The Effect of Pesticide Exposure on Metabolic Syndrome: An Epidemiological Analysis in an Agricultural Population

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ABSTRACT

Metabolic syndrome, characterised by hyperglycaemia, dyslipidaemia, hypertension, and central obesity, is a global health problem, and exposure to pesticides is an important risk factor for agricultural workers. This study aims to analyse the effects of pesticide exposure, socio-demographic factors, and Personal Protective Equipment (PPE) usage behaviour on glucose levels, HDL, and LDL in farmers in Kubu Raya District, West Kalimantan. A cross-sectional study was conducted on 60 farmers selected using stratified random sampling. Data were collected through structured interviews, fasting blood tests, and analysed using the chi-square test with a significance level of 95%. The results showed a high prevalence of high blood glucose (56.7%), low HDL (35.0%), and high LDL (55.0%). Pesticide exposure was significantly associated with glucose levels (p=0.043), with hyperglycaemia being higher in the high-exposure group (70.8%) compared to the low-exposure group (33.3%). Age was also significant for glucose (p = 0.046), with a higher prevalence in the ≥40 years group (65.8%) compared to the 40 years group (40.9%). The use of PPE showed a significant association with all metabolic parameters: higher glucose levels were more common in the non-routine PPE use group (70.6% vs. 38.5%; p = 0.012), lower HDL levels were higher in the non-routine group (44.1% vs. 23.1%; p=0.043), and higher LDL levels were more common in the non-routine group (64.7% vs. 42.3%; p = 0.046). These findings confirm that pesticide exposure, age, and APD usage behaviour contribute to metabolic disorders among farmers. Occupational health interventions emphasizing APD use, routine metabolic screening, and community-based education are needed to reduce the risk of metabolic syndrome in the agricultural population.

INTRODUCTION

In recent decades, the prevalence of metabolic syndrome, characterised by impaired blood glucose levels, abnormal lipids, hypertension, and central obesity, has increased globally and become a major public health concern. Metabolic syndrome not only increases the risk of type 2 diabetes mellitus but also deadly cardiovascular diseases.[1] On the other hand, farmers, as a group that is regularly exposed to pesticides, are very likely to face a high risk of metabolic disorders due to exposure to chemicals that are lipophilic, residual, and persistent in the environment and the human body.[2]

Various epidemiological studies and meta-analyses have confirmed that exposure to pesticides, particularly persistent organochlorines, is significantly associated with an increased risk of metabolic syndrome. A meta-analysis by Lamat et al., showed that exposure to organochlorines increases the risk of metabolic syndrome by nearly 30% (higher for compounds such as hexachlorocyclohexane).[3] The proposed biological mechanisms include the accumulation of lipophilic compounds in adipose tissue, disruption of hormone function and glucose metabolism, and chronic oxidative stress.[4]

Similar results were also found in experimental studies on animals. Exposure during gestation to pesticides such as chlorpyrifos and imidacloprid caused hyperglycaemia, insulin resistance, decreased HDL, and increased LDL in mothers and their offspring, as well as changes in GLUT4 and NF expression.-κB indicating fundamental metabolic damage.[5] These findings highlight the ability of pesticides to disrupt metabolic homeostasis through cellular and epigenetic pathways.

Another systematic review highlighted the link between pesticide exposure and various metabolic diseases associated with insulin resistance, including diabetes, obesity, hypertension, and metabolic syndrome.[6] Such pesticide exposure not only involves acute toxic pathways, but also disrupts metabolic systems through redox stress, inflammation, and insulin signalling disorders. In addition, repeated or cumulative exposure, especially among agricultural workers, exacerbates these conditions.[7]

A cohort epidemiological study in Thailand showed that farmers who used insecticides and fungicides more intensively had higher total cholesterol, LDL, and HDL levels than organic farmers. Although an increase in HDL is usually considered beneficial, disproportionate HDL levels in the context of overall dyslipidaemia reflect metabolic disorders, not protective imbalances.[8] This study shows that the type and frequency of exposure play a central role in metabolic conditions, in addition to sociodemographic factors.

Furthermore, the relationship between pesticide exposure and metabolism is not limited to glucose and lipids, but also extends to the metabolomic realm. A general population study in Europe found that pesticide exposure was associated with a decrease in apolipoprotein A1 and an increase in the apoB/apoA1 ratio, a cardiovascular risk indicator, as well as changes in metabolites reflecting disturbances in the glycolysis pathway and the Krebs cycle.[9] This highlights that pesticide exposure affects the metabolic system more than traditional research has focused on.

In the practical context of agriculture, exposure to pesticides can occur through inhalation, skin contact, or residues in food or the surrounding environment. Studies in Malaysia have documented that rice farmers have high exposure to airborne pesticides, with significant concentrations detected in blood serum and closely related to each other.[10] The minimal use of Personal Protective Equipment (PPE) increases this exposure. In fact, PPE is an important barrier to reduce occupational exposure and toxicity risks.

Although previous studies have demonstrated a link between pesticide exposure and metabolic disorders such as elevated blood glucose levels, dyslipidaemia, and insulin resistance, most of these studies were conducted outside the Indonesian context and often did not consider socio-demographic factors Or Personal Protective Equipment (PPE) use simultaneously. Furthermore, studies specifically evaluating metabolic syndrome parameters such as blood glucose levels, HDL, and LDL in relation to pesticide exposure among Indonesian farmers remain extremely limited. On the other hand, the role of PPE use as a protective factor against the metabolic effects of pesticides has not been thoroughly explored in population epidemiological approaches. The lack of comprehensive data on how work characteristics, age, gender, and duration of work exposure can influence the metabolic profiles of pesticide-exposed farmers

highlights a significant gap in the current scientific literature.

Based on the background and research gaps, this study aims to comprehensively examine the effects of pesticide exposure on glucose, HDL, and LDL levels among farmers in Kubu Raya District, West Kalimantan, and analyse how sociodemographic variables and PPE usage behaviour contribute to these metabolic conditions. This research is expected to provide a more comprehensive understanding of the metabolic risks associated with pesticide exposure and serve as a foundation for developing more effective and contextually appropriate occupational health intervention strategies for farming communities in intensive agricultural areas.

MATERIAL AND METHOD

Research Design

This study used a quantitative analytical design with a cross-sectional approach to evaluate the relationship between pesticide exposure, socio-demographic characteristics, and the use of personal protective equipment (PPE) on glucose, HDL, and LDL levels as indicators of metabolic syndrome in farmers.

Research Location and Time

"The study was carried out in Kubu Raya Regency, West Kalimantan Province, Indonesia, which is recognised as one of the largest agricultural production areas in the province, particularly for rice and vegetable farming. This region was purposively selected because farmers in Kubu Raya rely heavily on intensive pesticide use due to the tropical climate that favours high pest infestation. In addition, local agricultural extension services have reported increasing health complaints among farmers related to pesticide exposure.

Data collection was conducted over a three-month period, from May to July 2023, which coincided with the main planting and harvesting season. This period was chosen because farmers were actively engaged in pesticide application during land preparation and crop maintenance, thus providing more representative exposure conditions for the study. The timing also allowed better coordination with local health facilities and farmer groups for blood sampling and interviews."

Population and Sample

The population in this study consisted of all active farmers registered in farmer groups in five subdistricts in Kubu Raya District. Inclusion criteria included farmers who had been working for at least two years, were aged 20–60 years, and were willing to participate in the entire examination process. Respondents with a history of chronic diseases such as type 1 diabetes mellitus or familial hyperlipidaemia were excluded from the analysis.

Sampling was conducted using stratified random sampling with stratification based on sub-district areas. The sample size was calculated using the population proportion formula with $\alpha = 0.05$, $P = 0.5$ (prevalence of metabolic syndrome among farmers from local literature), and $d = 0.1$ (precision). The calculation resulted in a minimum requirement of 60 respondents. The sample size obtained was in accordance with the minimum calculation results. This number was limited by the availability of funds, research time, and laboratory limitations for biochemical testing. Efforts to increase the sample size were constrained because only some farmers met the inclusion criteria and were willing to follow the entire procedure.

Research Variables

In this study, the variables examined consist of dependent and independent variables that are interrelated in the context of the effect of pesticide exposure on metabolic parameters in farmers. The dependent variables in this study include fasting blood glucose levels, HDL cholesterol levels, and LDL cholesterol levels. These three parameters were selected because they are key indicators in the diagnosis of metabolic syndrome and reflect glucose and lipid metabolism disorders that can occur due to exposure to toxic substances such as pesticides. Glucose levels are measured in milligrams per decilitre (mg/dL) and are categorised as high if the measurement results show a value of ≥100 mg/dL according to the criteria of the American Diabetes Association. HDL levels are classified by gender: low if 40 mg/dL in men and 50 mg/dL in women, according to the criteria of the National Cholesterol Education Programme Adult Treatment Panel III (NCEP ATP III). LDL levels are considered high if ≥130 mg/dL, which is the general threshold for atherosclerotic risk.

The independent variables in this study included pesticide exposure, socio-demographic characteristics, and personal protective equipment (PPE) usage behaviour. Pesticide exposure was classified into three levels: low, moderate, and high, based on a combination of pesticide usage duration (years), application frequency per week, and daily exposure duration. These categories were determined with reference to the WHO (2019) guidelines on Exposure to Highly Hazardous Pesticides.[11] dan Guidelines for Human Exposure Assessment from EPA (2024)[12], modified according to the local context. The sociodemographic characteristics studied included age, gender, length of time working as a farmer, and daily working hours; age was grouped into 40 years and ≥40 years because metabolic risk increases with age.[13] PPE usage behaviour was assessed based on the consistency of farmers in using protective equipment such as masks, gloves, and protective clothing whenever interacting with pesticides. Respondents who used PPE completely and consistently were categorised as regular users, while those who were inconsistent were categorised as non-regular users, as per the method used in the studies by Sapbamrer et al. and Lari et al.[14,15]

Data Collection Instruments and Procedures

Primary data were collected through structured interviews using questionnaires that had been tested for validity and reliability. Additional data such as age, length of employment, and medical history were obtained from identity cards and consultations with local farmer cadres.

All biological data were measured by trained health workers in a clinical laboratory facility using standard enzymatic methods. Blood samples were collected in the morning after respondents had fasted for at least eight hours to ensure the accuracy of blood glucose and lipid levels. All measurement procedures were performed using a semi-automatic spectrophotometer and followed the protocols of the Clinical and Laboratory Standards Institute (CLSI) to maintain the validity of the results. The quantitative data obtained were subsequently analysed statistically to assess the relationships between variables, serving as the basis for drawing conclusions regarding the effects of pesticide exposure and related factors on the metabolic profiles of farmers in the study area.

Exposure Assessment

The level of pesticide exposure is determined by developing an Exposure Index based on the principles of exposure assessment in WHO guidelines and occupational exposure assessment frameworks. Operationally, the Exposure Index is formed from three components: (1) length of time working as a farmer (duration, years), (2) frequency of pesticide application per week, and (3) hours of exposure per day when applying pesticides. Each component is scored 0–2 as follows: Duration: 5 years = 0; 5–14 years = 1; ≥15 years = 2. Frequency/week: 2x = 0; 2–4x = 1; >4x = 2. Hours/day: 4 hours = 0; 4–7 hours = 1; ≥8 hours = 2. Scores are added up (range 0–6). Exposure categories are defined as Low = 0–2; Moderate = 3–4; High = 5–6. This adaptation was made to suit local work patterns and based on consultation with local agricultural extension workers and occupational exposure literature.[16]

Data Analysis

Data were analysed using SPSS statistical software version 26. Univariate analysis was performed to describe the frequency distribution of variables. Bivariate analysis was performed to evaluate the relationship between independent variables and each dependent variable using the chi-square test. The significance of the relationship was determined at a 95% confidence level.

Research Ethics

This study has obtained ethical approval from the Health Research Ethics Committee of the Surabaya Ministry of Health Polytechnic (No. 121/UN22.9.3/KEPK/2025). All respondents were provided with an explanation of the purpose and procedures of the study and signed an informed consent form before participating in the study. Personal data is guaranteed to remain confidential and will only be used for scientific purposes.

RESULTS

Table 1 shows an overview of the study respondent's. Most farmers were aged ≥40 years (63.3%), with a slightly higher proportion of women (51.7%) than men (48.3%). The most common length of employment is 10–19 years

(45.0%), followed by ≥20 years (30.0%). The majority of respondents work ≥8 hours per day (65.0%), indicating high exposure to work. In terms of behaviour, only 43.3% of respondents use PPE regularly, while 56.7% do not. Pesticide exposure levels were evenly distributed between moderate (40.0%) and high (40.0%), while low exposure was only 20.0%. This distribution indicates that respondents tend to have a high risk of exposure due to age, long tenure, prolonged working hours, and low PPE usage.

Table 2 shows the results of laboratory tests indicating that 56.7% of respondents had high blood glucose levels (≥100 mg/dL), while 43.3% were normal. Regarding lipid profiles, 35.0% had low HDL, while 55.0% had high LDL levels. These data indicate that metabolic disorders are quite prevalent among the farming population, with more than half of the respondent's experiencing hyperglycaemia or atherogenic dyslipidaemia (high LDL).

The results of the analysis showed a significant relationship between pesticide exposure levels and blood glucose levels in farmers (p=0.043). As shown in Table 3, the proportion of hyperglycaemia cases increased with pesticide exposure levels. Of the total 34 respondents with high glucose levels, most were from the high exposure group (50.0%), followed by the moderate exposure group (38.2%), and only 11.8% were from the low exposure group. This shows a tendency that the higher the pesticide exposure, the greater the likelihood of farmers experiencing glucose metabolism disorders.

Table 1. Distribution of Respondent Characteristics

Variable	n = 60	%
Age		
< 40 years old	22	36.7
≥40 years old	38	63.3
Gender		
Male	29	48.3
Female	31	51.7
Length of Service		
< 10 years	15	25.0
10-19 years	27	45.0
≥20 years	18	30.0
Working Hours		
< 8 hours per day	21	35.0
≥8 hours per day	39	65.0
Use of PPE		
Consistent	26	43.3
Not consistent	34	56.7
Pesticide Exposure		
Low	12	20.0
Currently	24	40.0
Height	24	40.0

Source: Primary Data, 2025

Table 2. Distribution of Dependent Variables

Parameter	n = 60	%
Glucose Level		
Normal (<100 mg/dL)	22	43.3
High (≥100 mg/dL)	34	56.7
HDL		
Normal (≥40 mg/dL)	39	65.0
Low (less than 40 mg/dL)	21	35.0
LDL		
Normal (<130 mg/dL)	27	45.0
High (≥130 mg/dL)	33	55.0

Source: Primary Data, 2025

Meanwhile, the relationship between pesticide exposure and HDL and LDL levels did not reach statistical significance (p=0.217 and p=0.386). However, the data distribution still showed a consistent pattern. Of the 21 respondents with low HDL levels, most came from the moderate exposure group (42.9%) and the high exposure group (42.9%), while only 14.3% came from the low exposure group. Similarly, of the 33 respondents with high LDL levels, 45.4% were from the high exposure group, 39.4% from the moderate exposure group, and 15.2% from the low exposure group.

Table 4 shows that age is significantly associated with glucose levels (p=0.046). with farmers aged ≥40 years having a high glucose prevalence of 65.8% compared to those aged 40 years (40.9%). For HDL and LDL levels. although not significant. the prevalence pattern was worse in the older age group. The gender variable did not show significant differences in all metabolic parameters. Work experience was also not significant but there was a trend indicating that those with ≥20 years of work experience had higher prevalence of low HDL (44.4%) and high LDL (61.1%) compared to those with 10 years of work experience (26.7% and 46.7%). This suggests that age is a more influential factor on metabolism than work experience or gender.

The results of the analysis in Table 5 show a significant relationship between the use of PPE and all metabolic parameters. Farmers who did not routinely use PPE had a high glucose prevalence of 70.6% compared to 38.5% in the routine group (p=0.012). Similarly. the prevalence of low HDL was higher in the non-routine group (44.1% vs 23.1%; p=0.043). and high LDL was more common in the non-routine group (64.7% vs 42.3%; p=0.046). These findings indicate that protective behaviour through consistent PPE use plays a crucial role in reducing the risk of metabolic disorders among farmers.

DISCUSSION

Long-term exposure to pesticides in agricultural work environments has long been associated with various metabolic disorders. Including changes in blood glucose levels. Decreased HDL cholesterol. and increased LDL cholesterol. The results of this study reinforce this evidence by showing that workers exposed to high levels of pesticides have a higher preva-lence of disorders in all three parameters.

High blood glucose levels in pesticide exposed farmers reflect glucose metabolism disorders that can occur due to the toxic effects of chemicals on the endocrine system particularly the pancreas. Several pesticide compounds are known to have endocrine disruptor activity. which can interfere with pancreatic beta cell function and inhibit normal insulin secretion. Research by Suhartoyo et al. indicates that exposure to organophosphates can lead to increased insulin resistance and significant impaired glucose tolerance among agricultural workers.[17] This occurs because pesticides affect insulin signalling pathways and increase oxidative stress, which damages pancreatic function.[17]

In addition. a study by Masyithah et al. showed that increased blood glucose levels are often found in individuals with chronic exposure to pesticides. particularly carbamate and organochlorine types.[18] The proposed mechanism is through changes in genetic expression in metabolic tissues and increased systemic inflammatory response that inhibits insulin effectiveness. Therefore, the findings in this study are consistent with previous literature that pesticide exposure is a real risk factor for blood glucose homeostasis disorders.[18]

Table 3. Relationship Between Pesticide Exposure and Glucose, HDL, and LDL Levels

Pesticide Exposure	n	High Glucose n (%)	Low HDL n (%)	High LDL n (%)
Low	12	4 (11.8)	3 (14.3)	5 (15.2)
Moderate	24	13 (38.2)	9 (42.9)	13 (39.4)
High	24	17 (50.0)	9 (42.9)	15 (45.4)
Total	**60**	**34 (100)**	**21 (100)**	**33 (100)**
p-value		**0.043***	**0.217**	**0.386**

Source: Primary Data, 2025

Table 4. Social Demographic Factors and Glucose, HDL, and LDL Levels

Variable	n	Glucose Normal n (%)	Glucose High n (%)	p-value	HDL Normal n (%)	HDL Low n (%)	p-value	LDL Normal n (%)	LDL High n (%)	p-value
Age										
Age <40	22	13 (59.1)	9 (40.9)	0.046*	16 (72.7)	6 (27.3)	0.091	13 (59.1)	9 (40.9)	0.068
Age ≥40	38	13 (34.2)	25 (65.8)		23 (60.5)	15 (39.5)		14 (36.8)	24 (63.2)	
Gender										
Male	29	12 (41.4)	17 (58.6)	0.883	18 (62.1)	11 (37.9)	0.920	14 (48.3)	15 (51.7)	0.726
Female	31	14 (45.2)	17 (54.8)		21 (67.7)	10 (32.3)		13 (41.9)	18 (58.1)	
Length of Service										
Service <10 y	15	8 (53.3)	7 (46.7)	0.228	11 (73.3)	4 (26.7)	0.117	8 (53.3)	7 (46.7)	0.207
Service ≥20 y	18	6 (33.3)	12 (66.7)		10 (55.6)	8 (44.4)		7 (38.9)	11 (61.1)	

Source: Primary Data, 2025
Note: Glucose (G), HDL (H), LDL (L)

Table 5. Relationship Between PPE Use and Glucose, HDL, and LDL Levels

Use of PPE	n	Glucose Normal n (%)	Glucose High n (%)	p-value	HDL Normal n (%)	HDL Low n (%)	p-value	LDL Normal n (%)	LDL High n (%)	p-value
Consistent	26	16 (61.5)	10 (38.5)		20 (76.9)	6 (23.1)		15 (57.7)	11 (42.3)	
Not Consistent	34	10 (29.4)	24 (70.6)	0.012*	19 (55.9)	15 (44.1)	0.043*	12 (35.3)	22 (64.7)	0.046*

Source: Primary Data, 2025

A decrease in HDL levels is also an important indicator of metabolic syndrome and is often associated with exposure to pesticides and other occupational factors. HDL is known as a protective lipoprotein because of its function in transporting cholesterol from peripheral tissues to the liver for excretion. In the context of exposure to xenobiotics such as pesticides, toxic compounds can trigger a chronic inflammatory response that disrupts lipid metabolism, including inhibiting the activity of the LCAT enzyme, which is essential for HDL maturation. A review by Feingold & Grunfeld explains that inflammation can suppress LCAT activity, thereby disrupting cholesterol esterification in HDL and reducing plasma HDL.[19] Khovidhunkit et al. also mention that in the inflammatory response, LCAT and CETP activity decreases, disrupting the reverse cholesterol transport pathway and accelerating the loss of HDL.[20] Animal studies by Petropoulou et al. support that LCAT deficiency increases susceptibility to inflammatory responses, sup-

porting a functional link between LCAT, HDL, and inflammation.[21] Reviews of HDL metabolism confirm that decreased LCAT activity is directly associated with decreased HDL levels and that chronic inflammation can alter the composition of HDL, reducing its function in antioxidant and cholesterol transport.[22]

Another study by Badmus et al also reported that agricultural workers exposed to pesticides for more than five years had significantly lower HDL levels than the control group.[23] This study emphasises the importance of cumulative effects and duration of exposure on the risk of dyslipidaemia.[23] These results are consistent with the findings in this study which indicate that irregular use of personal protective equipment (PPE) tends to be associated with lower HDL levels. This suggests that preventing direct exposure may help maintain lipid balance in the blood.

In addition to glucose and HDL levels. elevated LDL levels are another critical component of metabolic syndrome that indicates car-

diometabolic risk. LDL is known as "bad" cholesterol which, when accumulated in excess. can cause atherosclerosis and coronary heart disease.[24] Elevated LDL levels in the context of agricultural work may be attributed to lipid metabolism changes caused by oxidative stress and inflammation induced by pesticide exposure.[25] Sasso et al., in their study of farmers in intensive agricultural areas found that LDL levels increased with length of service and number of weekly working hours. especially among workers who did not consistently use PPE.[24]

This study also shows that sociodemographic factors such as age and length of employment affect glucose and LDL levels. As age increases, insulin sensitivity decreases, antioxidant enzyme activity weakens, and the body's ability to neutralise toxic exposure decreases, thereby increasing the risk of metabolic disorders. Huang et al. (2023) reported that individuals over the age of 40 have lower insulin sensitivity compared to younger age groups.[26] Meanwhile, Guo et al. (2022) explain that increased MMP14 activity in the ageing process can damage insulin receptors and disrupt glucose regulation.[27] This condition is exacerbated by pesticide exposure, as reported by Zhu et al. (2025) that elderly agricultural workers are more susceptible to glucose regulation disorders due to multiple pesticide exposure.[28] The study by Kongtip et al. (2020) also found increased glucose and LDL levels in farmers with long-term pesticide exposure.[29] This is in line with the review by Arab et al. (2023), which confirms that pesticides are an important environmental factor causing insulin resistance and lipid metabolism dysfunction.[6]

Longer working periods also showed a consistent relationship with increased glucose and LDL levels. This suggests that cumulative exposure to pesticides over many years plays a significant role in causing metabolic disorders. This phenomenon is known as the bioaccumulation effect whereby lipophilic pesticides can be stored in fatty tissue and the liver over long periods of time. thereby affecting metabolism systemically.[30] A study by Kim et al. showed that long-term exposure to pesticides is associated with increased oxidative stress biomarkers and decreased lipid regulation. leading to dyslipidaemia.[11]

Another important factor observed in this study was the use of personal protective equipment (PPE) while working on agricultural land.[31] PPE is the first line of defence in preventing direct contact between workers and pesticides. Unfortunately, in practice, many farmers in rural Indonesia do not use PPE regularly, either due to limited access or lack of knowledge. The findings of this study show that inconsistent use of PPE is associated with poorer glucose. HDL and LDL levels compared to workers who use PPE regularly.[32]

Research by Aksüt and Eren reinforces this by stating that proper use of PPE can reduce metabolic damage biomarkers by up to 35% compared to workers who do not use it.[33] In addition, the use of PPE also plays an important role in reducing the accumulation of toxic compounds in the skin and respiratory tract, two main routes of pesticide absorption. The implications of these findings are clear: simple interventions such as training and distribution of PPE can have a significant impact on preventing metabolic disorders in farmers.[34]

Overall, the findings of this study emphasise the importance of a multi-faceted approach in addressing metabolic syndrome risk among agricultural workers, not only chemical exposure factors but also individual characteristics (such as age), occupational factors (length of service and daily working hours), and preventive behaviours (use of PPE) should be considered as interrelated variables.[35]

This study also has important implications for occupational health policies in the agricultural sector. Routine health screening programmes are needed that focus not only on general physical parameters but also include metabolic tests such as glucose levels and lipid profiles.[36] Community-based interventions that emphasise the importance of using PPE, education about the dangers of pesticides, and regulation of working hours and job rotation are also very important in prevention efforts. In the Indonesian context, integrating these programmes into the activities of community health centres and agricultural extension workers could be a realistic and sustainable strategy.[37]

However, this study has several limitations including a cross-sectional design that does not

allow for the investigation of causal relationships between pesticide exposure and changes in metabolic levels. Additionally, pesticide exposure data and PPE usage were obtained through subjective interviews, which are prone to recall bias. This study also did not directly measure specific biomarkers of pesticide exposure such as, cholinesterase levels, nor did it identify pesticide types in detail, which could affect the accuracy of the interpretation of results regarding metabolic risk. A study by Kim et al., showed that organochlorines such as DDT have a much higher potential for causing lipid disorders than plant-based pesticides.[38] This study also has other limitations related to the relatively small sample size compared to the ideal calculation for 10% precision, which may limit the ability of this study to detect weak associations.

For further research, it is recommended to use a longitudinal or cohort approach with serial measurements of metabolic levels and pesticide biomarkers to understand the causal relationship more strongly. The addition of quantitative data on pesticide types, application frequency, and laboratory measurements of pesticide exposure can enrich the strength of the analysis.

CONCLUSION AND RECOMMENDATION

The results of this study indicate that pesticide exposure has a significant relationship with changes in blood glucose, HDL, and LDL levels in agricultural workers. Workers with high levels of pesticide exposure tend to have higher glucose and LDL levels and lower HDL levels compared to those exposed at low to moderate levels. Additionally, sociodemographic factors such as age and years of work experience amplify the effects of exposure, while regular use of Personal Protective Equipment (PPE) has been shown to potentially protect against metabolic disorders. These findings confirm that metabolic disorders among farmers are not only influenced by exposure to toxic chemicals but are also significantly influenced by preventive behaviours and individual characteristics.

Therefore, comprehensive promotional and preventive efforts are needed, including strengthening education on the use of PPE. routine monitoring of metabolic biomarker levels, and more adaptive occupational health policies tailored to agricultural environmental risks. Further re-search with longitudinal designs and toxicolog-ical biomarker approaches is recommended to strengthen the understanding of the causal rela-tionship between pesticide exposure and metabolic disorders in greater depth.

AUTHOR CONTRIBUTIONS

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest in this study.

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