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Occupational Pesticide Exposure and Reduced eGFR in Farmers

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Pesticides are frequently utilized in modern farming to sustain crop productivity. However, improper use may pose occupational health risks, including chronic renal toxicity. In Indonesia, evidence regarding long-term kidney effects among farmers remains limited. This study aimed to determine the prevalence of reduced estimated glomerular filtration rate (eGFR) and examine its association with pesticide exposure among horticultural farmers in Wanasari District, Brebes Regency. A cross-sectional analytical study was conducted among 367 farmers aged 18-63 years. Data on pesticide use, personal protective equipment (PPE), smoking habits, health complaints, and hypertension were collected through interviews. Serum creatinine levels were measured enzymatically and used to estimate eGFR. Multivariate logistic regression analysis was applied to identify factors associated with reduced renal function. Several variables showed a significant association with decreased renal function, namely smoking status (OR = 2.972; 95% CI: 1.299-6.001; $p = 0.009$), pesticide dosage (OR = 4.555; 95% CI: 2.415-8.291; $p < 0.001$), PPE use (OR = 0.383; 95% CI: 0.199-0.737; $p = 0.004$), health complaints (OR = 2.972; 95% CI: 1.567-5.636; $p = 0.001$), hypertension (OR = 2.367; 95% CI: 1.278-4.382; $p = 0.006$), working period (OR = 15.057; 95% CI: 3.510-64.591; $p < 0.001$). Working period was the dominant factor associated with decreased kidney function in farmers. This indicates, the importance of chronic exposure duration in increasing the risk of pesticide-induced nephrotoxicity. Prevention efforts should focus on controlling exposure duration, improving adherence to PPE use, providing education on pesticide use, and regularly monitoring kidney function.

Keywords: Agricultural Workers, eGFR, Pesticide Exposure, Occupational Health, Renal Function

INTRODUCTION

Pesticides are extensively employed in agricultural systems to control pests and maintain crop productivity. Nevertheless, inappropriate handling, excessive application, and inadequate safety measures may generate substantial environmental contamination and pose significant health risks to exposed populations. Both acute intoxication and long-term toxic effects have been documented among agricultural workers and surrounding communities. In recent years, growing epidemiological evidence has highlighted a rise in (CKDu), or Chronic Kidney Disease of unknown aetiology (Bagchi et al., 2025). Marked clusters have been reported in several countries within the Mesoamerican region, such as Nicaragua, Costa Rica, and El Salvador, where the condition has been referred to as Mesoamerican MenN, or Nephropathy (Arroyo et al., 2023; Vald et al., 2023). This emerging nephropathy has resulted in substantial public health consequences, including thousands of premature deaths, and has attracted considerable international scientific

attention (Kovesdy, 2022). In contrast to traditional chronic kidney disease (CKD), CKDu is not strongly associated with established risk factors such as hypertension, diabetes mellitus, or advanced age (Gomes et al., 2024). The absence of traditional etiological determinants has complicated both clinical management and prevention strategies. Consequently, the precise risk factors, underlying pathophysiological pathways, and optimal diagnostic and therapeutic approaches remain incompletely understood and continue to be actively investigated (Park & Park, 2025). Several mechanistic hypotheses have been proposed. One leading explanation implicates recurrent episodes of subclinical acute kidney injury triggered by repeated dehydration and sustained fluid loss during prolonged work under extreme heat conditions (Chicas et al., 2023). In conjunction with this thermal stress theory, environmental and occupational exposures including pesticides, heavy metals, and other nephrotoxic chemicals are increasingly recognized as

potential contributors to chronic renal injury among agricultural workers (Chapman et al., 2024).

Agricultural workers engaged in prolonged, high-intensity labor under extreme heat conditions, particularly in lowland environments, have been identified as the population most vulnerable to CKD (Chapman et al., 2024). Concurrent exposure to occupational heat stress, persistent dehydration, and direct pesticide contact may collectively contribute to renal impairment (Chapman et al., 2024). Limitations in occupational health surveillance within Indonesia's agricultural sector remain substantial, potentially leading to considerable underrecognition and underdiagnosis of CKDu. This gap underscores the pressing need for population-based investigations focusing on high-risk worker populations.

As an agrarian nation characterized by intensive pesticide utilization, Indonesia faces comparable occupational and environmental health risks, including potential renal impairment among agricultural workers. Despite this concern, epidemiological evidence regarding CKDu within Indonesian farming populations remains scarce. Brebes Regency is recognized as one of the country's principal shallot-producing regions and is distinguished by sustained, high-frequency pesticide application. Within this regency, Wanasari District represents a major cultivation area where pesticide exposure occurs continuously throughout the entire agricultural cycle, from planting to harvest.

Preliminary screening conducted among 40 pesticide sprayers indicated that 35% exhibited reduced kidney function, suggesting a possible emerging occupational health issue within this workforce. However, no prior study has quantified the prevalence of CKDu or assessed renal function decline based on estimated eGFR among shallot sprayers in Wanasari District.

The lack of localized epidemiological data on renal dysfunction in high-risk agricultural populations constitutes a critical knowledge gap, particularly in elucidating the contribution of environmental and occupational exposures to CKDu in Indonesia. Accordingly, this research aims to determine the frequency of decreased renal function, as measured by eGFR, among shallot pesticide sprayers. The findings are expected to generate an evidence base to inform environmental health policy development and strengthen preventive strategies in agricultural communities.

METHODS

This research was an analytical observational study using a cross-sectional design. All variables were measured simultaneously while the data were being collected. The research was conducted in Wanasari District, Brebes Regency, which consists 20 villages. The area was deliberately selected due to the intensive application of pesticides in shallot cultivation. Wanasari District covers approximately 144.92 ha and is geographically situated between 6°49'–6°53' South Latitude and 108°53'–109°11' East Longitude.

The study was implemented in collaboration with the Brebes Regency Department of Food Security and Agriculture, the Brebes Regency Office of Health, and the CITO Laboratory located in Tegal City. Data collection and laboratory analyses were carried out from April 2025 to January 2026. The Health Research Ethics Committee at Universitas Diponegoro's Faculty of Public Health granted ethical permission (No: 157/EA/KEPK-FKM/2025). Before enrollment, every participants received comprehensive information on the goals, methods, and possible advantages of the study. Each participant provided written informed consent before participation. Furthermore, participants received individualized feedback based on the results of their clinical examinations.

The study included 367 respondents aged between 18 and 63 years. The sample size was determined based on findings from a preliminary assessment of renal function conducted within the same target population. Invitations to participate were distributed through farmer associations across all areas of Wanasari District. Individuals who expressed interest and were registered as potential participants received detailed information regarding the study objectives, procedures, and potential benefits, along with a scheduled appointment for data collection. Participants were selected using purposive sampling, contingent upon their voluntary consent to participate. Only individuals who were generally in good health at the time of recruitment were included in the study.

All interviews and clinical assessments were conducted at the sub-district administrative offices within each village in Wanasari District, Brebes Regency, under the supervision of local healthcare personnel and representatives from the Brebes Regency Department of Agriculture and Food Security. Information on sociodemographic characteristics, occupational history, and medical conditions was obtained through structured questionnaire-based interviews. Anthropometric evaluations, including measurements of blood pressure, height, and body weight, were performed by trained health professionals.

Approximately 3 mL of venous blood was collected by trained laboratory personnel using vacuum tubes containing a serum-separating gel clot activator. Following collection, specimens were maintained at 2-8°C and transported on the same day to the CITO Laboratory in Tegal for biochemical analysis.

Serum was isolated through centrifugation at standard laboratory-recommended speeds. Serum creatinine (SCr) concentrations were measured using the Indiko Plus Analyzer via an enzymatic assay calibrated according to standards established by the Indonesian Association of Clinical Pathology and Laboratory Medicine, ensuring analytical accuracy and traceability. eGFR was subsequently calculated using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation, incorporating serum creatinine levels, age, and sex. Classification of renal function decline was based on the Kidney Disease: Improving Global Outcomes (KDIGO)

guidelines, with eGFR values of 60–89 mL/min/1.73 m² considered indicative of early-stage renal impairment (Iatrudi et al., 2025; Navaneethan et al., 2025). However, in this study, a cut-off of less than 90 mL/min/1.73 m² was utilized as an indicator of early-stage decline for public health epidemiological purposes. The laboratory facilities adhered to both internal and external quality assurance protocols. All analytical procedures were performed in accordance with established clinical laboratory standard operating procedures, including routine instrument calibration and the application of quality control materials to ensure measurement validity and reliability. After receiving comprehensive information regarding the procedure and its potential benefits, all respondents signed an agreement. All data were handled with strict confidentiality, and analyses were conducted using anonymised datasets. No personal identifiers were collected or reported, ensuring participant privacy.

Baseline characteristics of the participants were summarized using descriptive statistics, including measures such as mean, median, 95% confidence interval

(CI), standard deviation, and the interquartile range. For continuous variables that did not follow a normal distribution, the Mann-Whitney test was applied, while categorical variables were analyzed using the Chi-square or Fisher's Exact test as appropriate. Bivariate analysis was conducted to explore the association between independent variables and renal status. Subsequently, multivariate logistic regression was used to find variables that were independently linked to reduced kidney function. The results of the analysis were presented in the form of an odds ratio [Exp(B)] with 95% CI. A p-value of less than 0.05 was deemed statistically significant.

RESULT AND DISCUSSION

This study analyzed the characteristics of respondents aged 18–63 years. Based on the estimated glomerular filtration rate (eGFR) measurement, 72 out of 367 participants (19.6%) showed decreased renal function (eGFR < 90 mL/min/1.73 m²), while 295 participants (80.4%) had normal renal function (eGFR ≥ 90 mL/min/1.73 m²).

Table 1
Distribution of Respondent Characteristics by eGFR (<90 vs ≥ 90 mL/min/1.73 m²)

Characteristic	Overall (%) (n=367)	eGFR, mL/min/1.73 m ²		p-value
		< 90 (n=72) (%)	≥ 90 (n=295) (%)	
Sociodemographics				
Age (Year), Median (IQR)	44 (39.00-50.00)	49 (44.00-50.00)	43 (38.00-49.00)	< 0.001 ^a
Education				
University	12 (3.2)	4 (5.6)	8 (2.7)	0.271 ^b
High School	84 (22.9)	21 (29.2)	63 (21.4)	
Junior High School	77 (21.0)	14 (19.4)	63 (21.4)	
Elementary School	194 (52.9)	33 (45.8)	161 (54.6)	
Smoking Status				
Yes	253 (68.9)	61 (84.7)	192 (65.1)	0.001 ^b
No	114 (31.1)	11 (15.3)	103 (34.9)	
Dosage				
Yes	107 (29.2)	36 (50.0)	71 (24.1)	< 0.001 ^b
No	260 (70.8)	36 (50.0)	224 (75.9)	
Use of PPE				
Yes	168 (45.8)	21 (29.2)	147 (49.8)	0.002 ^b
No	199 (54.2)	51 (70.8)	148 (50.2)	
Complaint				
Yes	177 (48.2)	48 (66.7)	129 (43.7)	< 0.001 ^b
No	190 (51.8)	24 (33.3)	166 (56.3)	
BMI				
Underweight (< 18.5)	268 (73.0)	70 (97.2)	198 (67.1)	< 0.001 ^b
Normal (18.5-24.9)	99 (27.0)	2 (2.8)	97 (32.9)	
Overweight (25.0-29.9)				
Obesity (≥ 30.0)				
Hypertension				
Yes	48 (13.1)	5 (6.9)	43 (14.6)	0.279 ^b
No	225 (61.3)	50 (69.4)	175 (59.3)	
	74 (20.2)	14 (19.4)	60 (20.3)	
	20 (5.4)	3 (4.2)	17 (5.8)	
Creatinine (mg/dL)				
High (> 1.20)	253 (68.9)	61 (84.7)	192 (65.1)	0.001 ^b
Normal (≤ 1.20)	114 (31.1)	11 (15.3)	103 (34.9)	

eGFR: estimated Glomerular Filtration Rate; IQR: Interquartile Range; a: Mann-Whitney; b: Chi-square; c: Fisher Exact; PPE: Personal Protective Equipment; BMI: Body Mass Index

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The median age of the participants was 44 years (IQR 39.00–50.00), as shown in the sociodemographic data in Table 1. Individuals with reduced eGFR were significantly older than those with normal renal function (49 vs 43 years; $p < 0.001$). This observation is in line with results from a large population-based study in Germany, which demonstrated a gradual decline in eGFR with increasing age, following a linear pattern from early adulthood to older age (Herold et al., 2024). Furthermore, a recent systematic review reported that age-related decline in kidney function is a common physiological process in the older population (Guppy et al., 2024). These results imply that age may serve as an important factor associated with renal function status in the general population.

Educational attainment was not significantly associated with eGFR category ($p = 0.271$), with a relatively similar distribution observed across both groups. Previous studies have suggested that the relationship between education and CKD risk is often mediated by lifestyle behavioral factors (Hossain et al., 2026; López-Gálvez et al., 2021). Evidence from younger populations also indicated that the association between education and CKD may vary depending on socioeconomic conditions (Winitzki et al., 2022). Therefore, education may be better interpreted as a proxy for socioeconomic status influencing indirect risk pathways, rather than as an independent determinant of kidney function.

Smoking status was substantially connected with eGFR category ($p = 0.001$). A higher proportion of smokers was observed among individuals with reduced eGFR < 90 mL/min/1.73 m², in contrast to individuals with normal renal function. These results are in line with earlier studies indicating that both active and passive smoking are associated with elevated creatinine levels and impaired kidney function (Eid et al., 2022). A longitudinal study in Japan further identified smoking as an important factor associated with eGFR decline and CKD progression in both men and women (Takeuchi et al., 2026). From a biological perspective, smoking contributes to systemic oxidative stress and vascular damage, which may adversely affect renal function (Albrakati, 2025; Park & Park, 2025). Additionally, co-exposure to pesticides and tobacco smoke may result in synergistic toxic effects on the kidney (Sule et al., 2022). A recent meta-analysis reported that smokers have approximately 1.5-2 times higher risk of developing CKD compared to non-smokers, reinforcing its

relevance as an important associated factor. This confirms that smoking is an important risk factor that needs to be considered in the prevention of CKD (Sule et al., 2022). In populations exposed to pesticides, these combined exposures may further exacerbate renal impairment through mechanisms involving chronic inflammation and endothelial dysfunction (Park & Park, 2025; Rosa et al., 2022). Consequently, the results of this investigation suggest that smoking behavior may act as a contributing factor that strengthens the correlation between exposure to pesticides and reduced renal function.

Pesticide dosage was substantially connected with eGFR category ($p < 0.001$). A higher proportion of respondents who reported pesticide use exceeding recommended levels was observed in the group with reduced eGFR < 90 mL/min/1.73 m², compared to those with normal renal function. In this study, dosage classification was based on self-reported information obtained through interviews. "Appropriate use" referred to adherence to the instructions provided on pesticide labels, whereas "inappropriate use" indicated application beyond the recommended. Previous studies have reported that agricultural workers with chronic pesticide exposure tend to have lower eGFR values in contrast to the overall population (Aguilar-Ramirez et al., 2021). Similarly, epidemiological evidence has demonstrated an association between pesticide exposure and reduced eGFR, including case-control studies showing significantly lower eGFR among pesticide sprayers compared to unexposed individuals (Lozano-Paniagua et al., 2023a; Nosratabadi et al., 2025). Therefore these findings suggest that inappropriate pesticide use could be linked to an increased likelihood of declining kidney function.

Using personal protective equipment was also significantly associated with the eGFR category ($p = 0.002$). Respondents who did not use PPE were more frequently observed in the group with reduced eGFR compared to those with normal renal function. This finding is consistent with previous studies indicating that inadequate protection during pesticide exposure is associated with impaired kidney function (Intana et al., 2026; Nosratabadi et al., 2025). Consequently, compliance with the use of PPE is a crucial protective measure for agricultural workers (Intana et al., 2026). These results highlight the importance of PPE compliance as a protective measure in reducing occupational exposure and its potential health impacts among agricultural workers.

Exposure-related health complaints were significantly associated with eGFR category ($p < 0.001$), with a higher proportion of symptomatic individuals observed in the group with reduced renal function. Previous studies have reported higher pesticide levels among patients with chronic kidney disease, which were associated with decreased eGFR. Additionally, pesticide exposure, including domestic use, has been linked to CKD of unknown origin (CKDu) and renal impairment (Requena

& Hern, 2023). These results indicate that self-reported health complaints may serve as an early indication of renal dysfunction. In this context, symptom-based screening could provide a practical approach for early detection in settings where laboratory testing is limited. However, such information should be interpreted cautiously due to the potential for reporting bias.

Working period was significantly associated with reduced kidney function. Compared to respondents with shorter working periods (≤ 5 years), those with longer employment durations (> 5 years) had a higher proportion of lower eGFR. Previous studies have also suggested that prolonged exposure to pesticides and other environmental contaminants, including heavy metals, may increase the risk of CKD, particularly among long-term workers (Park & Park, 2025; Rao, 2023). These findings indicate that the working period may reflect cumulative exposure and could be considered an important factor associated with renal function decline among agricultural workers.

Body mass index (BMI) was not significantly associated with eGFR category ($p = 0.279$), with a relatively similar distribution observed between groups. This finding is consistent with evidence from the Global Burden of Disease analysis, which suggests that although obesity is linked to a higher chance of CKD, its effects are often mediated by comorbid elements like diabetes and high blood pressure (Chen et al., 2025). Other studies have also reported associations between obesity and reduced eGFR. However, these relationships tend to be more pronounced in populations with additional risk factors (Park & Park, 2025). These findings suggest that BMI may not function as an independent determinant of renal function in this population, but rather reflects indirect risk pathways influenced by comorbidities. Therefore, BMI alone may have limited utility as a predictor of renal impairment, particularly within a cross-sectional study design.

Hypertension was significantly associated with the eGFR category ($p=0.007$), with a higher proportion of hypertensive individuals observed in the group with reduced eGFR. Previous epidemiological studies on CKD of Unknown origin (CKDu) have indicated that, in addition to environmental exposures such as pesticides, comorbid conditions, including hypertension, may contribute to the progression of renal impairment among agricultural workers (Strasma et al., 2023). Furthermore, pesticide exposure in agricultural settings has been suggested to indirectly increase the risk of hypertension through multiple exposure pathways, including inhalation, dermal absorption, and dietary intake (Masyithah et al., 2025). Some CKDu epidemiological studies have also shown that, Parallel to these environmental elements like pesticide exposure, comorbidities such as hypertension can exacerbate the progression of kidney damage in the agricultural worker population (Park & Park, 2025), and

recent meta-analyses have demonstrated its association with accelerated decline in kidney function. Hypertension accelerates the progression of CKD and increases the risk of decreased eGFR (Kidney & Collaborators, 2023). These findings indicate that hypertension may play an important role as a contributing factor to reduced renal function. Consequently, blood pressure management represents a key strategy in CKD prevention and control.

Serum creatinine levels showed a strong association with eGFR category ($p < 0.001$), with all individuals presenting elevated creatinine levels (>1.20 mg/dL) classified within the reduced eGFR group. This finding is consistent with the established role of creatinine as a key biomarker of kidney function (Lozano-Paniagua et al., 2023b). Recent studies have demonstrated that the implementation of the CKD-EPI equation without regard to race improves the accuracy of creatinine-based CKD classification (Lv et al., 2022). Research in Europe also reported re-classification of CKD based on the latest creatinine equation (Rutter et al., 2025). KDIGO confirms that creatinine remains a key parameter in kidney evaluation, although it needs to be combined with other biomarkers to improve accuracy (Iatridi et al., 2025; Navaneethan et al., 2025; Stevens et al., 2024). This is consistent with the role of creatinine as a major biomarker of kidney function. These results reinforce the validity of using creatinine as a clinical indicator in the screening and diagnosis of CKD, although it still needs to be combined with other parameters to improve accuracy.

Blood glucose levels were not significantly associated with eGFR category ($p = 0.140$), with a comparable distribution observed between groups. This finding is aligned with previous studies suggesting that random blood glucose measurements may be less sensitive in identifying CKD risk compared to long-term glycemic indicators such as HbA1c or fasting plasma glucose (Vanessa et al., 2025). The same article also states that intermediate hyperglycemia is associated with a decrease in eGFR, but the association is weak (Vanessa et al., 2025). Community-based studies further suggest that single-point glucose measurements are less reliable predictors of CKD compared to long-term metabolic indicators (Arroyo et al., 2023). Although limited in sensitivity, blood glucose assessment remains relevant within the context of epidemiological surveillance, particularly in resource-limited settings.

Table 2 displays the results of the evaluation of renal biomarkers, which showed an average of 0.8984 mg/dL (95% CI: 0.8821-0.9130), a standard deviation of 0.1486, and a median serum creatinine concentration of 0.88 mg/dL. Creatinine levels ranged between 0.46 mg/dL and 1.42 mg/dL, indicating inter-individual variability in renal function and highlighting a subset of participants with elevated concentrations.

Table 2
Summary of Serum
Creatinine and estimated Glomerular Filtration Rate (eGFR) Values.

	Median	Mean (95% CI)	Std. Deviation	Min	Max
Creatinine (mg/dl)	0.8800	0.8984 (0.8821-0.9130)	0.14861	0.46	1.42
eGFR (mL/min/1.73 m ²)	103.00	100.64 (99.18-102.14)	14.323	55	136

eGFR: estimated Glomerular Filtration Rate

The median eGFR was 103.00 mL/min/1.73 m², while the mean eGFR was 100.64 mL/min/1.73 m² (95% CI: 99.18–102.14), with a standard deviation of 14.32. Observed eGFR values ranged from 55 to 136 mL/min/1.73 m². Although the overall mean renal function remained within the normal physiological range, a proportion of participants exhibited eGFR values indicative of reduced renal function.

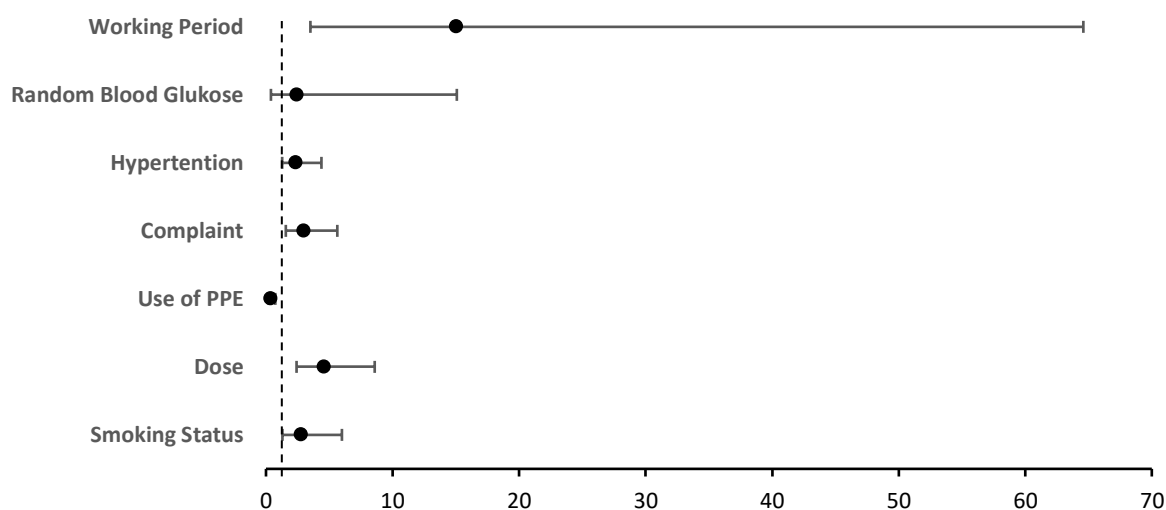
impaired renal function (eGFR < 90 mL/min/1.73 m²). The variables included in the model were smoking status, pesticide dose, use of personal protective equipment (PPE), health complaints, hypertension, random blood sugar, and working period.

Multivariate Logistic Regression Analysis of Risk Factors for Decreased eGFR

Multiple logistic regression analysis was performed to evaluate factors that were independently related to

Table 3
Results of Multivariate Logistic Regression Analysis of Risk Factors for Decreased eGFR

	B	Exp (B)	95% CI	p-value
Smoking Status	1.027	2.792	1.299 – 6.001	0.009
Dose	1.516	4.555	2.415 – 8.591	< 0.001
Use of PPE	-0.960	0.383	0.199 – 0.737	0.004
Complaint	1.089	2.972	1.567 – 5.636	0.001
Hypertension	0.861	2.367	1.278 – 4.382	0.006
Random Blood Sugar (RBG)	0.886	2.425	0.390 – 15.080	0.342
Working Period	2.712	15.057	3.510 – 64.591	< 0.001



Graph 1. Forest Plot of Odds Ratios from Multivariate Logistic Regression Analysis of eGFR Decline

Several variables were shown to be significantly linked to decreased renal function based on multivariate logistic regression analysis. Personal Protective Equipment (PPE) use (OR = 0.383; 95% CI: 0.199–0.737; $p = 0.004$), smoking status (OR = 2.792; 95% CI: 1.299–6.001; $p = 0.009$), health complaints (OR = 2.972; 95% CI: 1.567–5.636; $p = 0.001$), and hypertension (OR = 2.367; 95% CI: 1.278–4.382; $p = 0.006$), pesticide dosage (OR = 4.555; 95% CI: 2.415–8.591; $p < 0.001$)

Working period showed the highest correlation among these variables (OR = 15.057; 95% CI: 3.510–64.591; $p < 0.001$), and after controlling for other factors, it indicates that individuals with longer employment durations were more likely to show decreased renal function than people with shorter working durations. Nevertheless, the magnitude of this correlation should be interpreted with caution, as it may reflect not only cumulative exposure but also the impact of sample size, distribution, and classification techniques used in the analysis.

These findings indicate that the working period may serve as an important proxy for chronic exposure in occupational health settings. Extended exposure to pesticides has the potential to result in the accumulation of toxic substances in the body, which may contribute to renal impairment. From a biological perspective, pesticide exposure—particularly to organophosphate compounds—has been associated with oxidative stress and renal cellular damage. This process may involve acetylcholinesterase inhibition and increased production of reactive oxygen species (ROS), which have been suggested in previous studies to disrupt cellular integrity and function (Sule et al., 2022; Wu et al., 2023). Sustained exposure over time may contribute to cumulative toxic burden, which could plausibly be linked to kidney function decline.

To further support the statistical findings, visualization using a forest plot provides a clearer representation of the relative strength of associations among variables. The point estimate for the working period is positioned farthest to the right of the null value (OR = 1), indicating the strongest association among the variables included in the model. Although the confidence interval for the working period appears relatively wide—suggesting variability in the data—it remains entirely above the null value, thereby supporting the consistency and statistical significance of the observed association. In contrast, PPE use is located on the protective side of the axis, indicating a potential protective effect. Other variables, including pesticide dosage, smoking status, hypertension, and health complaints, demonstrate consistent positive associations with reduced renal function.

Blood glucose levels measured at the time of assessment were not significantly associated with renal function. This may be partly explained by the high variability of non-fasting measurements, as well as the limited ability of single-point glucose indicators to reflect long-term metabolic status. These findings suggest that more specific glycemic parameters, such as long-term

biomarkers, should be considered in future studies to improve the sensitivity of risk detection.

This study offers valuable insights; nevertheless, certain limitations must be recognized. Primarily, the observational cross-sectional design does not allow for causal inference, meaning that the identified relationships should be regarded as associations. Second, potential confounding factors—including heat exposure, dehydration, and genetic susceptibility—were not fully controlled and may have influenced the observed relationships between pesticide exposure and renal function.

The results of this investigation are in line with previous research indicating that exposure to organophosphate pesticides is connected to a steady deterioration in kidney function, particularly when assessed through biomarkers of chronic exposure such as urinary metabolites (Requena & Hern, 2023; Zhang et al., 2025). Furthermore, large population-based studies have demonstrated that individuals exposed to pesticides typically have a greater likelihood of kidney dysfunction compared to unexposed populations (Ben Khadda et al., 2022; Gomes et al., 2024; Panis et al., 2022). In occupational health research, working duration is frequently used as a proxy for cumulative exposure. Prior studies have identified factors such as duration of employment, frequency of pesticide application, and exposure-related behaviors as key determinants influencing both exposure levels and toxic effects (Hossain et al., 2026; López-Gálvez et al., 2021). Notably, the present study found that the strength of association for the working period exceeded that of pesticide dosage. This suggests that prolonged exposure duration may be more strongly associated with renal function decline than short-term exposure intensity. These findings highlight the potential importance of chronic, low-dose exposure over extended periods as a contributing factor to kidney impairment.

Consistent with this interpretation, previous literature has reported that chronic kidney disease among agricultural workers (CKDu) is often linked to long-term pesticide exposure, although additional elements like dehydration and heat stress may also act as confounders (López-Gálvez et al., 2021; Silva et al., 2022). In the present study, while variables such as pesticide dosage and PPE use were also significantly associated with renal function, their magnitude of association was lower compared to the working period. This suggests that, although exposure intensity remains relevant, the duration of exposure may play a more substantial role in influencing renal outcomes.

These results have significant ramifications for public health, particularly in agricultural settings. Preventive strategies should prioritize the control of cumulative exposure by managing working duration, implementing job rotation, and improving compliance with personal protective equipment use. In addition, strengthening education on safe pesticide handling and establishing routine kidney function monitoring programs

are essential. At the policy level, efforts to promote safer and more environmentally sustainable pesticide use should be reinforced to mitigate long-term health risks among agricultural workers.

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CONFLICT OF INTEREST

The authors affirm that none of the work presented in this study was influenced by any known conflicting financial interests or personal relationship.

CONCLUSIONS

This research shows that several factors are associated with decreased kidney function in farmers exposed to pesticides, and working period being the most dominant factor. This indicates that the duration of long-term exposure has a significant part in increasing the risk of decreased renal function, reflecting the cumulative effects of pesticide exposure. Alongside the working period, other factors such as dose, smoking status, hypertension, and health complaints also contribute to increased risk, while the use of personal protective equipment mitigates this risk.

The forest plot visualization reinforces that the working period has the strongest association compared to other variables. However, these results need to be interpreted carefully because the observational research design only shows associations, as well as the presence of potential confounding factors that have not been fully controlled. These results highlight the significance of controlling exposure duration through working period management, and increasing compliance with the safe use of pesticides, and implementing regular monitoring of kidney function is also necessary, especially in groups of workers with long working periods.

SUGGESTION

Based on the findings of this study, it is necessary to focus on controlling the duration of exposure as the dominant factor, through limiting the working period. In addition, increasing compliance with the use of personal protective equipment, education on the safe use of pesticides, and the implementation of regular kidney health monitoring are important steps in prevention efforts. Interventions also need to consider individual factors such as smoking status and hypertension. At the policy level, it is necessary to strengthen regulations on the use of pesticides, provision of PPE, and the integration of occupational health and environmental health programs to minimize long-term risks to the farmer population.

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