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Factors associated with personal protective equipment use among agricultural pesticide handlers in Samarahan, Sarawak, Malaysia: a cross-sectional study

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Abstract

Introduction Personal protective equipment (PPE) mitigates pesticide harm, but adherence remains inconsistent among smallholder farmers. We estimated the prevalence of full PPE use and identified associated factors among agricultural pesticide handlers in Samarahan, Sarawak using the Health Belief Model (HBM).

Methods A cross-sectional survey of 297 farmers who handled pesticides within the past six months was conducted using interviewer-administered questionnaire on sociodemographic, knowledge and HBM constructs. Logistic regression with purposeful selection examined factors associated with full PPE use.

Results Full PPE adherence was 17.2% (51/297). Most clothing items were widely used, while ocular and face protection were lowest (goggles 39.1%; face shield 27.3%). Younger age (aOR = 0.887 per year increase, 95% CI [0.839, 0.938], $p < 0.001$) and more farming years (aOR = 1.046, 95% CI [1.006, 1.088], $p = 0.024$) were associated with full PPE use. Among HBM constructs, higher perceived susceptibility and severity (aOR = 2.618; 95% CI 1.571, 4.365; $p < 0.001$) and cues to action (aOR = 2.665, 95% CI [1.499, 4.740], $p < 0.001$) increased odds, whereas perceived barriers decreased the odds (aOR = 0.529, 95% CI [0.355–0.790], $p = 0.002$). Perceived benefits showed an unexpected inverse association, possibly reflecting competing discomforts or practical barriers to comprehensive PPE use (aOR = 0.303, 95% CI [0.100, 0.921], $p = 0.035$).

Conclusion Full PPE use was uncommon with ocular and face protection notably underused. Factors clustered around threat appraisal, cues and barriers alongside age and experience, illustrating operation of HBM in smallholder tropical agriculture. Findings provided a baseline for targeted training, prompts and barrier-reduction strategies in Sarawak.

Keywords Personal protective equipment, Pesticide exposure, Agricultural workers, Health belief model, Occupational health, Sarawak

1 Introduction

Pesticides are important to global agricultural productivity, yet their use is closely linked to a wide range of occupational and environmental health concerns. The United Nations Environment Programme estimated around 300 million agricultural workers experienced acute pesticide poisoning annually, with many cases underreported in low- and middle-income countries (LMICs) [1]. In addition to acute poisonings [2, 3], chronic pesticide exposure has been associated with respiratory, neurological and carcinogenic outcomes, particularly among those who handle them regularly [4–13]. Personal protective equipment (PPE) serves as a fundamental preventive measure in mitigating such risks, acting as a barrier between pesticide handlers and toxic exposures.

Despite this, adherence to PPE guidelines is highly variable, with patterns of PPE use among farmers varied from full to partial adoption across regions or crops. In high income countries, regulation and enforcement mechanisms are more established resulting in higher compliance [14]. Contrarily, smallholder farmers in tropical and developing countries often face barriers such as cost, discomfort in hot climates and limited access to appropriate equipment [15]. Studies in Asia, Africa and Latin America have shown that while basic clothing such as long sleeves or boots were widely used, specialized protective gears including goggles, face shields and respirators were far less common [16–20]. These gaps raise concerns over preventable pesticide-related illnesses in agricultural communities that are already vulnerable due to limited access to health services.

In Malaysia, agriculture continues to rely heavily on pesticides to maintain yields, particularly among smallholder farmers who contribute to food production. Although national regulations including the Pesticides Act 1974 and related occupational safety laws recommend PPE use during pesticide handling, actual practice remains inconsistent. Reports from peninsular Malaysia and Sabah indicate that farmers often prioritise convenience and affordability over full protective adherence, with respiratory and eye protection being the most neglected [21, 22]. In Sarawak, agriculture employs a significant share of workforce including rural divisions such as Samarahan, yet it lacked empirical data on the extent of PPE adherence and its determinants. Without context-specific evidence, it would be difficult for public health and agricultural agencies to plan interventions that address both structural and psychosocial barriers to safe pesticide handling.

The challenge is not solely material or structural; individual perceptions of risk and benefit play a substantial role in shaping protective behaviours. The Health Belief Model (HBM) offers a well-established theoretical framework to examine how farmers perceive their vulnerability and severity to pesticide-related harm and how perceived benefits and barriers influence their willingness to adopt protective measures. Additionally, cues to action such as health education campaigns and enforcement visits and self-efficacy in one's ability to use PPE properly are also central to the model's explanatory power. Applying the HBM to pesticide safety provides a structured approach in understanding why farmers may neglect certain protective practices despite awareness of potential risks.

International studies applying the HBM to occupational safety behaviours have reported mixed findings. Some highlighted the importance of perceived susceptibility and severity as strong motivators [19, 23–25] while others emphasise barriers such as discomfort, cost or cultural norms as overriding factors [17, 18, 26, 27]. Within Malaysia, only a limited number of studies have incorporated behavioural theory to explain PPE practices, with most investigations being descriptive [28, 29] or focused on acute health effects [30–34] rather than psychosocial determinants. Despite PPE being a key preventive strategy, no prior studies in Sarawak have explicitly applied the HBM to investigate psychosocial determinants of PPE adherence among smallholder pesticide handlers in a tropical agricultural setting. This gap limits the development of theory-driven and context-sensitive interventions to improve pesticide safety practices.

This study aimed to determine the prevalence of full PPE use and to identify factors associated with PPE adherence among agricultural pesticide handlers in Samarahan, Sarawak. By grounding the analysis to HBM, the study contributes not only empirical prevalence data but also theoretical insights into the psychosocial dimensions of protective behaviour in smallholder tropical agriculture. The findings are expected to provide baseline data for local stakeholders and inform interventions that address both material barriers and perceptual drivers, ultimately supporting safer agricultural practices and reducing the burden of pesticide-related harm in Sarawak.

2 Methods

2.1 Study design, criteria and sampling

This study employed a cross-sectional design to assess the prevalence and factors associated with PPE use among agricultural pesticide handlers in Samarahan division, Sarawak. The division spanned 2928 km^2 with agriculture accounted for 32.5% of Samarahan's land use. Data were collected over one agricultural season through January until March 2025 to capture recent experience of pesticide use.

Farmers aged 18 years and above residing in Samarahan division (Asajaya, Samarahan or Simunjan districts) who personally mixed, loaded, sprayed, cleaned pesticide application equipment or handled contaminated containers in the past six months and were registered in the Department of Agriculture's farmer lists were included in the survey. The six-month timeframe was chosen to minimise recall bias and reflect current practices. Farmers who were mentally incapacitated or otherwise unable to participate were excluded from the survey.

In this study, smallholder farmers were defined operationally as individuals engaged in small-scale agricultural activities who were classified as non-estate farmers within the local agricultural administrative system in Sarawak. This classification reflects farmers who operate independently or at household level, in contrast to large-scale commercial plantations or estate-based agricultural enterprise workers. Operationally, participant selection was conducted through district agricultural offices' farmer listings, comprising of small-scale, non-commercial farmers.

Sample size was calculated using Cochran's single-proportion formula. In the absence of a local estimate, we adopted a conservative proxy from a regional meta-analysis [15] reporting 76.2% of farmers wore long-sleeved protective clothing during pesticide handling. We noted that this proxy reflected a single PPE item rather than the composite outcome in this study. A sample size of 306 with 10% attrition rate was obtained at 95% confidence interval and margin of error of 0.05.

Proportionate stratified random sampling method was used with the three administrative districts serving as strata. Proportional allocation was based on each district's share of the farmer population reported in the 2020 Agricultural Statistics of Sarawak [35]:

Asajaya 4626 (30.5%), Samarahan 3098 (20.4%) and Simunjan 7401 (48.9%). Percentages are rounded to one decimal place; therefore, the total may not sum exactly to 100%. Sampling frame within each district stratum was provided by the respective district agriculture office. Lists were independently randomised in Microsoft Excel using a random number generator, and the top entries equal to district quota were selected as primary sample while the remaining entries were retained as replacements for non-contact or refusal.

2.2 Variables and measurements

Full PPE was defined as wearing all seven required items (googles, face mask, face shield, long-sleeved shirt, long trousers, rubber gloves and rubber/PVC boots) continuously from the start to the end of pesticide handling, covering preparation (mixing/loading), application (spraying) and post-application (equipment cleaning and storage). Partial PPE was defined as missing any required item or removing PPE at any stage.

For explanatory variables, sociodemographics included age, sex, education level, monthly household income, farming experience and farm ownership. Knowledge score was operationalised as dichotomous items scored 1 = correct and 0 = incorrect/don't know, with higher score representing better knowledge. HBM constructs included perceived susceptibility and severity, perceived benefits, perceived barriers, cues to action and self-efficacy. Items were operationalised as dichotomous where higher scores indicated higher likelihood of PPE use except for barriers, where lower scores indicated fewer perceived barriers.

2.3 Data collection instrument

For data collection instrument, we used a structured questionnaire adapted from Suratman, Ross [36] and subsequently used in Malaysia [37], available in Bahasa Malaysia and English. The instrument comprised of eight sections: sociodemographics, behaviour, knowledge, perceived vulnerability and severity, perceived benefits, perceived barriers, cues to action and self-efficacy. A pre-test was conducted with 30 farmers excluding from the main sample. Cronbach's alpha for Knowledge = 0.890, Susceptibility and Severity = 0.738, Benefits = 0.718, Barriers = 0.766, Cues to action = 0.714, Self-efficacy = 0.730, indicating acceptable reliability for field settings.

The questionnaire was developed by adapting items from previously published instruments used in Malaysian and regional studies assessing pesticide handling practices and related psychosocial constructs. Perceived susceptibility and perceived severity were analysed as a combined construct representing perceived threat, consistent with the conceptual structure of the HBM. Content validity was supported through expert review by a UNIMAS Public Health Medicine specialist with experience in occupational health research, assessing item relevance, clarity and contextual appropriateness to local agricultural practices.

Data collection was conducted by the principal investigator using interviewer-administered or supervised self-administered questionnaires. The use of mixed administration modes was necessary to accommodate varying literacy levels and respondent preferences within rural farming communities, with the aim of maximising participation and data completeness. To minimise information bias and reduce the risk of differential responses between modes, a standardised questionnaire with neutral wording was used and uniform instructions were provided to all respondents. On-site supervision was used to allow clarification of questions without leading or prompting. Respondents were assured of confidentiality, and direct identifiers were removed and replaced with unique codes prior to analysis. Recency of pesticide activity was verified by asking respondents for the month of their most recent handling. Data were entered with validation checks in IBM SPSS Statistics version 29 and prepared for analysis. Missing data were handled via listwise deletion.

Several sources of bias were anticipated a priori in this study. These included recall bias related to self-reported pesticide handling activities, social desirability bias in reporting PPE use and potential interviewer bias associated with questionnaire administration. The procedures that were implemented to minimise these biases including restriction of the recall period, assurance of confidentiality, neutral questionnaire wording and standardised administration with limited interviewer involvement were described as above.

2.4 Statistical analysis

Analyses were conducted in IBM SPSS Statistics version 29. Descriptive statistics summarised demographic characteristics and PPE prevalence. For descriptive group comparisons by PPE use status, chi-square tests were used for categorical variables and t-tests or Welch's *t*-tests for continuous variables as appropriate. These analyses were conducted as exploratory comparisons to describe unadjusted group differences and to characterise the study sample and were not intended for confirmatory hypothesis testing or causal inference.

Age was modelled as a continuous variable measured in years. Screening for multivariable modelling was based on simple logistic regression with crude odds ratios (cORs), 95% confidence intervals (CIs) and p-values reported. Variables with $p < 0.25$ in the simple logistic model were entered into multiple logistic regression using purposeful selection approach, whereby variables were iteratively retained or removed based on statistical significance, assessment of confounding effects and theoretical relevance. Variables meeting the initial screening criterion but not retained in the final model were excluded if they did not materially confound associations between retained predictors, failed to remain statistically significant after adjustment or were considered theoretically upstream of the HBM constructs. Model diagnostics included variance inflation factor (VIF) for multicollinearity, Box-Tidwell test for linearity in the logit for continuous predictors and inspection of residuals and influence statistics. All predictors retained in the final model demonstrated VIF values below commonly accepted thresholds, indicating no problematic multicollinearity. Where evidence of non-linearity was identified, a quadratic term was introduced to improve model specification. Model fit was assessed with Hosmer-Lemeshow test while explanatory power was reported using Cox-Snell and Nagelkerke R^2 values. Discrimination was assessed with the area under the receiver operating characteristic (ROC) curve. Final model results were presented as adjusted odds ratios (aORs) with 95% CI and p-values.

2.5 Ethical considerations

was granted by the UNIMAS Ethics Review Board, Ref: UNIMAS/TNC(PI)09–65/01 Jld. 4 (61) dated 10 March 2025. Administrative permissions were obtained from the Samarahan Division Department of Agriculture and the respective district agriculture offices.

Written informed consent was obtained from all participants prior data collection with confidentiality maintained throughout. Participation was voluntary with respondents were free to withdraw at any stage of data collection without consequence.

3 Results

A total of 297 farmers completed the survey with a 97.1% response rate. In descriptive comparisons by PPE status, full PPE users were younger on average than non-full users (47.84 ± 9.80 vs. 56.65 ± 9.50, t(295) = −9.00, p < 0.001) and reported higher household income (RM 1541.18 ± 692.86 vs. RM 1302 ± 706.17, t(295) = 2.20, p = 0.028). Farming experience was lower among full PPE users, although the difference was not statistically significant (p = 0.098). Education differed by PPE status (χ^2 [2] = 6.166, p = 0.032). Full PPE users scored higher knowledge (15.47 ± 3.26 vs. 14.41 ± 3.19, t(295) = 2.160, p = 0.032), higher perceived susceptibility and severity (combined construct) (8.63 ± 0.80 vs. 7.37 ± 1.25, t(107.70) = 9.160, p < 0.001), stronger cues to action (4.65 ± 0.69 vs. 3.87 ± 0.97, t(96.26) = 6.793, p < 0.001), lower perceived barriers (2.57 ± 0.96 vs. 2.93 ± 1.39, t(98.43) = −2.244, p = 0.027) and lower self-efficacy (4.63 ± 1.23 vs. 5.07 ± 1.21, t(295) = −2.373, p = 0.018). Full characteristics by PPE status are shown in Table 1.

Overall adherence to full PPE, defined as concurrent use of long trousers, long-sleeved shirt, boots, gloves, face mask, goggles and face shield was 17.2% (51/297). Clothing coverage was high while ocular and face protection were lowest: long trousers 98.7%, long-sleeved shirts 93.9%, boots 91.9%, face masks 83.2%, gloves 63.6%, goggles 39.1% and face shields 27.3% (Table 2). The distribution of total items worn showed that most farmers used five or four items, whereas only 17.2% used all seven (Table 2).

Simple logistic regression were conducted as exploratory, unadjusted screening analyses to identify candidate variables for multivariable modelling. In these analyses, increasing age (cOR = 0.909, 95% CI [0.877, 0.942], p < 0.001) and higher income (cOR = 1.050, 95% CI [1.005, 1.096], p = 0.030) showed crude associations with full PPE use. Farming experience showed a non-significant crude inverse association (cOR = 0.981, 95% CI [0.958, 1.004], p = 0.103). Among HBM constructs, perceived susceptibility and severity (combined construct) (cOR = 3.150, 95% CI [2.105, 4.713], p < 0.001), cues to action (cOR = 3.266, 95% CI [2.017, 5.289], p < 0.001) and knowledge (cOR = 1.132, 95% CI [1.010, 1.269], p = 0.033) demonstrated positive crude associations with full PPE use, while self-efficacy (cOR = 0.761, 95% CI [0.604, 0.959], p = 0.020) and perceived barriers (cOR = 0.810, 95% CI [0.640, 1.024], p = 0.078) showed inverse crude associations. These unadjusted findings were used to inform variable selection for multivariable analysis. Full results are presented in Table 3.

Interpretation of associations is based on results from the multivariable logistic regression model. The final multivariable logistic regression model included age, farming experience, perceived susceptibility and severity (combined construct), perceived benefits, perceived barriers, cues to action and self-efficacy (with quadratic term). The quadratic term for self-efficacy was retained to account for a non-linear association with full PPE use, as indicated by model diagnostics. Although knowledge score and ownership status met the initial screening criterion, they were excluded from the final model as they did not materially alter effect estimates of retained predictors and did not remain statistically significant after adjustment. Each additional year of age was associated with lower odds of full PPE use (aOR = 0.887, 95% CI [0.839, 0.938], p < 0.001), whereas

Table 1 Characteristics of respondents by full Ppe use status ($N=297$)

Factors	Total (N = 297)	Full PPE (n = 51)	Partial PPE (n = 246)	Test Statistic	p value
Age, years (M ± SD)	55.14 ± 10.09	47.84 ± 9.80	56.65 ± 9.50	t(295) = − 6.00	< 0.001*
Income, RM (M ± SD)	1,343.64 ± 708.49	1,541.18 ± 692.86	1,302 ± 706.17	t(295) = 2.20	0.028*
Farming experience, years (M ± SD)	17.10 ± 15.63	13.81 ± 15.45	17.79 ± 15.62	t(295) = − 1.66	0.098
Sex (%)					
Male	220 (74.1)	38 (74.5)	182 (74.0)	$\chi^2(1)=0.006$	0.938
Female	77 (25.9)	13 (25.6)	64 (26.0)		
Ethnicity (%)					
Iban	228 (76.8)	41 (80.4)	187 (76.0)	$\chi^2(1)=0.454$	0.501
Others (Malay, Chinese, Bidayuh)	69 (23.2)	10 (19.6)	59 (24.0)		
Marital Status (%)					
Married	264 (88.9)	43 (84.3)	221 (89.8)	$\chi^2(1)=1.305$	0.253
Others (Single/Divorced/Widowed)	33 (11.1)	8 (15.7)	25 (10.2)		
Education (%)					
None	29 (9.8)	4 (7.8)	25 (10.2)	$\chi^2(2)=6.166$	0.043*
Primary	111 (37.4)	12 (23.5)	99 (40.2)		
Secondary/Tertiary	157 (52.8)	35 (68.6)	122 (49.6)		
Farm Ownership (%)					
Owner	285 (96.0)	45 (88.2)	240 (97.6)	$\chi^2(1)=9.475$	0.008*
Worker	12 (4.0)	6 (11.8)	6 (2.4)		
Knowledge score (M ± SD)	75.30 ± 12.82	15.47 ± 3.26	14.41 ± 3.19	t(295) = 2.160	0.032*
Susceptibility and Severity score	84.29 ± 14.15	8.63 ± 0.80	7.37 ± 1.25	t(107.70) = 9.160**	< 0.001*
Benefits score	98.18 ± 6.83	4.88 ± 0.33	4.91 ± 0.35	t(295) = − 0.614	0.540
Barriers score	57.37 ± 26.61	2.57 ± 0.96	2.93 ± 1.39	t(98.43) = − 2.244**	0.027*
Cue to Action score	80.07 ± 19.42	4.65 ± 0.69	3.87 ± 0.97	t(96.26) = 6.793**	< 0.001*
Self-Efficacy score	83.22 ± 20.32	4.63 ± 1.23	5.07 ± 1.21	t(295) = − 2.373	0.018*

*Significant at α = 0.05. ** Welch's t-test used where variances were unequal

Percentages are calculated using data within each PPE group. Minor deviation from 100% i.e. total % for Ethnicity in the full PPE group 99.9%, is due to rounding

Table 2 PPE use prevalence and item uptake ($N=297$)

Characteristics	N (%)
A. PPE item	
Long trousers	293 (98.7)
Long-sleeved shirts	279 (93.9)
Rubber/PVC boots	273 (91.9)
Face mask	247 (83.2)
Rubber gloves	189 (63.6)
Goggles	116 (39.1)
Face shield	81 (27.3)
B. Total PPE items worn	
7 (Full PPE)	51 (17.2)
6	43 (14.5)
5	94 (31.6)
4	76 (25.6)
3	25 (8.4)
2	6 (2.0)
1	2 (0.7)

Table 3 Simple logistic regression (Crude odds Ratios) for full PPE use ($N=297$)

Factors	B	SE	cOR	95% CI	*P* value
Age (per year)	−0.095	0.018	0.909	[0.877, 0.942]	< 0.001*
Income (per RM100)	0.048	0.022	1.050	[1.005, 1.096]	0.030*
Farming Experience (per year)	−0.020	0.012	0.981	[0.958, 1.004]	0.103*
Male (vs. female)	0.028	0.353	1.028	[0.515, 2.052]	0.938
Iban (vs. non-Iban)	0.129	0.191	1.294	[0.611, 2.740]	0.502
Education (Primary vs. None)	−0.278	0.619	0.758	[0.224, 2.550]	0.654
Education (Secondary/Tertiary vs. None)	0.584	0.572	1.793	[0.585, 5.498]	0.307
Married (vs. others)	−0.498	0.439	0.608	[0.257, 1.438]	0.257
Owner (vs. worker)	−1.674	0.600	0.188	[0.058, 0.607]	0.005*
Knowledge Score	0.124	0.058	1.132	[1.010, 1.269]	0.033*
Susceptibility and Severity Score	1.147	0.206	3.150	[2.105, 4.713]	< 0.001*
Benefits Score	−0.249	0.408	0.779	[0.350, 1.733]	0.541
Barriers Score	−0.211	0.120	0.810	[0.640, 1.024]	0.078*
Cues to Action Score	1.184	0.246	3.266	[2.017, 5.289]	< 0.001*
Self-Efficacy Score	−0.273	0.118	0.761	[0.604, 0.959]	0.020*

*Significant at α = 0.25

Table 4 Multivariable logistic regression of factors associated with full PPE use

Predictors	B	SE	aOR	95% CI	*p*-value
Age	−0.119	0.028	0.887	[0.839, 0.938]	< 0.001*
Income (per RM100)	−0.12	0.038	0.988	[0.918, 1.065]	0.759
Farming experience (per year)	0.045	0.020	1.046	[1.006, 1.088]	0.024*
Susceptibility and severity score (per point)	0.963	0.261	2.618	[1.571, 4.365]	< 0.001*
Benefits score (per point)	−1.192	0.567	0.303	[0.100, 0.921]	0.035*
Barriers score (per point)	−0.637	0.204	0.529	[0.355, 0.790]	0.002*
Cues to action score (per point)	0.980	0.294	2.665	[1.499, 4.740]	< 0.001*
Self-efficacy score (per point)	0.600	0.478	1.823	[0.715, 4.648]	0.209
Self-efficacy^2 (quadratic term)	−0.392	0.161	0.676	[0.493, 0.926]	0.015*

*Significant at α = 0.05

greater farming experience was associated with higher adjusted odds (aOR = 1.046, 95% CI [1.006, 1.088], p = 0.024). Higher perceived susceptibility and severity (aOR = 2.618, 95% CI [1.571, 4.365], p < 0.001) and cues to action (aOR = 2.665, 95% CI [1.499, 4.740], p < 0.001) were positively associated with full PPE use, while greater perceived barriers were inversely associated (aOR = 0.529, 95% CI [0.355, 0.790], p = 0.002). Perceived benefits also showed an inverse association (aOR = 0.303, 95% CI [0.100, 0.921], p = 0.035). Adjusted estimates are shown in Table 4 and visualised in Fig. 1.

4 Discussion

4.1 Key findings

Only 17.2% of farmers reported full PPE use with partial adherence common and coverage highest for clothing (pants, shirts, boots) but lowest for face and eye protection (goggles 39.1%, face shield 27.3%). The pattern is consistent with studies from Sabah, Selangor and Thailand where basic protective clothing is widely used while face and eye PPE is underutilised likely due to discomfort, fogging and interference with vision in hot, humid environments [3, 22, 38]. These low-use items also carry the highest risk for pesticide splash and drift, suggesting a protection gap.

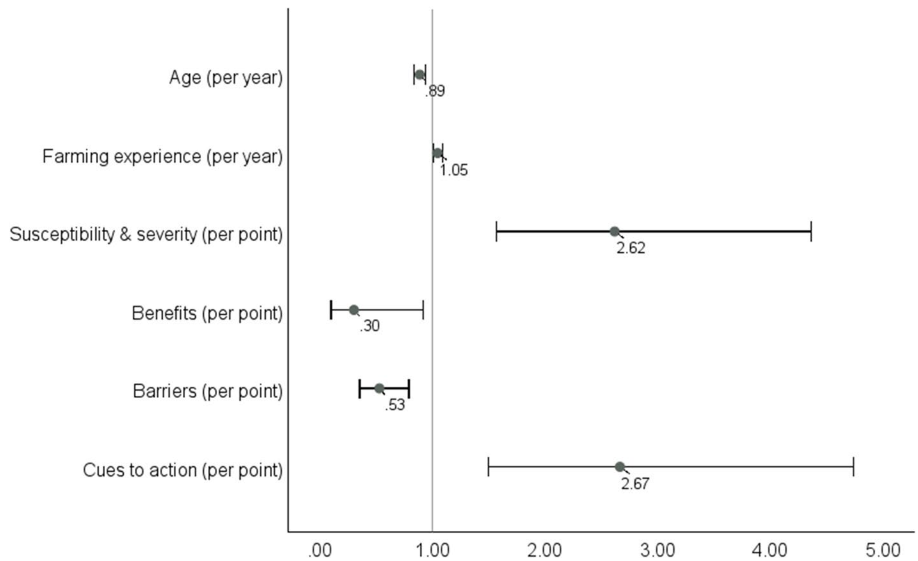

Fig. 1 Adjusted odds ratios for full PPE use with 95% confidence intervals among agricultural pesticide handlers in Samarahan, Sarawak. Odds ratios (dark circles) and CIs (horizontal "T"s) derived from the multivariable logistic regression including age, farming experience, perceived susceptibility and severity, perceived benefits, perceived barriers and cues to action; quadratic self-efficacy term was retained in the model but omitted from the display for clarity

The persistence of low utilisation of face and eye protection despite well-documented risks may plausibly reflect a combination of behavioural and contextual factors. Farmers may prioritise immediate comfort, visibility and task efficiency over protection against hazards that are less immediately perceptible such as aerosolised pesticide drift or splash exposure. Repeated exposure without acute adverse outcomes may also contribute to risk normalisation, whereby perceived vulnerability diminishes over time despite awareness of potential harm. Geographical and climatic conditions may further shape PPE adherence patterns. In tropical settings such as Malaysia, high ambient temperatures and humidity could exacerbate discomfort associated with goggles and face shields including fogging, heat retention and impaired vision. Variations in microclimate, crop type and spraying practices across Malaysian states may therefore influence the feasibility and acceptability of certain PPE components. These contextual constraints suggest that PPE adherence, particularly for face and eye protection is influenced not only by risk awareness but also by environmental and occupational realities.

In the multivariable model, age and farming experience were significant sociodemographic factors. Younger farmers and those with greater farming experience were more likely to adopt full PPE. Notably, the adjusted analysis indicated opposing effects: increasing age was associated with lower odds of full PPE use, whereas greater farming experience was associated with higher odds. This apparent contrast may reflect cohort and practice effects, whereby older farmers may be less inclined to change entrenched habits, while accumulated hands-on experience may increase risk awareness and encourage more comprehensive protective practices. These findings mirror observations from Nepal, Peru and Thailand, where older farmers often resisted changes in safety behaviour due to discomfort and established routines [17, 19, 39]. Although age and farming experience are conceptually related, formal assessment indicated no problematic multicollinearity, supporting the stability of their independent associations in the adjusted model. Education, income and ownership effects in bivariate analyses diminished after adjustment, suggesting that sociodemographic influences operate indirectly through psychosocial constructs.

Among HBM predictors, perceived susceptibility and severity that were analysed as a combined construct representing perceived threat, strongly promoted full PPE use, while perceived barriers suppressed it. These findings were consistent with prior studies in Peru, Ghana, Ethiopia and Iran [17, 19, 23, 40] and systematic reviews in tropical agriculture [15, 41]. Cues to action (training, prompts) also encouraged PPE use, showing the importance of external reinforcement in safety behaviour.

Interestingly, perceived benefits showed a negative association after adjustment, which is best interpreted as a behavioural trade-off rather than lack of perceived utility. While perceived benefits are typically framed in terms of long-term health protection or risk reduction, such outcomes may be too abstract or temporally distant to outweigh immediate experiential costs during daily pesticide handling. In tropical farming contexts, the anticipated benefits of comprehensive PPE may be weighed against immediate and tangible costs including physical burden from heat retention and discomfort, the complexity of donning and managing multiple PPE items and opportunity costs arising from workflow disruption or reduced task efficiency. This trade-off is likely amplified in this study, where full PPE was defined as the simultaneous use of seven protective items, increasing cumulative discomfort and perceived inconvenience during routine work. When protective behaviour requires sustained use of several items, farmers may prioritise short-term functionality and comfort over longer-term health protection, leading to selective rather than comprehensive PPE use. Framing perceived benefits within this trade-off highlights how environmental and occupational constraints could modify expected HBM relationships in real-world agricultural settings.

Self-efficacy displayed a counter-intuitive inverse association with full PPE use after adjustment. Although self-efficacy is generally expected to facilitate protective behaviour within the HBM, this finding may reflect context-specific dynamics. Among experienced pesticide handlers, higher perceived self-efficacy may indicate confidence in managing pesticide risks without full PPE, potentially reflecting risk normalisation or habituation. In such settings, familiarity with routine hazards may lead to selective PPE use rather than comprehensive protection. This finding should therefore be interpreted cautiously and points to the importance of contextualising self-efficacy within real-world agricultural practice.

Knowledge was excluded from the final model after adjustment, which is consistent with its role as a distal determinant within the HBM. While knowledge is necessary to inform risk awareness, it may not directly translate into protective behaviour when more proximal psychosocial constructs such as perceived threat, barriers, cues to action and self-efficacy are taken into account. This pattern reflects the knowledge-behaviour gap in public health, whereby increases in awareness do not necessarily result in behavioural change in the absence of enabling or motivating factors.

Taken together, these findings refine the application of the HBM in tropical agricultural settings by demonstrating that the functional roles of key constructs may be shaped by environmental and occupational constraints. While perceived threat and cues to action operated in expected directions, the inverse or non-linear effects observed for perceived benefits and self-efficacy suggest that these constructs may not uniformly promote protective behaviour in contexts characterised by heat, humidity and physically demanding work. In such settings, farmers may weigh perceived benefits against immediate discomfort or task efficiency, and high self-efficacy may reflect confidence in managing risk without full PPE rather than motivation for comprehensive protection. These results highlight the need for HBM-informed interventions to be context-sensitive, rather than assuming uniform construct-behaviour relationships across settings.

4.2 Limitations and recommendations for research

We acknowledged several limitations in our study. First, the cross-sectional design restricted causal inference. Second, the sample was limited to Samarahan division which may not represent other agricultural settings in Malaysia. Third, reliance on self-reported PPE use could introduce recall and social desirability bias, particularly for items like goggles and face shields. Fourth, outcome measurement was dichotomous (partial vs. full PPE), which obscures variation among partial users. Finally, contextual variables such as crop type, pesticide formulation and work conditions were not fully captured.

Future research should expand geographically, adopt longitudinal or intervention designs and employ mixed methods to better explain underuse of specific PPE items. Measurement of HBM constructs would benefit from confirmatory factor analysis, pre-specified modelling of non-linear effects and item response theory. Direct observation or photo verification of PPE use should complement self-reports. Employment status and PPE procurement pathways should be systematically measured, as provision and supervision differ between self-employed farmers and hired workers.

4.3 Implications

The findings showed a protection gap in Samarahan especially for eye and face PPE, with implications for acute and chronic pesticide exposure. Risk communication should emphasise older farmers who had lower adherence, while reinforcing safe routines among experienced operators. Extension and occupational health programmes should target perceived barriers (cost, heat, comfort) and provide timely cues to action (reminders, supervision, vendor prompts). Screening tools based on key predictors (age, perceived threat, barriers, cues) could help extension officers identify high-risk farmers for focused interventions.

This study refined HBM theoretical application in tropical smallholder agriculture. Threat appraisal (susceptibility and severity) and cues emerged as proximal determinants, barriers suppressed adoption, and knowledge had limited independent effect. The inverted-U relationship with self-efficacy suggested the need to model non-linearities, while the negative coefficient for perceived benefits illustrated how construct effects depended on how protection is operationalised (all seven items vs. partial use).

Improving PPE adherence requires structural support and behaviour change. At system level, safer formulations, mechanisation such as drone spraying and cooperative purchasing of comfortable and affordable PPE should be promoted. On the farm, safety could be reinforced by formalising PPE routines through posted standard operating procedures, pre-spray checklists and regular toolbox talks. Regulatory measures also play a role, with pesticide sales licensing and MyGAP (Malaysian Good Agriculture Practice) certification needing to align with auditable PPE standards to secure provision, maintenance and record keeping. At the point of purchase, vendors could deliver simple PPE checklists and sprayer stickers to provide cues and create feedback loops supporting extension activities. In workforce settings, employers bear responsibility for providing and monitoring PPE under Malaysia's Occupational Safety and Health Act (OSHA) 1994 and Use and Standard of Exposure of Chemicals Hazardous to Health (USECHH) 2000 regulations, while smallholders could benefit from simplified templates provided by the Department of Agriculture. Finally, the health sector can contribute by integrating PPE safety checks into occupational health outreach and by developing light monitoring frameworks that supply actionable data back to farmers, cooperatives and extension services.

5 Conclusion

Full PPE use among agricultural pesticide handlers in Samarahan was uncommon, with only 17.2% reporting simultaneous use of all seven items and the lowest uptake seen for eye and face protection. Younger age and greater farming experience were associated with higher adherence, while HBM constructs differentiated users: higher perceived susceptibility and severity and stronger cues to action increased the odds of full PPE, whereas perceived barriers reduced them. Perceived benefits were inversely associated in the adjusted model. These results indicated that adherence is shaped by both perception and context, with barriers in hot, humid field conditions particularly important for ocular and facial protection. Programme and policy efforts should prioritise strengthening risk appraisal, embedding practical cues at the point of work and purchase, and reducing thermal and comfort burdens through provision of appropriate equipment and supportive supervision. The study provides baseline evidence for Sarawak and a theory-informed roadmap for interventions that combine behavioural strategies with structural support to reduce pesticide-related harm.

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Author contributions

ZEA–conceptualization, methodology, data management, statistical analysis, writing of original draft. LSH–methodology, validation, writing review and editing. SFJ–study design, data analysis and results validation.

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Data availability

In compliance with ethical requirements set by the institution, the dataset is not publicly available. However, de-identified data may be obtained from the corresponding author upon request and with appropriate approvals.

Declarations

Disclaimer

The view expressed are those of the author and do not necessarily represent the Ministry of Health Malaysia.

Ethics approval

This study was reviewed and approved by the Universiti Malaysia Sarawak (UNIMAS) Ethics Review Board, Ref: UNIMAS/TNC(PI)09–65/01 Jld. 4 (61) dated 10 March 2025. All methods were carried out in accordance with the Declaration of Helsinki and Malaysian Good Clinical Practice Guideline.

Consent to participate

Administrative approvals were obtained from the Samarahan Division Department of Agriculture and the respective district agriculture offices. All participants were provided with clear information about the study objectives, potential risks and benefits before consent was sought. Written informed consent was obtained from each participant and confidentiality of responses was maintained throughout the study. Participation was entirely voluntary, and respondents were informed of their right to decline or withdraw from the study at any stage without any consequence.

Consent for publication
All participants provided consent for anonymised data to be used for research publication purposes. No identifying information of individual participants was included in this manuscript.

Competing interests
The authors declare no competing interests.

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