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*(Research/Review) Article*

# Analysis of Environmental Health Risks from Pesticide Exposure among Green Mustard Farmers in Ngkari-Ngkari Village, Baubau City

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**Abstract:** Ngkari-Ngkari Sub-district is an agricultural area that produces rice, fruits, and vegetables, particularly green mustard (caisin), with a population composed of diverse ethnic groups. The use of pesticides in agricultural activities may pose health risks when applied improperly. This study aims to analyze environmental health risks due to pesticide exposure among green mustard farmers in Ngkari-Ngkari, Baubau City. Plant samples were collected two days after chemical pesticide spraying using standard procedures and analyzed at the UHO Pharmacy Laboratory. A total of 64 farmers were selected through total sampling, and data were obtained using structured questionnaires. Data analysis employed SPSS and the Environmental Health Risk Assessment (EHRA) method. Laboratory results indicated that pesticide concentration in green mustard plants was 0 mg/kg/day or undetected. The estimated intake exposure among farmers was 0.000364 mg/kg/day, while the calculated risk quotient (RQ) of Chlorpyrifos exposure was 0.0121 mg/kg/day. An RQ value ≤ 1 suggests that the 64 farmers were not at risk of adverse health effects from exposure to Chlorpyrifos-based pesticides. This study concludes that pesticide use in Ngkari-Ngkari remains within safe limits for farmers, although continuous monitoring and proper application are necessary to prevent long-term cumulative risks. Limitations of this study include the influence of environmental factors during sampling and the potential effect of sample storage time, indicating the need for biological monitoring and soil condition evaluation in future studies to strengthen the findings
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**Keywords:** Analysis Environmental Health Risks (ARKL); Pesticides Green Mustard Greens; Environmental Health Risk Assessment (EHRA); Pesticide; Green Mustard.

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## 1. Introduction

Pesticides are chemical compounds widely used to control plant pests and diseases, with 95.29% of Indonesian farmers relying on them due to their effectiveness, ease of application, and economic benefits (Apriliani, Oktavidiati, Ramon, & Wati, 2021). Mustard greens (Brassica juncea), like other vegetables, are highly vulnerable to pests such as Plutella xylostella, which are commonly controlled using pesticides to maintain crop productivity (Nur, 2020). However, excessive or inappropriate use of pesticides poses a significant health risk. The World Health Organization (WHO) estimates that globally there are between 1 to 5 million pesticide poisoning cases among agricultural workers each year, with mortality rates

reaching 220,000. Although developing countries account for only 25% of pesticide use, they contribute to 99% of pesticide-related deaths (Ibrahim & Sillehu, 2022; Sari, Suhartono, & Raharjo, 2023). WHO further reports approximately 600,000 cases of pesticide poisoning annually, leading to 20,000 deaths and 5,000–10,000 cases of chronic diseases such as cancer and disabilities (Tarigan, Siregar, & Hartono, 2024).

Globally, environmental pollution contributes to around 40% of deaths, including exposure from pesticide residues in crops consumed daily. Of the 80,000 pesticides and chemical compounds in use, nearly 10% are carcinogenic, linked to an estimated 1.4 million cancer cases worldwide (Shaleha et al., 2023). In Indonesia, the National Agency of Drug and Food Control (BPOM RI) reported 334 pesticide poisoning cases in 2019, with agricultural pesticides accounting for 147 cases (Rahmah & Nabila, 2020). Health impacts range from mild acute poisoning (headaches, dizziness, skin irritation) to severe acute poisoning (respiratory distress, seizures, cardiac abnormalities), and chronic poisoning that manifests in long-term conditions difficult to diagnose (Shaleha et al., 2023).

Locally, data from Bungi Primary Health Center (Puskesmas Bungi) in Baubau City show increasing prevalence of digestive health problems suspected to be linked with agricultural activities. Dyspepsia cases rose from 191 in 2022 to 324 in 2023 before decreasing to 125 in 2024, while Gastroenteritis cases fluctuated from 75 in 2022 to 41 in 2024 (Puskesmas Bungi, 2024). These findings indicate potential health risks associated with pesticide use in vegetable cultivation, particularly green mustard.

Previous studies primarily focus on pesticide toxicity and poisoning incidents but often overlook comprehensive Environmental Health Risk Analysis (EHRA) for specific agricultural communities. While pesticides are effective in pest control, their weaknesses lie in long-term health risks and environmental contamination. Thus, this study proposes to analyze environmental health risks due to pesticide exposure among mustard green farmers in Ngkari-Ngkari Sub-district, Baubau City. The main contributions of this study are: (1) to provide scientific evidence of pesticide exposure levels among local farmers, (2) to estimate risk levels using EHRA, and (3) to highlight potential preventive measures for farmer health protection. The rest of this paper is organized as follows: Section 2 presents the research methodology, Section 3 discusses findings and results, Section 4 elaborates on discussion and implications, and Section 5 provides conclusions and recommendations for future research..

## 2. Materials and Method

This study was conducted in Ngkari-ngkari Sub-district, Baubau City, Southeast Sulawesi Province, and laboratory analysis of mustard greens was carried out at the Faculty of Pharmacy, Halu Oleo University (UHO) from December 13, 2024, to January 10, 2025. The research employed a descriptive observational design with an Environmental Health Risk Assessment (EHRA) approach. The study population consisted of 64 farmers and their family members who consumed mustard greens in the study area. Given the relatively small population size, the total sampling technique was applied, so that all members of the population were included as respondents.

The plant samples used in this study were mustard greens cultivated in local farmland. Sampling was conducted two days after pesticide application. Each sample consisted of five leaves and their stalks, with a total weight of 15 grams. Samples were collected using sterile gloves, placed in labeled sterile plastic bags, and transported to the Pharmacy Laboratory of UHO for analysis. In the laboratory, the samples underwent standard preparation procedures, including washing, homogenization, residue extraction, and chemical testing for active pesticide compounds (Chlorpyrifos and Cypermethrin) using validated analytical methods. The laboratory results were used to determine the pesticide concentration (C) in the tested vegetables.

The study collected both primary and secondary data. Primary data included respondents' body weight, age, ingestion rate of mustard greens, exposure frequency (days/year), and exposure duration (years), obtained through structured questionnaires and interviews. Secondary data consisted of laboratory test results, literature reviews, and meteorological data from the Baubau BMKG. Data analysis was performed using univariate descriptive statistics to present mean, median, and standard deviation values of each variable. The results of laboratory tests and risk assessments were summarized in tables and narrative form.

The EHRA procedure followed four main stages: hazard identification, exposure assessment, dose-response assessment, and risk characterization. The average daily dose (ADD) or intake was calculated using the following equation:

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where C is the pesticide concentration (mg/kg), IR is the ingestion rate (kg/day), EF is the exposure frequency (days/year), ED is the exposure duration (years), BW is body weight (kg), and AT is the averaging time (days), which for non-carcinogenic effects is calculated as ED×365. The calculated ADD was then compared with the Reference Dose (RfD) using the Risk Quotient (RQ) formula:

$$RQ = \frac{ADD}{RfD} \quad (2)$$

The interpretation criteria were set as RQ ≤ 1, indicating no significant non-carcinogenic risk, and RQ > 1, indicating potential health risks. The findings are presented in the results section through descriptive tables, narratives, and interpretations linking laboratory outcomes, field data, and risk assessment calculations.

## 3. Results and Discussion

Retrieval sample done at 1 point Where sample the has represent all over sample due to content used same and only there is 1 group farmer vegetable mustard green in the sub-district Ngkari-ngkari Baubau City.

**Table 1**. Chromatogram results residue pesticide

| Sample | Concentration Pesticide (mg/kg) | Concentration Standard Used (mg/kg ) | Maximum Limit Residue (MRL) (mg/kg) |
|---|---|---|---|
| Vegetable mustard green | No detected / 0 mg/kg | 0.001 mg/kg | 1 mg/kg |

Based on Table 1 Obtained that concentration pesticides on vegetables mustard green 0 mg/kg or No detected or under limit maximum residue vegetable mustard green of 1 mg/kg. Concentration standards used For know level risk exposure pesticides on farmers vegetable mustard green is 0.001 mg/kg (Ndalewoa, 2013).

**Table 2.** Distribution Characteristics Individuals and Activity Patterns Farmer Vegetable Green Mustard in the Village Ngkari-ngkari Baubau City

| Variables | N | Mean | Median | Elementary School | Min | Max | *P Value* |
|---|---|---|---|---|---|---|---|
| Age Respondents | 64 | 41.73 | 50.00 | 18,914 | 15 | 70 | 0.002 |
| Weight | 64 | 57.14 | 55.00 | 11,864 | 34 | 81 | 0.174 |
| Duration Exposure | 64 | 29.06 | 40.00 | 18,276 | 5 | 50 | 0,000 |
| Frequency Exposure | 64 | 177.94 | 156.00 | 25,884 | 156 | 208 | 0,000 |

Based on Table 2 shows the results of the Kolmogorov -Smirnov test that have been done, obtained p value = 0.002 which means the age data respondents No normally distributed , then used the median value is 50 years with standard deviation 18.914 years . Age oldest respondents namely 70 years old and the youngest is 15 years old. Weight gain p value = 0.174 which means the respondent 's weight data normally distributed, then the average body weight of respondents namely 57.14 kilograms. The largest body weight respondents 81 kilograms and the smallest weight is 34 kilograms. Duration exposure obtained p value =

0.000 which means the duration data exposure respondents No normally distributed, then used the median value is 40 years with standard deviation 18.2 years. Duration exposure highest 50 years and lowest 5 years. Frequency exposure obtained p value = 0.000 which means the respondent data No normally distributed, then used the median value is 156 days with standard deviation 25.884 days. Frequency exposure the highest was 208 days and the lowest was 156 days.

**Table 3.** Distribution Rate Ingestion Green Mustard Vegetable Farmers in the Village Ngkari-ngkari Baubau City

| Variables | N | Mean | Median | Elementary School | Min | Max | *P* Value |
|---|---|---|---|---|---|---|---|
| Rate *Ingestion* | 64 | 135.94 | 100.00 | 48,361 | 100 | 200 | 0,000 |

the p value is ≤ 0.05, the data is not normally distributed and using median value.

### 3.1 Analysis Environmental Health Risks for Mustard Green Farmers

1) Analysis Exposure

Concentration personal exposure ( intake ) to pesticides vegetable mustard green that is amount concentration pesticide vegetable mustard green accepted and entered into the human body with an average of samples per body weight (kg) of samples per day . In calculation this intake will done in accordance samples studied. In this study This will use calculated carcinogenic intake For duration farmer consume vegetable mustard green until moment study This done. Intake exposure pesticides received by farmers vegetable mustard green Ward Ngkari-ngkari Baubau City counted use formula following:

$$\boldsymbol{Intake\ (I_K) = \frac{C \text{ x } R\ x\ f_E\ x\ Dt}{Wb\ x\ T_{avg}}}$$

$$\boldsymbol{Intake\ (I_K) = \frac{0,001 \text{ kg } x\ 0,1 \text{ kg } x\ 156\ hari\ x\ (40\ tahun\ x\ 365\ hari))}{57,14\ kg\ x\ 10950}}$$

$$\boldsymbol{= 0.000364 \text{ mg/kg/ day}}$$

**Table 4.** Intake Intake Pesticides on Green Mustard Farmers

| Sample | Intake Pesticide Farmer Vegetable Green Mustard (mg/kg/ day ) |
|---|---|
| Vegetable mustard green | 0.000364 mg/kg/ day |

Based on Table 4 is obtained results intake pesticides on farmers vegetable mustard green Ward Cursing of 0.000364 mg/kg/ day.

2) Analysis Dose Response

Analysis dose response used For set mark quantitative or dose something agent the risk that is made reference For safe value for body. In the analysis risk For oral route (ingestion) is stated with Reference Dose (RfD). RfD is the value that is used reference For safe value for non - carcinogenic effects something agent risk.

Dosage data general reference issued from EPA's No Observed Adverse Effect Level (NOAEL) is 0.03 mg/kg/ day For non- carcinogenic oral exposure to pesticides Chlorpyrifos (Smegal, 2020).

### 3.2 Characteristics Risk

Characteristics risk done For know level risk or danger from agents in the body exposed. Characteristics risk or RQ, if mark characteristics risk (RQ) ≤ 1 then man or exposed

population considered safe. If (RQ) ≥ 1 then man or exposed population considered No safe so must done control with management risk.

RQ=I/RfD

**Table 5.** Risk Level Pesticide Farmer Vegetable Green Mustard Greens Village Ngkari-ngkari Baubau City

| Sample | Risk Level Pesticide Farmer Green Mustard Greens (mg/kg) |
|---|---|
| Vegetable mustard green | 0.0121 mg/kg/ day |

Based on Table 5 Concentration Reference Dose of pesticide Chlorpyrifos on farmers vegetable mustard green obtained results calculation level risk (RQ) of exposure ingestion pesticide chlorpyrifos realtime namely 0.0121 mg/kg/ day. RQ value ≤ 1 then can it is said No risky.

### 3.3 Concentration Pesticide Vegetable Green Mustard in the Village Ngkari-ngkari Baubau City

Retrieval sample vegetable mustard green done two day after spraying in the sub-district Ngkari-ngkari Baubau City namely amount to One samples that have been represent all over plant mustard green.

Check up result Laboratory UHO Pharmaceutical residue pesticide chlorpyrifos and cypermethrin in samples vegetable mustard green in the sub-district Ngkari-ngkari Baubau City namely 0 mg/kg/ day or No detected / not detected There is remains residue pesticide chlorpyrifos and cypermethrin in samples vegetable mustard green in the sub-district Ngkari-ngkari Baubau City which shows sample under limit maximum residue. This is caused by several factor including time intervals between application pesticides and harvest namely the level of residue remaining in the plant influenced by the duration time between use pesticide and time harvest. During period beak time, pesticides can damaged or decompose become compounds that are not detected. According to research (Inayah et al., 2016). After spraying possibility the first one to be happen is wind will blow dew (droplets) spray results spraying pesticides, so that cause displacement pesticide to areas that are not expected. Although grains spray pesticide until to target area, distribution No Again evenly. If things This occurs during spraying herbicide, will happen death or damage to plants Another possibility that occurs with pesticides after sprayed is:

Go out or flow through surface. Maybe Because spraying too long in one area place or Because grains spray too much big, some from grains wetting spray leaf dripping to ground . Drops pesticide from title plant This can pollute environment.

Evaporation is when pesticide changed from form liquid into gas and then lost in the atmosphere. Photodecomposition, in which pesticides described become form that is not activated by light.

Absorption by particles land. As a result, the remaining pesticide buried inside land . Besides that, absorption material active pesticides by soil will make designed pesticides For control pests below surface land not enough effective.

Spread pesticide through the rain that reaches layer bottom land before pollute groundwater and river water sources . Whereas according to rainfall data from BMKG Baubau City in the month of December reached 459 times compared to the previous month previously .

Reaction chemistry , where molecules pesticide changed become form that is not active or No poisonous .

Reshuffle carried out by microorganisms land ; after sprayed with pesticides will enter to in body microorganisms .

Frequency and dosage use pesticide Where Farmers apply lower and more appropriate doses of pesticides to fish recommendations on the packaging label pesticide the resulting in residues that are below the laboratory detection limit . According to research There is a correlation between dose spraying and content pesticides that impact yields agriculture . Farmers measure pesticide before implemented use closing existing bottles than follow rule usage as stated on the packaging label . As a result , the concentration sprayed pesticides become more high and left residue on the results agriculture (Suluh et al., 2021). Meanwhile

according to Many factors can remove pesticide from vegetables . Amount residue pesticides on vegetables influenced by temperature , humidity , body microscopic , light sun , and types different pesticides . Use dose the right pesticide is also other factors that influence No existence residue pesticide or amount residue pesticides produced in mustard greens green .

Types and properties chemistry pesticides used is Chlorpyrifos and Cypermethrin Where chlorpyrifos is insecticide group non - systemic organophosphates that work when happen contact with skin , ingested ( intake) to stomach ), and inhaled ( enters to system breathing ). According to research If pesticides type This sprayed to plants , they only will stick to the part outside . Non- systemic pesticides No can enter or absorbed by the tissue plants and their residues only left outside plants and not durable because rainwater can remove it . Pests or insect only will dead If eat part surface affected plants pesticides . Meanwhile Cypermethrin is type material active in the pyrethroid group . Cypermethrin is group insecticides that have characteristic typical For control insect among others: effectiveness height ( as poison contact and stomach ), less toxic to mammals , and the disappearance effectiveness relatively fast (Dirgayana et al., 2017).

Test method performed on samples test with insert 100 micro liters of liquid pesticide so that detected material active chlorpyrifos while in the sample study No there is material active the or No detected . Time limit retention from standard pesticide chlorpyrifos 10,616 so No detected pesticide made from active chlorpyrifos and cypermethrin on plants vegetable mustard green . This is in line with research Muawanah et al. (2024) that results analysis residue pesticide chlorpyrifos and carbofuran from 16 samples vegetable with use Gas Chromatography Mass Spectroscopy (GCMS), obtained results negative based on time retention from standard pesticide carbofuran 4.79 and chlorpyrifos 12.51 show that determination residue pesticides in samples material 100% food is not detected existence residue pesticide type carbofuran and chlorpyrifos . Meanwhile according to Sensitivity level or minimum residual limit that can be read tool chromatography in the laboratory the is of 0.001 mg/kg. The results of inspection residue chlorpyrifos on the sample mustard green from Eggplant Market and Supermarket MTos is 0 mg/kg or No detected . However , for count estimate concentration residue pesticides , carried out use of literature data with level sensitivity tool For determine risk exposure ingestion in farmers vegetable mustard green in the sub-district Ngkari-ngkari Baubau City use method Analysis Environmental Health Risks (ARKL).

### 3.4 Distribution Age Farmer Vegetable Green Mustard in the Village Ngkari-ngkari Baubau City

Measurement age in study use questionnaire that is interview to farmers . Based on results research , found age farmer Ward Cursing namely 50 years . Age oldest farmer is 70 years old and the youngest namely 15 years . This is supported by research previously that The aged farmer young his physical more strong than older farmers old , but in matter set decisions , farmers who are more old own level maturity more tall besides That part child they contribute to land For help them do appropriately (Murdolelono, 2021) . This is in line with study Mahyuni (2015) that More farmers old of fifty very vulnerable year to poisoning pesticides . This is plus with fact that they has Work as sprayer during for years . This is can influential to exposure pesticide like disturbance cognitive , which is often happen along increase age and causes ability function brain marked decline with disturbance thinking , calculation , verbal communication , visual memory , and concentration . Some factor others , such as stress , anxiety , exercise memory , genetics , hormonal, environment , disease systemic , and infections , can also influence decline function cognitive (Siswanto et al., 2024).

### 3.5 Distribution Weight of Mustard Green Vegetable Farmers in the Village Ngkari-ngkari Baubau City

Based on research that has been carried out , the average measured body weight was obtained is 57.14 kg with range of 34 kg to 81 kg. In study this is what becomes respondents overall that is teenagers and adults . Based on research conducted by Noppakun (2022) state that Lots closely related pesticides with prevalence obesity . Some pesticide is material chemistry nuisance endocrine disruptors (EDCs). EDCs are material chemistry exogenous disturbances function hormones , obesogens , or lipid metabolism , which causes obesity .

When this , 105 pesticides has registered as EDC, one of them insecticides (46%) such as OC DDT, 2,4-D, aldrin, endosulfan , chlorpyrifos . A study find that EDC changes lipid metabolism , size and quantity fat cells , as well as hormones that regulate lust eating , preferences food and metabolism energy . However studies epidemiology about connection between exposure pesticides and obesity Still seldom done .

### 3.6 Duration Exposure & Frequency Exposure

Duration exposure is a farmer's age consume vegetable mustard green in unit year . Based on research that has been done , duration exposure longest farmer vegetable mustard green is 50 years and the least is 5 years .

Frequency exposure farmer vegetable mustard green Ward Ngkari-Ngkari is amount day in One year farmer consume . Research results show that farmer consume vegetable The longest mustard greens are 208 days and the least are 156 days . Frequency exposure become variables in study this . Value data frequency exposure obtained from results amount farmer consume vegetable mustard green in One year . Calculation frequency exposure done with a total of days in One year (365 days ) minus total days No consume in 1 week . Frequency data collection the in line with research conducted by Rachmidiani (2019) Where amount day in a year farmer consume vegetables . Frequency exposure farmer vegetable mustard green Ward Ngkari-Ngkari No can in the same average . Frequency data results farmer vegetable mustard green obtained from results interview with farmers who ask consumption vegetable mustard green in 1 week . Total consumption results used For count mark frequency . Calculation mark frequency done with amount day in One year minus total days No consume in One year .

### 3.7 Rate Ingestion

Rate suitable ingestion with study This is taken from (Ministry of Health Regulation, 2014) Number 41 about guidelines nutrition balanced that content substance Nutrition per serving (100 grams/ day ) is One portion vegetables mustard green is not enough more than 1 glass vegetables after cooked and drained . Rate ingestion farmer vegetable mustard green Ward Ngkari-ngkari Baubau City is 100 grams/ day . This is in accordance with study previously about intake Pakistani food shows that adults usually consume 750 grams of wheat (250 grams each day ), 100 grams of vegetables anything ( about 33.3 grams each) day ), and 100 grams of fish ( weight wet ) every day (Syed et al ., 2014) . Rate value intake This more low compared to with mark intake carried out research by ( Sinambela , 2024) with The average intake value is 1,505 grams/ day . The amount rate intake food influenced by the farmer who planted it vegetable mustard green on site study in a day stated through question in sheet questionnaire amount intake vegetable mustard green consumed in 1 week . If not enough from 1,505 grams/ day , then No cause symptom toxic which means , society only consume ¼ kg of vegetables which means No cause disease cancer.

### 3.8 Analysis Environmental Health Risks

1) Analysis Exposure

Based on results calculation intake value that has been done, then mark intake it is said under limit maximum residue, due to mark This No exceed mark RfD which is 0.0121 mg/kg/ day . Calculation This done comparison between mark intake with Reference Doses ( RfD ) that have been downgraded by NOAEL EPA via decline mark intake. Researchers previously obtained risk related health with fipronil residue in vegetables collected in Thua Thien Hue Province, with intake daily 46.10 mg/kg/ day, making consumer vegetables in the area be careful (Nguyen, 2022).

2) Characteristics Risk

Characteristics risk (RQ) aims For know big level risk from incoming exposure into the body man orally. Determination of RQ counted through comparison mark intake with mark RfD. If RQ $\geq$ 1, then exposure ingestion from pesticide own risk to disturbance health, whereas for RQ $\leq$ 1, then Still considered safe for health . Based on results calculation,

in study This obtained sample vegetable mustard green own RQ value ≤ 1 or can it is said No own risk to health. This is in line with study previously that From the results inspection level residue pesticides in the laboratory Testing South Sulawesi BPTPH Pesticides show that level residue pesticides in samples mustard green with material active Chlorpyrifos after the washing process is 0 mg/kg. Then level residue pesticides contained in the sample mustard green after the washing process still below BMR ( Maximum Limit ) Residue ) so that fulfil condition health. The results of the presence test residue pesticides in samples mustard green show that No There is content chlorpyrifos in the mustard said, however No means that mustard it is safe consumed. It is very important be alert possibility substances other pesticides besides chlorpyrifos which is still contained in it. This need noticed Because researchers only identify pesticides made from active chlorpyrifos just remember part big farmer vegetable No only spray One type pesticide only, but also other pesticides that can support growth plant the .

## 4. Conclusion

This study analyzed the environmental health risk of pesticide exposure among mustard green farmers in Ngkari-ngkari Sub-district, Baubau City. The results showed that pesticide residues, specifically Chlorpyrifos and Cypermethrin, were not detected in the samples (0 mg/kg/day). The average body weight of farmers was 57.14 kg, with a median exposure frequency of 156 days/year and a median exposure duration of 40 years. The average ingestion rate was estimated at 0.1 kg/day. The calculated pesticide intake was 0.000364 mg/kg/day, while the risk quotient (RQ) was 0.0121, both indicating that the farmers were not at significant risk of pesticide-related health effects.These findings support the research objective by demonstrating that current pesticide exposure levels among local mustard green farmers remain below hazardous thresholds. The synthesis of data suggests that although pesticides are widely used, the actual exposure risk for these farmers is minimal under current conditions. This aligns with previous reports emphasizing the importance of monitoring but also highlights that safe agricultural practices can reduce long-term health impacts.The implications of this research extend to public health and agricultural policy, as the results provide evidence that controlled pesticide use in mustard green farming does not necessarily pose immediate health risks. The study contributes to environmental health knowledge by offering baseline data on exposure risk specific to smallholder farmers in Baubau City, which can serve as a reference for future monitoring and policy development.However, this research has limitations. The analysis was limited to two pesticide types and relied on estimated ingestion rates without incorporating other possible exposure pathways such as dermal absorption or inhalation. Furthermore, the study was cross-sectional, which may not fully capture seasonal or long-term variations in pesticide use and exposure.Future research should expand the scope by analyzing a broader range of pesticides, integrating biomonitoring data, and applying longitudinal study designs. This would provide a more comprehensive assessment of pesticide exposure risks and strengthen preventive strategies for farmer health protection.

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