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Organophosphate Residues in Maize and Health Risk Implications in Selected Communities of Kogi State, Nigeria

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Abstract
The escalating dependence on synthetic pesticides for agricultural purposes in Nigeria has heightened apprehension regarding food safety and public health, especially in rural communities where regulatory oversight is limited. In Kogi State, maize, a principal dietary staple, is routinely exposed to chemical pesticides during cultivation and storage processes. This study investigated the concentration of organophosphate pesticide residues in maize and evaluated associated dietary health risks in four selected villages, Osara, Nagazi, Osara Gada, and Ogaminana. Composite maize samples were collected from farms, markets, and households and were analyzed using Gas Chromatography coupled with an Electron Capture Detector (GC-ECD), following the QuEChERS extraction protocol. The detected pesticides, including Dichlorvos, Chlorpyrifos, and Azinphos-methyl, were all identified as organophosphates. The mean concentrations of Dichlorvos (0.0448 µg/kg) and Chlorpyrifos (0.0449 µg/kg) were below the established FAO/WHO Maximum Residue Limits (MRLs) of 100 µg/kg and 50 µg/kg, respectively. Conversely, Azinphos-methyl recorded a mean concentration of 20.9966 µg/kg, slightly exceeding its MRL of 20 µg/kg. Health risk assessment based on Estimated Daily Intake (EDI) and Hazard Quotient (HQ) showed that Dichlorvos and Chlorpyrifos pose minimal risk (HQ<1), while Azinphos-methyl exhibited a HQ significantly above 1, indicating a potential for chronic health effects. The findings conclude that although most residues were within permissible limits, the presence of high-risk organophosphates such as Azinphos-methyl poses a concern for consumer safety. It is recommended that regular residue monitoring, farmer training on responsible pesticide use, and adoption of integrated pest management (IPM) be prioritized to enhance food safety in Kogi State.
Keywords: Pesticide Residues, Organophosphates, Maize, Health Risk Assessment, Kogi State

Introduction
Pesticides are indispensable to global agricultural productivity, playing a vital role in crop protection and yield optimization. In Nigeria and other low and middle-income countries, the widespread adoption of organophosphate pesticides is driven by their proven efficacy, affordability, and accessibility (Olawale et al., 2023). Compounds such as Dichlorvos, Chlorpyrifos, and Azinphos-methyl are routinely employed in the management of pests affecting cereal crops, particularly maize. However, the intensive and often unregulated use of these chemicals has raised concerns regarding environmental degradation, food safety, and public health. The persistence of residues in agricultural produce, especially maize, poses a significant risk of chronic toxicity, particularly when concentrations exceed the maximum residue limits (MRLs) established by international regulatory bodies such as FAO/WHO and Codex Alimentarius (Ogah et al., 2021). In Nigeria, weak pesticide regulations, inadequate farmer education, and noncompliance with pre-harvest intervals exacerbate this issue, allowing unsafe levels of residues to enter the food chain (Sosan et al., 2020). Kogi State, a key maize-producing region, exemplifies these challenges, with indiscriminate pesticide

application contributing to elevated levels of agrochemical exposure in both agricultural and market settings. Although organophosphate pesticides are widely effective against various pests, their prolonged ingestion, even at low concentrations, can pose serious health risks. These chemicals function by inhibiting acetylcholinesterase, a vital enzyme in the nervous system, resulting in neurotoxic effects, hormonal imbalances, and immune system disruptions (Nwanze et al., 2022). Azinphos-methyl, specifically, has been recognized by multiple regulatory agencies as moderately hazardous due to its persistence in the environment and tendency to bioaccumulate (FAO/WHO, 2021). In this study, maize samples from Kogi Central were found to contain Azinphos-methyl levels exceeding the Maximum Residue Limit (MRL), representing a significant health concern as indicated by a Hazard Quotient (HQ) well above the acceptable limit of 1. These results are consistent with the observations of Eniola et al. (2023), who also reported high HQ values for organophosphates in common food items in north-central Nigeria. Additionally, the lack of detection of other pesticide groups suggests a heavy dependence on organophosphates, which could contribute to the development of resistant pest populations and lead to persistent contamination of soil and water systems. Since maize is a staple food widely consumed on a daily particularly in rural areas. The likelihood of long-term exposure is significantly elevated (Adeleye et al., 2022). This study offers valuable preliminary data on the concentrations and associated risk profiles of pesticide residues in maize sourced from Osara, Nagazi, Osara Gada, and Ogaminana, four key farming communities in Kogi State. The detection of pesticide residues in post-harvest household maize underscores deficiencies in safe storage methods and indicates persistent contamination throughout the agricultural value chain. The finding that Azinphos-methyl levels surpass established regulatory thresholds further emphasizes the urgent necessity for governmental action to strengthen the regulation of pesticide distribution and usage in rural areas of Nigeria. There is a pressing demand for farmer education programs on integrated pest management (IPM), safer chemical alternatives, and adherence to pre-harvest intervals (Uka et al., 2021). Additionally, investment in pesticide residue surveillance infrastructure and enforcement of national food safety standards must be prioritized to protect public health. Future research should extend monitoring to other crops and agrochemical classes to provide a more comprehensive exposure profile for communities in Kogi State. Biomonitoring studies that assess pesticide biomarkers in humans could also validate estimated health risks and inform evidence-based policy decisions. This study, therefore, contributes meaningfully to the growing literature on food safety in Nigeria and sets the stage for multidisciplinary interventions that safeguard consumers from pesticide-related hazards.

Materials and Methods

Description of the Study Area

The study was conducted in four maize-producing villages in Kogi State, Nigeria: Osara, Nagazi, Osara Gada, and Ogaminana. These communities are located in the Guinea savannah ecological zone and are characterized by seasonal rainfall, subsistence farming practices, and routine pesticide use. The selection of these villages was based on their agricultural significance and reported pesticide application trends, making them suitable for monitoring pesticide residue levels in maize.

Sample Collection and Handling

Maize samples were collected using a stratified random sampling technique. In each village, four composite samples were obtained from local farms, markets, and household stores. Each composite consisted of sub-samples pooled from different locations to represent the typical maize consumption pattern in the area. The samples were collected into sterile, labeled polyethylene bags and transported in ice-cooled containers to maintain sample integrity. Upon arrival at the laboratory, samples were stored at –20°C before analysis.

Extraction and Pesticide Residue Analysis

Pesticide residues were extracted using the QuEChERS method, optimized for cereal matrices. Briefly, 10 g of homogenized maize sample was weighed into a 50 mL centrifuge tube, and 10 mL of acetonitrile was added. The mixture was vortexed and treated with 4 g $MgSO_4$ and 1 g NaCl. After centrifugation, 6 mL of the supernatant was cleaned with dispersive SPE (150 mg PSA + 900 mg $MgSO_4$). The cleaned extract was then concentrated and analyzed using Gas Chromatography equipped with an Electron Capture Detector (GC-ECD). Quantification was done using calibration curves constructed from known standards of Dichlorvos, Chlorpyrifos, Azinphos-methyl, Disulfoton, and Ronnel. The concentration of pesticide residue was calculated as:

$$\text{Residue concentration } (\mu g/kg) = \frac{A_s}{A_{std}} \times C_{std} \times \frac{V_{final}}{W_s}$$

Where

- A_s = the peak area of the sample
- A_{std} = peak area of the standard
- C_{std}= concentration of standard (µg/mL)
- $V_{final} = Final\ volume\ of\ extract\ (mL)$
- W_g =Weight of sample extracted (kg)

Recovery studies were conducted by spiking maize samples with known pesticide concentrations, and were calculated as

$$\text{Recovery } (\%) = \left(\frac{C_{found}}{C_{spiked}}\right) \times 100$$

Quality Control and Assurance

To ensure analytical reliability, all glassware was acid-washed and rinsed with deionized water. Analytical-grade solvents and certified reference materials were used throughout. Method validation was performed via recovery tests, and procedural blanks were included in each batch. All sample analyses were done in triplicate, and GC-ECD calibration was verified daily using standard mixtures. The instrument's detection limits were confirmed to be well below international MRLs, ensuring sensitivity for trace-level detection.

Health Risk Assessment

Health risk was evaluated by calculating the Estimated Daily Intake (EDI) and the Hazard Quotient (HQ) for each pesticide.

$$\text{EDI } (\mu/kg/bw/day) = \frac{C_r \times IR}{BW}$$

Where

- C_r= mean residue concentration in maize (µg/mg)
- IR= ingestion rate (400 g/day or 0.4 kg/day)
- BW= Average body weight (60 kg)

The Hazard Quotient (HQ0 was computed to assess risk severity

$$HQ = \frac{EDI}{ADI}$$

Where

- ADI $= Acceptable\ Daily\ Intake$ (µg/kg bw/day)
- HQ > 1: Indicates potential health risk
- HQ < 1: Implies the negligible risk

These calculations allowed for a quantitative assessment of chronic dietary exposure to organophosphate pesticides via maize consumption.

Data Analysis

Descriptive statistics, including mean, minimum, maximum, standard deviation (SD), and standard error of the mean (SEM), were calculated using Microsoft Excel and SPSS Version 25. Pesticide concentrations were compared against FAO/WHO Maximum Residue Limits (MRLs). Results were presented in tabular formats to highlight residue distributions and potential health implications across the studied communities.

Results

Classification and Typical Use of Pesticides Detected in Maize Samples

Table 1 outlines five pesticides detected or monitored in maize samples from the study area, classified by their chemical group and functional role. All listed compounds belong to the organophosphate chemical class, which is known for its potent neurotoxic effects and widespread use in agriculture. The typical use for most Dichlorvos, Chlorpyrifos, Azinphos-methyl, and Ronnel is as contact or ingestion-based insecticides, used to manage chewing and sucking insect pests. Disulfoton differs slightly in that it is applied as a systemic insecticide, absorbed into plant tissues to offer internal protection. This table provides a foundational understanding of the chemical nature and role of pesticides prevalent in maize cultivation in Kogi State

Table 1: Classification and Typical Use of Pesticides Detected in Maize Samples from Four Villages in Kogi State, Nigeria

S/N	Pesticide Name	Chemical Class	Typical Use
1	Dichlorvos	Organophosphate	Insecticide
2	Chlorpyrifos	Organophosphate	Insecticide
3	Azinphos-methyl	Organophosphate	Insecticide
4	Disulfoton	Organophosphate	Systemic Insecticide
5	Ronnel	Organophosphate	Insecticide

Mean Concentration (±SEM) of Pesticide Residues Detected in Maize Samples

Table 1 presents the average concentrations of three commonly detected pesticide residues Dichlorvos, Chlorpyrifos, and Azinphos-methyl, in maize samples collected from four villages in Kogi State. The data are expressed as mean values accompanied by the standard error of the mean (±SEM), allowing assessment of both central tendency and variability in the residue levels. The measured concentrations are compared with international Maximum Residue Limits (MRLs) to determine compliance with food safety standards. Dichlorvos and Chlorpyrifos were recorded at 0.0448 µg/kg and 0.0449 µg/kg, respectively, which are below their Maximum Residue Limits (MRLs) of 100 µg/kg and 50 µg/kg. Azinphos-methyl showed a mean concentration of 20.9966 µg/kg, slightly above the MRL of 20 µg/kg. The standard error for Dichlorvos and Chlorpyrifos was small, indicating consistent levels across samples. Azinphos-methyl had a larger standard error, suggesting greater variability in concentration among the villages

Table 2: Mean Concentration (±SEM) of Pesticide Residues Detected in Maize Samples Collected from Four Villages in Kogi State, Nigeria

Pesticide	Mean Residue (µg/kg) ± SEM	Maximum Residue Limit (MRL, µg/kg)	MRL Status
Dichlorvos	0.0448 ± 0.0033	100	Below MRL
Chlorpyrifos	0.0449 ± 0.0026	50	Below MRL
Azinphos-methyl	20.9966 ± 0.9198	20	Above MRL

Village-Level Distribution of Pesticide Residues (µg/kg) in Maize Samples

Table 2 provides a breakdown of the individual pesticide concentrations recorded in maize samples across the four surveyed villages: Osara, Nagazi, Osara Gada, and Ogaminana. This table facilitates the identification of geographic differences in pesticide contamination and provides insight into village-specific residue profiles for Dichlorvos, Chlorpyrifos, and Azinphos-methyl. Dichlorvos values ranged from 0.0385 µg/kg to 0.0562 µg/kg. Chlorpyrifos ranged between 0.0398 µg/kg and 0.0512 µg/kg. Azinphos-methyl levels were highest in Osara (23.4309 µg/kg) and lowest in Osara Gada (18.7751 µg/kg). All villages recorded detectable amounts of the three pesticides. Azinphos-methyl concentrations exceeded the MRL in at least one location.

Table 3: Village-Level Distribution of Pesticide Residues (µg/kg) in Maize Samples from Selected Locations in Kogi State, Nigeria

Village	Dichlorvos	Chlorpyrifos	Azinphos-methyl
Osara	0.0434	0.0465	23.4309
Nagazi	0.0385	0.0421	20.1183
Osara Gada	0.0562	0.0512	18.7751
Ogaminana	0.0409	0.0398	19.6623

Descriptive Summary of Pesticide Residue Levels in Maize from Four Villages in Kogi State

Table 3 summarizes descriptive statistics, including mean, minimum, maximum, standard deviation (SD), and standard error of mean (SEM) for each pesticide residue across the four sampling locations. This statistical overview is crucial for understanding the distribution and variability of each pesticide within the study area. Dichlorvos had a mean of 0.0448 µg/kg, minimum 0.0385 µg/kg, and maximum 0.0562 µg/kg, with a standard deviation of 0.0066. Chlorpyrifos had a mean of 0.0449 µg/kg, a minimum of 0.0398 µg/kg, and a maximum of 0.0512 µg/kg. Azinphos-methyl had a mean of 20.9966 µg/kg, a minimum of 18.7751 µg/kg, and a maximum of 23.4309 µg/kg. The standard deviation and standard error for Azinphos-methyl were higher than those of the other pesticides, indicating wider variability in residue levels.

Table 4: Descriptive Summary of Pesticide Residue Levels in Maize from Four Villages in Kogi State

Pesticide	Mean (µg/kg)	Minimum	Maximum	Standard Deviation	Standard Error
Dichlorvos	0.0448	0.0385	0.0562	0.0066	0.0033
Chlorpyrifos	0.0449	0.0398	0.0512	0.0052	0.0026
Azinphos-methyl	20.9966	18.7751	23.4309	1.8396	0.9198

Comparison of Detected Pesticide Residue Levels in Maize Samples with FAO/WHO Maximum Residue Limits (MRLs)

Table 4 compares the measured pesticide residue levels in maize samples with the respective Maximum Residue Limits (MRLs) recommended by the Food and Agriculture Organization (FAO) and World Health Organization (WHO). This comparative table serves as a regulatory compliance check for each pesticide in the study. Dichlorvos (0.0448 µg/kg) and Chlorpyrifos (0.0449 µg/kg) were within their MRLs of 100 µg/kg and 50 µg/kg. Azinphos-methyl (20.9966 µg/kg) exceeded its MRL of 20 µg/kg. The table indicates compliance status based on these comparisons.

Table 5: Comparison of Detected Pesticide Residue Levels in Maize Samples with FAO/WHO Maximum Residue Limits (MRLs)

Pesticide	Mean Residue (µg/kg)	MRL (µg/kg)	Compliance Status
Dichlorvos	0.0448	100	Compliant
Chlorpyrifos	0.0449	50	Compliant
Azinphos-methyl	20.9966	20	Non-Compliant

Estimated Daily Intake (EDI), Acceptable Daily Intake (ADI), and Hazard Quotient

(HQ) for Pesticide Residues Detected in Maize

Table 5 presents a quantitative health risk assessment based on Estimated Daily Intake (EDI), Acceptable Daily Intake (ADI), and Hazard Quotient (HQ) values for each pesticide. These calculations are used to evaluate potential chronic exposure risks associated with consuming maize contaminated with pesticide residues. Dichlorvos and Chlorpyrifos had EDIs of 0.00179 µg/kg bw/day and 0.00180 µg/kg bw/day, respectively, with HQs of 0.00045 and 0.00018. Azinphos-methyl had an EDI of 0.83986 µg/kg bw/day and an HQ of 41.99. The HQs for Dichlorvos and Chlorpyrifos were below 1, while Azinphos-methyl's HQ was well above 1.

Table 6: Estimated Daily Intake (EDI), Acceptable Daily Intake (ADI), and Hazard Quotient (HQ) for Pesticide Residues Detected in Maize Consumed by Adults in Kogi State

Pesticide	EDI (µg/kg bw/day)	ADI (µg/kg bw/day)	HQ (EDI/ADI)	Health Risk Interpretation
Dichlorvos	0.00179	4.0	0.00045	No risk (HQ < 1)
Chlorpyrifos	0.00180	10.0	0.00018	No risk (HQ < 1)
Azinphos-methyl	0.83986	0.02	**41.99**	**High risk (HQ > 1)**

Assumptions: 0.4 kg/day maize consumption, 60 kg adult body weight.

Pesticide Detection Frequency and Occurrence Range in Maize Samples from Four Villages in Kogi State

Table 6 presents the detection frequency and the range of residue concentrations observed for each pesticide in the maize samples. This provides an overview of how widespread and variable each pesticide was across the study area. Dichlorvos, Chlorpyrifos, and Azinphos-methyl were detected in 100% of the maize samples. Dichlorvos ranged from 0.0385 µg/kg to 0.0562 µg/kg. Chlorpyrifos ranged from 0.0398 µg/kg to 0.0512 µg/kg. Azinphos-methyl ranged from 18.7751 µg/kg to 23.4309 µg/kg.

Table 7: Pesticide Detection Frequency and Occurrence Range in Maize Samples from Four Villages in Kogi State

Pesticide	Detection Rate (%)	Min Detected (µg/kg)	Max Detected (µg/kg)
Dichlorvos	100	0.0385	0.0562
Chlorpyrifos	100	0.0398	0.0512
Azinphos-methyl	100	18.7751	23.4309

Summary of Village-Level Health Risks Associated with Pesticide Residues in Maize

Table 7 identifies villages where pesticide residue levels exceeded MRLs or where the Hazard Quotient (HQ) was greater than 1. Azinphos-methyl exceeded safety limits in Osara, Nagazi, and Ogaminana. Osara Gada showed no exceedance. HQ values for Azinphos-methyl were 43.7 in Osara, 40.6 in Nagazi, and 39.4 in Ogaminana. This allows for spatial assessment of public health risk related to maize consumption in the four surveyed locations.

Table 8: Summary of Village-Level Health Risks Associated with Pesticide Residues in Maize

Village	Pesticides Above MRL or HQ > 1	Notable Risk Agent	Public Health Concern
Osara	Azinphos-methyl	HQ = 43.7	Yes
Nagazi	Azinphos-methyl	HQ = 40.6	Yes
Osara Gada	None	None	No
Ogaminana	Azinphos-methyl	HQ = 39.4	Yes

Discussion

Classification and Typical Use of Pesticides Detected in Maize Samples

The dominance of organophosphate (OP) pesticides such as Dichlorvos, Chlorpyrifos, Azinphos-methyl, Disulfoton, and Ronnel in maize agriculture in Kogi State, Nigeria, aligns with global trends in pesticide reliance within low and middle-income countries. Organophosphates are favored for their acute neurotoxicity against a broad spectrum of insect pests and their relatively rapid degradation compared to persistent organochlorines (Hasan & Das, 2022; Lutterodt et al., 2022). Dichlorvos and Chlorpyrifos are particularly effective against foliar-feeding pests and have been widely adopted due to their cost-effectiveness and efficacy (Mdeni et al., 2022). However, the classification of Disulfoton as a systemic insecticide highlights a growing shift towards persistent and internalized chemical defenses in crops, which may result in prolonged consumer exposure (Adeniji et al., 2022). The global regulatory trend is moving away from organophosphates due to mounting evidence of their health effects, including neurodevelopmental impairments and endocrine disruption (Okoffo et al., 2021; Tarbill et al., 2005). Nonetheless, in many African nations, these chemicals are still in use due to regulatory gaps, lack of farmer training, and insufficient pesticide alternatives.

Mean Concentration (±SEM) of Pesticide Residues Detected in Maize Samples

The quantified levels of Dichlorvos and Chlorpyrifos below their MRLs reflect acceptable residue management practices in parts of Kogi State. However, the Azinphos-methyl concentration (20.9966 µg/kg) slightly exceeding its 20 µg/kg MRL raises significant food safety concerns. This deviation, albeit numerically small, is epidemiologically significant given the pesticide's neurotoxicity (Stan, 1990). The small standard error values for Dichlorvos and Chlorpyrifos suggest homogenous distribution across samples, indicative of standardized application practices or environmental persistence (Mwila, 2012). In contrast, Azinphos-methyl's high variability may reflect inconsistent application practices or differing maize storage and pest control techniques. Studies in South Africa and Ghana similarly document pesticide residue fluctuations across sites, often linked to localized agricultural training and pesticide accessibility (Quinn et al., 2011; Mdeni et al., 2022). Despite the regulatory thresholds, long-term consumption of even sub-threshold levels of OPs has been linked to cognitive effects and neurobehavioral changes (Perry et al., 2013; LaVerda, 2013), hence regular surveillance and farmer sensitization remain critical.

Village-Level Distribution of Pesticide Residues

Village-level data offers important insights into the spatial heterogeneity of pesticide contamination. Osara reported the highest Azinphos-methyl concentration (23.43 µg/kg), exceeding the FAO/WHO MRL. This geographic disparity may stem from differing pest pressures or cultural practices in pesticide storage and application. For instance, Osara Gada, with the lowest Azinphos-methyl levels (18.77 µg/kg), might practice either reduced pesticide application or possess better handling protocols (Adeniji et al., 2022; Mdeni et al., 2022). Comparative research in Ethiopia and Bangladesh revealed similar rural discrepancies in pesticide residues, often driven by knowledge gaps or inadequate personal protective equipment (Hasan & Das, 2022; Rainbow & Phillips, 1994). The close concentration range of Dichlorvos and Chlorpyrifos across villages might be due to their volatility and atmospheric spread, reflecting their use not only in agriculture but also in domestic pest control (Dem, 2004). These findings highlight the importance of localized intervention strategies, including village-specific training and monitoring programs.

Descriptive Summary of Pesticide Residue Levels in Maize from Four Villages in Kogi State

Descriptive statistics of pesticide residues offer vital insights into contamination consistency and variability. The mean and standard deviation for Dichlorvos (0.0448 ± 0.0066 μg/kg) and Chlorpyrifos (0.0449 ± 0.0052 μg/kg) indicate stable contamination levels, suggesting regular and perhaps standardized usage across sampled villages. However, the broader standard deviation in Azinphos-methyl (1.8396) points to erratic application practices or environmental persistence, further raising health risk flags due to its above-MRL presence (LaVerda, 2013; Yess et al., 1991). Other studies reinforce that pesticides with high lipophilicity and bioaccumulation potential, like Azinphos-methyl, often show increased variability due to uneven environmental degradation or plant uptake rates (Adeniji et al., 2022; Tarbill et al., 2005). In maize-growing regions across sub-Saharan Africa, similar variability has been observed due to unregulated pesticide markets, inadequate extension services, and seasonal pest outbreaks leading to inconsistent application rates (Mdeni et al., 2022; Quinn et al., 2011). This emphasizes the urgent need for harmonized usage protocols and robust farmer education programs.

Comparison with FAO/WHO Maximum Residue Limits (MRLs)

Comparison with FAO/WHO MRLs reveals a critical public health divide: while Dichlorvos and Chlorpyrifos levels are compliant, Azinphos-methyl exceeds safe thresholds. This deviation, even if minor, violates food safety norms and demands policy redress. MRLs are designed to prevent chronic exposure effects, especially for vulnerable populations such as children and pregnant women (Perry et al., 2013). Azinphos-methyl's neurotoxicity and suspected endocrine-disrupting properties compound this issue (SNl4y3Mhu7cJ, 2013). Cross-country evaluations, including maize samples from Ghana and Bangladesh, have also flagged Azinphos-methyl exceedances, correlating with improper storage, low awareness, and the lack of post-application withholding periods (Hasan & Das, 2022; Mdeni et al., 2022). The presence of residues below MRLs for other pesticides, while technically compliant, still calls for risk minimization considering cumulative exposure effects from multiple pesticide types—an aspect not captured by current MRL frameworks (Stan, 1990).

Estimated Daily Intake (EDI), Acceptable Daily Intake (ADI), and Hazard Quotient (HQ)

Health risk assessments using Estimated Daily Intake (EDI) and Hazard Quotient (HQ) show a stark contrast between Azinphos-methyl and the other two pesticides. Dichlorvos and Chlorpyrifos yield HQs well below 1, denoting negligible risk. However, Azinphos-methyl shows a dangerously elevated HQ of 41.99—far beyond safety thresholds—signaling a major chronic exposure hazard (Lutterodt et al., 2022; WHO/FAO, 2023). This disparity could stem from the systemic nature of Azinphos-methyl and its prolonged retention in plant tissues, especially when applied during the grain-filling phase. Similar studies in South Asia and West Africa confirm the disproportionate health risks of systemic OPs when ADI is exceeded, linking them with increased incidences of neurodegenerative disorders and reproductive toxicity (Adeniji et al., 2022; Mdeni et al., 2022). The EDI calculation, based on an assumed daily maize consumption of 0.4 kg/day, may even underestimate risk for maizedependent rural populations where intake exceeds this baseline.

Pesticide Detection Frequency and Occurrence Range in Maize Samples

The uniform detection rate (100%) of all three pesticides across villages signifies widespread and consistent pesticide use. Although detection alone doesn't equate to toxicity, it highlights pervasive agricultural dependence on chemical pest control. This prevalence raises concerns over environmental buildup and bioaccumulation, especially in soils and water sources where runoffs concentrate these agents (Rainbow & Phillips, 1994; Dem, 2004). The narrow range for Dichlorvos and Chlorpyrifos (approx. 0.0385–0.0562 µg/kg) may reflect uniformity in their application, possibly for stored grain protection. Conversely, Azinphos-methyl's broader range (18.7751–23.4309 µg/kg) again signals less controlled use or variable degradation rates under different environmental conditions. These findings support calls from public health researchers for integrated pest management (IPM) to reduce reliance on hazardous chemicals and ensure safe residue levels in staple foods (Tarbill et al., 2005; Quinn et al., 2011).

Summary of Village-Level Health Risks Associated with Pesticide Residues in Maize

The health risk summary identifies Osara, Nagazi, and Ogaminana as zones with critically high hazard levels due to Azinphos-methyl. The hazard quotient values (HQ > 39) in these locations vastly exceed safe margins, indicating a systemic public health threat (FAO/WHO, 2023). Osara Gada appears to be an exception, likely due to either better agricultural practices or lower application frequencies. These spatial distinctions underscore the need for place-based interventions. Education, regulation, and enforcement must be targeted at high-risk communities where informal pesticide markets and low literacy combine to exacerbate exposure risks (Okoffo et al., 2021). Risk mapping studies in sub-Saharan Africa have advocated for geospatial health risk zoning as a policy tool to prioritize mitigation (Hasan & Das, 2022; Adeniji et al., 2022).

Conclusion

This study assessed the presence, distribution, and health implications of pesticide residues in maize samples collected from four villages in Kogi State, Nigeria. The analysis revealed widespread contamination by organophosphate pesticides, specifically Dichlorvos, Chlorpyrifos, and Azinphos-methyl. While the residue levels of Dichlorvos and Chlorpyrifos were within acceptable limits set by international regulatory bodies, Azinphos-methyl exceeded its Maximum Residue Limit (MRL) in multiple locations. Health risk assessment based on Estimated Daily Intake (EDI) and Hazard Quotient (HQ) indicated no immediate risk from Dichlorvos and Chlorpyrifos; however, Azinphos-methyl posed a significant health concern with HQ values far above the safety threshold of 1. The uniform detection of organophosphate residues across all sites and the lack of diversity in pesticide classes suggest limited adoption of safer or integrated pest management practices. The findings underscore the urgent need for stronger pesticide regulation, farmer sensitization, and regular residue monitoring. Promoting safer alternatives and enforcing appropriate withdrawal periods before harvest can reduce exposure risks. This study provides critical baseline data for food safety surveillance in the region and highlights the importance of protecting public health through sustainable and responsible pesticide use in agriculture.

Recommendations for Further Studies

Based on findings from Osara Village, Nagazi, Osara Gada, and Ogaminana in Kogi Central of Kogi State, further studies should expand pesticide residue analysis to other commonly consumed crops such as rice, okro, beans, and vegetables. This broader surveillance will provide a more comprehensive understanding of contamination patterns across the local food system. Additionally, biomonitoring studies involving residents and farmers should be conducted to assess internal exposure levels through biological samples like blood or urine. Such investigations are essential for validating the health risks posed by pesticides like Azinphos-methyl, which exceeded safety thresholds in this study. These efforts will generate critical data to guide public health interventions, inform regional food safety policies, and promote the adoption of safer agricultural practices in Kogi State and similar agro-ecological settings.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this research.

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