

Impact of Pesticide Exposure on Serum Glutamic Oxaloacetic Transaminase and Serum Glutamic Pyruvic Transaminase Levels in Farmers

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ABSTRACT

Farmers are at risk of pesticide exposure, which may adversely affect liver function. However, evidence regarding the relationship between pesticide exposure and serum glutamate-oxaloacetate transaminase (SGOT) and glutamate-pyruvate transaminase (SGPT) levels among farmers in Sendangrejo Village, Sleman Regency, remains limited. This study aimed to determine the relationship between pesticide exposure levels and serum SGOT and SGPT levels among farmers in Sendangrejo Village, Sleman Regency. This analytical observational study employed a cross-sectional design involving 30 farmers selected using purposive sampling. Pesticide exposure was assessed using a questionnaire based on work duration, spraying frequency, and compliance with personal protective equipment (PPE) use. Serum SGOT and SGPT levels were measured using a clinical chemistry analyzer (Thermo Scientific Indiko) with the enzymatic kinetic method. Data were analyzed using Spearman's rank correlation test. No significant correlations were found between work duration, spraying frequency, or PPE compliance and serum SGOT or SGPT levels ($p > 0.05$), with correlation coefficients ranging from -0.271 to 0.071 . Pesticide exposure assessed through work duration, spraying frequency, and PPE compliance was not significantly associated with serum SGOT or SGPT levels among farmers. These findings suggest that assessment of pesticide-related liver effects should not rely solely on indirect exposure indicators but should also incorporate biological exposure biomarkers and other individual risk factors.

Keywords: liver function; hepatotoxicity; pesticide exposure; farmers

INTRODUCTION

Indonesia is widely recognized as an agrarian nation in which the agricultural sector plays a central role in economic development, rural livelihoods, and national food security. To sustain and enhance agricultural productivity, farmers rely heavily on pesticides as one of the primary methods for controlling pests, weeds, and plant diseases that threaten crop yields [1]. Globally, pesticide use has continued to rise in parallel with the intensification of modern agriculture, reaching more than 3.7 million tons of active ingredients and demonstrating an upward trend over the past decade [2]. Although pesticides contribute significantly to improved agricultural output, their extensive use has also raised substantial public health concerns, particularly regarding chronic exposure among farmers. The World Health Organization estimates that pesticide poisoning accounts for 1–5 million cases annually, with hundreds of thousands of deaths occurring predominantly in low- and middle-income countries where regulatory oversight and occupational safety practices remain limited [3].

Pesticide exposure among farmers may occur through inhalation of aerosolized particles, dermal absorption during mixing and spraying activities, and ingestion through contaminated hands or food. These exposure pathways are especially prominent during pesticide preparation, application, and equipment handling. Once pesticides enter the human body, the liver serves as the primary organ responsible for metabolizing and detoxifying these xenobiotic compounds. Hepatic biotransformation processes generate reactive oxygen species (ROS), which induce oxidative stress, disrupt endogenous antioxidant systems, and damage hepatocyte membranes through lipid peroxidation and inflammatory pathways [4].

Damage to hepatocytes results in the leakage of intracellular enzymes; most notably Serum Glutamic Oxaloacetic Transaminase (SGOT) and Serum Glutamic Pyruvic Transaminase (SGPT) into the bloodstream. Elevated serum concentrations of these enzymes serve as sensitive biomarkers of hepatocellular injury. Concurrent measurement of SGOT and SGPT provides a more comprehensive assessment of liver dysfunction associated with exposure to hepatotoxic substances, including various classes of pesticides [5]. In this study, SGOT levels were categorized as normal when <31 U/L and SGPT levels as normal when <34 U/L, based on the reference values of the laboratory utilized.

The magnitude of pesticide exposure experienced by farmers is influenced by several occupational factors, including duration of employment, frequency of spraying, and adherence to personal protective equipment (PPE) protocols. Longer work duration and higher spraying frequency increase cumulative exposure, thereby elevating the likelihood of chronic health effects. Conversely, incomplete or inconsistent use of PPE facilitates pesticide entry through the skin and respiratory tract. Previous studies have demonstrated that prolonged work duration and frequent spraying are associated with increased biological risk due to pesticide exposure [6]. Furthermore, evidence indicates that a substantial proportion of farmers do not use PPE consistently or correctly during spraying activities, thereby heightening their vulnerability to pesticide-related health problems [7].

Sleman Regency, located in the Special Region of Yogyakarta, is one of the major agricultural areas with a total cultivated land area of 19,131 hectares. This extensive agricultural activity contributes to continuous pesticide use and increases the potential for chronic exposure among farmers [8]. Sendangrejo Village, situated within Sleman Regency, shares similar agricultural characteristics and practices. Although several studies have examined the relationship between pesticide exposure and liver function impairment among farmers, the findings remain heterogeneous and are often derived from different geographical contexts. To date, no study has specifically investigated the association between pesticide exposure—measured through work duration, spraying frequency, and PPE compliance—and serum SGOT and SGPT levels among farmers in Sendangrejo Village, Sleman Regency. This gap in the literature underscores the need for a localized investigation.

Based on these considerations, the present study aims to determine the relationship between pesticide exposure levels and serum SGOT and SGPT concentrations among farmers in Sendangrejo Village, Sleman Regency. The study hypothesizes that pesticide exposure, assessed through work duration, spraying frequency, and PPE compliance, is significantly associated with alterations in SGOT and SGPT levels. The findings are expected to provide valuable insights into liver function status among farmers exposed to pesticides and to serve as an

evidence-based foundation for strengthening PPE awareness, promoting safer agricultural practices, and encouraging routine health monitoring in agricultural communities.

METHODS

This study employed an analytical observational approach using a cross-sectional design to examine the relationship between pesticide exposure levels and serum SGOT and SGPT concentrations among farmers in Sendangrejo Village, Sleman Regency. The cross-sectional framework was selected because it enables simultaneous measurement of exposure and outcome variables, allowing the identification of associative patterns within a defined population at a single point in time. The dependent variables in this study were serum SGOT and SGPT levels, while the independent variable was pesticide exposure level, operationalized through three occupational indicators: duration of employment, spraying frequency, and compliance with PPE use.

The study population consisted of all farmers residing in Sendangrejo Village. The sample was selected using purposive sampling based on predetermined inclusion and exclusion criteria to ensure that participants represented the target population and met the requirements for valid biochemical assessment. To reduce potential confounding, individuals with a history of liver disease or those taking medications known to influence SGOT and SGPT levels were excluded. This exclusion criterion was essential to ensure that variations in enzyme levels could be attributed more reliably to pesticide exposure rather than underlying hepatic pathology or pharmacological effects.

Data on respondent characteristics and pesticide exposure levels were collected through structured interviews using a standardized questionnaire. Exposure assessment was conducted by categorizing duration of employment into three groups (<5 years, 5–10 years, and >10 years), reflecting cumulative occupational exposure. Spraying frequency was classified into low and high categories based on the number of spraying episodes within a defined period. Compliance with PPE use was evaluated using five PPE components, each assigned a score that contributed to a total compliance score. This total score was subsequently categorized into low, moderate, and high compliance levels, providing a multidimensional assessment of protective behavior during pesticide handling.

Biochemical measurements of serum SGOT and SGPT were performed using a clinical chemistry analyzer (Thermo Scientific Indiko) with an enzymatic kinetic method. This method was selected due to its high analytical precision, reliability, and suitability for detecting subtle variations in hepatocellular enzyme release. All laboratory procedures adhered to standardized operating protocols to ensure accuracy and reproducibility of results.

Data analysis was conducted using the Spearman Rank correlation test to determine the relationship between pesticide exposure levels and serum SGOT and SGPT concentrations. Spearman Rank was chosen because the exposure variables were ordinal and the biochemical parameters exhibited non-parametric distribution characteristics. This statistical approach allowed for robust evaluation of monotonic associations between exposure indicators and liver enzyme levels without assuming linearity or normal distribution. The results of this analysis were used to determine whether higher exposure levels were associated with elevated SGOT and SGPT concentrations, thereby providing empirical evidence regarding the potential hepatotoxic effects of occupational pesticide exposure among farmers in Sendangrejo Village.

RESULTS

A total of 30 farmers in Sendangrejo Village, Sleman Regency met the inclusion criteria and participated in this study. The findings encompass respondent characteristics, the distribution of serum SGOT and SGPT levels, the distribution of pesticide exposure indicators; including duration of employment, spraying frequency, and PPE compliance and the results of correlation analyses examining the relationship between pesticide exposure and serum SGOT and SGPT levels using the Spearman Rank test.

The distribution of respondent characteristics in Table 1 indicates that the majority of participants were male (66.7%), reflecting the gendered nature of agricultural labor in rural Indonesia, where men typically dominate pesticide-related tasks such as mixing, spraying, and equipment handling. Female respondents accounted for 33.3% of the sample, suggesting that women also participate in agricultural activities, although often in supportive or less hazardous roles.

In terms of age, the largest proportion of respondents fell within the 55–65-year age group (46.7%), followed by those aged 66–75 years (30.0%) and 76–85 years (23.3%). This age distribution highlights the predominance of older adults in agricultural work in Sendangrejo Village, which may have implications for vulnerability to pesticide exposure due to age-related physiological changes, cumulative occupational exposure, and potential comorbidities.

Table 2 shows that most respondents exhibited normal SGOT levels (93.3%), with only 6.7% demonstrating elevated values. Similarly, SGPT levels were predominantly normal (80.0%), although a higher proportion of respondents (20.0%) showed elevated SGPT compared to SGOT. This pattern suggests that while pesticide exposure is present, overt hepatocellular injury may not be widespread among the sampled farmers. The higher proportion of elevated SGPT relative to

Table 1. Distribution of demographic characteristics of farmers

Demographic characteristics	Frequency	Percentage
Sex		
Male	20	66.7
Female	10	33.3
Age group (years)		
55–65	14	46.7
66–75	9	30.0
76–85	7	23.3

Table 2. Distribution of serum SGOT and SGPT levels

Variable	Frequency	Percentage
SGOT		
Normal	28	93.3
Elevated	2	6.7
SGPT		
Normal	24	80.0
Elevated	6	20.0

Table 3. The levels of serum SGOT and SGPT

Variable	Mean±SD (U/L)	Median (U/L)	Mini-max (U/L)
SGOT	20.22 ± 5.42	18.70	12.5–33.3
SGPT	17.24 ± 11.11	13.10	3.4–37.0

Table 4. Distribution of pesticide exposure levels

Variable	Frequency	Percentage
Duration of employment		
<5 years	1	3.3
5–10 years	1	3.3
>10 years	28	93.3
Spraying frequency		
1× per week	17	56.7
≥2× per week	13	43.3
PPE compliance		
Low	14	46.7
Moderate	12	40.0
High	4	13.3

SGOT may indicate mild hepatocellular stress, as SGPT is generally considered more specific to liver injury.

Based on Table 3, laboratory results indicate that serum SGOT levels had a mean of 20.22 ± 5.42 U/L, a median of 18.70 U/L, and a range of 12.5–33.3 U/L. Serum SGPT levels showed a mean of 17.24 ± 11.11 U/L, a median of 13.10 U/L, and a range of 3.4–37.0 U/L. These descriptive statistics demonstrate that although most values fall within normal reference ranges, the wide SGPT range suggests variability in hepatocellular response among farmers, potentially reflecting differences in exposure intensity, metabolic capacity, or protective behaviors.

Table 4 reveals that the vast majority of respondents (93.3%) had worked as farmers for more than 10 years, indicating substantial cumulative exposure to pesticides. Only two respondents had shorter employment durations (<5 years and 5–10 years). Regarding spraying frequency, 56.7% of respondents reported low frequency (1× per week), while 43.3% reported high frequency ($\geq 2\times$ per week), suggesting that nearly half of the farmers engage in relatively frequent pesticide application.

PPE compliance was predominantly low (46.7%), with only 13.3% demonstrating high compliance. This finding underscores persistent gaps in occupational safety practices, which may increase the risk of pesticide absorption through inhalation or dermal contact.

Table 5. The results of Spearman correlation test between pesticide exposure and SGOT levels

Criteria	SGOT normal: f (%)	SGOT elevated: f (%)	Total: f (%)	p-value	Correlation coefficient (r)
Duration of employment				0.708	0.071
<5 years	1 (3.3)	0 (0.0)			
5–10 years	1 (3.3)	0 (0.0)			
>10 years	26 (86.7)	2 (6.7)			
Total	28 (93.3)	2 (6.7)	30 (100)		
Spraying frequency				0.850	0.036
<2× per week	16 (53.3)	1 (3.3)			
$\geq 2\times$ per week	12 (40.0)	1 (3.3)			
Total	28 (93.3)	2 (6.7)	30 (100)		
PPE compliance				0.148	-0.271
Low	12 (40.0)	2 (6.7)			
Moderate	12 (40.0)	0 (0.0)			
High	4 (13.3)	0 (0.0)			
Total	28 (93.3)	2 (6.7)	30 (100)		

Table 6. The results of Spearman correlation test between pesticide exposure and SGPT levels

Criteria	SGPT normal: f (%)	SGPT elevated: f (%)	Total (n, %)	p-value	Correlation coefficient (r)
Duration of employment				0.288	-0.200
<5 years	0 (0.0)	1 (3.3)			
5–10 years	1 (3.3)	0 (0.0)			
>10 years	23 (76.7)	5 (16.7)			
Total	24 (80.0)	6 (20.0)	30 (100)		
Spraying frequency				0.724	0.067
<2× per week	14 (46.7)	3 (10.0)			
$\geq 2\times$ per week	10 (33.3)	3 (10.0)			
Total	24 (80.0)	6 (20.0)	30 (100)		
PPE compliance				0.618	-0.095
Low	11 (36.7)	3 (10.0)			
Moderate	9 (30.0)	3 (10.0)			
High	4 (13.3)	0 (0.0)			
Total	24 (80.0)	6 (20.0)	30 (100)		

The results presented in Tables 5 and Table 6 indicate that none of the pesticide exposure indicators; duration of employment, spraying frequency, or PPE compliance—were significantly associated with serum SGOT or SGPT levels ($p > 0.05$). For SGOT, the correlation coefficients were 0.071 ($p = 0.708$) for duration of employment, 0.036 ($p = 0.850$) for spraying frequency, and -0.271 ($p = 0.148$) for PPE compliance. For SGPT, the correlation coefficients were -0.200 ($p = 0.288$), 0.067 ($p = 0.724$), and -0.095 ($p = 0.618$), respectively.

These findings suggest that although farmers in Sendangrejo Village exhibit varying levels of pesticide exposure, these differences do not translate into statistically significant alterations in SGOT or SGPT levels. Several factors may explain this lack of association:

- 1) Adaptive physiological mechanisms: Long-term farmers may develop adaptive metabolic responses that mitigate acute hepatocellular injury, resulting in stable SGOT and SGPT levels despite chronic exposure.
- 2) Variability in pesticide types and toxicity: Farmers may use pesticides with differing hepatotoxic potentials, leading to heterogeneous exposure effects that dilute statistical associations.
- 3) Intermittent exposure patterns: Although spraying frequency varies, exposure intensity may not be sufficient to cause measurable biochemical changes.
- 4) Potential underreporting of PPE use: Self-reported PPE compliance may not accurately reflect actual protective behavior, introducing misclassification bias.
- 5) Healthy worker effect: Individuals with severe symptoms may have left agricultural work, resulting in a sample biased toward healthier farmers.
- 6) Small sample size: With only 30 respondents, the study may lack statistical power to detect subtle associations.

Overall, the absence of significant correlations does not necessarily imply that pesticide exposure poses no hepatotoxic risk. Rather, it highlights the complexity of exposure dynamics and the need for more detailed assessments, including biomonitoring of pesticide metabolites, longitudinal follow-up, and evaluation of cumulative exposure indices.

DISCUSSION

The characteristics of the respondents demonstrate that the majority of farmers participating in this study were male and predominantly belonged to the 55–65-year age group. The substantial proportion of male respondents reflects the gendered nature of agricultural labor in rural Indonesian communities, where pesticide mixing, spraying, and equipment handling are typically performed by men who assume the role of primary agricultural laborers [9]. This gender pattern is consistent with national agricultural workforce statistics, which indicate that men are more frequently involved in tasks requiring physical strength, prolonged field exposure, and direct handling of agrochemicals. Women, although involved in farming, often participate in planting, harvesting, or post-harvest activities that involve lower direct exposure to pesticides.

The dominance of late-adult and elderly respondents also highlights an important demographic trend in rural agricultural populations. Many farmers continue to engage in pesticide-related activities despite advancing age and long employment durations. This phenomenon may be attributed to socioeconomic factors, including limited alternative employment opportunities, cultural expectations regarding agricultural continuity, and reliance on farming as the primary source of livelihood. From a biological perspective, increasing age is associated with progressive physiological changes, such as reduced hepatic blood flow, diminished enzymatic activity, decreased metabolic capacity, and slower cellular regeneration. These age-related changes may alter the body's ability to metabolize and detoxify xenobiotic compounds, including pesticides, thereby influencing susceptibility to toxic effects [10]. Consequently, age must be considered a potential modifier when interpreting liver function biomarkers, as older individuals may exhibit different biochemical responses compared to younger farmers under similar exposure conditions.

The biochemical examination revealed that most respondents had SGOT and SGPT levels within normal ranges. Specifically, 28 respondents (93.3%) exhibited normal SGOT levels, while only 2 respondents (6.7%) showed elevated values. Similarly, 24 respondents (80.0%) had normal SGPT levels, whereas 6 respondents (20.0%) demonstrated elevated concentrations. Based on the laboratory reference values used in this study, SGOT levels were categorized as normal when <31 U/L and SGPT levels when <34 U/L. These findings suggest that, at the time of measurement, the majority of farmers did not exhibit detectable hepatocellular injury as reflected by these biomarkers, despite having a history of occupational pesticide exposure.

SGOT and SGPT are intracellular enzymes released into the bloodstream when hepatocyte membranes are damaged. SGOT is present not only in the liver but also in skeletal muscle, cardiac muscle, kidneys, and other tissues, whereas SGPT is predominantly localized in hepatocytes. For this reason, SGPT is considered more specific for detecting hepatocellular injury [11]. The release of these enzymes into circulation is influenced by the extent of cellular damage, which in turn depends on the dose of toxic substances absorbed, duration of exposure, frequency of contact, and the physicochemical properties of the active ingredients. Individual variations in absorption, metabolism, detoxification, and elimination also play a crucial role in determining the amount of pesticide that reaches hepatic tissue [12]. Therefore, the absence of elevated SGOT and SGPT levels in most respondents does not necessarily indicate the absence of pesticide exposure or biological effects. Instead, it suggests that the degree of hepatocellular injury at the time of examination may have been minimal or below the detection threshold of these biomarkers.

Interpretation of SGOT levels requires particular caution because SGOT is not liver-specific. Elevated SGOT may result from muscle injury, strenuous physical activity, or cardiac stress. Agricultural work often involves repetitive muscular exertion, prolonged physical labor, and exposure to environmental stressors, all of which may influence SGOT concentrations independently of pesticide exposure [13]. In contrast, SGPT is more specific to hepatocellular injury, making it a more reliable indicator of liver dysfunction. Nonetheless, SGPT levels may also remain within normal ranges despite chronic exposure if hepatocellular injury is mild, intermittent, or compensated by adaptive physiological mechanisms.

Regarding exposure characteristics, most respondents had worked for more than 10 years (93.3%), reported high spraying frequency (56.7%), and demonstrated low PPE compliance (46.7%). These indicators are commonly used to estimate potential pesticide exposure [6,12]. However, they do not fully represent internal exposure levels because the amount of pesticide absorbed by the body depends on numerous factors, including pesticide type and concentration, mixing dosage, spraying technique, wind direction, duration of contact, environmental conditions, and consistency of PPE use during spraying activities [7]. The absence of detailed information on pesticide types and active ingredients further limits the ability to assess toxicity variations across pesticide classes. Consequently, the exposure indicators used in this study reflect potential exposure rather than actual biological dose.

The Spearman Rank correlation analysis revealed no significant relationship between duration of employment, spraying frequency, or PPE compliance and serum SGOT or SGPT levels ($p > 0.05$). The correlation coefficients for SGOT ranged from -0.271 to 0.071 , indicating very weak associations. For SGPT, the correlation coefficients were -0.200 ($p = 0.288$), 0.067 ($p = 0.724$), and -0.095 ($p = 0.618$). These findings demonstrate that none of the exposure indicators analyzed were statistically associated with SGOT or SGPT levels among respondents.

The absence of significant associations does not imply that pesticide exposure has no potential impact on liver function. Instead, it suggests that changes in SGOT and SGPT levels are influenced by factors beyond the exposure characteristics measured in this study. These may include pesticide type and formulation, dosage and concentration used, application technique, exposure route, duration of contact, environmental conditions, and individual variations in absorption, distribution, metabolism, and elimination of toxic substances [15]. Consequently, variations in exposure characteristics do not necessarily correspond to measurable changes in SGOT or SGPT levels, resulting in non-significant statistical relationships.

The findings of this study differ from previous research reporting that duration of employment was associated with liver dysfunction among farmers. However, the same study also found that spraying frequency and PPE use were not significantly associated with liver impairment [13]. Differences in findings across studies highlight that the relationship between pesticide exposure and liver function is influenced by population characteristics and exposure assessment methods. Variations in pesticide types, spraying patterns, environmental conditions, sample size, and liver function measurement techniques may contribute to differing results. Therefore, discrepancies between studies do not necessarily indicate contradictions but rather reflect heterogeneity in exposure conditions across populations.

Conversely, the results of this study align with other research reporting that duration of employment was not significantly associated with cholinesterase activity among pesticide-exposed farmers [16]. This further supports the notion that exposure characteristics may not accurately represent the actual pesticide dose absorbed by individuals or the biological responses elicited. The relationship between pesticide exposure and biological effects is complex and cannot be fully explained by a single or limited set of exposure indicators.

This study has several limitations that should be carefully considered when interpreting the findings. First, the relatively small sample size and the use of purposive sampling restrict the extent to which the results can be generalized to broader farming populations with different demographic, occupational, or environmental characteristics [17-21]. Second, the study did not identify the specific types or active ingredients of pesticides used by respondents, thereby limiting the ability to analyze variations in toxicity, exposure potency, or metabolic pathways across different pesticide classes. Third, the assessment of pesticide exposure relied solely on indirect indicators; duration of employment, spraying frequency, and PPE compliance without incorporating direct biological exposure markers such as cholinesterase activity or pesticide metabolites in blood or urine. This reliance on indirect measures may not accurately reflect the internal dose absorbed by each individual.

Although respondents reported no history of liver disease and were not taking medications known to influence SGOT or SGPT levels, other potentially relevant factors; including nutritional status, physical activity, hydration, comorbid conditions, and inter-individual metabolic variability were not evaluated. These unmeasured variables may act as confounders and influence liver enzyme levels independently of pesticide exposure. Despite the absence of statistically significant associations between pesticide exposure indicators and SGOT or SGPT levels, the findings suggest that the exposure metrics used in this study may not fully capture the biological dose or the complexity of exposure dynamics experienced by farmers.

Future research should employ more comprehensive exposure assessment strategies, including identification of pesticide types and active ingredients, quantification of cumulative exposure doses, and integration of biological exposure biomarkers. Such approaches will allow for a more accurate and nuanced understanding of the relationship between pesticide exposure and liver dysfunction, thereby strengthening the evidence base for occupational health protection among agricultural workers.

CONCLUSION

In this study, it can be concluded that most farmers in Sendangrejo Village, Sleman Regency exhibited serum SGOT and SGPT levels within the normal range. The degree of pesticide exposure; assessed through duration of employment, spraying frequency, and adherence to PPE use showed no significant association with either SGOT or SGPT levels among the farmers. Nevertheless, preventive measures against pesticide exposure remain essential. Strengthening education on proper PPE use, promoting safe spraying practices, and implementing routine health monitoring are critical components of occupational health protection for farmers in this area.

Ethical consideration, competing interest and source of funding

- This study was conducted in accordance with established research ethics principles, ensuring informed participation, confidentiality, and responsible data handling throughout the research process.
- There is no conflict of interest related to this publication.
- Source of funding is authors.

REFERENCES

1. Juanda GR. Pengaruh paparan pestisida pada masa kehamilan terhadap kejadian autisme. *J Health Sci Physiother*. 2020;2(1):81–87.
2. Food and Agriculture Organization of the United Nations. Pesticides use and trade 1990–2022. Rome: Food and Agriculture Organization of the United Nations; 2024.
3. World Health Organization. The impact of pesticides on health: preventing intentional and unintentional deaths from pesticide poisoning. Geneva: World Health Organization; 2017.
4. Karami-Mohajeri S, Ahmadipour A, Rahimi HR, Abdollahi M. Adverse effects of organophosphorus pesticides on the liver: a brief summary of four decades of research. *Arh Hig Rada Toksikol*. 2017;68(4):261–275.
5. Kwo PY, Cohen SM, Lim JK. ACG clinical guideline: evaluation of abnormal liver chemistries. *Am J Gastroenterol*. 2017;112(1):18–35.
6. Himayati H, Susilowati IT. Hubungan masa kerja dan paparan pestisida terhadap kadar cholinesterase petugas penyemprot di perkebunan kelapa sawit. *J Kesehat*. 2023;14(2):235–240.
7. Rudzi SK, Ho YB, Tan ESS, Jalaludin J, Ismail P. Exposure to airborne pesticides and its residue in blood serum of paddy farmers in Malaysia. *Int J Environ Res Public Health*. 2022;19(11):6801.
8. Badan Pusat Statistik Kabupaten Sleman. Kabupaten Sleman dalam angka 2023. Sleman: Badan Pusat Statistik Kabupaten Sleman; 2023.
9. Zahrox IF, Hairrudin, Sofiana KD. Hubungan paparan pestisida dengan kadar SGOT dan SGPT petani di Desa Pakis Kabupaten Jember. *J Kesehat Lingkung Indones*. 2021;20(1):47–52.
10. Hall JE. Guyton and Hall textbook of medical physiology. 14th ed. Philadelphia (PA): Elsevier; 2021.
11. Ardiansyah RM, Setiani O, Suhartono S. Faktor-faktor yang berhubungan dengan kejadian gangguan neurologis pada petani (studi pada petani di Desa Bumen Kecamatan Sumowono Kabupaten Semarang). *J Kesehat Lingkung Indones*. 2024;23(3):257–266.
12. Maliga I, Rafi'ah. Hubungan penggunaan alat pelindung diri (APD) dengan kadar SGOT dan SGPT dalam darah pada petani padi. *VisiKes*. 2021;20(1):174–182.
13. Ariyani L, Siagian LRD, Yusran DI, Yulianti F. Pengaruh indeks hemolisis terhadap peningkatan kadar serum glutamate oxaloacetate transaminase (SGOT). *Husada Mahakam J Kesehat*. 2019;5(1):42–50.
14. Kahar H. Pengaruh hemolisis terhadap kadar serum glutamate pyruvate transaminase (SGPT) sebagai salah satu parameter fungsi hati. *J Muhammadiyah Med Lab Technol*. 2018;1(1):38–46.
15. Ibrahim I, Malisngolar MSJ, Dusra E, Cahyawati S. Faktor yang berhubungan dengan penggunaan pestisida kimia dengan gejala keracunan pada Kelompok Tani Ngudi Buko Desa Waimital. *J Penelit Kesehat Suara Forikes*. 2023;14(Special Issue):313–317.
16. Evitasari D, Martuti S. Hubungan masa kerja terhadap kadar enzim cholinesterase dalam darah petani padi pengguna pestisida di Kelurahan Tirtorahayu Kabupaten Kulon Progo. *J Kesehat Tambusai*. 2024;5(4):13048–13058.
17. Nugroho HSW. Ensuring validity in health research: The critical role of methodological reporting in minimizing bias. *Health Notions*. 2026 Mar 18;10(3):61-3.
18. Vasileiou K, Barnett J, Thorpe S, Young T. Characterising and justifying sample size sufficiency in interview-based studies: systematic analysis of qualitative health research over a 15-year period. *BMC Medical Research Methodology*. 2018 Nov 21;18(1):148.

19. Alvarez G, Núñez-Cortés R, Sola I, Sitja-Rabert M, Fort-Vanmeerhaeghe A, Fernández C, Bonfill X, Urrútia G. Sample size, study length, and inadequate controls were the most common self-acknowledged limitations in manual therapy trials: A methodological review. *Journal of Clinical Epidemiology*. 2021 Feb 1;130:96-106.
20. Qu L, Pei Y. A comprehensive review on discriminant analysis for addressing challenges of class-level limitations, small sample size, and robustness. *Processes*. 2024 Jul 2;12(7):1382.
21. Civelek ME. Comparison of covariance-based and partial least square structural equation modeling methods under non-normal distribution and small sample size limitations. *Eurasian Academy of Sciences Eurasian Econometrics, Statistics & Empirical Economics Journal*. 2018 Jun 28;10:39-50.