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ORIGINAL ARTICLE

Effect of pesticide exposure on hematological parameters in Vietnamese fruit farmers - A cross-sectional study

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ABSTRACT

Objective: The goal of this study is to investigate the differences in hematological parameters between pesticide-exposed fruit farmers and a non-exposed control group at a province in Northern Vietnam in 2022.

Methods: A cross-sectional study was conducted on 150 participants, including 100 pesticide-exposed farmers and 50 non-exposed controls at the intense fruit cultivation areas in Northern Vietnam. A face-to-face interview with both the fruit farmers and the control group was conducted by the trained research assistants using a structured questionnaire to collect the demographic characteristics and health behaviors of all 150 study participants. The blood samples were collected via venipuncture to be tested for complete blood count (CBC) parameters, including Red Blood Cells (RBC, HGB, HCT, MCV, MCH, MCHC, RDW), White Blood Cells (WBC, NEU, LYM, MONO, EOS, BASO), and Platelets (PLT, MPV, PCT, PDW).

Results: Significant differences were observed in several hematological parameters ($p < 0.05$). The values of MCHC, WBC, NEU (%), and PLT of the farmers (316.44 ± 10.59 g/L; 6.21 ± 1.60 G/L; 49.53 ± 8.36; 215.49 ± 64.99 G/L, respectively) were statistically different with those of the controls (334.09 ± 16.20 g/L; 5.37 ± 1.66 G/L; 46.21 ± 7.73; 238.68 ± 56.70 G/L; p = 0.0038, 0.0029, 0.019, 0.0334 respectively). In addition, 10.2% of the exposed group, who had worked in the fruit fields and were exposed to pesticides for over 20 years, had abnormal MCHC levels, resulting in lower mean value of MCHC for this group compared to the control group as mentioned above. After adjusting for the main measurable confounders in the multivariable model, only occupational pesticide exposure remained a significant predictor for MCHC (p = 0.025), WBC (p = 0.038), and PCT (p = 0.047). The magnitude of the standardized regression coefficient beta (β) showed that the length of employment in farming or length of pesticide exposure was significantly associated with decreases in MCHC (β = -1.217) and PLT (β = -0.196) and increases in WBC (β = 0.151) levels.

Conclusions: Pesticide use among fruit farmers may cause hematological alterations. An intensive intervention to provide knowledge about the potential risks of occupational pesticide exposure, to promote the appropriate use of personal protective equipment, and to practice hygiene protocols should be considered to minimize pesticide exposure.

Keywords: *pesticide exposure, hematological parameters, fruit farmers*

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INTRODUCTION

Pesticides are substances or microbial preparations that prevent, inhibit, repel, attract, kill, or control plant pests; regulate plant or insect growth; preserve plants; or increase the safety and effectiveness of pesticide use. The examples are insecticides, fungicides, herbicides, rodenticides, and plant growth regulators. Globally, pesticide consumption has seen a dramatic increase over the last few decades as agricultural intensification becomes necessary to feed a growing population, with an estimated 3.73 million tonnes applied annually worldwide especially in developing countries (1). In Vietnam, agriculture remains a cornerstone of the economy, and the transition toward high-yield fruit production has led to a surge in chemical dependency. The import of pesticides in Vietnam is enormous, with the total amount of import and application in the agricultural sector reaching up to 70,000 - 100,000 tonnes. According to the list published by the Ministry of Agriculture and Rural Development in 2019, there is a total of 503 mono-active ingredients that are categorized into the group of pesticides (133 active ingredients), fungicides (157 active ingredients), and herbicides (85 active ingredients) (2). Studies on agricultural workers in Vietnam and many developing countries have repeatedly shown that farmers frequently utilize a diverse array of compounds with different mixtures over different periods of time, and usually at higher concentrations and frequency than recommended, possibly due to frequent adulteration which included substandard products with low percentages of active ingredients and counterfeit agrochemicals (3-4).

The negative effects of pesticides on human health are a global concern, as these chemicals are designed to be biologically active. Exposure typically occurs through dermal contact during mixing and spraying, inhalation of aerosolized particles, or accidental ingestion. Chronic exposure, even at low doses, has been linked to various systemic toxicities, including dermatological, gastrointestinal, neurological, and reproductive disorders. Of particular clinical significance is the impact on the hematopoietic and immune systems. Blood cells are highly sensitive to toxic insults because they are rapidly dividing and constantly being replaced by the bone marrow (5).

Hematological parameters serve as vital indicators of physiological and pathological states in humans. Pesticides can induce hematotoxicity through several mechanisms: they may directly inhibit bone marrow activity, leading to reduced cell production, or induce oxidative stress that causes the destruction of circulating cells. For instance, exposure to organophosphates and carbamates can lead to significant changes in total white blood cell (WBC) counts, signaling an inflammatory response or immune system modulation (6). Studies in orchid and vegetable farmers have shown that chronic exposure—typically defined as a period ranging from 1 year to over 30 years—can alter not only total cell counts but also immune markers. Research in Thai orchid farmers demonstrated a significant broader immunotoxic effect, including a reduction in serum immunoglobulin levels (IgG and IgA) and complement components compared to non-exposed groups (7-9). Previous reports indicated that chronic exposure to pesticide mixtures (organophosphates and neonicotinoids) is associated with an increase in total WBC counts by approximately 15–20%, serving as a defense mechanism against chemical-induced oxidative stress. Similarly, red blood cell (RBC) counts and hemoglobin (HGB) levels may decrease due to oxidative damage to the erythrocyte membrane or interference with erythropoiesis, leading to anemia. Reported data from pesticides-exposed farmers showed significant decreases in HGB and MCHC (averaging a 1.5–2.0 g/dL reduction), often categorized as microcytic hypochromic changes (7-18).

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Despite the high intensity of pesticide use in Vietnam, there is currently limited data specifically evaluating the longitudinal or cross-sectional effects of these chemicals on the hematological parameters of farmers. Most local studies have focused on general occupational safety or acute poisoning incidents rather than the subtle, chronic physiological changes detectable through blood analysis (3-4). This lack of data hinders the development of evidence-based health surveillance programs. The selection of Luc Ngan District, Bac Giang Province, as the study site is significant due to its status as the "fruit capital" of Northern Vietnam. The region is dominated by intensive fruit cultivation, particularly lychee (*Litchi chinensis*), citrus, and apples. While comprehensive official reports on the exact volume of pesticide application in this specific region are limited, the scale of production suggests a heavy reliance on chemical plant protection products. In intensive cultivation hubs such as Thanh Hai, Giap Son, and Quy Son of Luc Ngan, farmers frequently utilized "cocktails" composed of multiple active ingredients, including insecticides, fungicides, and herbicides, to obtain high- yield fruit production. Therefore, this study was designed to evaluate the hematological status of pesticide-exposed fruit farmers in Luc Ngan, Bac Giang, providing a comparative analysis with non-exposed populations to better understand the occupational health risks inherent in Vietnamese agriculture.

RESEARCH METHODS

Study Design: The cross-sectional study.

Study Location and Duration: This cross-sectional study was conducted from April to October 2022 at Giap Son, Quy Son, and Thanh Hai Commune, Luc Ngan District, Bac Giang province.

Study Population

This cross-sectional study was conducted at the intense fruit cultivation areas in Bac Giang province in Vietnam. One hundred and fifty healthy adults, aged of 18– 65 years, participated in this study.

A convenient sampling method was employed to recruit 150 participants from the intensive fruit cultivation areas of Luc Ngan district, Bac Giang. Exposed Group (n=100): Farmers were selected based on active participation in fruit farming for at least one year and direct involvement in pesticide application. Control Group (n=50): Non-exposed participants were recruited from a local high school to ensure they shared the same geographical environment but had no occupational contact with pesticides.

Occupational exposure was characterized through a multi-step process to ensure a comprehensive understanding of the farmers' chemical environment, including 1) Occupational history: participants were required to have at least one year of active work experience in fruit cultivation to be included in the exposed group; 2) Self-reported data: A structured questionnaire was used to collect information on the frequency of application, duration of daily contact, and the time of using pesticides; 3) Label identification: Due to potential recall bias, researchers physically verified pesticide types by collecting and identifying labels and packaging left at the farmlands; 4) Toxicological Categorization: Active ingredients were cross-referenced with the WHO Recommended Classification of Pesticides by Hazard to identify hazardous compounds, such as Organophosphates and Carbamates.

Variables/Indicators/Study Topics

For characteristics of the study population: demographic variables (e.g., gender, age, body mass index, marital status, education), work-related information (e.g., work experience, farm size, and types of fruit cultivated), health behaviors (e.g., smoking, drinking alcohol, exercise, food consumption, and daily water consumption), types of pesticide use.

For measurement of haematological parameters in participants: RBC (Red blood cell); HGB (Hemoglobin); HCT (Hematocrit); MCV (Mean Corpuscular Volume); MCH (Mean Corpuscular Hemoglobine); MCHC (Mean Corpuscular Hemoglobine Concentration); RDW (Red Distribution Width); WBC (White Blood Cell); NEU (Neutrophil); LYM (Lymphocyte); MONO (Monocyte); EOS (eosinophil); BASO (basophil); PLT (Platelet); MPV (Mean Platelet Volume); PCT (Plateletcrit); PDW (Platelet Distribution Width).

Several measures were implemented to minimize the impact of extraneous variables on hematological outcomes: 1) Inclusion/Exclusion Criteria: All participants were healthy adults (18–65 years) free of underlying chronic conditions such as diabetes, hypertension, or kidney failure to prevent physiological confounding; 2) Matching: The control group was matched for age, residence duration (>10 years), and basic demographic characteristics to ensure baseline comparability; 3) Data Collection Control: Interviews were conducted using a structured questionnaire to standardize the assessment of smoking, alcohol consumption, and nutritional habits.

Techniques, Tools, and Data Collection Process

A face-to-face interview with both the fruit farmers and the control group was conducted by trained research assistants using a structured questionnaire to collect the demographic characteristics and health behaviors of all 150 study participants. For the control group, recruitment was carried out at a local high school in the same district to ensure consistency in geographical residence. All blood samples from both the exposed and non-exposed groups were collected by qualified nurses via venipuncture in the morning to minimize diurnal variation in hematological parameters. A 2 mL blood sample was obtained from each subject using an EDTA vacutainer tube. Following collection, all samples were immediately stored in an ice-cold chamber (2–8°C) and transported to the laboratory for processing within 6 hours of donation. The blood samples from all individuals were then analyzed for a complete blood count (CBC) examination using an Automatic Hematology Analyzer.

Potential Sources of Bias and Mitigation: 1) Recall bias: to mitigate the risk of farmers inaccurately remembering pesticide names, researchers identified chemical types by physically inspecting used labels and containers on the farmlands; 2) Technical bias: all blood samples were collected by qualified nurses in the morning to control for diurnal variation and were processed using the same automatic hematology analyzer within a strict 6-hour window to ensure technical consistency; 3) Selection bias: We explicitly acknowledge the difference in physical labor intensity between farmers and teachers as a potential source of bias in our limitations section.

Data Processing and Analysis

Data were entered in and analyzed by Microsoft Excel and the STATA statistical package version 14. The continuous variables in the study were summarized as mean ± SD. The categorical variables, including age, gender, and occupational exposure, were presented as frequency or percentage. Mann-Whitney U tests and Independent-sample t-tests were used to compare continuous and categorical variables between the two groups, respectively. To evaluate the association between pesticide exposure and hematological parameters while adjusting for potential confounders, we employed multivariable linear regression, and the model was defined as:

$$Y = B_0 + \beta_1 \textit{(Length of employment in farming (years) or Pesticide exposure)} + \beta_2 \textit{(Smoking)} + \beta_3 \textit{(Alcohol use)} + \beta_4 \textit{(BMI)} + \varepsilon$$

Where:

Y: The dependent variable (MCHC, WBC, NEU or PLT)

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B_0: Constant

β_1: The coefficient for the primary predictor (Exposed vs. Control).

β^{2-4}: The coefficients for the adjusted confounders.

ε: The difference between the actual observed value and the value predicted by the model (the residual).

The statistical significance level was $p < 0.05$ with exact *p*-values reported for all primary outcomes.

Research ethics: This study was approved by the Ethics Committee of the University of Public Health under Decision No. 441/2021/YTCC-HD3 on 17 December 2021.

RESULTS

Characteristics of the study population

Table 1. Characteristics of the study population

	Characteristics	Exposed group	Non-exposed group	*p*-Values
	Mean ± SD	49.38 ± 10.19	48.9 ± 5.51	> 0.05
Age	Max	60.0	55.0	
	Min	25.0	33.0	
BMI	Mean ± SD	22.81 ± 2.78	22.68 ± 2.66	> 0.05
Sex	Male	20 (20%)	16 (32%)	> 0.05
	Female	80 (80%)	34 (68%)	
Smoking	Non-smokers	100 (100%)	50 (100%)	> 0.05
Alcohol consumption	Non-drinkers	100 (100%)	50 (100%)	> 0.05
Marital status	Married	94 (94%)	45 (90%)	> 0.05
	Single	6 (6%)	5 (10%)	
Residence	Local residence (>10 years)	100 (100%)	50 (100%)	> 0.05

The personal characteristics and work-related information of the two groups are shown in Table 1. It was found that there were no differences in terms of proportions of age, sex, smoking, marital status, alcohol consumption between the two groups ($p > 0.05$).

There was no statistically significant difference in the mean age of farmers (49.38 ± 10.19) compared to the control group (48.9 ± 5.51) ($p > 0.05$). Females constituted the majority in both groups, representing 80% of the exposed group and 68% of the control group ($p > 0.05$). All participants (100%) in both groups were non-smokers and non-drinkers. In addition, all participants had been local residents for

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over 10 years, ensuring they shared similar environmental background exposures within the studied areas. The vast majority of participants were married (94% of farmers and 90% of controls), with no significant statistical difference between the groups ($p > 0.05$). In addition, the farmers had been working in the fruit farms ranging from 12 months to 37 years. The average work duration for this group is approximately 15.4 ± 9.2 years. Nearly half of the farmers (47%) had been working in fruit cultivation for over 15 years, indicating a population with significant long-term, chronic exposure to pesticides. Approximately 80% of the fruit farmers lived in an area near their farmlands (data not shown).

Main pesticides used in fruit farms in the study areas

Table 2. Toxicological classification of pesticides used in fruit farms according to WHO guidelines

Type	Brand name	Ingredients	Toxicological classification
Insecticides	Actatoc 200WP	Acetamiprid	Class II, moderately hazardous
	Repdor 250EC	Quinalphos, Lambda-cyhalothrin	Class II, moderately hazardous
	Than chop	Chlorfluazuron, Thiamethoxam, Profenofos	Class II, moderately hazardous
	SHEPATIN 75EC	Abamectin, Alpha-cypermethrin	Class II, moderately hazardous
	TANWIN 4.0EC	Emamectin Benzoate/ Avermectin	Biological class
	Fastphos 50ec	Alpha-cypermethrin	Class II, moderately hazardous
	Scorpion 36EC	Abamectin, Fipronil	Class II, moderately hazardous
	ROCKETASIA 650EC	Chlorpyrifos Ethyl, Alpha cypermethrin, Fenobucarb, Special Additives	Class II, moderately hazardous
	EMETIN 1.9 EC	Emamectin benzoate	Biological class
	Haihamec 1.8EC	Abamectin	Biological class
	CRYMERIN 100EC	Permethrin	Class II, moderately hazardous
	SAPEN ALPHA 5EC	Alpha Cypermethrin	Class II, moderately hazardous
	VK.Superlau 400SC	Buprofezin, Imidacloprid	Class II, moderately hazardous
	Map-Judo	Buprofezin	Class II, moderately hazardous
	Tasieu 1.0EC	Avermectin B1a 90 % + Avermectin B1b 10%	Class II, moderately hazardous

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Insecticides	Dratoc 666EC	Fenobucarb, Chlorpyrifos Ethyl, Lambda-cyhalothrin	Class II, moderately hazardous
	Lanomyl 680 WP	Mancozeb, Metalaxyl-M	Class II, moderately hazardous
	Elixir 750WG	Chlorothalonil, Mancozeb	Class II, moderately hazardous
Fungicides	Crystalusa 450SC	Azoxystrobin, Metalaxyl	Class II, moderately hazardous
	MAJETIC TOP 420SC	Azoxystrobin, Difenoconazole	Class II, moderately hazardous
	Asmiltatop Super 400sc	Azoxystrobin, Difenoconazole	Class II, moderately hazardous
	Carbenzim 500FL	Carbenzim	Class II, moderately hazardous
	Dosay 45WP	Cymoxanil, Zineb, Copper Oxychloride	Class II, moderately hazardous
Herbicides	Co chay	Glufosinate-Ammonium	Class II, moderately hazardous
	KHAI HOANG Q7	Glufosinate Amonium	Class II, moderately hazardous
Regulator	POLY - LIQUID	Phospholipid, N, P, K, Mn, Cu, Zn, Vitamin B6	
	A-K 205	N, P, K, Mg, Cu, Bo	

The list of pesticides used by the farmers is shown in Table 2. Most of the surveyed individuals could not remember the names of the pesticides they had used or were currently using. Therefore, the types of pesticides used by farmers was identified by collecting information from the labels left on their farmlands. The results showed that the used pesticides were mostly insecticides, fungicides, herbicides, and plant growth regulators. The types of the used pesticides were relatively diverse, belonging to the organic, synthetic pyrethroid, carbamate, and organophosphorus (organophosphate) groups. However, the list of the used pesticides still included banned substances in Vietnam, such as Chlorpyrifos.

Hematological parameters among fruit farmers

Table 3. Comparison of hematological parameters between the exposed and non-exposed groups

Hematological Analysis	Exposed group (n=100)	Non-exposed group (n=50)	Normal range	*p*-Value
	Mean ± SD	Mean ± SD		
Red Blood Cells (RBC)				
RBC (T/L)	4.76 ± 0.55	4.82 ± 0.47	4,0-5.4	> 0.05

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Hematological Analysis	**Exposed group (n=100)**	**Non-exposed group (n=50)**	**Normal range**	***p*-Value**
	Mean ± SD	Mean ± SD		
HGB (g/L)	130.16 ± 13.44	134.77 ± 13.34	125-145	> 0.05
HCT (L/L)	0.40 ± 0.03	0.39 ± 0.08	0.35-0.45	> 0.05
MCV (fL)	87.28 ± 6.58	85.53 ± 9.33	80-100	> 0.05
MCH (pg)	28.84 ± 4.22	27.66 ± 2.81	27-34	> 0.05
MCHC (g/L)	**316.44 ± 10.59**	**334.09 ±16.20**	**320-360**	**0.0038**
RDW (%)	11.80 ± 0.80	12.46 ± 1.37	10-17	> 0.05
White Blood Cells (WBC)				
WBC (G/L)	**6.21 ± 1.60**	**5.37 ± 1.66**	**4-10**	**0.0029**
NEU (%)	**49.53 ± 8.36**	**46.21 ± 7.73**	**45-70**	**0.019**
LYM (%)	37.25 ± 6.94	40.03 ± 6.86	20-50	>0.05
MONO (%)	7.67 ± 2.16	9.74 ± 3.15	0-8	>0.05
EOS (%)	2.55 ± 1.87	2.16 ± 1.55	0-8	>0.05
BASO (%)	1.98 ± 0.86	2.38 ± 1.21	0-1	>0.05
NEU (G/L)	2.51 ± 0.72	3.11 ± 1.10	1.8-7.0	>0.05
LYM (G/L)	2.05 ± 0.82	2.28 ± 0.61	1-5.0	>0.05
MONO (G/L)	0.53 ± 0.29	0.47 ± 0.15	0-0.8	>0.05
EOS (G/L)	0.10 ± 0.09	0.15 ± 0.16	0-0.8	>0.05
BASO (G/L)	0.11 ± 0.06	0.11 ± 0.04	0-0.1	>0.05
Platelets (PLT)				
PLT (G/L)	**215.49 ± 64.99**	**238.68 ± 56.70**	**150-450**	**0.0334**
MPV (fL)	7.45 ± 1.16	7.20 ± 1.41	5-15	> 0.05
PCT (%)	0.17 ± 0.04	0.16 ± 0.05	0.1-0.5	> 0.05
PDW (fL)	18.79 ± 1.17	18.64 ± 1.32	7-25	> 0.05

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Comparisons of the hematological parameters between the exposed group and non-exposed group are shown in Tables 3. There was no statistically significant difference between the two groups in terms of the following parameters ($p > 0.05$): Red blood cells (RBC, HBG, HCT, MCV, MCH), White blood cells (NEU, LYM, MONO, EOS, BASO), and Platelets (MPV, PCT, PDW). However, the mean values of MCHC (316.44 ± 10.59 vs 334.09 ± 16.20 g/L, $p = 0.0038$) and PLT (215.49 ± 64.99 vs 238.68 ± 56.70 G/L, $p = 0.034$) in the exposed group were significantly lower than the non-exposed group. While the mean value of WBC (6.21 ± 1.60 vs 5.37 ± 1.66 G/L, p = 0.0029) and NEU (%) (49.53 ± 8.36 vs 46.21 ± 7.73, $p = 0.019$) in the exposed group was significantly higher than the non-exposed group. In addition, 10.2% of the exposed group, who had worked in the fruit fields and were exposed to pesticides for over 20 years, had abnormal MCHC levels, resulting in lower mean value of MCHC for this group compared to the control group as mentioned above.

After adjusting for the main measurable confounders in the multivariable model, only occupational pesticide exposure remained a significant predictor for MCHC ($p = 0.025$), WBC (p = 0.038), and PCT ($p = 0.047$). The magnitude of the standardized regression coefficient beta showed that the length of employment in farming was significantly associated with decreases in MCHC (β = -1.217) and PLT (β = -0.196) and increases in WBC (β = 0.151) levels. In addition, the model summary indicated R-square (R2) values of 0.168, 0.145, and 0.112 for MCHC, WBC, and PCT levels respectively, also demonstrating the significant association.

DISCUSSION

Alterations in hematological parameters among fruit farmers

Complete Blood Count (CBC) is a standard clinical diagnostic tool used to measure blood components, including red blood cells, white blood cells, and platelets. This test is essential for detecting hematological abnormalities and assessing conditions such as anemia, infections, and coagulation disorders. By providing critical data on erythrocyte, leukocyte, and platelet indices, the CBC aids in the diagnosis and monitoring of physiological and pathological states in humans. In this study, differences in several hematological parameters were observed in the exposed and control group. The significant difference in blood cell indices, such as HGB, HCT, MCV, MCH and MCHC values, observed among Vietnamese fruit farmers aligns with established research in other countries including Pakistan, Iran, India, Mexico, Columbia, Brazil, Egypt, and Thailand (7-18).

For example, a study on 193 pesticide sprayers in Pakistan showed that the MCHC value was significantly reduced in the exposed group as compared to the non-exposed group (283.5 ± 1.97 vs. 344.2 ± 1.37, $p < 0.001$) (10,11). Mechanism of alterations in several hematological parameters in previous studies suggest that this may have been due to pesticide exposure altering iron homeostasis, which affects the red blood cells. Long-term exposure could disrupt the balance between free radical production and antioxidant defenses, resulting in DNA damage. In addition, previous studies showed that high sulfate content in pesticides can form sulfhemoglobin bonds, which will cause hemoglobin to become abnormal and unable to carry out its function in delivering oxygen. Anemia can occur in patients with organophosphate and carbamate pesticide poisoning because the form of sulfhemoglobin and methemoglobin in red blood cells causes a decrease in hemoglobin levels, resulting in hemolytic anemia. The incidence of hemolytic anemia occurs due to contact with pesticides caused by enzymatic defects in red blood cells and the amount of toxic substances that enter the body (5,6).

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Concerning the increased white blood cells of the exposed group compared to the control group (6.21 ± 1.60 vs 5.37 ± 1.66; $p = 0.0029$), this finding is also consistent with other studies, which reported significant variations in leukocyte profiles among those with high pesticide exposure (7,8,10). Similarly, research in orchid farmers in Thailand noted that while some specific immune components might decrease, the overall cellular profile often reflects a response to chemical-induced stress (7,8). Research in Pakistan also observed that farmers exposed to organophosphates exhibited elevated WBC counts (10.34 ± 3.22 G/L vs. 6.12 ± 1.72 G/L; $p < 0.001$), likely as a defense mechanism against chemical-induced oxidative stress (10,11). Compared to findings in other Southeast Asian countries, the hematological impact observed in Vietnamese fruit farmers appears comparable in magnitude, highlighting a regional public health issue. While some studies in Brazil and Mexico have reported more severe bone marrow suppression leading to leukopenia, our study—along with several studies in Thailand—primarily observed an inflammatory leukocytosis and erythroid-depressive effect (7-9,14-17). These variations likely stem from the specific types of pesticides used in different population, frequency, and duration in each study, as well as differences in individual immune responses (5,6).

Regarding platelets, the reduction in platelet indices is commonly associated with chronic exposure to pesticides. The finding is also consistent with previous studies in other countries (7-18). For example, the study in Pakistan also showed that PLT was significantly reduced in exposed group as compared to non-exposed group (150.84 ± 17.15 vs. 251.64 ± 51.92, $p < 0.001$) (10,11). The exposure to pesticides can suppress platelet production, and some pesticides can trigger formation of excessive clots, which augments the risk of thrombosis and other linked cardiovascular events. Moreover, severe exposure can precipitate disseminated intravascular coagulation (5,6).

Strength and limitations of the study

Our study provides essential cross-sectional data on the hematological status of fruit farmers in Vietnam, a population that has been under-represented in chronic occupational health research despite the high intensity of regional pesticide use. However, the study have several limitations, including: 1) Causal inference: Due to the cross-sectional study design, it is not possible to establish a definitive causal relationship between pesticide exposure and the observed hematological alterations as there are many factors making hematological changes, while in this present study, we mostly focused on pesticide effects on hematological changes. The multivariable linear regression showed that the length of employment in farming or pesticide exposure could explain 16.8%, 14.5%, 11.2% of the variation in the levels of MCHC ($R^2 = 0.168$), WBC ($R^2 = 0.145$), and PLT ($R^2 = 0.112$), respectively. Thus, many other factors, which also effects these hematological parameters, are outside the scope of this study; 2) Control group comparability: The selection of high school teachers as the control group introduced potential selection bias. Differences in daily physical workload, labor intensity, dietary habits, and socioeconomic status between teachers and farmers may act as confounding variables. By utilizing multivariable linear regression, we controlled for the main measurable confounders. The fact that the association between pesticide exposure and hematological parameters (MCHC, WBC, PLT) remained statistically significant suggests that the occupational environment of the fruit farms is a primary driver of these biological shifts, even when compared to a different professional group like high school teachers; 3) Quantitative exposure assessment: The study relied on self-reported data and label identification rather than quantitative assessment of pesticide metabolites in biological samples. Consequently, the research was unable to establish a clear dose-response relationship; 4) Lack of control for unmeasured confounders:

Factors such as nutrition, subclinical infections, and broader socioeconomic status were not fully controlled and may have impacted the results; 5) Generalizability: The relatively modest sample size (n=150) and potential recall bias in reporting pesticide use may limit the generalizability of these findings to other regions.

CONCLUSIONS

Our findings add to the evidence that occupational exposure to pesticides may alter hematological parameters. An intensive intervention to provide knowledge about the potential risks of occupational pesticide exposure, to promote the appropriate use of personal protective equipment (e.g. chemical respirators, chemical-resistant gloves and full-body protective clothing) and to practice hygiene protocols should be considered to minimize pesticide exposure. In addition, future investigations should undertake a main effort to evaluate the identity and the level of pesticides exposure and should control for the most possible potential confounders.

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Conflict of Interest

The authors declare no conflict of interest.

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