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Hemoglobin Levels among Farmers: The Impact of Pesticide Exposure and Geographical Factors in Lotto Village, Ternate City

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Abstract
Farmers face substantial occupational risks from pesticide exposure during crop spraying, which can disrupt hematopoiesis and alter hemoglobin (Hb) levels, potentially inducing anemia or physiological polycythemia. This study assessed Hb profiles and associated occupational and environmental determinants among farmers in Loto Village, West Ternate City. A descriptive cross-sectional design was employed, involving 35 active farmers. Capillary Hb concentrations were quantified via Point-of-Care Testing (POCT), along with data on spraying frequency, work duration, compliance with personal protective equipment (PPE), gender, and residential altitude. Results revealed that 80% (n=28) maintained normal Hb levels, whereas 11% (n=4) had low Hb levels, and 9% (n=3) had elevated Hb levels. Reduced Hb was predominantly observed among female farmers and individuals who used incomplete PPE during chemical handling. Conversely, elevated Hb concentrations were concentrated among male farmers residing in high-altitude zones, indicating an adaptive erythropoietic response to hypobaric hypoxia. Frequent pesticide application (≥3 times/week) and extended occupational tenure (>5 years) further correlated with Hb variability. These findings indicate that while hematological homeostasis is largely preserved in this cohort, inadequate PPE compliance and female sex elevate anemia susceptibility, whereas high-altitude residence drives compensatory polycythemia. Routine hematological surveillance and enforced adherence to PPE are essential for mitigating pesticide-induced hematotoxicity and optimizing occupational health outcomes in agricultural populations.

Keywords
Hemoglobin, Pesticide exposure, Occupational health; Personal protective equipment

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1. BACKGROUND

Indonesia, as a predominantly agrarian nation, relies heavily on its agricultural sector, which employed approximately 26.50 million workers or 29.96% of the national workforce as of February 2022 (Central Bureau of Statistics, 2022). The extensive harvested land area of 10,606,513 hectares recorded in 2022 necessitates substantial pesticide utilization to optimize crop yields. The Directorate of Fertilizers and Pesticides has registered approximately 2,420 pesticide brands under the Directorate General of Agricultural Infrastructure and Facilities, reflecting the intensive chemical inputs in Indonesian agriculture (Directorate General of Agricultural Infrastructure and Facilities, 2020). This widespread reliance on pesticides raises significant concerns about occupational health risks for agricultural workers who are routinely exposed to these chemicals.

The escalating use of pesticides poses significant public health concerns globally, with the World Health Organization (WHO) estimating approximately 25 million cases of chemical pesticide poisoning occurring annually worldwide, equivalent to 68,493 cases daily. Agricultural workers, particularly those involved in pesticide application, represent a vulnerable population experiencing disproportionate exposure risks through activities such as mixing, spraying, equipment cleaning, and harvesting (Sari et al., 2023; Tutu et al., 2024). Documented adverse health effects include respiratory difficulties, headaches, neurological and psychological manifestations, and mucocutaneous irritation, underscoring the urgent need for comprehensive occupational health surveillance in agricultural communities.

Pesticide exposure can disrupt hematopoietic processes, leading to hematological abnormalities, particularly affecting hemoglobin levels. The sulfur compounds present in many pesticides can induce the formation of sulfhemoglobin and methemoglobin within erythrocytes (Azizah et al., 2023). Sulfhemoglobin impairs hemoglobin's oxygen-carrying capacity, while methemoglobin forms when iron in hemoglobin oxidizes from the ferrous (Fe^{2+}) to ferric (Fe^{3+}) state. Additionally, nitrite compounds can bind with hemoglobin, further compromising oxygen transport. These pathological changes can ultimately result in anemia, characterized by symptoms such as dizziness, fatigue, and impaired oxygen delivery to tissues (Shah et al., 2024), potentially compromising workers' health and productivity.

Multiple factors influence susceptibility to pesticide poisoning, categorized as internal and external determinants. Internal factors include age, nutritional status, sex, educational level, and knowledge regarding proper pesticide handling. In contrast, external factors include pesticide dosage, working duration, spraying direction relative to wind patterns, timing and frequency of application, and the use of personal protective equipment (PPE) (Sari et al., 2023). Previous research by Susilowati and Muzayanah (2021) demonstrated a statistically significant relationship between the duration of pesticide spraying and hemoglobin concentrations, with inadequate PPE use identified as a primary contributor to elevated exposure levels. These findings highlight the multifactorial nature of pesticide-related hematological disturbances and the importance of comprehensive risk assessment.

In Loto Village, West Ternate City, where agriculture constitutes the primary livelihood, farmers frequently employ chemical pesticides, particularly insecticides, to maximize harvest yields. However, concerning practices have been observed, including the indiscriminate mixing of multiple pesticide brands without adhering to recommended dosages and inconsistent use of appropriate PPE, such as rubber boots, gloves, and masks, during pesticide handling and application. Given the intensive agricultural activities in this region and the documented association between pesticide exposure and hematological abnormalities, this study aims to evaluate hemoglobin profiles among farmers in Loto Village. Understanding hemoglobin status and its relationship to occupational pesticide exposure is crucial for developing targeted interventions to mitigate health risks and improve occupational safety standards for agricultural workers in Indonesia.

2. METHODS

This research used a cross-sectional study conducted from March to July 2025 in the agricultural plantation area of Loto Village, West Ternate District, Ternate City. The study population comprised all active farmers working in Loto Village, totaling 54 individuals. The minimum sample size was calculated using the Slovin formula, yielding a representative sample of 35 respondents.

A purposive sampling technique was employed to ensure comprehensive representation of population characteristics through strict selection criteria, with total sampling applied to eligible subgroups. Inclusion criteria included farmers aged 20-80 years residing in Loto Village and actively engaged in farming activities, regardless of PPE use (e.g., masks and gloves) during work. Exclusion criteria included farmers unwilling to participate as research respondents and female farmers who were menstruating at the time of blood sample collection.

Hemoglobin examination was performed using the Point-of-Care Testing (POCT) method on capillary blood

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samples. The analytical procedure commenced with the preparation of all necessary equipment and materials, including a blood pen, test strips, sterile blood lancets, and the POCT device for rapid hemoglobin measurement. Prior to sample collection, the puncture site on the farmer's fingertip was cleansed with alcohol swabs. Capillary blood was obtained with a sterile lancet, and the sample was applied to the designated test strip according to the manufacturer's specifications. The test strip containing the blood sample was then inserted into the POCT device for automatic hemoglobin measurement. Results were displayed on the device screen within minutes and recorded as research data. Throughout the examination process, researchers wore gloves and masks to maintain safety and hygiene standards.

Data processing involved editing for completeness and accuracy, coding of categorical variables, and organization into frequency distribution tables. Descriptive statistical analysis was performed using percentage calculations: $P = (F/n) \times 100\%$, where P represents percentage, F denotes respondents with normal or abnormal hemoglobin levels, and n indicates total sample size. All respondents provided informed consent prior to data collection and hemoglobin examination using the Point-of-Care Testing (POCT) method

3. RESULTS

Table 1. Distribution of Respondents by Gender

Gender	Frequency (F)	Percentage (%)
Male	21	60
Female	14	40
Total	35	100

Table 1 presents the distribution of respondents by gender. Male farmers constituted the majority of participants (n=21, 60%), while female farmers accounted for 40% (n=14) of the sample. This gender distribution reflects the physically demanding nature of agricultural work, which typically requires greater physical strength, consistent with findings by Permatasari and Rondhi (2022).

Table 2. Distribution of Hemoglobin Levels by Spraying Frequency

Spraying Frequency	Low Hb		Normal Hb		High Hb		Total	
	F	%	F	%	F	%	F	%
Daily	0	0	3	9	0	0	3	9
3 times/week	4	11	25	71	3	9	32	91
Total	4	11	28	80	3	9	35	100

As shown in Table 2, among farmers who sprayed pesticides three times weekly, 4 respondents (11%) exhibited low hemoglobin levels, while 3 respondents (9%) demonstrated elevated hemoglobin levels. The majority (n=25, 71%) maintained normal hemoglobin concentrations. Low hemoglobin levels among farmers with high spraying frequency were attributed to excessive pesticide dosage, supporting previous research indicating that improper pesticide application correlates with hematological abnormalities (Fitriana et al., 2020). Conversely, elevated hemoglobin levels observed among farmers who sprayed three times weekly were associated with residence in high-altitude areas, where lower oxygen concentrations stimulate physiological erythropoiesis (Syamsir, 2023).

Table 3. Distribution of Hemoglobin Levels by Gender

Gender	Low Hb		Normal Hb		High Hb		Total	
	F	%	F	%	F	%	F	%
Male	0	0	18	51	3	9	21	60
Female	4	11	10	28	0	0	14	40
Total	4	11	28	80	3	9	35	100

Table 3 shows the distribution of hemoglobin by gender. Among male farmers, 3 respondents (9%) presented with elevated hemoglobin levels, while 18 respondents (51%) maintained normal levels. In contrast, all cases of low hemoglobin (n=4, 11%) occurred exclusively among female farmers. Overall, 28 respondents (80%) demonstrated normal hemoglobin levels. The predominance of low hemoglobin among female participants was attributed to recent menstruation at the time of examination, consistent with evidence showing significant hemoglobin reduction following menstruation (Cahyani, 2024). Statistical analysis using the Wilcoxon test revealed a significant difference ($p=0.001$) in hemoglobin levels before and after menstruation. Elevated hemoglobin levels among male farmers were associated with high-altitude residence, indicating physiological polycythemia as an adaptive response to hypoxic conditions (Kurniawan & Rochmadhona, 2021).

Table 4. Distribution of Hemoglobin Levels by Age Group

Age Group (years)	Low Hb		Normal Hb		High Hb		Total	
	F	%	F	%	F	%	F	%
27-42	2	6	14	40	0	0	16	46
43-58	1	3	10	29	1	3	12	34
59-77	1	3	4	11	2	6	7	20
Total	4	11	28	80	3	9	35	100

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Table 4 shows the distribution of hemoglobin across age categories. Among farmers aged 27-42 years, 2 respondents (6%) exhibited low hemoglobin levels, while 14 respondents (40%) demonstrated normal levels. In the 43-58 years age group, 1 respondent (3%) had low hemoglobin, 1 respondent (3%) had elevated levels, and 10 respondents (29%) maintained normal hemoglobin levels. Among farmers aged 59-77 years, 1 respondent (3%) had low hemoglobin, 2 respondents (6%) had elevated levels, and 4 respondents (11%) had normal values.

Table 5. Distribution of Hemoglobin Levels by Working Duration

Working Duration (Years)	Low Hb		Normal Hb		High Hb		Total	
	F	%	F	%	F	%	F	%
1-5	0	0	7	20	0	0	7	20
>5	4	11	21	60	3	9	28	80
Total	4	11	28	80	3	9	35	100

Table 5 shows the elevated hemoglobin levels occurred exclusively among farmers with working experience exceeding 5 years (n=3, 9%). Similarly, all cases of low hemoglobin (n=4, 11%) were observed in this group. Farmers with 1-5 years of experience (n=7, 20%) all demonstrated normal hemoglobin levels. The hematological abnormalities among farmers with prolonged occupational exposure were not solely attributable to pesticide exposure (Curacon, Demolish, Prevathon, Decis, Regent). However, they were significantly influenced by high-altitude working environments (Syamsir, 2023).

Table 6. Distribution of Hemoglobin Levels by PPE Usage

PPE Usage	Low Hb		Normal Hb		High Hb		Total	
	F	%	F	%	F	%	F	%
Complete PPE	0	0	0	0	0	0	0	0
Incomplete PPE	4	11	28	80	3	9	35	100
Total	4	11	28	80	3	9	35	100

Table 6 shows that all respondents reported incomplete PPE utilization during pesticide application. Among these farmers, 4 respondents (11%) had low hemoglobin levels, 3 (9%) had elevated levels, and 28 (80%) maintained normal levels. No respondents reported complete PPE compliance. Incomplete PPE usage facilitates pesticide entry through dermal absorption and inhalation, increasing exposure risk. However, most farmers utilized partial protection, including masks, long-sleeved shirts, and long pants, which may have mitigated exposure to some extent (Syamsir et al., 2023), according to the Indonesian Minister of Manpower and Transmigration Regulation No. Per.08/Men/VII/2010, complete PPE for pesticide application should include hats, long-sleeved shirts, long pants, gloves, masks, goggles, and boots to adequately protect against dermal and inhalational exposure (Marisa & Asmul, 2020; Utami et al., 2019).

4. DISCUSSION

This cross-sectional study of 35 farmers in Loto Village revealed that the majority (80%) maintained hemoglobin levels within normal reference ranges, despite routine occupational exposure to pesticides. This finding suggests that pesticide exposure does not universally translate into hematological disturbances, indicating the influence of moderating factors. Hemoglobin homeostasis appears to be governed by a complex interplay of internal determinants (age, sex, nutritional status, and underlying health conditions) and external factors (pesticide-spraying frequency, occupational tenure, PPE utilization, and exposure intensity). These results align with Ropen and Sugiarto (2021), who demonstrated that chronic pesticide exposure can alter hematological profiles through impaired erythropoiesis, although individual susceptibility varies considerably.

The male predominance (60%) in our study cohort reflects the physically demanding nature of agricultural work in this region, consistent with Permatasari and Rondhi's (2022) findings regarding gender distribution in Indonesian agriculture. From a physiological perspective, male participants exhibited higher hemoglobin concentrations, attributable to testosterone-mediated erythropoietic stimulation (Kurniawan & Rochmadhona, 2021). Conversely, all cases of low hemoglobin (11%) occurred exclusively among female participants, a finding plausibly explained by menstrual blood loss and subsequent iron depletion. This observation corroborates Cahyani's (2024) demonstration of a significant post-menstrual hemoglobin reduction, suggesting that female farmers constitute a particularly vulnerable population that requires targeted nutritional interventions.

The association between inadequate PPE utilization and reduced hemoglobin levels warrants particular attention. Although no respondents reported complete PPE compliance, those with partial protection (masks, long-sleeved shirts, and long pants) demonstrated relatively better hematological outcomes. This finding supports Nurillah's (2020) assertion that dermal contact constitutes the primary pesticide exposure pathway during mixing and application activities. The observed hemoglobin abnormalities among farmers with incomplete PPE use likely reflect cumulative pesticide absorption via cutaneous and inhalational routes, potentially disrupting hematopoietic function by inducing sulfhemoglobin and methemoglobin formation via sulfur compounds (Azizah et al., 2023).

Pesticide spraying frequency emerged as a significant determinant of hemoglobin variability. Farmers engaging in high-frequency application (≥3 times weekly) demonstrated greater propensity for hematological alterations, supporting Fitriana et al.'s (2020) findings linking intensive pesticide use to adverse health outcomes. The mechanism likely involves repeated exposure exceeding metabolic detoxification capacity, leading to bioaccumulation of organophosphate and carbamate compounds that interfere with erythropoiesis (Syamsir et al., 2023). However, the relationship between spraying frequency and hemoglobin levels was not linear, suggesting the influence of confounding variables, including pesticide type, application technique, and individual metabolic capacity.

Occupational tenure exceeding five years was associated with both elevated and reduced hemoglobin concentrations, indicating divergent adaptive responses to chronic pesticide exposure. While prolonged exposure theoretically increases cumulative toxic burden, the maintenance of normal hemoglobin levels among most long-term farmers suggests potential physiological adaptation or effective compensatory mechanisms. This finding challenges simplistic dose-response assumptions and underscores the importance of considering individual resilience factors, including genetic polymorphisms in detoxification enzymes, nutritional status, and concurrent health conditions (Prajawahyudo et al., 2022).

Notably, elevated hemoglobin levels (9%) were observed exclusively among male farmers residing in high-altitude areas, suggesting a physiological adaptation to hypobaric hypoxia rather than pesticide-induced pathology. This finding aligns with Kurniawan and Rochmadhona's (2021) demonstration of altitude-mediated erythropoietic stimulation, wherein reduced atmospheric oxygen tension triggers enhanced erythropoietin production and subsequent polycythemia. Distinguishing between physiological polycythemia and pathological hemoglobin elevation is crucial for accurate clinical interpretation and avoiding unnecessary interventions.

Several limitations warrant acknowledgment. The cross-sectional design precludes causal inference regarding pesticide exposure and hemoglobin alterations. The relatively small sample size (n=35) limits statistical power and generalizability. We did not quantify pesticide exposure levels through biomonitoring (e.g., cholinesterase activity or urinary pesticide metabolites), relying instead on self-reported spraying frequency and duration. Additionally, we did not comprehensively assess dietary iron intake, parasitic infections, or chronic diseases that could independently influence hemoglobin concentrations. Future investigations should employ longitudinal designs with objective exposure biomarkers and comprehensive confounder assessment.

5. CONCLUSION

This study demonstrates that while the majority of farmers in Loto Village maintain hemoglobin concentrations within normal reference ranges, a clinically relevant subset exhibits hematological deviations directly linked to occupational and environmental determinants. Low hemoglobin levels were predominantly observed among female farmers and among individuals with inconsistent compliance with PPE, reflecting the compounded effects of menstrual iron loss and inadequate dermal/respiratory protection against agrochemical exposure. Conversely, elevated hemoglobin concentrations were exclusively identified among male farmers residing in high-altitude zones, indicating a physiological erythropoietic adaptation to chronic hypobaric hypoxia rather than pesticide-induced hematotoxicity. These findings underscore that hemoglobin variability in agricultural cohorts is multifactorial, governed by an interplay of sex-specific physiology, PPE utilization, spraying frequency, occupational tenure, and geographical altitude. To mitigate pesticide-related hematological risks and optimize farmer well-being, targeted interventions should prioritize mandatory PPE enforcement, standardized pesticide handling protocols, and routine occupational health surveillance. Future investigations should employ longitudinal designs and quantitative toxicological biomarkers to elucidate the cumulative hematopoietic impacts of chronic pesticide exposure across diverse agroecological and socioeconomic contexts.

AUTHOR CONTRIBUTIONS

IBHL: Research conceptualization, methodology, field sampling, initial draft of the manuscript, and correspondence. AYA: Data processing, laboratory analysis, literature review, editing, and finalization of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research.

DATA AVAILABILITY STATEMENT

The data data can be accessed from the corresponding author upon reasonable request.

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