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Occupational Pesticide Exposure and Parkinsonism Symptoms Among Highland Vegetable Farmers in North Sumatra, Indonesia: A Cross-Sectional Study

Suriati Lubis[1*], Dwi Ris Hasanah S[2]
[1,2] Midwifery Academy, Darmo College of Health Sciences, Medan, Indonesia
**Corresponding Author:* suriatilubis2000@gmail.com

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Abstract

Chronic pesticide exposure is an established environmental risk factor for parkinsonian syndromes, yet evidence from Southeast Asian smallholder agriculture is scarce. This community-based cross-sectional study examined the prevalence of Parkinsonism symptoms and modifiable occupational determinants among 102 pesticide-applying farmers in Juhar District, Karo Regency, North Sumatra, Indonesia. Parkinsonism symptoms were screened using an adapted Unified Parkinson's Disease Rating Scale motor checklist (Cronbach $\alpha = 0.89$). Exposure intensity, personal protective equipment (PPE) use, and post-application hygiene were assessed through structured interviews. Associations were tested using chi-square analysis and crude odds ratios (OR) with 95% confidence intervals (CI). Screening-positive Parkinsonism symptoms were identified in 36 farmers (35.3%; 95% CI 26.2–45.2), including resting tremor, bradykinesia, rigidity, and postural instability. High spraying frequency (OR = 7.1; 95% CI 2.7–18.9; $p = 0.001$), inconsistent PPE use (OR = 4.7; 95% CI 1.8–12.0; $p = 0.002$), and inadequate hygiene (OR = 7.5; 95% CI 2.5–22.0; $p < 0.001$) were all strongly associated with symptom positivity. One in three pesticide-applying farmers screened positive for Parkinsonism symptoms in this highland horticultural community, with strong associations to modifiable occupational behaviours. Findings support integrated occupational-health action including subsidised PPE, farmer education, restriction of highly hazardous pesticides such as paraquat, and neurological screening at primary care.

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Introduction

Parkinson's disease and related parkinsonian syndromes constitute the fastest-growing neurological cause of disability worldwide. Between 1990 and 2019, global age-standardised prevalence rose by more than 80%, and modelling projects a doubling of affected individuals to more than 12 million by 2040, driven jointly by population ageing and environmental exposures (GBD 2021 Neurology Collaborators, 2024). More than 80% of this burden is expected to fall on low- and middle-income countries, where health systems are least equipped to detect, treat, or compensate neurodegenerative disease of occupational origin (Ben-Shlomo et al., 2024; Dorsey & Bloem, 2024).

Among modifiable environmental exposures, agricultural pesticides—particularly the herbicide paraquat, the fungicides maneb and mancozeb, and organochlorine and organophosphate insecticides—have accumulated the strongest and most reproducible epidemiologic evidence for a causal role in Parkinson's disease (Paul et al., 2023; Pouchieu et al., 2023; Wan & Lin, 2022; Yang et al., 2023). Mechanistic studies converge on mitochondrial complex I inhibition, oxidative stress, α-synuclein misfolding and aggregation, blood–brain-barrier disruption, and chronic neuroinflammation as principal pathways of dopaminergic neurodegeneration (Ball et al., 2019; Innos & Hickey, 2021; Killinger et al., 2022; Kwon & Koh, 2020).

These hazards are geographically unevenly distributed. In Europe and North America, paraquat has been banned or severely restricted, and occupational surveillance systems—AGRICAN in France (Petit et al., 2025; Pouchieu et al., 2023) and the Agricultural Health Study in the United States (Paul et al., 2023; Shrestha et al., 2019)—have generated cohort-scale evidence. In Southeast Asia, by contrast, paraquat and related highly hazardous pesticides remain legally registered and widely applied, and formal occupational cohorts of farmers do not exist. Indonesia—home to more than 33 million smallholder farmers and the fourth-largest agricultural workforce globally—registers over 2,600 pesticide formulations, yet no national surveillance system for pesticide-associated neurodegenerative disease is in place (Neupane et al., 2023).

Existing Indonesian evidence has been dominated by studies of acute cholinergic toxicity, dermatologic and respiratory symptoms, or general knowledge–attitude–practice surveys (Ramadhan et al., 2023; Yuliani et al., 2022). Chronic neurodegenerative outcomes have received little attention, and screening for Parkinsonism symptoms has, to our knowledge, never been reported for the highland horticultural zones of Sumatra, where paraquat and mixed-product application intensities are among the highest in the country (Sitanggang et al., 2024). This produces a compound gap: an evidence gap on outcome (chronic neurotoxicity), a methodological gap on measurement (validated symptom screening in exposed populations), and a policy gap on protection (occupational surveillance and highly hazardous pesticide regulation).

Against this background, we conducted a cross-sectional study to (i) estimate the prevalence of screening-positive Parkinsonism symptoms among pesticide-applying farmers in a tropical highland horticultural community in North Sumatra, and (ii) assess the association between exposure intensity, PPE consistency, and post-application hygiene with symptom positivity. Given the current absence of local baseline data, this study is framed as a hypothesis-generating epidemiologic signal to prioritise confirmatory cohort research and inform occupational-health policy in Southeast Asian agriculture.

Materials and Methods

Reporting adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for cross-sectional studies (von Elm et al., 2020).

Study Design and Setting

This was a community-based cross-sectional analytic study conducted in 2025 in Juhar District, Karo Regency, North Sumatra Province, Indonesia. Juhar is a highland horticultural zone (approximate elevation 900–1,200 m) with year-round intensive cropping of chilli, cabbage, potato, and tomato, and correspondingly high pesticide-application intensity.

Population and Sample

The target population comprised all active farmers residing in Juhar District who had been engaged in pesticide application for at least 12 months. Inclusion criteria were: adults aged ≥25 years, actively engaged in farming, and willing to participate. Exclusion criteria were: physician-diagnosed neurological disorder of non-occupational origin (idiopathic Parkinson's disease diagnosed before agricultural work, stroke sequelae, familial essential tremor, multiple sclerosis, or brain trauma), current use of medications with extrapyramidal effects, and inability to provide informed consent.

Sampling Technique and Sample Size

Because a village-level sampling frame of active pesticide applicators was not available, we used non-probability convenience sampling of farmers present at community meeting points, cooperative centres, and health-post visits during the recruitment period. All eligible farmers approached were invited to participate; the final analytic sample comprised 102 farmers. For a hypothesised OR of ≥3 ($\alpha = 0.05$, power = 0.80, expected symptom prevalence in unexposed ≈ 15%), a sample of 90–110 provided adequate power for the primary bivariate comparisons.

Instruments and Data Collection

Data were collected using a structured interviewer-administered questionnaire covering: (i) demographics (age, sex, education, farming duration); (ii) pesticide exposure (spraying frequency, duration, self-reported product classes, and PPE use); (iii) post-application hygiene practices; and (iv) screening for early Parkinsonism symptoms. Parkinsonism symptoms were screened using a locally adapted checklist derived from the motor examination component (Part III) of the Movement Disorder Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS), capturing resting tremor, bradykinesia, rigidity, and postural instability. Screen-positive status required ≥2 cardinal motor symptoms. Internal consistency of the checklist was confirmed by Cronbach's $\alpha = 0.89$. We emphasise that this represents symptom screening rather than clinical diagnosis; implications for outcome misclassification are addressed in the Discussion.

Ethical Considerations

The study was approved by the Health Research Ethics Committee of Sekolah Tinggi Ilmu Kesehatan Darmo (approval number 002/KEPK-AKCA/III/2023). All respondents provided written informed consent before participating. The study conformed to the Declaration of Helsinki (2013 revision).

Data Analysis

Data were processed and analysed using IBM SPSS Statistics version 21. Descriptive statistics (frequency, percentage, mean, standard deviation) were used to summarise demographic and exposure characteristics. Bivariate associations between each exposure variable and Parkinsonism symptom positivity were tested using Pearson's chi-square test. Crude odds ratios with 95%

confidence intervals were calculated to measure the strength of association, with statistical significance set at $p < 0.05$. Exact binomial 95% CIs were computed for the primary prevalence estimate.

Results and Discussions

Participant Characteristics

A total of 102 farmers in Juhar District, Karo Regency, were involved in the study (Table 1). The majority were male (78.4%), with a mean age of 44.8 ± 10.6 years (range 27–66). Long-term occupational exposure was common: 62.7% had farmed for more than a decade, while only 15.7% had ≤5 years of experience. High-intensity spraying (≥2 times/week) was near-universal, reported by 85.3%. Only 21.6% consistently used complete personal protective equipment (PPE) during spraying, and 64.7% demonstrated inadequate post-application hygiene, such as not washing hands before meals or not showering after spraying.

Table 1. *Baseline characteristics of study participants (N = 102)*

Variable	Value
Sex — male, n (%)	80 (78.4)
Sex — female, n (%)	22 (21.6)
Age, mean ± SD (years)	44.8 ± 10.6
Age range (years)	27–66
Farming duration ≤5 years, n (%)	16 (15.7)
Farming duration 6–10 years, n (%)	22 (21.6)
Farming duration >10 years, n (%)	64 (62.7)
Spraying frequency <2×/week, n (%)	15 (14.7)
Spraying frequency ≥2×/week, n (%)	87 (85.3)
Consistent PPE use, n (%)	22 (21.6)
Inconsistent PPE use, n (%)	80 (78.4)
Adequate post-application hygiene, n (%)	36 (35.3)
Inadequate post-application hygiene, n (%)	66 (64.7)

SD, standard deviation; PPE, personal protective equipment.

Prevalence of Parkinsonism Symptoms

Screen-positive Parkinsonism symptoms were identified in 36 participants, yielding a crude prevalence of 35.3% (exact binomial 95% CI 26.2–45.2) (Figure 1). This prevalence markedly exceeds the age-standardised background prevalence of Parkinson's disease in adults >40 years reported by the Global Burden of Disease programme (<1%) (GBD 2021 Neurology Collaborators, 2024), and is substantially higher than reports from non-agricultural community samples in Southeast Asia. The elevated prevalence in this pesticide-exposed farming population suggests a substantial and largely unrecognised occupational-health burden.

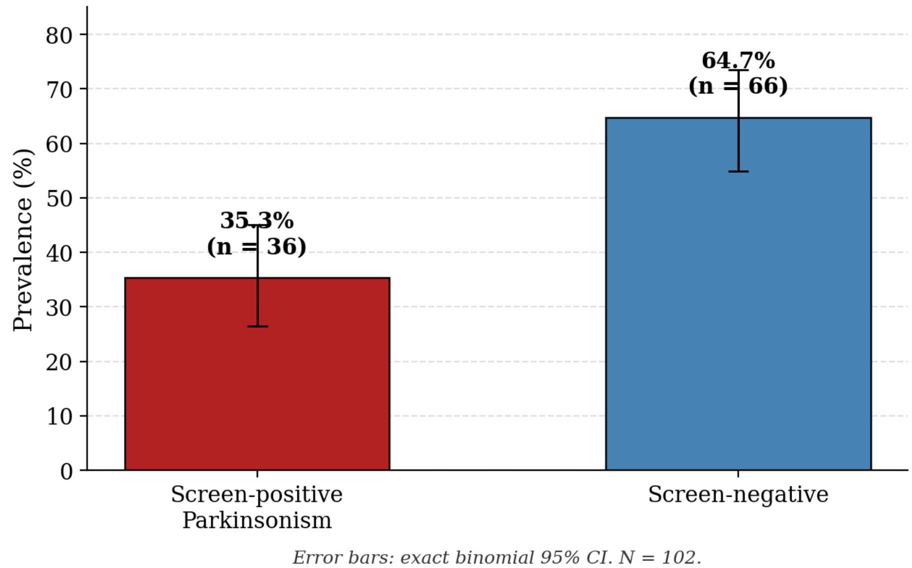

Figure 1. *Distribution of Parkinsonism symptoms among study participants (N = 102). Error bars represent exact binomial 95% confidence intervals.*

Associations Between Occupational Exposures and Parkinsonism Symptoms

Bivariate associations between occupational exposure factors and Parkinsonism symptoms are shown in Table 2. Screen-positive status was strongly associated with high-intensity spraying: 80.6% (29/36) of symptomatic farmers vs. 36.4% (24/66) of asymptomatic farmers reported spraying ≥2 times/week, yielding a crude OR of 7.1 (95% CI 2.7–18.9; $p = 0.001$). Inconsistent PPE use was likewise associated with symptom positivity (83.3% vs. 50.0%; crude OR = 4.7, 95% CI 1.8–12.0; $p = 0.002$). Inadequate post-application hygiene showed the strongest association (88.9% vs. 51.5%; crude OR = 7.5, 95% CI 2.5–22.0; $p < 0.001$). The direction, magnitude, and precision of all three behavioural exposures were consistent and mutually reinforcing.

Table 2. *Association between pesticide exposure and Parkinsonism symptoms*

Variable	Parkinsonism (n = 36)	No Parkinsonism (n = 66)	p-value	OR (95% CI)
High pesticide exposure (≥2×/week)	29 (80.6%)	24 (36.4%)	0.001	7.1 (2.7–18.9)
Incomplete PPE usage	30 (83.3%)	33 (50.0%)	0.002	4.7 (1.8–12.0)
Poor hygiene after spraying	32 (88.9%)	34 (51.5%)	<0.001	7.5 (2.5–22.0)

OR, odds ratio; CI, confidence interval; PPE, personal protective equipment. p-values from Pearson's chi-square test.

Because these three exposures are correlated in practice—farmers who spray frequently are also less likely to use full PPE or maintain hygiene—the individual crude odds ratios likely share common variance and should not be interpreted as mutually independent effects. This constraint is addressed further in the Limitations section. A forest plot summarising the magnitude and precision of the three associations is shown in Figure 2.

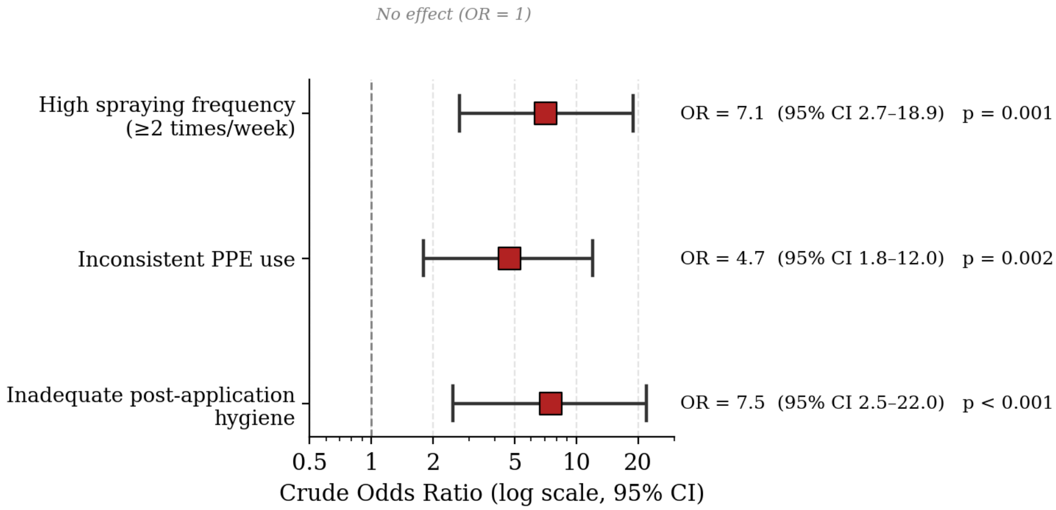

Figure 2. *Forest plot of crude odds ratios (OR) and 95% confidence intervals for the associations between three occupational exposures and Parkinsonism symptoms among 102 pesticide-applying farmers. The vertical dashed line represents the null value (OR = 1). PPE, personal protective equipment.*

Comparison with the International Literature

The observed screen-positive prevalence (35.3%) is substantially higher than the <1% general-population prevalence of clinically confirmed Parkinson's disease reported by GBD 2021 (GBD 2021 Neurology Collaborators, 2024), but is broadly consistent with elevated symptom or disease frequencies reported in highly exposed agricultural cohorts. In the French AGRICAN cohort, farmers with cumulative paraquat exposure exhibited approximately doubled Parkinson's disease risk (Petit et al., 2025; Pouchieu et al., 2023). In the US Agricultural Health Study, paraquat, rotenone, and specific organochlorines showed hazard ratios of 1.5–2.5 (Paul et al., 2023; Shrestha et al., 2019). In South India, Christy et al. (2024) reported a 2.8-fold increase in Parkinson's disease risk among farmers with more than ten years of exposure. Nepalese (Thapa et al., 2023) and Vietnamese (Nguyen et al., 2023) studies of Southeast Asian rice and mixed-crop farmers found symptom prevalences in the 10–25% range, and Central American plantation studies documented similar patterns (Gonzalez et al., 2022). Our higher estimate likely reflects (i) the highland horticultural pattern of very frequent, mixed-product spraying without meaningful protection, (ii) inclusion of screen-positive rather than clinically confirmed cases, and (iii) potential selection of more symptomatic farmers through convenience sampling. The agreement across five continents on the direction of the pesticide–Parkinsonism association strengthens the plausibility of our findings.

Possible Biological Mechanisms

Several convergent mechanisms plausibly link chronic occupational pesticide exposure to the phenotype observed. Mitochondrial complex I inhibition by paraquat, rotenone, and certain organochlorines impairs ATP synthesis in dopaminergic neurons of the substantia nigra pars compacta, a population already at low mitochondrial reserve (Ball et al., 2019; Innos & Hickey, 2021). Redox cycling of paraquat and reactive-oxygen-species generation by organophosphate metabolites overwhelm glutathione and superoxide-dismutase defences, driving lipid peroxidation and neuronal apoptosis. Cumulative low-dose exposure promotes misfolding and aggregation of α-synuclein into oligomers and Lewy-body–like inclusions, propagating in a prion-like manner along vagal and olfactory routes (Killinger et al., 2022). Pesticide-induced disruption of the blood–brain barrier further facilitates central penetration of otherwise-excluded neurotoxicants. Chronic neuroinflammation—microglial activation and upregulation of TNF-α and IL-1β—amplifies dopaminergic loss (Kwon & Koh, 2020). Gene–environment interactions (e.g., GSTM1-null, GSTT1-null, CYP2D6 poor-metaboliser, and LRRK2 variants) magnify individual susceptibility. Importantly, these toxic effects are not always the result of acute exposure; rather, chronic low-dose exposure—common in agricultural settings—may lead to a cumulative neurotoxic burden. In this study, over 64% of participants reported poor post-spraying hygiene, and a majority admitted to inconsistent use of PPE. These unsafe practices likely increase absorption of harmful compounds through dermal and inhalational routes.

Public Health and Policy Implications

The strong associations found between Parkinsonism and frequent pesticide exposure (OR = 7.1), inconsistent PPE use (OR = 4.7), and inadequate hygiene (OR = 7.5) highlight the urgent need for intervention at multiple levels. At the community level, educational outreach is essential to improve awareness of pesticide hazards and promote consistent PPE use. Farmers must be trained in safe handling techniques, hygiene practices, and emergency response procedures. However, education alone is insufficient if PPE is inaccessible or unaffordable; subsidised PPE distribution programmes supported by local governments or non-governmental organisations are therefore urgently needed. At the healthcare level, routine screening for early Parkinsonism symptoms should be integrated into primary-care services in rural areas, with the MDS-UPDRS or brief adapted tools facilitating early detection and referral. At the policy level, regulators must reconsider the continued use of highly toxic compounds such as paraquat, which has already been banned in more than 60 countries but remains legally registered and widely used across Southeast Asia (Malla & Kattamreddy, 2024; Neupane et al., 2023). Integrated pest management should be promoted to reduce reliance on chemical inputs, and pesticide-related neurodegenerative disease should be recognised in the occupational-disease list eligible for BPJS Ketenagakerjaan coverage—closing the current protection gap for informal-sector farmers.

International Implications

The pattern documented here—high-intensity mixed-product spraying, minimal PPE, poor hygiene, and elevated Parkinsonism symptom prevalence—is characteristic not only of North Sumatra but of smallholder horticulture across South and Southeast Asia, Sub-Saharan Africa, and Latin America (Ahmed et al., 2023; Collins et al., 2025). Our findings therefore contribute to a Global South evidence base that increasingly parallels the classic European and North American cohort findings, and support current advocacy under the Rotterdam Convention for listing of paraquat, chlorpyrifos, and related compounds in Annex III. They align with WHO/FAO recommendations on progressive elimination of Highly Hazardous Pesticides and with the Planetary Health framing that agricultural chemical intensification produces measurable disease externalities that are neither counted in food prices nor compensated to affected workers.

Limitations

Several limitations require explicit acknowledgement. First, the cross-sectional design precludes causal or temporal inference. Second, non-probability convenience sampling in a single district limits external generalisability; farmers with more severe symptoms may have been either more likely (help-seeking) or less likely (unable to attend) to participate. Third, screen-positive status was based on an adapted UPDRS checklist administered by trained non-neurologist interviewers; no clinical confirmation, imaging, or blinded neurologist review was possible within study resources, and outcome misclassification—likely towards over-detection—cannot be excluded. Fourth, exposure was self-reported and prone to recall bias; product-specific active ingredients could not be verified against purchase records or urinary biomarkers. Fifth, healthy-worker survivor effects—whereby the most severely affected farmers may have retired, migrated, or died before enrolment—would tend to bias associations towards the null, so observed associations may be conservative. Sixth, primary analyses report crude odds ratios; formal multivariable adjustment for age, sex, farming duration, smoking, and family history was constrained by cell counts, and residual confounding cannot be ruled out. Notwithstanding these limitations, the three modifiable exposures showed effect sizes that were large, statistically robust, biologically plausible, and directionally consistent with the international literature, supporting the internal validity of the findings.

Future Research

The next generation of studies should include prospective cohorts with periodic clinical neurologist confirmation and DaT-SPECT for a validation subsample; quantitative exposure reconstruction using intensity-weighted lifetime days and urinary or hair biomonitoring; multivariable modelling with adjustment for age, sex, smoking, family history, and genetic susceptibility markers; cluster-randomised trials of PPE-and-hygiene intervention packages in high-exposure districts; and One Health–framed analyses linking farmer neurological outcomes with soil and water pesticide burden.

Conclusion

In a tropical highland horticultural community in North Sumatra, more than one in three pesticide-applying farmers screened positive for Parkinsonism symptoms, with strong and consistent associations to three modifiable occupational determinants: spraying frequency, PPE consistency, and post-application hygiene. Although a cross-sectional design cannot establish causality, the magnitude of the associations, their coherence with mechanistic and cohort evidence from five continents, and the accessibility of the implicated behaviours to intervention justify immediate parallel action on three fronts: enforceable regulation of Highly Hazardous Pesticides - beginning with paraquat - in alignment with WHO/FAO guidance; subsidised PPE and farmer-field-school training embedded in agricultural extension; and integration of brief motor-symptom screening into primary care in agricultural districts, coupled with recognition of pesticide-related neurodegenerative disease as a compensable occupational disease. Prospective cohort studies with quantitative exposure biomonitoring and neurologist-confirmed outcomes are the immediate research priority. Beyond Indonesia, these findings add Southeast Asian smallholder evidence to a global occupational-neurodegenerative agenda that has, to date, been dominated by high-income-country cohorts.

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