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Insecticide cocktail mixing practices and farmer knowledge scores across two delta regions of Vietnam

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Abstract
The practice of mixing multiple insecticide products into cocktail formulations is widespread among Vietnamese vegetable farmers, yet systematic comparison of this behavior across major production regions and its relationship to farmer knowledge levels remains limited. This research compared insecticide cocktail mixing patterns, knowledge scores, and economic outcomes between vegetable farmers in the Red River Delta (n = 150) and Mekong Delta (n = 150) of Vietnam during 2025-2026. Five cocktail combinations were identified, with organophosphate-pyrethroid (OP+PY) mixtures being most prevalent in the Red River Delta (28.5%) and organophosphate-carbamate (OP+CA) mixtures most common in the Mekong Delta (25.3%). Knowledge scores, assessed across a seven-point scale incorporating age group and education level variables, ranged from 1.8 (no education, age 56+) to 6.5 (tertiary, age 36-45). A significant positive linear relationship was established between over-application rate and seasonal economic loss (r = 0.72, $p < 0.001$), with farmers applying insecticides at rates exceeding label recommendations incurring substantially higher costs without proportional pest reduction benefits. These findings underscore the need for region-specific extension strategies that address the distinct cocktail mixing cultures of each delta while improving farmer knowledge and economic efficiency.

Keywords: Insecticide cocktail mixing, farmer knowledge scores, red river delta, mekong delta, over-application, economic loss, Vietnam, crop protection

Introduction

Vietnam's two major river delta systems, the Red River Delta in the north and the Mekong Delta in the south, collectively constitute the most intensive vegetable production landscapes in mainland Southeast Asia. These regions supply the vast majority of fresh vegetables consumed in Hanoi, Ho Chi Minh City, and the surrounding urban agglomerations, supporting livelihoods for millions of farming households across both deltas.

The intensive nature of vegetable production in these delta environments creates conditions conducive to persistent and diverse pest populations. The warm, humid climate, continuous cropping cycles, and high planting densities characteristic of delta vegetable systems promote the proliferation of multiple pest species simultaneously, including whiteflies, leaf miners, fruit borers, aphids, and diamondback moths. In response to this complex pest pressure, Vietnamese vegetable farmers have developed a practice of mixing two or more insecticide products into a single tank-mix application, colloquially referred to as "cocktail mixing."

Cocktail mixing is driven by the farmer perception that combining products from different chemical classes or with different modes of action provides superior pest control compared to single-product applications. While this rationale has some scientific basis in the concept of synergistic or additive effects, the actual cocktail formulations used by farmers are typically created without reference to compatibility data, recommended mixing ratios, or potential antagonistic interactions. Furthermore, the use of cocktails complicates dose calculation and may result in total chemical loads that substantially exceed label-recommended rates for individual products.

The knowledge base that informs farmer decision-making about insecticide use, including cocktail formulation, is shaped by education, training, experience, and information access, all of which may differ between the two delta regions due to their distinct social, economic, and

Agricultural histories. Comparative analysis of insecticide cocktail practices and knowledge levels between these two critical production regions can inform the design of targeted extension strategies.

This research was designed with three objectives:

1. To characterize and compare insecticide cocktail mixing patterns between Red River Delta and Mekong Delta vegetable farmers,
2. To assess farmer knowledge scores regarding insecticide use across age and education strata, and
3. To quantify the economic consequences of over-application associated with cocktail mixing practices.

The economic consequences of insecticide cocktail mixing practices represent an understudied dimension of the broader pesticide use efficiency challenge in Vietnamese agriculture. When farmers combine multiple products in a single tank mix, the total chemical load applied per unit area frequently exceeds the recommended rates for any individual product, resulting in higher input costs without proportional improvement in pest control outcomes. This over-application phenomenon is compounded by the tendency of cocktail-mixing farmers to apply at shorter intervals than recommended, further amplifying both the economic cost and the environmental and health burden of their pest management activities.

The information pathways through which Vietnamese vegetable farmers acquire knowledge about insecticide use, cocktail formulation, and dosage calculation differ substantially between the two major delta regions. In the Red River Delta, the agricultural extension system maintains a more structured presence through commune-level extension workers and regular training activities, while in the Mekong Delta, farmers rely more heavily on informal networks, agrochemical dealers, and cross-border information exchange with neighboring countries. Understanding how these different information environments shape cocktail mixing behaviors and knowledge levels is essential for designing region-appropriate extension strategies that address the specific knowledge gaps and behavioral patterns prevalent in each delta system.

Materials and Methods

Material

The research was conducted across six provinces representing the two major delta regions of Vietnam. In the Red River Delta, the provinces of Ha Nam, Hung Yen, and Hai Duong were selected, while the Mekong Delta was represented by An Giang, Dong Thap, and Vinh Long Provinces. These provinces were chosen based on their significance in commercial vegetable production and the documented prevalence of intensive insecticide use practices.

Methods

A total of 300 vegetable farmers were surveyed, with 150 drawn from each delta region (50 per province). Farmers were selected using a two-stage random sampling procedure, first selecting communes (xa) within each province and then randomly selecting farmers from commune-level agricultural registers.

Data were collected through structured interviews conducted in Vietnamese between September 2025 and August 2026. The questionnaire captured detailed information on insecticide products used, cocktail mixing combinations and rationale, application rates (actual vs. recommended), knowledge assessment items, seasonal expenditure records, and demographic characteristics.

The knowledge assessment component comprised 14 items covering insecticide mode of action, dosage interpretation, safety precautions, pre-harvest intervals, environmental impact awareness, pesticide resistance concepts, and beneficial insect recognition. Each item was scored on a scale of 0 (no knowledge) to 0.5 (correct answer), yielding a maximum composite score of 7.0. Scores were analyzed across age group and education level strata using two-way ANOVA.

Over-application rate was defined as the percentage by which the farmer's actual applied dose exceeded the label-recommended dose for the primary insecticide product in the cocktail. Economic loss was calculated as the difference between the farmer's total insecticide expenditure and an estimated optimal expenditure based on recommended application rates and frequencies. Pearson correlation analysis assessed the relationship between over-application rate and economic loss. All analyses were performed using R version 4.4.1.

The cocktail mixing documentation procedure involved presenting farmers with a comprehensive list of insecticide trade names and active ingredients available in local markets, along with visual aids depicting common product containers. Farmers identified each product used in their tank-mix preparations and reported the quantities added per sprayer load. The research team subsequently classified each cocktail by its constituent chemical classes and calculated the total active ingredient load per hectare per application. Cocktails containing three or more different active ingredients from at least two chemical classes were classified as triple-mix formulations. Product compatibility was assessed retrospectively by cross-referencing identified cocktail combinations against manufacturer-published compatibility matrices and published chemical interaction databases. Incompatible combinations were defined as those known to produce physical separation, reduced efficacy, phytotoxicity, or enhanced mammalian toxicity.

Results

The combined sample of 300 farmers comprised 186 males (62.0%) and 114 females (38.0%), with a mean age of 44.2 years (SD = 11.8). Mean farming experience was 15.8 years (SD = 7.2). Education distribution showed 8.0% with no formal education, 24.0% primary, 48.0% secondary, and 20.0% tertiary.

Table 1: Comparison of insecticide cocktail mixing patterns between Red River Delta and Mekong Delta vegetable farmers

Cocktail Combination	Red River Delta (%)	Mekong Delta (%)	Overall (%)	Chi-sq p-value
OP + PY	28.5	22.1	25.3	0.184
PY + NE	22.4	18.5	20.5	0.382
OP + CA	18.7	25.3	22.0	0.148
NE + BIO	15.2	12.8	14.0	0.528
Triple mix	15.2	21.3	18.2	0.152

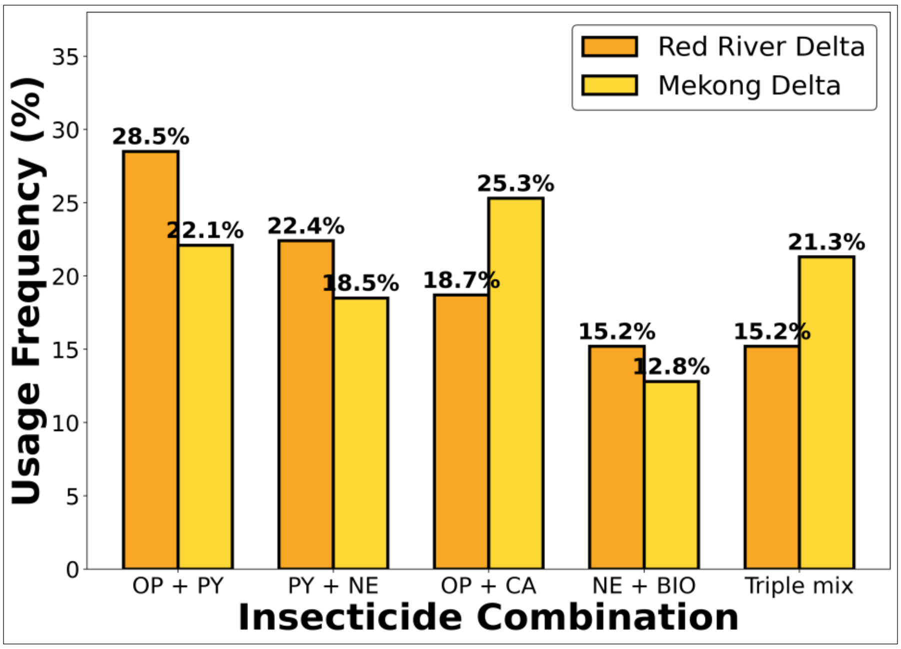

Fig 1: Insecticide cocktail combination preferences among vegetable farmers in the Red River Delta and Mekong Delta regions of Vietnam (*n* = 300)

Five insecticide cocktail combinations were identified across both regions. In the Red River Delta, organophosphate-pyrethroid (OP+PY) was the most common combination (28.5%), followed by pyrethroid-neonicotinoid (PY+NE) at 22.4% and organophosphate-carbamate (OP+CA) at 18.7%. In the Mekong Delta, OP+CA dominated (25.3%), followed by triple-mix formulations containing three or more active ingredients (21.3%) and OP+PY (22.1%). The neonicotinoid-biological (NE+BIO) combination was used by 15.2% and 12.8% of farmers in the Red River and Mekong Deltas respectively.

Table 2: Knowledge scores (mean ± SD) by education level and age group among Vietnamese vegetable farmers

Age Group	No Education	Primary	Secondary	Tertiary
18-25	2.1 ± 0.8	3.2 ± 0.9	4.5 ± 0.7	5.8 ± 0.6
26-35	2.4 ± 0.7	3.5 ± 0.8	4.8 ± 0.6	6.2 ± 0.5
36-45	2.8 ± 0.9	3.8 ± 0.7	5.1 ± 0.7	6.5 ± 0.4
46-55	2.2 ± 0.8	3.1 ± 0.9	4.4 ± 0.8	5.5 ± 0.6
56+	1.8 ± 0.7	2.6 ± 0.8	3.8 ± 0.9	4.9 ± 0.7

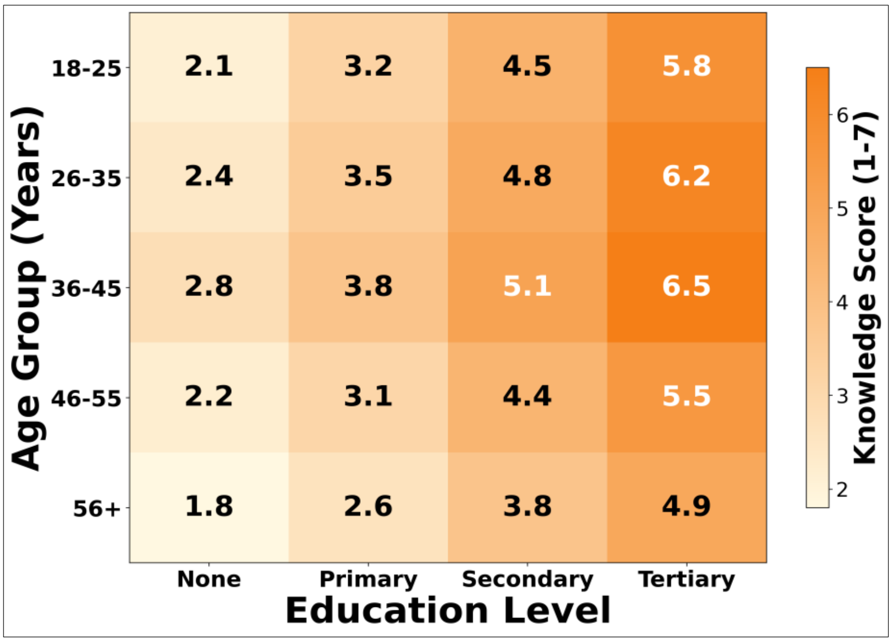

Fig 2: Heatmap of farmer insecticide knowledge scores by age group and education level across two delta regions of Vietnam

Knowledge score analysis by age group and education level revealed systematic patterns. The lowest mean knowledge scores were observed among farmers aged 56 and above with no formal education (1.8 out of 7.0), while the highest scores were achieved by tertiary-educated farmers aged 36-45 (6.5). Two-way ANOVA confirmed significant main effects for both education ($F = 42.18$, $p < 0.001$) and age group ($F = 8.52$, $p < 0.001$), with a significant interaction effect ($F = 2.84$, $p = 0.008$) indicating that the education-knowledge relationship varied across age groups.

The economic analysis revealed a significant positive correlation between over-application rate and seasonal economic loss ($r = 0.72$, $p < 0.001$). Farmers who exceeded recommended rates by more than 50% incurred an average additional cost of USD 185 per hectare per season without corresponding improvements in pest control outcomes. The mean over-application rate was 42.8% in the Red River Delta and 38.5% in the Mekong Delta, a difference that was not statistically significant ($t = 1.34$, $p = 0.182$).

Gender-disaggregated analysis revealed that female farmers (38.0% of the sample) had significantly lower knowledge scores than male farmers across both delta regions (mean 3.6 vs. 4.4; $t = 3.82$, $p < 0.001$). The gender gap was more pronounced in the Red River Delta (mean difference 1.2 points) than in the Mekong Delta (mean difference 0.5 points), possibly reflecting regional differences in female access to agricultural training opportunities. Female farmers were also more likely to use cocktail formulations recommended by agrochemical dealers (68.4% vs. 51.1%; chi-square = 8.94, $p = 0.003$), suggesting greater reliance on commercial information sources among women in both regions.

Product compatibility assessment of the documented cocktail combinations revealed that 34.2% of all identified cocktails involved at least one incompatible or not-recommended product pairing. Among triple-mix formulations, the proportion of incompatible combinations rose to 52.8%. The most commonly identified incompatibility was the combination of organophosphate and carbamate compounds, which share the same cholinesterase-inhibition mechanism and pose additive toxicity risks. Only 12.3% of farmers who used incompatible combinations were aware of the potential negative interactions, highlighting a critical gap in farmer knowledge regarding pesticide compatibility.

Table 3: Economic parameters of insecticide usage by over-application category

Parameter	Within Label (*n*=82)	1-50% Over (*n*=128)	>50% Over (*n*=90)
Mean dose (mL/L)	2.1 ± 0.4	3.5 ± 0.6	5.2 ± 0.8
Sprays/season	5.2 ± 1.4	6.8 ± 1.8	8.5 ± 2.2
Seasonal cost (USD/ha)	125 ± 32	218 ± 48	345 ± 72
Estimated loss (USD/ha)	0	95 ± 28	220 ± 55
Pest control rating (1-10)	6.8 ± 1.2	7.0 ± 1.1	6.5 ± 1.4

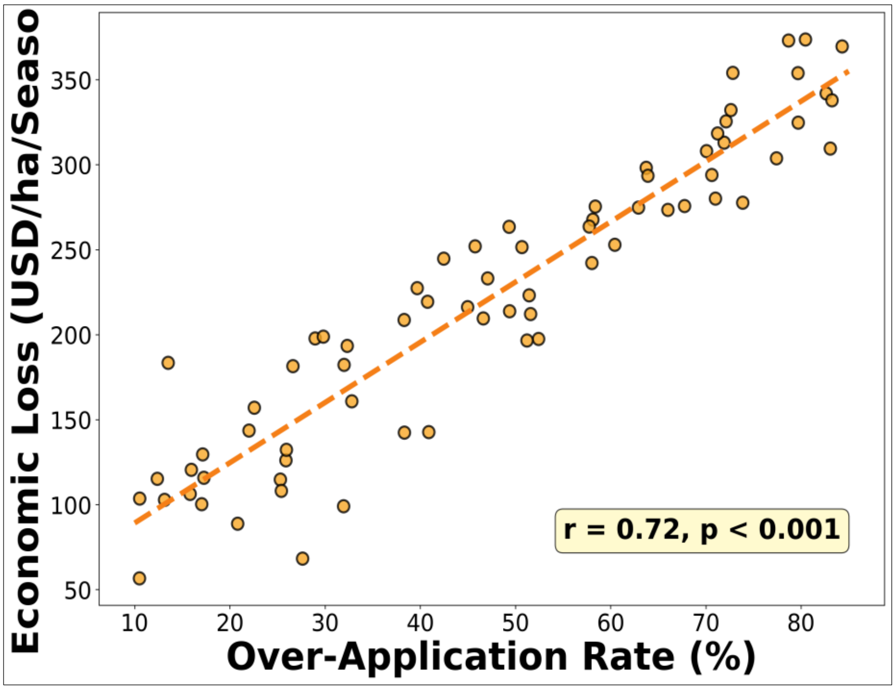

Fig 3: Relationship between insecticide over-application rate (%) and seasonal economic loss (USD/ha) among Vietnamese vegetable farmers (*n* = 300)

Discussion

The distinct cocktail mixing preferences between the two delta regions reflect the different agricultural histories, market structures, and pest management cultures that have evolved independently in northern and southern Vietnam. The Red River Delta's preference for OP+PY combinations may be rooted in the longer tradition of organophosphate usage in northern Vietnamese agriculture, while the Mekong Delta's higher prevalence of OP+CA mixtures and triple-mix formulations may reflect the influence of cross-border trade with Cambodia and the greater diversity of insecticide products available in southern markets.

The knowledge score analysis provides a nuanced picture of the human capital dimensions underlying insecticide use decisions. The strong positive effect of education on knowledge scores was expected, but the significant age-education interaction reveals important complexity: among tertiary-educated farmers, knowledge scores remained relatively stable across age groups, while among less educated farmers, older individuals showed markedly lower scores than their younger counterparts. This pattern may reflect generational differences in exposure to agricultural education, with younger less-educated farmers having benefited from more recent informal learning opportunities through media and peer networks.

The demonstration that over-application rates exceeding 50% are associated with substantial economic losses without commensurate pest control benefits provides a compelling economic argument for extension programs focused on dosage accuracy. This finding challenges the commonly held farmer belief that "more is better" by quantifying the financial penalty associated with excessive application. When communicated effectively, this economic evidence may prove more persuasive than health-based arguments in motivating behavioral change among cost-conscious vegetable farmers.

The high prevalence of triple-mix cocktails in the Mekong Delta (21.3%) is particularly concerning from both regulatory and environmental perspectives. Combining three or more insecticide products in a single application creates unpredictable chemical interactions, complicates residue monitoring, and substantially increases the risk of exceeding maximum residue limits on harvested produce. The regulatory framework in Vietnam does not explicitly address cocktail mixing, representing a policy gap that should be addressed to protect both farmer health and consumer safety.

The finding that older, less educated farmers represent the most knowledge-deficient group has practical implications for the design and delivery of extension programs targeting cocktail mixing behavior modification. Traditional extension approaches that rely heavily on printed materials, formal classroom sessions, and technical terminology may be poorly suited to reaching this demographic. Alternative delivery methods, including visual demonstration, peer-to-peer learning through experienced farmer networks, and community-based participatory learning approaches, may prove more effective for engaging older farmers with limited formal education. The significant interaction between age and education on knowledge scores suggests that extension strategies should be differentiated not only by region but also by the demographic profile of the target audience.

The regional comparison of cocktail mixing preferences highlights the importance of understanding the historical, economic, and social factors that shape pest management cultures within different agricultural landscapes. The Red River Delta's stronger preference for organophosphate-pyrethroid combinations appears to be rooted in the historical dominance of state-directed agricultural supply systems that promoted these product classes during earlier periods of Vietnamese agriculture. In contrast, the Mekong Delta's higher prevalence of triple-mix formulations and organophosphate-carbamate combinations may reflect the influence of the region's more market-oriented agricultural economy, where a wider diversity of insecticide products is available through private sector distribution channels and cross-border trade with Cambodia.

The documented correlation between over-application rate and seasonal economic loss provides one of the more compelling arguments for behavioral change intervention in the Vietnamese context. While health-based arguments for reducing insecticide use have shown limited effectiveness in motivating behavioral change among cost-sensitive smallholder farmers in previous investigations across the region, the demonstration that excessive application directly translates into quantifiable financial losses may resonate more strongly with farmers whose primary decision-making framework is economic rather than health-oriented. Extension programs that frame insecticide use optimization as a cost-saving strategy, supported by farm-level economic demonstrations, may achieve greater behavioral impact than approaches that emphasize abstract health risk messages.

Conclusion

This research reveals that insecticide cocktail mixing is a deeply embedded practice among vegetable farmers in both major delta regions of Vietnam, with distinct regional preferences reflecting different agricultural histories and market dynamics. Farmer knowledge levels are strongly determined by the interaction of education and age, with older, less educated farmers representing the most knowledge-deficient and potentially highest-risk group. The documented economic losses associated with over-application provide a practical incentive framework for extension programs aimed at promoting dosage accuracy and reducing unnecessary chemical inputs. Region-specific extension strategies that leverage the economic efficiency argument while addressing the unique cocktail mixing cultures of each delta are recommended as the most promising approach for improving insecticide use practices in Vietnamese vegetable production.

Reagents and chemicals

The insecticide products identified during the survey spanned multiple chemical classes. Organophosphates included chlorpyrifos ethyl 480 EC and profenofos 500 EC. Pyrethroids comprised cypermethrin 25 EC, lambda-cyhalothrin 25 EC, and permethrin 50 EC. Carbamates included methomyl 40 SP and carbosulfan 250 EC. Neonicotinoids encompassed imidacloprid 100 SL and thiamethoxam 250 WG. Biological products included *Bacillus* thuringiensis var. kurstaki (Bt) formulations and abamectin 36 EC. Product identifications were verified against the Vietnam Plant Protection Department's approved pesticide list for 2025.

Clinical implications

The cocktail mixing practices documented in this research have implications for clinical toxicology in the Vietnamese context. When farmers present to healthcare facilities with acute insecticide exposure symptoms, the cocktail mixing practice means that they may have been simultaneously exposed to multiple chemical classes with different toxicological profiles and treatment requirements. Clinicians should be aware that organophosphate-carbamate cocktails present additive cholinesterase inhibition risks, while pyrethroid-neonicotinoid combinations may produce complex neurological symptom presentations that do not correspond to single-class exposure profiles. Medical history intake for suspected pesticide poisoning cases should specifically inquire about cocktail mixing practices.

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