

FACTORS INFLUENCING PESTICIDE RISK-REDUCTION BEHAVIOUR AMONG VEGETABLE FARMERS IN NORTHWESTERN TAMIL NADU: A HEALTH BELIEF MODEL-BASED PLS-SEM APPROACH

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ABSTRACT

Vegetable farmers face pesticide exposure during mixing, spraying, and disposal, yet recommended precautions are not consistently practised. This study examined how six Health Belief Model constructs are associated with pesticide risk-reduction behaviour among vegetable farmers in northwestern Tamil Nadu. A cross-sectional survey was conducted from September to October 2025 with 200 farmers in 20 villages across Dharmapuri and Krishnagiri districts. Face-to-face interviews used a structured schedule covering perceived susceptibility, severity, benefits, barriers, cues to action, self-efficacy, and seven protective practices. Descriptive statistics and partial least squares structural equation modelling were used to assess the measures and test the hypothesised paths. Protective practices varied considerably: 88.1% reported washing their hands after pesticide use, but only 34.1% wore gloves and 21.0% wore goggles; 61.6% reported mixing pesticides with bare hands. The six constructs explained 71.5% of the variance in pesticide risk-reduction behaviour ($R^2 = 0.715$; adjusted $R^2 = 0.706$). Perceived severity ($\beta = 0.832$), self-efficacy ($\beta = 0.378$), cues to action ($\beta = 0.173$) and perceived benefits ($\beta = 0.223$) showed significant positive associations (all $p < 0.001$). Perceived susceptibility ($\beta = -0.222$, $p = 0.001$) showed significant negative associations, contrary to the hypotheses, while perceived barriers were negatively associated with behaviour ($\beta = 0.035$, $p = 0.412$). Extension programmes should strengthen practical safety skills and prompts, improve access to protective equipment.

KEYWORDS: agricultural extension; health belief model; partial least squares structural equation modelling; pesticide risk-reduction behaviour; vegetable farmers

1. INTRODUCTION

Globally, pesticide use in agriculture has raised concerns about public health and environmental sustainability. Although pesticides help protect vegetable crops from pests and diseases, excessive use and unsafe handling can increase exposure and associated health risks among farmers and farmworkers. Yet the people who handle them may face occupational exposure throughout mixing, application, equipment cleaning, storage and disposal. Global agricultural pesticide use reached 3.92 million tonnes of active ingredients in 2024 (Food and Agriculture Organization of the United Nations [FAO], 2026). A recent review estimated 402–433 million cases of unintentional acute pesticide poisoning and approximately 11,000 associated deaths worldwide each year, with southern Asia accounting for the highest estimated number of non-fatal cases (Boedeker *et al.*, 2026). These are modelled global estimates, but they demonstrate the scale of the health concern associated with pesticide exposure (Hailu *et al.*, 2025).

Studies in farming communities have recorded a range of health complaints following pesticide use. In Nepal, 18.7% of pesticide users surveyed in Chitwan district reported at least one acute symptom during the preceding year; unsafe handling was associated with a greater likelihood of reported acute poisoning (Kafle *et al.*, 2021). In a separate study in Tokha Municipality, 73% of respondents reported health effects, most commonly headache (69.5%), skin irritation (42.8%) and burning eyes (31.3%) (Karki & Dangol, 2023). Evidence from India adds to this concern. Among rice farmers studied in Odisha, skin irritation was the most frequently reported acute symptom, and eating or drinking during insecticide application was associated with significantly greater symptom reporting (Kumar *et al.*, 2025). In Chikkaballapura district, Karnataka, farmers exposed to agrochemicals reported backache (32%), neck pain (36%), skin burns (21%), blisters (15%), eye irritation (11%) and blurred vision (8%);

several complaints were more frequent than in the study's comparison group (Venugopal *et al.*, 2025). A study among agricultural farmers and workers in Kerala reported symptoms after pesticide use that included sleep disturbance, dizziness, recurring headache and breathing difficulty, while also investigating the association of exposure and socioeconomic factors with diabetes prevalence (R A *et al.*, 2026). In Villupuram district, Tamil Nadu, a cross-sectional study reported post-spraying symptoms among 14.5% of participants ("Prevalence of Pesticides Usage," 2024). These studies document reported symptoms and associations.

The recorded complaints must be considered alongside how pesticides are handled. Among farmers in Ghana, most respondents knew that pesticides could harm health and the environment, yet only 35% wore full personal protective equipment (PPE) during application; unsafe handling and storage practices were also observed (Okoffo *et al.*, 2016 and Cazagrande *et al.*, 2026). In Nepal, safer pesticide-handling knowledge was associated with safer mixing, spraying, storage and disposal (Kafle *et al.*, 2021). Among apple-orchard workers in the western Himalayan region of India, most respondents recognised that pesticides were poisonous, but some still mixed pesticides by hand, many considered household storage harmless, and only 24% had received formal spraying training (Kumari *et al.*, 2021). Research among Bangladeshi smallholder vegetable farmers has further examined how handling practices relate to occupational risks and expenditure on health and safety measures (Hossain *et al.*, 2026). Together, the health findings and handling studies establish the problem that this article addresses: exposure-related complaints have been recorded, yet knowledge of danger does not consistently translate into precautions.

For vegetable farmers, changing practice is not a simple matter of telling them that pesticides are harmful. Pest damage poses an immediate threat to yield and income, while a possible health consequence may seem uncertain or less immediate. Farmers may continue practices they regard as necessary for crop protection even when they recognise a health risk. Exposure can involve not only the person operating a sprayer but also hired applicators, family members and others assisting with mixing, application or equipment cleaning (Mehmood *et al.*, 2021; Ssekkadde *et al.*, 2024). Frequent application and unsafe handling create additional opportunities for contact with pesticides. Farmers' decisions may also be shaped by experience, available advice and input-dealer recommendations. These circumstances make it necessary to understand why a farmer judges a precaution to be worthwhile, difficult or feasible before designing measures to improve practice (Meira *et al.*, 2025).

The Health Belief Model (HBM) provides a framework for examining those judgements. Perceived susceptibility concerns whether farmers believe exposure could affect them personally, while perceived severity concerns how serious they consider its consequences. Perceived benefits and barriers address the expected value and practical difficulty of precautions; cues to action represent prompts to act; and self-efficacy reflects confidence in carrying out protective measures. An Indonesian study has applied an HBM-based partial least squares approach to factors associated with pesticide-poisoning risk (Hossain *et al.*, 2026). A study in northern India has also used the HBM and partial least squares structural equation modelling (PLS-SEM) to examine pesticide-related protective behaviour (Muslim *et al.*, 2022). Separately, research on rice farmers in eastern India has shown the value of studying behavioural determinants of pesticide-use decisions, although intention to use pesticides differs from the adoption of precautions while using them (Govindharaj *et al.*, 2021 and Shah *et al.*, 2026).

Evidence on symptoms and unsafe handling in other settings cannot explain which health beliefs are most closely associated with risk-reduction practices among vegetable farmers in northwestern Tamil Nadu (Champion & Skinner, 2008). Therefore, this study aimed to: (i) assess pesticide-related health symptoms and risk-reduction practices among vegetable farmers; (ii) assess the six Health Belief Model constructs among vegetable farmers; and (iii) examine the influence of these constructs on pesticide risk-reduction behaviour using PLS-SEM. Pesticide risk-reduction behaviour refers to precautions and identifying the beliefs and barriers associated with these practices can guide agricultural extension programmes towards more relevant advice, training, and practical support.

1.1. PROBLEM STATEMENT

The central problem is that awareness of pesticide-related health risks does not consistently translate into safer handling practices among vegetable farmers. Immediate pressure to prevent crop losses may outweigh concerns about health effects that are less visible or delayed. Understanding the beliefs and practical barriers behind this gap is essential for designing effective safety interventions.

1.2. THEORETICAL FRAMEWORK AND HYPOTHESES DEVELOPMENT

The Health Belief Model (HBM) explains health-related behaviour through individual's perceptions of a health threat and their assessment of actions available to address it. Its core constructs are perceived susceptibility, perceived severity, perceived benefits and perceived barriers; cues to action and self-efficacy are also used to explain what prompts action and whether an individual feels capable of carrying it out (Rosenstock *et al.*, 1988 and Champion & Skinner, 2008). The model is relevant to pesticide safety. A recent study of farmers in northern India has demonstrated the relevance of HBM constructs to pesticide-related protective behaviour (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). In this study, Pesticide risk-reduction behaviour (PRRB) refers to the reported frequency with which vegetable farmers follow recommended precautions during pesticide use and handling. These practices include consulting label instructions, applying the recommended dose, using appropriate protective equipment, avoiding eating or drinking while handling pesticides, storing products safely, observing

the pre-harvest interval and disposing of containers safely. The six HBM constructs are proposed as direct predictors of PRRB and shown in Figure 1.

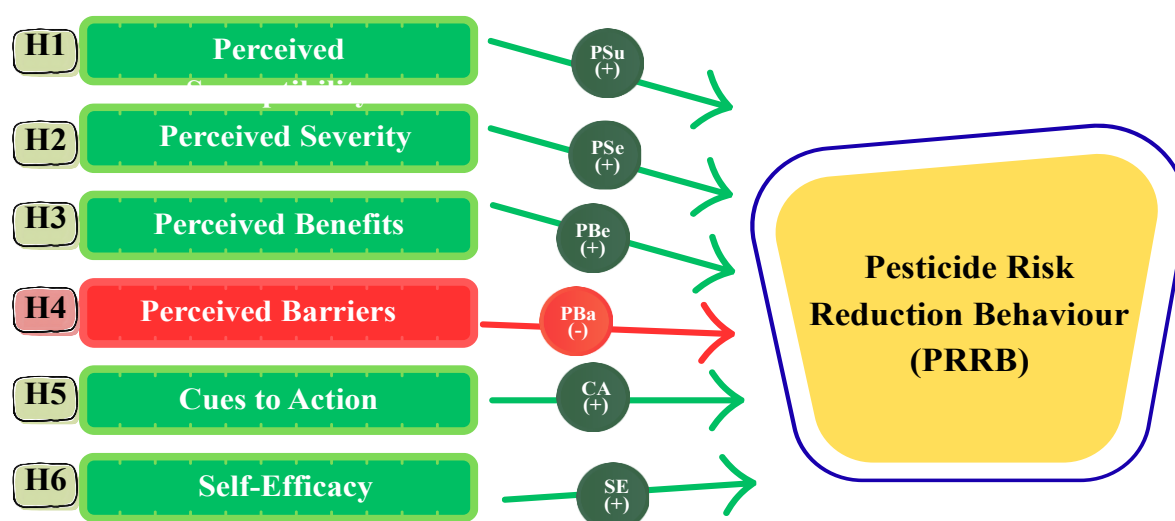


Figure 1 – Conceptual Health belief model

I. Perceived susceptibility

Perceived susceptibility is a farmer's belief that pesticide-handling activities could result in personal exposure or related health harm. Exposure may occur through inhalation, skin contact or entering a treated field too soon after application, even when no immediate symptom is noticed (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). Farmers who consider these situations personally relevant may be more likely to take precautions. Therefore,

H1: Perceived susceptibility is positively associated with pesticide risk-reduction behaviour among vegetable farmers.

II. Perceived severity

Perceived severity concerns how seriously a farmer regards the potential consequences of occupational pesticide exposure, including illness requiring medical attention, life threatening health issues (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). If farmers regard these outcomes as serious, they may place greater importance on preventing exposure during pesticide-related tasks. Therefore,

H2: Perceived severity is positively associated with pesticide risk-reduction behaviour among vegetable farmers.

III. Perceived benefits

Perceived benefits refer to a farmer's belief that recommended precautions can reduce harmful consequences. Belief in the usefulness of protective equipment, correct dosage, equipment maintenance and post-spraying hygiene may encourage safer handling (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). Observing the pre-harvest interval also protects consumers by reducing the likelihood of residues in harvested vegetables. Farmers who see clear benefits in these measures may practise them more consistently. Therefore,

H3: Perceived benefits are positively associated with pesticide risk-reduction behaviour among vegetable farmers.

IV. Perceived barriers

Perceived barriers are the obstacles farmers believe make precautions difficult to follow. In this study include the cost or limited availability of protective equipment, heat and discomfort during its use, difficulty understanding label instructions, and the time required to follow safety measures (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). Even farmers who recognise pesticide-related risks may adopt precautions less consistently when they perceive these barriers as substantial. Therefore,

H4: Perceived barriers are negatively associated with pesticide risk-reduction behaviour among vegetable farmers.

V. Cues to action

Cues to action are prompts that bring pesticide safety to a farmer's attention when a decision or action is needed. They may include extension advice, training, warnings on pesticide containers and previous experiences of pesticide-related illness (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). Such prompts may encourage farmers to apply precautions they already know about but do not routinely practise. Therefore,

H5: Cues to action are positively associated with pesticide risk-reduction behaviour among vegetable farmers.

VI. Self-efficacy

Self-efficacy is a farmer's confidence in their ability to carry out recommended safety practices. A farmer may understand the importance of precautions yet be uncertain about interpreting label warnings, measuring the correct dose, using protective equipment properly or rejecting an unsafe recommendation (Rosenstock *et al.*, 1988; Shah *et al.*, 2026). Greater confidence in performing these tasks is expected to support more consistent protective practice. Therefore,

H6: Self-efficacy is positively associated with pesticide risk-reduction behaviour among vegetable farmers. Together, these hypotheses specify six direct paths from the HBM constructs to PRRB.

2. MATERIALS AND METHODS

2.1. Research design and study area

A cross-sectional observational survey was conducted among vegetable farmers in Dharmapuri and Krishnagiri districts of northern Tamil Nadu, India, between September and October 2025. The districts were purposively selected for this study of pesticide handling in vegetable cultivation. The five crops considered were okra (*bhendi*), brinjal, tomato, onion and chilli. Dharmapuri and Krishnagiri are included in the description of Tamil Nadu's Northwestern agro-climatic zone (TNAU,2010). The locations of the study districts are shown in Figures 2 and 3.

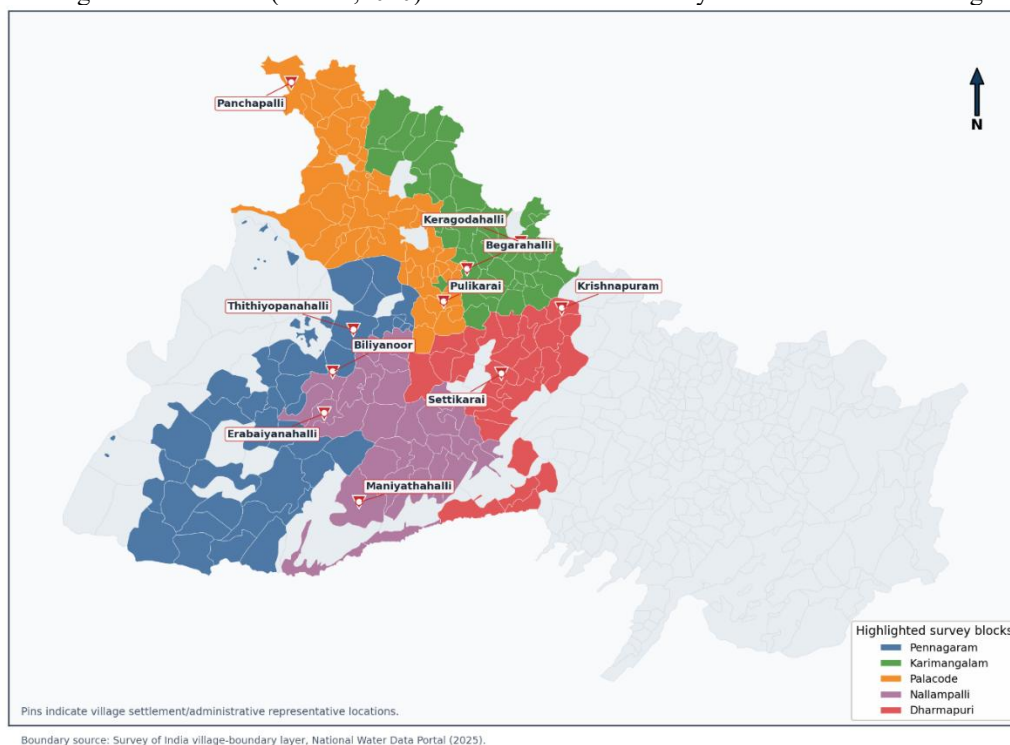


Figure 2 – Map of the study area – Dharmapuri district (selected blocks and villages)

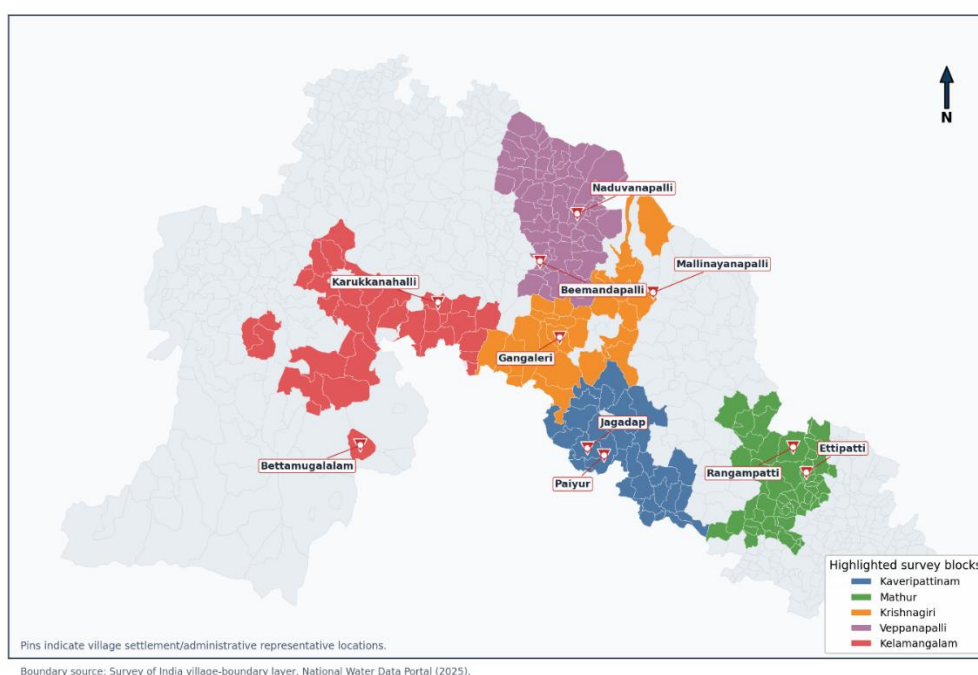


Figure 3 – Map of the study area – Krishnagiri district (selected blocks and villages)

2.2. Selection of study locations and respondents

A multistage selection procedure was followed. Five blocks in each district were selected on the basis of their relevance to the cultivation of the study crops. The selected blocks in Dharmapuri were Pennagaram,

Karimangalam, Palacode, Nallampalli and Dharmapuri. Those in Krishnagiri were Kaveripattinam, Mathur, Krishnagiri, Veppanapalli and Kelamangalam. Two villages were selected from each block, giving 20 study villages in total (Table 1).

Table 1. Study blocks and villages

District	Block	Villages
Dharmapuri	Pennagaram	Billiyanoor; Thithiyopanahalli
Dharmapuri	Karimangalam	Begarahalli; Keragodahalli
Dharmapuri	Palacode	Pulikarai; Panchapalli
Dharmapuri	Nallampalli	Maniyathahalli; Errabaiyanahalli
Dharmapuri	Dharmapuri	Krishnapuram; Settikarai
Krishnagiri	Kaveripattinam	Jagadap; Paiyur
Krishnagiri	Mathur	Ettipatti; Rangampatti
Krishnagiri	Krishnagiri	Malliyanapalli; Gangleri
Krishnagiri	Veppanapalli	Naduvanapalli; Beemandapalli
Krishnagiri	Kelamangalam	Karukkanahalli; Bettamugilalam

The study included farmers involved in cultivating at least one of the five selected vegetable crops and in decisions or activities related to pesticide use. A total of 200 farmers were interviewed, with 100 respondents from each district.

2.3. Sample size

The initial sample size was estimated using Cochran's formula for a population proportion (Cochran, 1977; Al-Sarar *et al.*, 2025),

$$n_0 = \frac{Z^2 p(1-p)}{e^2}$$

where n_0 is the initial sample size, $Z = 1.96$ corresponds to a 95% confidence level, $p = 0.50$ is the assumed population proportion used when no reliable prior estimate is available, and $e = 0.07$ is the specified margin of error. Substitution gives:

$$n_0 = \frac{(1.96)^2(0.50)(0.50)}{(0.07)^2} = 196.0$$

The target sample was set at 200 farmers to allow equal allocation of 100 respondents to each district. Cochran's calculation provides an initial sample-size rationale; the stated margin of error should not be claimed as the achieved precision of estimates from purposively selected districts and blocks.

2.4. Data collection and measures

Primary data were collected through face-to-face interviews using a structured interview schedule that was pre-tested before the main survey. The schedule recorded respondents demographic and farming characteristics, Pesticide safe-handling practices, and responses to the study constructs. The Health Belief Model (HBM) measures comprised perceived susceptibility (five items), perceived severity (three items), perceived benefits (six items), perceived barriers (four items), cues to action (four items) and self-efficacy (four items). Pesticide risk-reduction behaviour (PRRB) was measured using seven items concerning label consultation, recommended dosage, protective equipment, avoiding eating or drinking while handling pesticides, safe storage, the pre-harvest interval and container disposal. The 33 construct items are presented in Supplementary Table (S1).

Responses to the six HBM constructs were recorded on a five-point agreement scale ranging from 1 (strongly disagree) to 5 (strongly agree). PRRB items used a five-point frequency scale ranging from 1 (never) to 5 (always). Higher PRRB responses therefore indicated more frequent adoption of the specified safety practices.

2.5. Statistical analysis

Respondent characteristics and Pesticide safe-handling practices were summarised using descriptive statistics. The hypothesised relationships between the six HBM constructs and PRRB were examined using partial least squares structural equation modelling (PLS-SEM) (Shah *et al.*, 2026). This approach permits simultaneous assessment of the construct measures and their proposed relationships with PRRB (Al-Sarar *et al.*, 2025). The analysis proceeded in two stages: assessment of the measurement models, followed by assessment of the structural model.

Measurement-model assessment was matched to the way each construct was specified. For reflectively measured constructs, indicator loadings, Cronbach's alpha, composite reliability and average variance extracted (AVE) were examined. Internal consistency values of approximately 0.70 or higher and AVE above 0.50 were used as assessment guidelines. Discriminant validity was examined using the heterotrait-monotrait ratio (HTMT), with values below 0.90 considered in light of the construct's conceptual similarity (Muslim *et al.*, 2022; Shah *et al.*, 2026; Rosenstock *et al.*, 1988). For any construct specified formatively, indicator collinearity, the significance and relevance of outer weights, and content coverage were assessed instead; alpha, composite reliability and AVE are not appropriate criteria for judging formative indicators.

Before interpreting the structural paths, collinearity among predictor constructs was examined using variance inflation factors (VIFs). The six hypothesised paths were assessed using a nonparametric bootstrap procedure with 5,000 subsamples, reporting standardised path coefficients, 95% confidence intervals and p values. The

explanatory performance of the model was evaluated through the coefficient of determination (R^2) for PRRB and the effect size (f^2) of each predictor (Al Sarar *et al.*, 2025). If predictive performance is reported using SmartPLS 4, PLS predict and its cross-validated prediction results should be used. SmartPLS 4 has discontinued the older blindfolding procedure for calculating Stone–Geisser’s Q^2 ; therefore, the proposed blindfolding omission distance of 10 should be removed from this methods section.

3. RESULTS

Demographic variables

The following section presents the demographic, farming characteristics, self-reported health symptoms and pesticide safe handling practices of the 200 vegetable farmers surveyed in Dharmapuri and Krishnagiri districts.

3.1. Age (n=200)

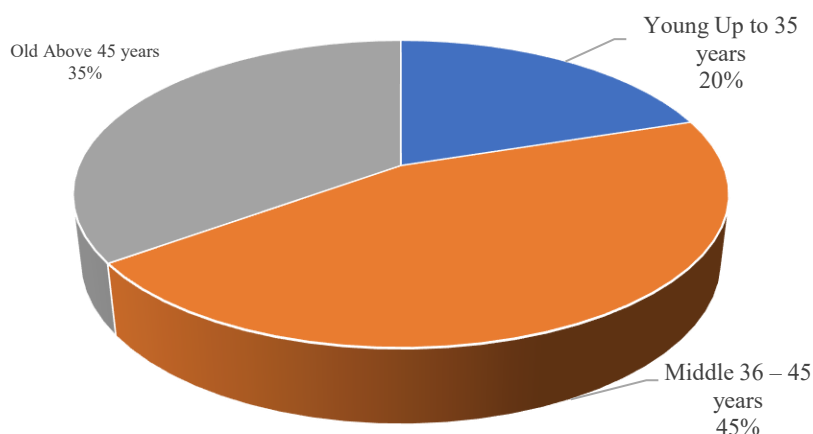


Figure 4 - Age of the respondents

Figure 4 shows that 45% of respondents were aged 36–45 years, 35% were above 45 years, and 20% were aged 35 years or below. Thus, most surveyed vegetable farmers were over 35 years old. This age profile is relevant because farmers experience may shape how they perceive pesticide exposure and the practicality of safety measures.

3.2. Educational status (n=200)

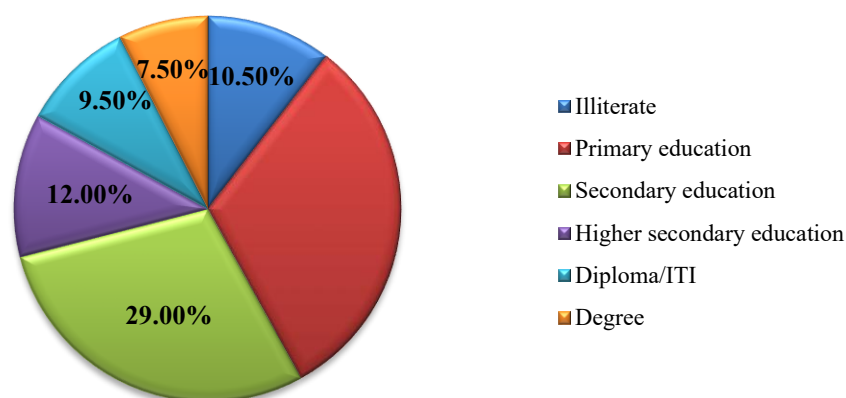


Figure 5: Educational status of the respondents

Figure 5 shows that 31.5% of respondents had primary education and 29.0% had secondary education. Another 10.5% had no formal education, while 12.0% had completed higher secondary education, 9.5% held a diploma or ITI qualification, and 7.5% had a degree or higher qualification. Education may be relevant to pesticide risk-reduction behaviour because reading labels and understanding dosage and safety instructions can help farmers follow precautions.

3.3. Annual Income (n=200)

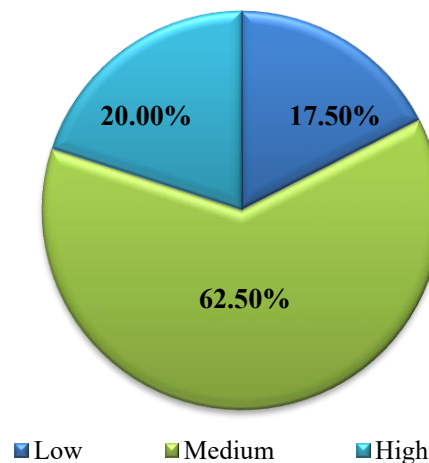


Figure 6 – Annual Income of the respondents

Figure 6 shows that 62.5% of respondents were in the medium-income group, followed by 20.0% in the high-income group and 17.5% in the low-income group. Income may affect farmers ability to purchase protective equipment and other safety supplies.

3.4. Self-reported health symptoms (n=200)

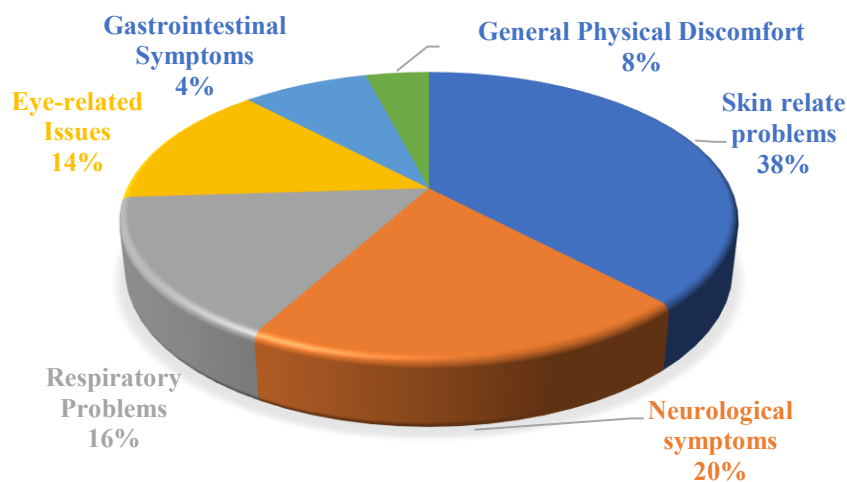


Figure7- Self-reported health symptoms

Figure 7 indicates that skin-related problems were the most commonly reported health complaints (38%), including rashes, skin allergies, burning sensation, and irritation of the hands and face, suggesting that skin contact may be an important concern during pesticide-related activities. Neurological symptoms (20%), comprising headache, giddiness, ear numbness, and occasional fits, were the second most frequently reported category. Respiratory problems (16%), including breathing difficulty, throat irritation, and chest discomfort, were also reported, while eye-related issues (14%) included eye irritation, watering, temporary blurred vision, and, in rare cases, partial vision disturbance. General physical discomfort (8%), particularly extreme tiredness and weakness, was reported by some farmers, whereas gastrointestinal symptoms (4%), including nausea and vomiting sensation, were least frequently reported. Farmers also described self-treatment as an initial response, with some seeking care at a local clinic when symptoms worsened.

3.5. Pesticide safe-handling practices

**Table 2. Self-reported pesticide-handling and safety practices among vegetable farmers
(n=200)**

Pesticide-handling practices	Respondents reporting the practice (%)
Used a mask and face shield	61.6
Wore protective gloves	34.1

Wore long-sleeved clothing	32.5
Wore protective goggles	21.0
Wore waterproof boots	9.5
Washed hands after pesticide use	88.1
Bathed after spraying	68.3
Read pesticide labels	29.0
Followed field re-entry intervals	24.0
Changed clothes after spraying	41.6
Consulted knowledgeable sources	38.6
Mixed pesticides while positioned upwind	36.6
Avoided spraying in windy conditions or during the afternoon	69.3
Selected pesticides using label information	28.6
Used spraying equipment correctly	8.0
Mixed pesticides with bare hands	61.6
Left empty pesticide containers in the field	78.5
Buried empty pesticide containers	37.5
Reused pesticide containers	31.6
Sprayed across the crop rather than targeting affected areas	87.5

Table 2 shows uneven adoption of safe pesticide-handling practices among vegetable farmers, with greater adherence to personal hygiene than to comprehensive protective measures, label-based decisions and safe container disposal. Unsafe practices also remained common, showing that farmers followed selected precautions without consistently adopting safety measures throughout pesticide handling.

(i) Personal protection and hygiene - Washing hands after pesticide use was the most frequently reported hygiene practice (88.1%), followed by bathing after spraying (68.5%). However, only 41.6% changed their clothes after spraying. Regarding protective equipment, 61.6% reported using a mask and face shield, whereas fewer wore protective gloves (34.1%), long-sleeved clothing (32.5%), protective goggles (21%) or waterproof boots (9.5%). This pattern may reflect farmers greater familiarity with washing and bathing, which can be incorporated into their daily routines with relatively little additional expenditure. Lower use of protective clothing and equipment may be associated with discomfort during fieldwork, cost, limited availability or difficulties in carrying out spraying operations. These explanations are plausible but require supporting evidence from farmers responses (figure 8).

(ii) Use of information and observance of precautions - Only 29.0% read pesticide labels, and 28.6% selected pesticides using label information. Furthermore, 38.6% consulted knowledgeable sources, while just 24.0% followed field re-entry intervals. These findings suggest limited use of formal safety information in pesticide-related decisions. Possible explanations include difficulty understanding technical instructions, reliance on familiar products or advice from others, and the pressure to resume routine cultivation activities after spraying. However, label non-reading alone should not be interpreted as evidence of illiteracy or lack of awareness.

(iii) Mixing and application practices. - Although 69.3% reported avoiding spraying in windy conditions or during the afternoon, only 36.6% mixed pesticides while positioned upwind. Moreover, 61.6% reported mixing pesticides with bare hands. Together, these findings suggest that precautions related to spraying conditions were more widely followed than those related to pesticide preparation. Farmers may perceive weather conditions as directly affecting spraying efficiency, while giving less attention to exposure during mixing. Only 8.0% reported using spraying equipment correctly, indicating a substantial reported gap in this practice, although the criteria used to define “correct use” should be specified. Additionally, 87.5% sprayed across the crop rather than targeting affected areas. This may reflect a preference for uniform crop protection or concern about pest spread; its appropriateness nevertheless depends on the pest, crop and recommended application method.

(iv) Container disposal - Leaving empty pesticide containers in the field was reported by 78.5%, while 37.5% burned containers and 31.5% reused them. These practices may reflect inadequate access to collection facilities, limited disposal guidance or the perceived usefulness of empty containers (figure 9).





Figures 8, 9: Using a battery sprayer without gloves, boots, and PPE – Dharmapuri (Tomato farmer); Disposal of the empty containers in the field itself

3.7. Factors influencing farmer's Pesticide Risk Reduction Behaviour

3.7.1. PLS-SEM results

Partial least squares structural equation modelling (PLS-SEM) was used to examine how the six Health Belief Model constructs relate to pesticide risk-reduction behaviour among the surveyed vegetable farmers. The results are presented in two stages: first, the measurement model is assessed to determine whether the survey items adequately represent each construct; second, the structural model is examined to estimate the strength and direction of the hypothesised relationships with protective behaviour (Mariani *et al.*,2026).

3.7.1.1. Measurement model – PLS SEM Algorithm

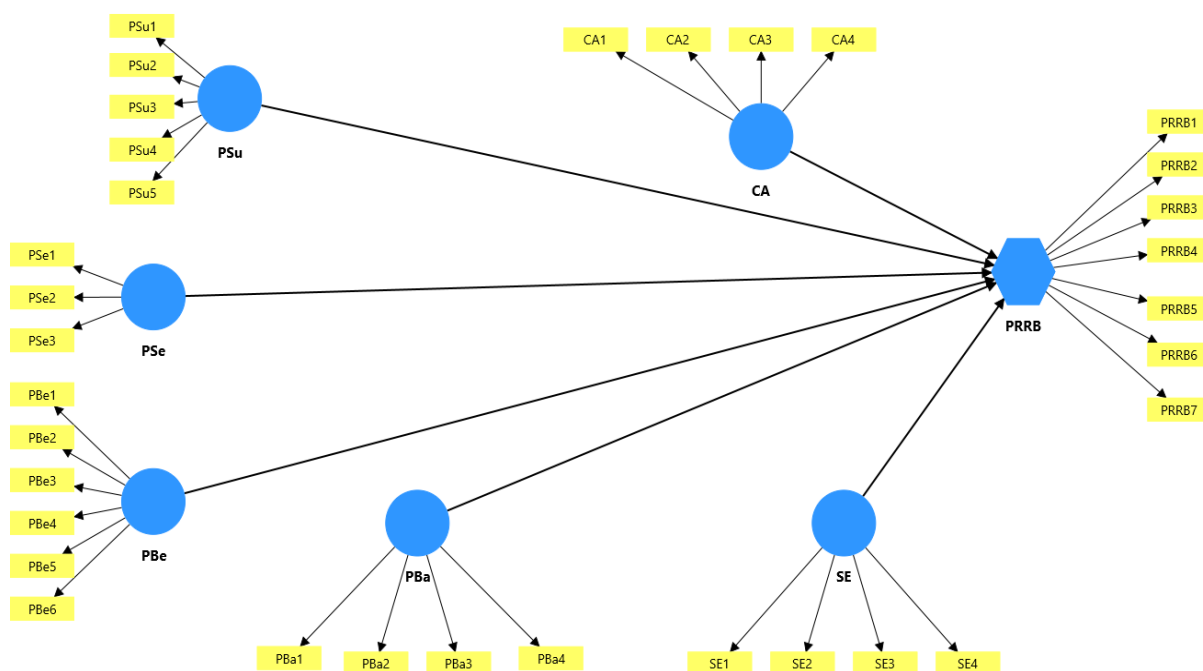


Figure 10: Measurement model

The outer loadings of the indicators for cues to action, perceived benefits, perceived severity, perceived susceptibility, self-efficacy and pesticide risk-reduction behaviour were above 0.70

3.7.1.2. Construct reliability and validity

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
CA	0.775	0.803	0.848	0.584
PBa	0.758	0.742	0.829	0.548
PBe	0.908	0.994	0.914	0.646
PRRB	0.838	0.871	0.878	0.511

PSe	0.8	0.84	0.881	0.713
PSu	0.842	0.883	0.879	0.593
SE	0.818	0.862	0.878	0.645

Table 3: Construct reliability and validity

As shown in Table 3, Cronbach's alpha and composite reliability exceeded 0.70 for all constructs, indicating acceptable internal consistency. AVE values also exceeded 0.50, supporting convergent validity. Perceived barriers met these construct-level criteria ($\alpha = 0.758$; composite reliability = 0.829; AVE = 0.548).

3.7.1.3. R²

	R-square	R-square adjusted
PRRB	0.715	0.706

Table 4: R-square and adjusted R-square

As shown in Table 4, the Health Belief Model constructs collectively explained 71.5% of the variation in pesticide risk-reduction behaviour among the surveyed farmers ($R^2 = 0.715$). The adjusted R^2 was 0.706 after accounting for the number of predictors, indicating that the model retained similar explanatory power after this adjustment.

3.7.1.4. Discriminant validity

	CA	PBa	PBe	PRRB	PSe	PSu	SE
CA							
PBa	0.241						
PBe	0.17	0.389					
PRRB	0.409	0.345	0.407				
PSe	0.268	0.398	0.831	0.832			
PSu	0.589	0.355	0.412	0.311	0.377		
SE	0.455	0.364	0.328	0.573	0.34	0.705	

Table 5- Heterotrait-monotrait ratio (HTMT)

	CA	PBa	PBe	PRRB	PSe	PSu	SE
CA	0.764						
PBa	0.054	0.74					
PBe	0.077	0.372	0.804				
PRRB	0.363	0.339	0.468	0.795			
PSe	0.196	0.401	0.712	0.728	0.845		
PSu	0.467	0.194	0.279	0.28	0.305	0.77	
SE	0.386	0.229	0.274	0.487	0.271	0.589	0.803

Table 6 - Fornell- Larcker criterion

As shown in Tables 5 and 6, it shows that Discriminant validity was examined using the heterotrait–monotrait ratio (HTMT) and the Fornell–Larcker criterion. All pairwise HTMT values were below the specified threshold of 0.90, with the highest value approximately 0.832. Under the Fornell–Larcker criterion, each construct's square root of average variance extracted (shown on the diagonal) was greater than its correlations with the other constructs. Both assessments therefore support discriminant validity: the measures of susceptibility, severity, benefits, barriers, cues to action, self-efficacy and pesticide risk-reduction behaviour are empirically distinguishable in this sample. All inner-model VIF values were below 3.0, indicating that collinearity was not a critical issue and that the individual path coefficients could be examined. The measurement-model results also showed acceptable internal consistency and convergent and discriminant validity for the reflectively measured constructs. Taken together, these assessments supported proceeding to the structural-model analysis.

3.7.2. Structural model assessment – Bootstrapping

The structural model was assessed to determine which of the Health Belief Model constructs were associated with farmers pesticide risk-reduction behaviour, and whether each relationship followed the direction proposed in the

hypotheses. Standardised path coefficients (β) show the direction and strength of the relationships; bootstrapped confidence intervals and p values indicate the statistical evidence for each path. R^2 shows how much variation in behaviour the six constructs collectively explain, while f^2 shows the contribution of each predictor.

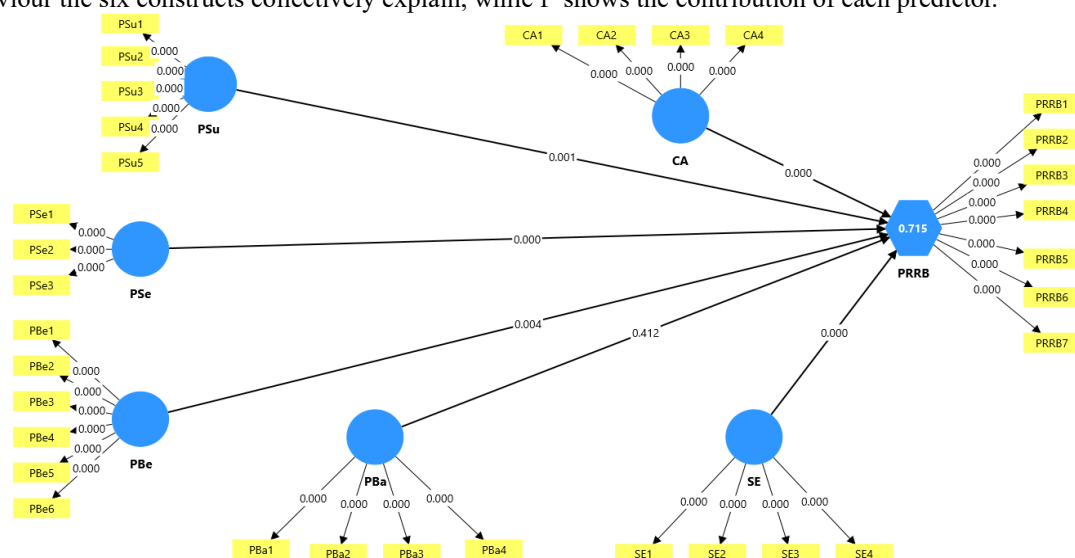


Figure 11 – Structural model

Hyp.	Path	Hypothesised direction	Actual β (Total effects)	p	Significance
H1	PSu $\rightarrow$ PRRB	Positive	-0.222	0.001	Significant
H2	PSe $\rightarrow$ PRRB	Positive	0.832	<0.001	Significant
H3	PBe $\rightarrow$ PRRB	Positive	0.223	<0.001	Significant
H4	PBa $\rightarrow$ PRRB	Negative	- 0.035	0.412	Not significant
H5	CA $\rightarrow$ PRRB	Positive	0.173	<0.001	Significant
H6	SE $\rightarrow$ PRRB	Positive	0.378	<0.001	Significant

Table 7 - Hypothesis testing results for Health Belief Model constructs and pesticide risk-reduction behaviour

Perceived severity ($\beta = 0.832$), self-efficacy ($\beta = 0.378$), perceived benefits ($\beta = 0.223$, $p = 0.004$) and cues to action ($\beta = 0.173$) were positively associated with pesticide risk-reduction behaviour (all $p < 0.001$). Perceived susceptibility ($\beta = 0.222$, $p < 0.001$) and showed significant associations opposite to the hypothesised directions. Perceived barriers were negatively significant associated with behaviour ($\beta = -0.035$, $p = 0.412$).

4. DISCUSSIONS

Hypothesis-based Analysis of Individual Factors

The study examined pesticide risk-reduction behaviour (PRRB) among vegetable farmers using the Health Belief Model (HBM) showed substantial explanatory power, with an R^2 of 0.715, indicating that 71.5 per cent of the variation in PRRB was explained by the six HBM constructs. The results showed significant relationships for perceived susceptibility, perceived severity, perceived benefits, cues to action and self-efficacy, while perceived barriers had a negative relationship with PRRB. The individual hypotheses are discussed below.

H1: Perceived Susceptibility and PRRB

H1 proposed that perceived susceptibility would have a opposite relationship with PRRB. Perceived susceptibility refers to farmers perception that pesticide handling can expose them to health risks through inhalation, skin contact and premature entry into treated fields. The result showed a significant opposite relationship ($\beta = 0.222$; $p = 0.001$). Thus, H1 was not varied in the hypothesised direction. This finding may reflect the normalisation of repeated pesticide exposure among vegetable farmers. Farmers may know that spraying and mixing pesticides expose them to risk, but repeated exposure without immediate serious symptoms can make the risk appear normal. Some may not recognise that chronic health problems can develop gradually and may therefore not connect long-term illness with repeated pesticide exposure. The study reported skin problems (38%), neurological symptoms (20%) and respiratory problems (16%) among farmers, showing the relevance of these health concerns. The same pattern is visible in pesticide practices: although hand washing was commonly reported, fewer farmers used gloves, goggles and waterproof boots, while unsafe practices such as mixing pesticides with bare hands were also reported. Thus, recognising susceptibility did not necessarily translate into protective behaviour. Education may help farmers understand less visible and long-term risks, while farming experience may have a dual effect: it can improve practical knowledge but may also reinforce familiar practices and normalise repeated exposure.

H2: Perceived Severity and PRRB

H2 proposed a positive relationship between perceived severity and PRRB. Perceived severity concerns the seriousness farmers attach to pesticide-related illness, long-term health problems and potentially life-threatening consequences. The result showed a strong positive and significant relationship ($\beta = 0.832$; $p < 0.001$), supporting H2. This indicates that farmers who perceive pesticide exposure as capable of causing serious health consequences are more likely to adopt risk-reduction practices. When farmers understand that pesticide exposure may result in lasting health problems rather than only temporary symptoms, they may give greater importance to preventive measures. This can encourage practices such as avoiding eating, drinking or smoking while spraying, using PPE, bathing and changing, disposing of clothes after application, and following the pre-harvest interval. The reported symptoms, particularly skin, neurological and respiratory problems, may make pesticide-related health risks more tangible to farmers. Education can further help farmers understand long-term consequences, while income may determine their ability to respond through purchasing protective materials and also safe handling practices, self-reported health symptoms.

H3: Perceived Benefits and PRRB

H3 proposed that perceived benefits would positively influence PRRB. Perceived benefits represent farmers' belief that recommended precautions can actually reduce pesticide exposure and its consequences. The statements included PPE use, correct dosage, equipment maintenance, suitable weather conditions, bathing and changing clothes, and observing the pre-harvest interval. The result showed a positive and significant relationship ($\beta = 0.223$; $p < 0.004$), supporting H3. Farmers are more likely to follow safety practices when they understand the practical benefit behind them. For example, using PPE reduces body contact, following the recommended dosage reduces unnecessary exposure, spraying under suitable weather conditions reduces drift, and bathing and changing clothes help remove pesticide residues. This is particularly important because farmers showed greater adoption of simple hygiene practices than complete PPE use. Hand washing was widely reported, whereas glove, goggles and boot use were considerably lower. Farmers may therefore recognise the benefit of hygiene but may not fully understand the importance of preventive protection. Repeated exposure can also normalise risk, especially when no immediate illness is experienced. Education, farming experience and income may influence how effectively farmers understand and act upon these perceived benefits.

H4: Perceived Barriers and PRRB

H4 proposed a negative relationship between perceived barriers and PRRB. Barriers included PPE cost and availability, heat and discomfort, difficulty understanding labels and the time required for maintaining protective equipment. The result showed a negative but non-significant relationship ($\beta = -0.035$; $p = 0.412$). The negative direction nevertheless reflects practical difficulties faced during pesticide application. Complete PPE may be uncomfortable in hot field conditions, difficult to obtain locally or considered costly. This may explain the uneven PPE adoption, with 34.1% reporting glove use, 21% goggles and only 9.5% waterproof boots. However, since the relationship was non-significant, barriers alone did not explain substantial differences in PRRB. This suggests that reducing barriers needs to be accompanied by stronger perceptions of severity and benefits and greater confidence in performing safety practices.

H5: Cues to Action and PRRB

H5 proposed that cues to action would positively influence PRRB. These included extension advice, health-professional guidance, pesticide-safety or IPM training, container warnings and previous pesticide-related illness. The result showed a positive and significant relationship ($\beta = 0.173$; $p < 0.001$), supporting H5. This indicates that external reminders can help farmers convert existing knowledge into action. Extension personnel and training programmes can remind farmers about correct dosage, PPE, safe disposal and pre-harvest intervals. This is important because only 38.6% reported consulting knowledgeable sources and 28.6% reported selecting pesticides using label information. Repeated cues may therefore be particularly useful because pesticide application occurs repeatedly throughout the crop season. Practical demonstrations and regular extension contact can reinforce safety behaviour rather than relying on one-time awareness programmes.

H6: Self-Efficacy and PRRB

H6 proposed that self-efficacy would positively influence PRRB. Self-efficacy represents farmers' confidence in understanding labels, calculating the correct dose, using PPE and rejecting unsafe pesticide recommendations. The result showed a positive and significant relationship ($\beta = 0.378$; $p < 0.001$), supporting H6. This finding highlights that farmers need not only knowledge but also confidence and practical ability to implement safety measures. A farmer may know that the correct dosage should be followed but may still be uncertain about calculating the quantity for a spray tank. Similarly, farmers may know that PPE is required but lack confidence in selecting and using complete PPE. A major practical concern is the belief that pesticides are the most immediate solution to pest attacks: "If I do not use pesticides, what will I do when the pest attack occurs?" If farmers are not confident in identifying alternative pest-management methods, they may continue depending heavily on chemical control. Similarly, inability to select the appropriate pesticide or dosage and reliance on recommendations from others can increase risk. Partial PPE use also reflects this gap between knowledge and confidence. Education, annual income can strengthen label interpretation and dosage calculation, while practical training can improve confidence in PPE use and alternative pest-management practices.

The findings suggest that pesticide risk-reduction behaviour among vegetable farmers depends not simply on knowing that pesticides are dangerous, but on understanding the seriousness of the consequences, recognising the

practical benefits of precautions, receiving repeated safety cues and having confidence to perform the recommended practices. The ground-level challenge is that repeated exposure can become normalised, chronic health effects may not be immediately treated, pesticides may be viewed as the only practical solution to pest attacks didn't know farmers are affecting more and farmers may have difficulty choosing handling in safe way. Therefore, interventions should combine risk communication, practical demonstrations, repeated extension support, PPE guidance, dosage training and promotion of alternative pest-management practices rather than relying only on general awareness.

WAY FORWARD

Table 8 presents domain-wise strategies to address the identified issues among vegetable growers in Dharmapuri and Krishnagiri districts. The recommendations focus on awareness creation, skill development, safe pesticide handling, institutional support, community participation, health monitoring, and sustainable pest management to promote safer and more responsible pesticide use.

Table 8 – Suggestions to overcome the challenges

Domain	Issue addressed	Suggestions
Awareness and Risk Communication	• Low perceived severity of pesticide exposure • Reliance on input dealers • Poor awareness of chronic health and environmental impacts • Lack of awareness regarding banned/restricted pesticides	✓ Develop severity-based, locally relevant awareness campaigns and seasonal village-level “near-miss” sharing sessions through KVKs and extension networks, highlighting actual pesticide poisoning cases, treatment costs, hospitalisation experiences and lost workdays ✓ Display visual posters and pictorial safety messages at input shops, panchayat offices, Primary Health Centres (PHCs), and other public gathering places ✓ Prepare and regularly update pictorial Local (Tamil) -language lists of approved, restricted, and banned pesticides at KVKs and agro-input outlets ✓ Use short local-language video testimonials from farmers who experienced pesticide-related health problems ✓ Strengthen awareness on environmental impacts, residue issues, pre-harvest intervals and eco-friendly practices.
Capacity Building / Skill Development	• Inadequate practical knowledge • Incorrect pesticide application practices • Poor PPE usage • Low confidence in implementing safety measures	✓ Conduct hands-on, field-based training instead of lectures, demonstrating proper PPE use, including correct donning and doffing. ✓ Train farmers on: ❖ Correct dose calculation and dilution ❖ Spray tank calibration ❖ Proper nozzle selection and maintenance ❖ Wind-direction awareness during spraying ❖ Appropriate nozzle height and spray techniques ❖ Avoidance of spraying during peak heat hours ✓ Conduct Tamil-language pictorial label-reading exercises for farmers with lower literacy levels ✓ Provide specialized training programmes with subsidies and periodic refresher sessions
Safe Handling, Hygiene and Disposal Management	• Unsafe mixing and spraying practices • Secondary household exposure • Improper disposal of pesticide containers	✓ Develop and institutionalize standard pre-spray, during-spray and post-spray protocols Pre-spray ❖ Designated mixing areas away from water bodies ❖ Use measuring devices and mixing tools instead of bare hands (like wooden sticks and etc.,) ❖ Inspect equipment for leaks ❖ Wear dedicated spray clothing & PPE During Spray ❖ Follow recommended dosage ❖ Maintain proper spray direction and nozzle height ❖ Avoid eating, drinking, or smoking during application Post-spray ❖ Mandatory bathing after spraying ❖ Immediate change of clothes ❖ Separate washing of spray clothes from household laundry Disposal ❖ Demonstrate triple-rinse procedures ❖ Establish container collection and recycling centres ❖ Organize monthly community container-return campaigns through panchayats and KVKs

Personal Protective Equipment (PPE) Accessibility	• High cost and poor accessibility of PPE • Low adoption due to discomfort under hot climatic conditions	✓ Establish PPE lending or rental services through FPOs and Custom Hiring Centres ✓ Promote lightweight, breathable, climate-suitable PPE ✓ Provide PPE kits through subsidy programmes ✓ Ensure PPE availability at local agro-input shops ✓ Introduce incentive schemes for regular PPE users
Institutional Advisory and Extension Support	• Excessive dependence on private input dealers • Limited access to scientific advisory services • Inadequate follow-up support	✓ Establish toll-free and WhatsApp-based government pesticide advisory services ✓ Schedule regular KVK and Agricultural Officer visits aligned with crop growth stages ✓ Display official dose charts and safety guidelines at licensed agro-input shops ✓ Strengthen extension follow-up after training programmes ✓ Promote government institutions as primary information sources for pesticide management ✓ Create a one-stop information system for pesticide recommendations, safety precautions, health concerns, and price information
Sustainable Pest Management and Alternative Technologies	• Overreliance on chemical pesticides • Limited adoption of safer alternatives • Poor availability of biopesticides	✓ Increase availability of low-cost biopesticides and bio-agents such as Trichoderma, NPV, Neem-based formulations, Pheromone traps ✓ Establish local biopesticide production units through FPOs and cooperatives ✓ Provide subsidized bio-input kits ✓ Conduct on-farm demonstrations comparing conventional pesticide use with IPM-based approaches ✓ Promote advanced eco-friendly Integrated Pest Management (IPM) practices ✓ Simplify licensing and distribution mechanisms to improve biopesticide availability
Community-Based Approaches	• Weak community-level reinforcement of safe practices • Limited peer support mechanisms	✓ Establish Farmer Field Schools (FFS) and IPM clubs ✓ Develop village-level peer safety champions ✓ Organize regular community pesticide safety campaigns ✓ Promote collective learning through farmer groups and FPOs
Health Surveillance and Monitoring	• Under-reporting of pesticide-related illnesses • Lack of health monitoring systems • Absence of exposure databases	✓ Conduct periodic cholinesterase testing and health screening camps ✓ Strengthen collaboration between Government hospitals, PHCs, KVKs, and agricultural departments ✓ Create a district-level pesticide exposure surveillance system ✓ Maintain databases on pesticide-related symptoms and health complaints among farmers ✓ Introduce pesticide exposure helplines for immediate consultation and referral ✓ Track occupational exposure trends for early detection and intervention
Documentation, Traceability and Regulatory Monitoring	• Poor record-keeping practices • Lack of traceability of pesticide use • Difficulty linking exposure to health outcomes	✓ Encourage farmers to maintain pesticide-use records including product name, source of purchase, cost, crop treated, target pest, quantity applied and date of application ✓ Integrate agricultural and health-sector databases for tracking exposure-related illnesses ✓ Strengthen monitoring of banned and restricted pesticides at the retail level and Conduct periodic compliance checks at agro-input outlets ✓ Establish a farm-to-field pesticide traceability system where pesticide purchase details, product batch number, dealer information, crop treated, date of application, and quantity used are recorded digitally . This would enable authorities to trace pesticide-related health incidents, residue problems, or environmental contamination back to the specific product source and application history

CONCLUSION

The study revealed considerable gaps in pesticide risk-reduction behaviour among vegetable farmers, particularly in PPE use, safe handling, and disposal practices. Perceived severity, perceived benefits, cues to action, and self-efficacy significantly influenced the adoption of protective behaviours, highlighting the importance of behavioural and skill-based interventions. The findings suggest that awareness alone is insufficient unless supported by practical training, continuous reminders, and confidence-building measures. Unsafe practices such as mixing pesticides with bare hands, improper container disposal, and limited PPE use indicate the need for targeted extension efforts. Strengthening institutional advisory services, improving access to protective equipment, and promoting sustainable alternatives such as IPM and biopesticides can reduce exposure risks. Community participation, health surveillance, and traceability systems can further support long-term behavioural change. Overall, an integrated approach involving farmers, extension agencies, health institutions, and policymakers is essential for safer and more sustainable pesticide use.

ACKNOWLEDGEMENT

The authors would like to express their deepest gratitude to the Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore, for their support throughout the study. Special thanks to the Indian Council of Social Science Research (ICSSR), New Delhi, for funding support and the Directorate of Extension Education (DoEE) for valuable feedback and suggestions.

AUTHORS CONTRIBUTION

AS conceptualized and formulated the research manuscript; AJR helped in writing; PPM helped in tabulation and editing of the manuscript; KSB helped in collecting data; KS helped in summarizing and revising; GV helped in statistical analysis; ES helped in reviewing the manuscript; all authors read and approved the final manuscript.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: Authors don't have any conflicts of interest to declare

Ethical Issues: None

REFERENCES

- Al-Sarar, A. S., Bayoumi, A. E., Herab, A. H., Alzabib, A. A., Bazeyad, A. Y., & Abobakr, Y. (2025). Knowledge and attitude of vegetable farmers toward pesticide labels in Saudi Arabia: A cross-sectional study. *International Journal of Agricultural Sustainability*, 23(1). <https://doi.org/10.1080/14735903.2025.2589026>
- Bindu, G. N. H. (2022). Pesticide use, health risks, and environmental implications: A case study of farmers' practices in Bapatla and Guntur districts, Andhra Pradesh. *Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences*, 12(3).
- Boedeker, W., Watts, M., Clausen, P., & Marquez, E. (2026). Worldwide unintentional acute pesticide poisonings: Reassessing the occupational and non-occupational burden. *Frontiers in Public Health*, 14. <https://doi.org/10.3389/fpubh.2026.1825899>
- Cazagrande, I. C., de Almeida, R. F., Smaniotto, L. L., de Andrade Berny, M. P., Coradi, C., Rech, D., et al. (2026). Hidden risks associated with occupational pesticide exposure in women with breast cancer: High frequency of the luminal B molecular subtype and occurrence of poor prognostic features. *PLOS ONE*, 21(2), e0339471. <https://doi.org/10.1371/journal.pone.0339471>
- Champion, V. L., & Skinner, C. S. (2008). The health belief model. In K. Glanz, B. K. Rimer, & K. Viswanath (Eds.), *Health behavior and health education: Theory, research, and practice* (4th ed.). Jossey-Bass.
- Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). John Wiley & Sons.
- Food and Agriculture Organization of the United Nations. (2026). *Pesticides use and trade: 1990–2024*. <https://www.fao.org/statistics/highlights-archive/highlights-detail/pesticides-use-and-trade.-1990-2024/en>
- Govindharaj, G. P. P., Gowda, B., Sendhil, R., Adak, T., Raghu, S., Patil, N., et al. (2021). Determinants of rice farmers' intention to use pesticides in eastern India: Application of an extended version of the planned behavior theory. *Sustainable Production and Consumption*, 26, 814–823.
- Hailu, A., Tucho, G. T., Gure, A., & Mekonen, S. (2025). Pesticide exposure and acute health problems among pesticide processing industry workers in Ethiopia. *Toxicology Reports*, 14, Article 101997.
- Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, 31(1), 2–24. <https://doi.org/10.1108/EBR-11-2018-0203>
- Hossain, M. S., Fahad, S., Sarker, T., Rabbany, M. G., Yeasmin, S., & Roy, R. (2026). Pesticide handling practices, occupational risks, and health expenses among Bangladeshi smallholder vegetable farmers. *Journal of Agriculture and Food Research*, 26, Article 102727. <https://doi.org/10.1016/j.jafr.2026.102727>
- Kafle, S., Vaidya, A., Pradhan, B., Jørs, E., & Onta, S. (2021). Factors associated with practice of chemical pesticide use and acute poisoning experienced by farmers in Chitwan District, Nepal. *International Journal of Environmental Research and Public Health*, 18(8), Article 4194. <https://doi.org/10.3390/ijerph18084194>
- Karki, R., & Dangol, K. (2023). Pesticide use and health effects among Nepalese farmers: A cross-sectional study in Tokha Municipality. *Indian Journal of Occupational and Environmental Medicine*, 27(3), 255–259.

- Kumar, N., Nie, V., Palaniappan, K., & Bohatko-Naismith, J. (2025). Insecticide exposure and associated acute health effects in farmers in a rice growing district of India. *International Journal of Environmental Health Research*, 35(5), 1143–1155. <https://doi.org/10.1080/09603123.2024.2382305>
- Kumari, D., Sebastian, A. J., & John, S. (2021). Pesticide handling practices and health risks among the apple orchard workers in western Indian Himalayan region. *Human and Ecological Risk Assessment: An International Journal*, 27(1), 15–29. <https://doi.org/10.1080/10807039.2019.1689353>
- Mariani, M., Saftarina, F., Daulay, S. A., & Larasati, T. A. (2026). Study of literature: Health belief model components influencing the use of personal protective equipment among farmers. *International Journal of Health Science*, 6(1), 400–408.
- Mehmood, Y., Arshad, M., Kaechele, H., Mahmood, N., & Kong, R. (2021). Pesticide residues, health risks, and vegetable farmers' risk perceptions in Punjab, Pakistan. *Human and Ecological Risk Assessment: An International Journal*, 27(3), 846–864.
- Meira, A. P. G., Zanin, L. M., Favaro, B. F., Stedefeldt, E., & da Cunha, D. T. (2025). Pesticide risk perception as an attitudinal mediator: Exploratory research with farm managers and consumers. *Food Research International*, 200, Article 115449.
- Muslim, A., Dadang, D., Indrasti, N. S., & Syaukat, Y. (2022). Application of structural equation model–partial least square for factors affecting the risk of pesticide poisoning. *Jurnal Aisyah: Jurnal Ilmu Kesehatan*, 7(1), 317–324. <https://doi.org/10.30604/jika.v7i1.920>
- Okoffo, E. D., Mensah, M., & Fosu-Mensah, B. Y. (2016). Pesticides exposure and the use of personal protective equipment by cocoa farmers in Ghana. *Environmental Systems Research*, 5. <https://doi.org/10.1186/s40068-016-0068-z>
- Prevalence of pesticides usage and its effect on the health of farmers above 18 years in Villupuram district: A cross-sectional study. (2024). *Zenodo*. https://zenodo.org/records/13120431/files/193CP24V21107_13120431.pdf
- Rosenstock, I. M., Strecher, V. J., & Becker, M. H. (1988). Social learning theory and the Health Belief Model. *Health Education Quarterly*, 15(2), 175–183. <https://doi.org/10.1177/109019818801500203>
- Shah, S. S., van Dam, J., Fan, L., Kumar, S., Singh, A., Bundela, D. S., et al. (2026). Understanding farmers' protective behavior towards pesticide use in Northern India: A health belief model approach using PLS-SEM and fsQCA. *Environmental Impact Assessment Review*, 117, Article 108193. <https://doi.org/10.1016/j.eiar.2025.108193>
- Ssekkadde, P., Tomberge, V. M. J., Brugger, C., Atuhaire, A., Dalvie, M. A., Rother, H. A., et al. (2024). Evaluating and enhancing an educational intervention to reduce smallholder farmers' exposure to pesticides in Uganda through a digital, systematic approach to behavior change: Protocol for a cluster-randomized controlled trial. *JMIR Research Protocols*, 13(1), Article e55238. <https://www.researchprotocols.org/2024/1/e55238>
- Tamil Nadu Agricultural University. (2010). *Krishnagiri district: Agro-climatic zone*. <https://www.agritech.tnau.ac.in/kvk/annual%20report2011/Krishnagiri.pdf>
- Venugopal, D., Beerappa, R., Chauhan, D., Karunamoorthy, P., Ambikapathy, M., Mohankumar, T., et al. (2025). Occupational health complaints and demographic features of farmers exposed to agrochemicals during agricultural activity. *BMC Public Health*, 25, Article 2416. <https://doi.org/10.1186/s12889-025-23174-5>
- R, A., Golime, R., M. P., Nenavathu, B. P. N., & Kumar, A. (2026). Impact of pesticide exposure and socioeconomic determinants on diabetes prevalence among agricultural farmers/workers in Kerala, India: A mixed-method study. *Sustainable Chemistry and Climate Action*, 8, Article 100214. <https://doi.org/10.1016/j.scca.2026.100214>

SUPPLEMENTARY DATA (S1)

Code	Statement
PSu1	Because of my pesticide-handling activities, I consider myself vulnerable to pesticide exposure
PSu2	Repeated pesticide exposure may affect my health even when I do not experience immediate symptoms.
PSu3	Breathing pesticide spray droplets or vapour places me at risk of exposure.
PSu4	Skin contact with pesticides while mixing or spraying places me at risk of exposure.
PSu5	I may be exposed to pesticide residues if I enter a field too soon after pesticide application
PSe1:	Serious illness caused by exposure to pesticides during farm work may require immediate medical treatment.
PSe2:	Long-term occupational exposure to pesticides may cause serious and lasting health problems.
PSe3:	Severe occupational exposure to pesticides can be life-threatening
PBe1:	Appropriate protective equipment can reduce pesticide contact with a farmer's body.
PBe2:	Following the recommended pesticide dosage helps minimise unnecessary pesticide exposure.

PBe3	Properly maintained spraying equipment can prevent accidental pesticide leakage.
PBe4:	Choosing suitable weather conditions for spraying can reduce pesticide drift.
PBe5:	Bathing and changing clothes after spraying can remove pesticide residues from the body.
PBe6:	Observing the recommended pre-harvest interval can reduce pesticide residues in harvested vegetables.
PBa1	high cost and limited availability of complete protective equipment near my village prevent me from using it regularly
PBa2	Heat and physical discomfort make it difficult for me to wear protective clothing throughout pesticide application.
PBa3	Difficulty understanding pesticide-label information prevents me from following all safety instructions.
PBa4	Cleaning and maintaining protective equipment after each application is time-consuming, making it difficult to consistently follow safety measures during pest outbreaks
CA1	Advice from extension personnel and health professionals encourages me to take precautions against pesticide exposure
CA2	Participation in pesticide-safety or IPM training reminds me to adopt protective practices.
CA3	Safety warnings displayed on pesticide containers remind me about pesticide-related risks.
CA4	A previous pesticide-related illness experienced by me or another farmer reminds me to take precautions.
SE1	I am confident that I can understand the hazard warnings and safety instructions on pesticide labels.
SE2	I am confident that I can calculate and measure the correct pesticide dose for my spray tank.
SE3	I am confident that I can correctly use suitable protective equipment while mixing and spraying pesticides
SE4	I am confident that I can reject an unsafe pesticide mixture or dose even when another person recommends it.
PRRB1	I read or obtain an explanation of the pesticide label before using the product.
PRRB2	I measure and apply pesticides according to the dosage recommended on the label.
PRRB3	I use appropriate protective equipment while mixing and spraying pesticides.
PRRB4	I avoid eating, drinking, smoking or chewing while handling pesticides.
PRRB5	I store pesticides securely away from food, children and animals.
PRRB6	I wait for the recommended pre-harvest interval before harvesting treated vegetables.
PRRB7	I dispose of empty pesticide containers using recommended safe-disposal methods.