likely to be in the intermediate pesticide

Table 6. Mutually adjusted associations of pesticide safety knowledge with pesticide practice (intermediate vs. unsafe and good vs. unsafe)*.

	Practices intermediate vs. poor			Practices good vs. poor		
Variables	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Knowledge:						
Low	1.00			1.00		
High	1.65	1.02–2.66	0.040	8.96	2.58–31.12	<0.001
Monthly income (Mio. VND):	1.01	0.98–1.03	0.610	0.96	0.91–1.02	0.192
Farm size (Ha):	1.39	1.11–1.74	0.004	1.55	1.14–2.10	0.005
Gender:						
Female	1.00			1		
Male	0.77	0.32–1.88	0.572	1.87	0.21–16.49	0.574
Age, years:	0.98	0.97–1.00	0.109	1.00	0.97–1.03	0.850
Communes:						
Truong Xuan	1.00			1.00		
Truong Xuan B	2.50	1.45–4.32	0.0009	2.23	0.97–5.06	0.059
Thoi Tan	2.39	1.33–4.27	0.003	0.80	0.26–2.49	0.702

*Multinomial logistic regression analysis of pesticide practices based on the adjustment set identified with the DAG and additional adjustment for commune.

practice group, compared to people living in Trường Xuân who expressed worse practices than Trường Xuân B and not significantly better practices than Thới Tân. Associations of main exposures in all models were similar but more pronounced when unadjusted (see Supplementary Tables 7 and 8).

Discussion

This study describes current pesticide safety practices and related knowledge of Vietnamese farmers of the Mekong Delta. The findings show limited access and use of personal protective equipment covering the face, torso, arms, hands, legs, and feet. This study demonstrated that higher school attainment and official educational programs on pesticide use, learning from government extension services, and peer-to-peer knowledge exchange were independently associated with higher pesticide safety knowledge, translating into safer pesticide use practices. This highlights the importance of sustainable agriculture educational programs for promoting beneficial and healthy agricultural practices.

To our knowledge, this is the first study assessing the impact of educational programs on pesticide-related knowledge in smallholder farmers in the Vietnamese Mekong Delta. Previous studies focused on either studying the impact of educational programs on good agricultural practices but did not assess changes in pesticide-related knowledge in that context (Huan et al. 2008), or they described the general KAP of those farmers (Van Mele et al. 2001, 2002). The present study suggests that different educational programs, including official ones, independently relate to increased pesticide safety knowledge. In addition, the level of school attainment appeared to contribute substantially to the level of pesticide safety knowledge. A recent systematic review on the success of educational interventions in agriculture stressed the need to adapt interventions to the level of literacy or school education of participants (Coman et al. 2020). This recommendation becomes particularly important after observing that educating farmers with lower school attainment appeared to be the most effective. This underscores the importance of the right target audience for educational programs for achieving the highest impact. On the same note, the co-development of education programs together with the affected communities was shown to be a key success factor for health and safety education interventions (Salvatore et al. 2009; Coman et al. 2020).

Overall, the findings of this study are in line with some previous studies that showed educational agricultural interventions to improve pesticide practices (DeRoo and Rautiainen 2000; Coman et al. 2020). Inconsistent results from previous studies seem to be based on different modalities of how the educational interventions were delivered, with more success in community-based approaches (DeRoo and Rautiainen 2000; Coman et al. 2020). The official educational programs assessed in this study were combined into the variable "any exposure" as some were infrequent and programs often co-occurred and lead to multicollinearity issues. Similarly, other sources of information co-occurred frequently. This did not allow for further disentangling of the contributions of individual educational programs or learning sources. Moreover, additional information on the extent or frequency of educational programs was not attainable. A better understanding thereof will be necessary to determine an optimal educational program design. Overall, in the context of the Mekong Delta, the government's efforts through educational programs and government extension services appeared to be successful, even though, school education remains to be a crucial contributor to the farmer's knowledge and associated safe pesticide use behaviors.

Farmers in this study had difficulties remembering or knowing what pesticides they applied. Neither the active ingredients nor the commercial names and pictures of the packaging were easily identified. Farmers mentioning to use organic pesticides in addition to synthetic pesticides performed equally poorly. Similarly, it was not feasible to accurately determine the use of biological or more hazardous pesticides. These issues already had occurred during piloting and a short list of the 16 most frequently used pesticides was developed to ensure response options that were generally known. In addition, farmers frequently confused fertilizers and pesticides or used those terms interchangeably, indicating that the farmer's understanding and knowledge of pesticide products and their target crops is limited. Accurate information about the full range of employed pesticides would be crucial to determine potential health risks, and efforts should be taken in future studies to capture pesticide use on the subject level objectively.

The observed poor understanding of pesticides (when identifying pesticides previously used) might reflect an aspect of knowledge that might not have been fully captured with our questions. K&P surveys are known to be an effective assessment tool, but the definition of knowledge often relies on the researchers as well (Launiala 2009). In that sense, knowledge was assessed based on what risks are related to pesticides but might have missed to what extent the farmers were aware of whether they were using pesticides (or their specific toxicity) in the first place. Knowledge groups were most distinctively separated by correct pictogram identification, which was deemed the most objective assessment of knowledge in the context of this study. Taken together, future knowledge testing should try to more comprehensively and objectively assess different aspects of knowledge (e.g., pest recognition, differentiation of pests and commensal insects, pictogram recognition, and pesticide quantity calculations according to instructions of the products).

Almost all of the participants purchased their products from local agro-input dealers. Knowledge was not statistically significantly associated with the type of pesticide supplier in this study. There were, however, some limitations to assess this association due to multi-collinearity issues with other sources of knowledge. Interestingly, previous research in the Mekong Delta identified agro-input dealers as a primary source of knowledge for farmers (Van Mele et al. 2001, 2002). The lack of association in our findings may partly be based on the high availability of different knowledge sources, including varying governmental efforts and limited availability of options for pesticide acquisition. Nonetheless, because agro-input dealers constitute one of the sole access points for pesticide acquisition, their knowledge and role in advising farmers need to be investigated further to guarantee appropriate and safe pesticide choices and practices (Staudacher et al. 2021).

The use of specific PPE was infrequent in this study population. This was largely determined by the fact that specific PPE was accessible for less than half of all farmers, mostly due to their absence in agro-input shops, and that PPE was perceived to be uncomfortable. Interestingly, surgical masks and cloth face coverings were used persistently. While these masks might be perceived as protective, the frequent use of these masks is concerning as they are not designed for pesticide application. In fact, the toxic chemicals can accumulate in the tissue of the masks, exposing the mask user to pesticides over long periods (Hock et al. 2017; Sapbamrer et al. 2021). Literature reporting PPE use in Vietnam is inconsistent but the majority of reports concluded that the use of PPE, despite usual agricultural clothing, is limited due to lack of knowledge or access (Phung et al. 2012; Thuy et al. 2012; Phung et al. 2013; Nguyen 2017). In this study, further information on limiting factors regarding access to PPE was missing, but future efforts to better understand those could offer key leverage points to improved uptake.

More than two-thirds of the participants in this study reported a lack of comfort as a reason for not wearing PPE. Discomfort as a reason for not using PPE is an important additional finding for the Vietnamese context, where otherwise lack of knowledge and lack of access was reported as the main issues (Phung et al. 2013). In particular, big, bulky, and impermeable PPE was not worn by the farmers in the present study despite having access. Impermeable PPE does not allow evaporation of sweat and can therefore lead to higher heat stress for the farmers (De Almeida et al. 2012; Watson et al. 2019). In addition, PPE can restrict the movement of the farmers (Snipes et al. 2016). The problem of discomfort in PPE has been observed in many other agricultural contexts, especially with high temperatures and humidity (Garrigou et al. 2020; Sapbamrer and Thammachai 2020; Sanchez-Gervacio et al. 2021). However, only very few studies have objectively investigated this issue and recommendations to address the discomfort of PPE are scarce (De Almeida et al. 2012; Garrigou et al. 2012). In a systematic review on the role of PPE in risk prevention, Garrigou et al. (2020) found that many agro-chemical products would not receive market authorization without the recommendation to use PPE. At the same time, the recommended PPE is seldom tested in real-world settings and therefore is often unsuitable in terms of risk reduction and comfort (Garrigou et al. 2020). Additional measures supporting PPE as the main safeguard of farmers' health are needed; market authorization processes should be reevaluated to favor authorization of less toxic products and agricultural practices reducing the use of pesticides overall need to be promoted.

More than half of the participants reported burning their empty containers. This practice is of particular concern as toxic gaseous chemical residues are directly released into the environment together with CO_2 from the burning process (Arias-Estevez et al. 2008). This container disposal practice has been also reported to be one of the most common practices in Vietnam by the World Bank Agricultural Pollution report in 2017 and other studies (Houbraken et al. 2016; Nguyen 2017, 2020). In 2018, a report from the Mekong Delta stated that initiatives to reduce the open burning of containers and their improper disposal in canals, rivers, and fields, were not successful with the main limitation being appropriate funding for the correct burning of toxic waste (Nguyen 2020).

Strengths and limitations

To our knowledge, this is the most comprehensive study exploring current aspects of pesticide practices, from acquisition to disposal, as well as investigating determinants of knowledge and use of protective equipment in the South Vietnamese rural region. A DAG conceptual approach was used, to identify a parsimonious set of covariates to arrive at unbiased estimates. The resulting minimal adjustment sets avoided overfitting and relevant unmeasured factors were taken into consideration. The participants' crop types were not assessed, which might have affected the relationships under investigation, as crop type might affect all aspects relating to pesticides. Assuming that farm size is related to crop types, the significant association of farm size with good farming practices suggests that the differences in crops and farm type should be taken into account when studying pesticide exposure. A latent class analysis was used to identify farmers who were homogenous in their pesticide-related behaviors and practices. As there was a lack of prior information on what constitutes high knowledge or good practices in this context, the latent class analysis allowed us to identify the subgroup model that best reflected the multidimensional data structure inherent in this sample. This approach was limited in that it did not further quantify associations of specific response items. Furthermore, the set of knowledge questions was limited to six general knowledge and three pictogram questions and additional questions may be needed to improve the model. Attitudes toward pesticides were not assessed in this survey which may have contributed to better understanding the presented relationships. While inquiring about PPE use, we did not specify the material of gloves used. This should be asked in future studies, as the use of leather or cloth gloves could increase pesticide exposure in farmers. Moreover, types of respirators could not be differentiated as detailed information was not collected.

The cross-sectional nature of this study limited causal inference, however, it allowed to generate hypotheses for future prospective studies. Also, the retrospective collection of data is prone to recall bias and sensitive questions might have been impacted by social desirability. The exact proportions of farmers in the communes were not available due to restricted access to local commune data. However, local representatives selected farming communes expected to be comparable regarding their farming population. Due to this limited access to demographic information, the originally planned strictly randomized sampling strategy had to be adapted. By randomly choosing the starting points of transect walks, the sampling strategy was kept as random as possible. Additionally, the sample was tested for daily clustering. Despite communes being nearby, their differences in location, accessibility, and access to services such as education might be related to participants' characteristics. Due to the low number of communes, potential commune effects were accounted for by including the communes as fixed effects in the models. Only 7.0% of participants were female, which did not allow for further investigation of gender differences. This was expected as, even though up to one-third of small Vietnamese family farms are headed by women (Schenck 2018), Nhàn et al. (2014) reported that in the Mekong Delta specific agricultural activities are often gendered, and 7.3% of their respondents involved in pesticide application were female (Nhàn et al. 2014).

Finally, the present population is expected to be representative of the Mekong Delta; as climatic conditions, cultural and potentially even farming practices in the Mekong Delta are unique to this region (CGIAR 2016;

Minderhoud et al. 2018; Schneider and Asch 2020), the findings are of limited generalizability.

Conclusion

This study provides information on pesticide safety knowledge and safety aspects of smallholder farmers of the Vietnamese Mekong Delta. The findings suggest that educational programs for smallholders lead to better knowledge, which translates to improved practice. This seems particularly true for people with less general education who might be a special target group for extension activities. Despite the positive association of educational programs, the findings also demonstrate the limits of educational approaches. Better knowledge by itself might be insufficient for maximizing favorable practices if the necessary tools such as PPEs are not available or if they are impracticable for daily use due to discomfort. These findings are not only relevant for developing strategies for improving pesticide practices but should also be considered for pesticide registration. Any protection measures that fail in practical application with farmers should not be considered as tools for providing sufficient environmental or human protection. More detailed studies investigating different toxicity classes and quantities of pesticides used are needed to further estimate the potential health and environmental impacts of the studied pesticide practices.

Recommendations

Methods apart from K&P surveys, such as the use of (electronic) journals written by farmers, the collection of empty pesticide containers, or the use of biomarkers are recommended. Although official educational programs improved safety practices, there continues to be substantial improvement potential. Therefore, a more detailed understanding of the content and form of the programs could be crucial for improved training and uptake. In addition, a better understanding of the role of peers and government extension workers could help to maximize peer-to-peer knowledge exchange and to identify where government extension workers are needed the most. The 19 active agricultural cooperatives with 300 members in Thới Lai might be an opportunity to support the dissemination of peer-to-peer knowledge, maybe even with inputs from government extension workers. In addition, the possibility to supply farmers with more bio/organic pesticides to reduce health and environmental hazards should be explored. Finally, research and policy makers must identify and address potential barriers to PPE and rethink plant protection strategies while taking into consideration plant protection and human health jointly. This includes addressing financial and spatial access to PPE, but equally important to think about ways of making PPE discomfort less critical. Agricultural extension services should be empowered in communication and guiding farmers for farming practices that can protect natural resources, and the environment and produce safe agricultural products. In addition, creating an enabling environment for safe agricultural products through value chains with the involvement of enterprises for both domestic exporting markets should be researched as a potential solution for reducing pesticides.

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Ethics approval

All study materials received ethical clearance from the independent ethics committees REDACTED. Written informed consent was obtained from each participant before the study. Further, study identification numbers replaced the participants' names to guarantee confidentiality. All participants were compensated according to local standards with 80'000 Vietnamese Dong (3.40 US Dollars with an average exchange rate of March 2020) to reimburse time lost at work.

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Data availability statement

The data that support the findings of this study are available in an anonymized form from the corresponding author [AG] upon reasonable request.

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