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Koozakar

GLOBAL JOURNAL OF ENVIRONMENTAL SCIENCE & SUSTAINABILITY

# Organochlorine Pesticide Residues and Associated Health Risks in Nigerian Rice Samples: Implications for Food Safety and Environmental Policy

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## Article Information

https://doi.org/10.69798/62628184

**ISSN (Online):** 3066-3660


**Published by:** Koozakar LLC. Norcross GA 30071, United States.


**Edited by:** Oluseye Oludoye PhD

## Abstract

This study assessed OCP residues in rice grains and soils from various rice-producing regions in Nigeria, aiming to estimate human exposure and associated health risks from rice consumption. Samples were collected from Hadejia (Jigawa), Makwaro (Kano), Pategi (Kwara), Igbemo (Ekiti), Isoku (Ogun), and Akeke (Edo) using a stratified random sampling technique. Gas Chromatography-Mass Spectrometry (GC-MS) analysis revealed α-Lindane, β-Lindane, γ-Lindane, and δ-Lindane were only present in rice from Ogun, while Endosulfan II was detected across all locations, with concentrations ranging from 1.819 mg/kg in Igbemo rice to 20.706 mg/kg in Costus rice from Kano. Other OCPs, such as Aldrin and Dieldrin, also varied significantly across regions, with Aldrin levels peaking at 0.224 mg/kg in Ogun. The analysis highlighted substantial non-carcinogenic risks associated with OCP exposure, particularly in Ogun and Kano, with Heptachlor presenting the highest Target Hazard Quotient (THQ) values. The Lifetime Cancer Risk (LCR) analysis showed Ogun with the highest cumulative risk at 0.016107, indicating a critical public health concern. Overall, the findings underscore the urgent need for monitoring and regulatory measures to mitigate OCP exposure risks in rice consumption, particularly in regions where LCR and THQ values exceed safety thresholds.

**Keywords:** Paddy field contamination, Organochlorine Pesticides (OCPs), Rice grains, Health-risk

## INTRODUCTION

Organochlorine pesticides (OCPs) are persistent environmental pollutants with great potential to bioaccumulate in the food chain, posing significant health and ecological risks (Darko and Acquaah, 2007; Bhupander *et al.*, 2011; Chen *et al.*, 2014). OCPs, such as DDT, remain in the environment for decades, contaminating soil, water, and crops even long after their use has been banned (Keswani *et al.*, 2022). These chemicals have been linked to adverse health outcomes, including cancer, reproductive disorders, and neurodevelopmental delays, particularly in populations reliant on agriculture (Njoku *et al.*, 2019; Omoyajowo *et al.*, 2022; Bhoi *et al.*, 2023; Oshatunberu *et al.*, 2023). Their complex regulatory history, combined with their continued presence in the environment despite bans, necessitates vigilant monitoring to protect public health and ecosystems from their lingering effects (Darko and Acquaah, 2007; Bhoi *et al.*, 2023). Monitoring OCP residues in food is critical for ensuring compliance with food safety regulations and aligns with global initiatives such as the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 12 (Responsible Consumption and Production). This monitoring is essential for identifying and mitigating health risks, particularly in regions where rice is a staple food and popularly produced or domesticated.

Rice is a major staple food in Nigeria, enjoyed across all geopolitical zones and socioeconomic classes. Approximately 57% of the 6.7 million metric tons consumed annually are produced locally (KPMG, 2019). With a population of about 227,882,945, projected to rise by 58% to 359,185,556 by 2050 (WHO, 2021), Nigeria is the largest rice producer in West Africa. As consumers become more health-conscious, many prefer local rice varieties like Ofada for their higher nutrient content (KPMG, 2019). Beyond its nutritional value, rice is a precious commodity cherished by all Nigerians. It is often given as a gift during festive periods, donated by non-profits, or distributed by politicians during times of economic tension or for personal reasons. However, the country faces significant challenges related to national and food insecurity, which are exacerbated by border crises and the widespread sale of cheap, harmful chemicals to farmers for crop application. In response, the government is expected to prioritize sustainable agricultural initiatives through targeted policies designed to educate farmers and improve food security. More concerning is that research indicates that rice, as a paddy crop, is particularly susceptible to accumulating contaminants including OCPs (Watson and Gustave, 2022).

The health risks posed by OCP exposure are well documented. OCPs are known endocrine disruptors that interfere with hormonal systems, causing dysfunctions that can lead to developmental, reproductive, and immune system disorders (Omoyajowo *et al.*, 2018; WHO, 2019). OCPs bind Na+ channels in neurons increasing Na permeability (Rajak *et al.*, 2023). Chronic exposure to chemicals like DDT has been linked to increased risks of cancer, diabetes, and neurological disorders, making the health-risk assessment of OCP residues in food a critical public health concern (Alani *et al.*, 2019; Silva *et al.*, 2019; Adedokun *et al.*, 2023). In Nigeria, where rice is widely consumed, assessing pesticide residues in locally grown rice is crucial for estimating potential human exposure and long-term health risks, particularly for vulnerable populations.

Food contamination with pesticides is a global issue that puts the global population at risk. Several studies have reported high exceedances of pesticide residues across diverse food commodities in Nigeria (Omoyajowo *et al.*, 2018, Njoku *et al.*, 2019; Omoyajowo *et al.*, 2022). The widespread detection of pesticide residues in various food commodities in Nigeria suggests significant contamination of the food supply, raising serious public health concerns. Generally, pesticides have been detected in a variety of foods across different creeds and culture; vegetables (Njoku *et al.*, 2019), fruits (Omoyajowo *et al.*, 2018), fish (Bhoi *et al.*, 2023), meat (Darko and Acquaah, 2007), diary (Schopf *et al.*, 2023), beverages (Chen *et al.*, 2014), yam and cassava (Adedokun *et al.*, 2023). The fact that residues of pesticides have been detected in different studies and geographical locations suggests that the incursion of pesticides in the food chain indicates systemic issues in agricultural practices and regulatory oversight, and practically suggests the reality of bioaccumulation of pesticides in the food chain via agricultural soil and the environment.

Agricultural soils contaminated with OCPs, and heavy metals exacerbate food safety risks. Contaminated soil serves as a reservoir for these pollutants, which can be absorbed by crops and enter the human food chain (Amiolemen *et al.*, 2024). The co-occurrence of heavy metals and pesticides in agricultural soils can increase the toxicity and health risks associated with dietary exposure, leading to a higher incidence of non-communicable diseases such as cardiovascular and kidney disorders (Lee *et al.*, 2017; Omoyajowo *et al.*, 2018; Omoyajowo *et al.*, 2022). Continuous monitoring of pesticide residues and heavy metal contamination in food crops is therefore essential for mitigating health risks and promoting sustainable agricultural practices. This is especially important in regions where rice and other staple crops are grown in proximity to areas with historical pesticide use.

Studies have emphasized the need for effective environmental management by promoting alternative agricultural practices, such as organic farming. Organic farming has been shown to reduce pesticide residues in crops and improve food quality. Whilst public awareness campaigns and farmer education programs have been documented to inform consumers and agricultural communities about the risks associated with pesticide exposure (Adesuyi *et al.*, 2018; Njoku *et al.*, 2019; Omoyajowo *et al.*, 2024).
Given the devastating health implication of consuming pesticide-contaminated foods, this study is poised to assess the levels of organochlorine pesticide (OCP) residues in Nigerian-grown rice grains and soils from various rice-producing regions, and to estimate the associated human exposure and health risks related to the consumption of local rice samples.

## MATERIALS AND METHODS

### Sample Collection and Study Areas

Agricultural soil and mature rice grain samples were systematically collected from predominant accessible areas of rice production in Hadejia (Jigawa), Makwaro (Kano), Pategi (Kwara), Igbemo (Ekiti), Isoku (Ogun), and Akeke (Edo). Nigeria has a population of about 200 million people, and 84 million hectares of arable land, with only 40% of this under cultivation and one of the largest consumers of rice globally, depending on rice for more than 20% of their daily calorie (KPMG, 2019). The sampling followed a stratified random sampling technique to ensure representative data from different geographic and agronomic conditions within each state. Using a soil auger and following the soil sampling protocols and guidelines by Carter and Gregorich (2007), soil samples were collected at depths of 0-15 cm for surface soil and 15-30 cm for subsurface soil, with the auger being rinsed and cleaned between each collection to prevent cross-contamination. Each rice paddy field was divided into nine (9) uniform grids based on soil topography and historical land use, from which matured rice grains and soil samples were collected and combined into composite samples representative of each field; GPS coordinates were recorded for each site. A total of 108 samples (54 local rice and 54 soil samples) were carefully collected at harvest stage, and stored in clean, labelled plastic bags at room temperature to prevent cross-contamination. The collected samples were divided into smaller pieces and air-dried on paper for approximately two hours to remove excess moisture before further analysis. All sampling activities, including surveys, were conducted from May ─ December 2022.


**Figure 1:** Map of Study Area showing Sampling Locations

### Determination of Organochlorine Pesticide (OCPs) Residues: Gas chromatography–mass spectrometry (GC–MS)

GC-MS analysis was done at CTX-ION Laboratory, Ikeja, Lagos. The analysis of organochlorine pesticides (OCPs) involved several key steps to ensure accurate quantification and detection limits. Following the US EPA method, 30g of soil sample was weighed into a 400 ml beaker to avoid volatile extractable losses. The wet soil samples were mixed with anhydrous sodium sulfate until free flowing, followed by ultrasonic extraction for 20 minutes with 100ml of 1:1 methylene chloride: acetone solution. Subsequently, the extracts were decanted, filtered, dried using a drying column with sodium anhydrous sulfate, and concentrated to 1ml in a K-D apparatus before transferring to a GC vial for analysis (US. EPA, 1983)

For calibration, standard solutions ranging from 5ppm to 200ppm were prepared using graduated microliter syringes. Each standard solution was transferred to individual vials for calibration, starting from a blank and progressing through each concentration standard. The solutions were introduced into the GC-MS instrument according to operation guidelines, recording mass spectrometry signals and chromatograms for each standard concentration, from lowest to highest.

Instrumentation details included the use of an Agilent 7820A gas chromatograph coupled to a 5975C inert mass spectrometer with an electron-impact source. The GC column was an HP-5 capillary column coated with 5% Phenyl Methyl Siloxane, with specific parameters set for carrier gas flow, injection temperature, and oven temperature programming. The mass spectrometer operated in electron-impact ionization mode at 70eV in SIM mode to ensure detection of target OCP constituents. Quality control measures include the use of reagent blanks and method blanks for each analytical batch, verification of analytical system performance with standard samples, establishment of calibration curves, and auto-tuning with perfluorotributylamine (PFTBA) before sample analysis. These measures aimed to mitigate potential sources of contamination and ensure accurate and reliable results.

**Health Risk Assessment Estimates**

The U.S. Environmental Protection Agency (USEPA) health risk assessment method is a widely used model for evaluating nature and the possible adverse health effects of exposure to carcinogenic and noncancerous chemicals, applicable to almost all conditions of exposure of humans to toxic substances (USEPA, 1989; Kader *et al.*, 2023; Omoyajowo *et al.*, 2024c).To evaluate the significant contribution of organochlorine pesticides in rice and its influence on rice consumption, estimated daily intake (EDI) was calculated using Equation 1 (USEPA, 1989; Watson & Gustave, 2022). Target hazard quotient (THQ) resulting from consumption of rice containing organochlorine pesticides was calculated using Equation 2 as reported by Watson & Gustave (2022) and Taiwo *et al.* (2023). Hazard index (HI) which is the sum of all THQ of individual metal and pesticides provides potential non-carcinogenic risk from consumption of rice containing some toxic heavy metals and pesticides was also calculated. Exposure to potential health risk from rice consumption will be minimal and safe when HI < 1 but when HI > 1, its consumption is hazardous. Possible lifetime cancer risk (LCR) from exposure to carcinogenic pesticides from rice consumption was also calculated with Equation 3.

$$EDI = \frac{EF \ x \ ED \ x \ C \ x \ IR}{BW \ x \ AT} \qquad 1$$

EDI = $mgkg^{-1}$BW $day^{-1}$

$$THQ \ (mgkg^{-1} \ BW \ day^{-1}) = \frac{EF \ x \ ED \ x \ C \ x \ DAC}{RfD \ x \ BW \ x \ AT} = \frac{EDI}{RfD} \qquad 2$$

Exposure to OCPs is assumed to occur over a period. The parameters for the assessment include an intake rate or daily average consumption of rice (IR) which was assumed to be 0.07 kg/day/person (Cadoni & Angelucci, 2013; Adedire *et al.*, 2015), an exposure frequency (EF) of 365 days/year (Watson & Gustave, 2022), an exposure duration (ED) of 63.4 years, taken as life expectancy of average Nigerian (WHO, 2021), average body weight (BW) of 60 kg for Nigerian adults (Walpole *et al.*, 2012; Adedire *et al.*, 2015; Azeez *et al.*, 2020), and an average exposure time of non-carcinogen (AT) calculated as 365*ED (Watson & Gustave, 2022).

According to the available oral reference dose values reported in the US Environmental Protection

Agency (1989), pesticides such as aldrin, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyltrichloroethane (DDT), dieldrin, endosulfan sulfate, endrin, heptachlor, heptachlor epoxide, and methoxychlor are 0.00003, 0.0005, 0.0005, 0.0005, 0.00005, 0.006, 0.0003, 0.0001, 0.000013 and 0.005 respectively.

$$LCR = EDI \ x \ CSF \qquad 3$$

EDI: estimated dietary intake (mgkg$^{-1}$ BW Day$^{-1}$), LCR: lifetime cancer risk from exposure to carcinogenic metals, CSF: cancer slope factor/carcinogen potency factor (mgkg day)$^{-1}$ and CSF for aldrin, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyltrichloroethane (DDT), dieldrin, heptachlor and heptachlor epoxide are 17, 0.24, 0.34, 0.34, 16, 4.5 and 9.1(US EPA, 1989). The sum of LCR must range between $10^{-6}$ and $10^{-4}$. When the total LCR is below $10^{-6}$, the cancer risk is negligible between $10^{-6}$ to $10^{-4}$ is acceptable but when it is higher than $10^{-4}$, then there is a serious risk from lifetime exposure to OCPs.

**Statistical Analysis**

The use of a simple random sampling technique ensured the representative nature of the sample, allowing for valuable insights aligned with research objectives. A two-way analysis of variance (ANOVA) was conducted to analyze pesticide levels in different rice and soil samples across different sampling locations. Results were generally expressed as Mean ± SEM of triplicate determinations. Statistical tool packages used were SPSS v28 and Python 3.11.6

**Concentration of Pesticide Levels in Rice Samples**

Alpha-lindane (0.007±0.00 mg/kg), beta-lindane (0.007±0.00 mg/kg), gamma-lindane (0.009±0.00 mg/kg), delta-lindane (0.010±0.00 mg/kg) was only observed in rice samples from Ogun. Endosulfan II was detected across rice species across all sampling locations, ranged from 1.819±0.01 mg/kg in Igbemo rice (Ekiti) to 20.706±0.08 mg/kg in Costus rice (kano). Similarly, endosulfan I ranged from 0.045±0.00 to 0.597±0.00 mg/kg. The level of heptachlor assumed the order: Costus rice (0.745±0.00)>Umza rice (kano)> Ofada rice (0.018±0.00) but not detected in the rest of rice samples from Kwara, Jigawa, Edo and Ekiti. Aldrin levels in the various rice samples differs across sampling locations ($P<0.05$), ranged from 0.016±0.00 in Umza rice (Kano) to 0.224±0.00 mg/kg (Ogun). Dieldrin was detected in all samples, ranged from 0.029±0.00 in Danmodi rice (Jigawa) to 0.235±0.00 mg/kg in Ofada rice (Ogun). Similarly, Eldrin aldehyde was detected in all rice samples, ranged from 0.138±0.00 mg/kg in Umza rice (Kano) to 0.235±0.00 mg/kg in Ofada rice (Ogun). Endrin aldehyde was also detected in all rice samples, ranged from 0.133 mg/kg in Jigawa to 0.954±0.00 mg/kg. Heptachlor epoxide was detected in all samples ranged from 0.133 in Jigawa to 0.954±0.00 in Ofada rice (Ogun). Heptachlor epoxide (Isomer B) was detected in all rice samples at various levels that are not significant ($P>0.05$). 4,4'-DDD ranged from 0.005±0.00 to 0.074±0.00 mg/kg whilst 4,4 DDT was detected in all samples and ranged from 0.095±0.00 in Danmodi rice (Jigawa) to 0.495±0.00 in Ofada rice (Ogun). Methoxychlor was only detected in Ofada rice (Ogun), 0.008±0.00 to 0.005±0.00 for Sese rice (Edo) (Table 1).

**Concentration of Pesticide Levels in Soil**

The levels of OCP residues detected in this present study was consistent with previous studies (Alani *et al.*, 2019; Silva *et al.*, 2019). The concentration of alpha Lindane was 0.006 ± 0.00 mg/kg in both Kwara and Edo soils, while it was 0.008 ± 0.00 mg/kg in Jigawa soil and 0.009 ± 0.02 mg/kg in Kano soil. Alpha Lindane was not detected in Ekiti and Ogun soils. According to US EPA Maximum Residue Limit (MRL) guidelines, the permissible limit for alpha Lindane in soil is 0.01 mg/kg. The observed values are within the permissible limit. Beta Lindane was present at a concentration of 0.114 ± 0.00 mg/kg in Kwara soil. Jigawa soil had a lower concentration of 0.034 ± 0.00 mg/kg, whereas Kano and Edo soils had concentrations of 0.062 ± 0.00 mg/kg and 0.058 ± 0.00 mg/kg, respectively. This compound was not detected in Ekiti and Ogun soils. The US EPA Maximum Residue Limit (MRL) for beta Lindane in soil is 0.05 mg/kg. The concentration in Kwara soil exceeds the permissible limit, while Jigawa, Kano, and Edo soils are within the limit. Gamma Lindane concentrations varied significantly, with Kwara soil at 0.041 ± 0.00 mg/kg, Jigawa soil at 0.010 ± 0.00

**Table 1:** Concentration of Pesticide Levels in different Rice Species widely consumed in Nigeria

| Pesticide | Ogun | Kwara | Jigawa | Kano | | Edo | Ekiti | MRL |
|---|---|---|---|---|---|---|---|---|
| | | | | Umza | Costus | | | |
| α-Lindane | 0.007±0.00 | ND | ND | ND | ND | ND | ND | 0.05 |
| β-Lindane | 0.007±0.00 | ND | ND | ND | ND | ND | ND | 0.05 |
| γ-Lindane | 0.009±0.00 | ND | ND | ND | ND | ND | ND | 0.10 |
| δ-Lindane | 0.010±0.00 | ND | ND | ND | ND | ND | ND | 0.05 |
| Endosulfan II | 11.123±0.00[a] | 13.031±0.03[c] | 4.448±0.00[c] | 2.769±0.06[d] | 20.706±0.08[e] | 9.087±0.03[f] | 1.819±0.01[g] | 0.10 |
| Endosulfan I | 0.246±0.00[d] | 0.045±0.00[a] | 0.066±0.00[a] | 0.053±0.00[a] | 0.597±0.00[h] | 0.124±0.06[c] | 0.095±0.03[b] | 0.10 |
| Heptachlor | 0.018±0.00[a] | ND | ND | 0.045±0.01[c] | 0.745±0.00[d] | ND | ND | 0.03 |
| Aldrin | 0.224±0.00[e] | 0.022±0.00[a] | 0.129±0.00[d] | 0.016±0.00[a] | 0.073±0.00[bc] | 0.064±0.09[bc] | 0.018±0.00[a] | 0.01 |
| Dieldrin | 0.235±0.00[g] | 0.134±0.02[e] | 0.029±0.00[a] | 0.045±0.00[ab] | 0.106±0.00[d] | 0.086±0.09[cd] | 0.066±0.01[bc] | 0.04 |
| Endrin aldehyde | 0.954±0.00[f] | 0.321±0.02[cd] | 0.133±0.00[a] | 0.138±0.03[a] | 0.251±0.00[bc] | 0.331±0.23[cd] | 0.160±0.01[ab] | 0.01 |
| Heptachlor epoxide (Isomer B) | 0.614±0.01[a] | 0.273±0.02[a] | 0.097±0.00[a] | 0.556±0.04[a] | 0.277±0.00[a] | 0.182±0.05[a] | 0.237±0.00[a] | 0.03 |
| 4,4'-DDD | 0.074±0.00[d] | ND | 0.013±0.00[bc] | 0.016±0.00[c] | 0.032±0.00[e] | 0.021±0.03[c] | 0.005±0.00[ab] | 0.01 |
| 4,4'-DDT | 0.495±0.01[c] | 0.121±0.03[a] | 0.095±0.00[a] | 0.134±0.02[a] | 0.824±0.00[d] | 0.201±0.17[b] | 0.124±0.00[a] | 0.01 |
| Methoxychlor | 0.008±0.00[a] | ND | ND | ND | ND | 0.005±0.00[b] | ND | 0.10 |

Data are represented as mean ± standard error (n=9). Values with different superscripts across the group (states) ([a,b,c,d,e,f,g,h,I,j,k]) are significantly different at $p < 0.05$; ND: Not detected. MRL

mg/kg, Kano soil at 0.105 ± 0.00 mg/kg, and Edo soil at 0.035 ± 0.00 mg/kg. It was not detected in Ekiti and Ogun soils. The permissible limit set by US EPA (MRL) for gamma Lindane is 0.05 mg/kg. The concentration in Kano soil exceeds the permissible limit, while Kwara, Jigawa, and Edo soils are within the limit.

Delta Lindane was found at 0.234 ± 0.00 mg/kg in Kwara soil, 0.030 ± 0.00 mg/kg in Jigawa soil, 0.071 ± 0.00 mg/kg in Kano soil, and 0.087 ± 0.00 mg/kg in Edo soil. It was not detected in Ekiti and Ogun soils. The US EPA Maximum Residue Limit (MRL) for delta Lindane is 0.05 mg/kg. The concentrations in Kwara, Kano, and Edo soils exceed the permissible limit, while Jigawa soil is within the limit. Endosulfan II had the highest concentrations among the compounds studied, with 17.156 ± 0.00 mg/kg in Kwara soil, 24.350 ± 0.02 mg/kg in Jigawa soil, 30.517 ± 0.01 mg/kg in Kano soil, and 36.644 ± 0.02 mg/kg in Edo soil. It was detected at much lower concentrations in Ekiti (1.828 ± 0.05 mg/kg) and Ogun (1.834 ± 0.04 mg/kg) soils. The US EPA Maximum Residue Limit (MRL) for Endosulfan II is 0.1 mg/kg. All observed values exceed the permissible limit.

However, Heptachlor concentrations were 0.199 ± 0.00 mg/kg in Kwara soil, 0.377 ± 0.01 mg/kg in Jigawa soil, and 32.646 ± 0.44 mg/kg in Kano soil, while Edo soil had 0.269 ± 0.00 mg/kg. This compound was not detected in Ekiti and Ogun soils. US EPA sets the permissible limit for Heptachlor at 0.03 mg/kg. All observed values exceed the permissible limit. Aldrin was detected at 0.074 ± 0.00 mg/kg in Kwara soil, 0.139 ± 0.00 mg/kg in Jigawa soil, 0.530 ± 0.00 mg/kg in Kano soil, and 0.100 ± 0.00 mg/kg in Edo soil. It was found at lower concentrations in Ekiti and Ogun soils, both at 0.019 ± 0.00 mg/kg. The US EPA Maximum Residue Limit (MRL) for Aldrin is 0.05 mg/kg. The concentrations in Kwara, Jigawa, Kano, and Edo soils exceed the permissible limit, while Ekiti and Ogun soils are within the limit. Heptachlor epoxide (Isomer B) had concentrations of 0.575 ± 0.00 mg/kg in Kwara soil, 0.758 ± 0.00 mg/kg in Jigawa soil, 1.259 ± 0.01 mg/kg in Kano soil, and 0.930 ± 0.00 mg/kg in Edo soil. It was present at lower concentrations in Ekiti (0.238 ± 0.00 mg/kg) and Ogun (0.251 ± 0.38 mg/kg) soils. The US EPA Maximum Residue Limit (MRL) for Heptachlor epoxide is 0.03 mg/kg.

All observed values exceed the permissible limit. Endosulfan I was found at 0.885 ± 0.00 mg/kg in Kwara soil, 0.720 ± 0.00 mg/kg in Jigawa soil, 28.315 ± 0.00 mg/kg in Kano soil, and 0.315 ± 0.00 mg/kg in Edo soil. The concentrations in Ekiti and Ogun soils were both 0.105 ± 0.00 mg/kg. The US EPA Maximum Residue Limit (MRL) for Endosulfan I is 0.1 mg/kg. All observed values exceed the permissible limit. 4,4'-DDE was present at 0.031 ± 0.00 mg/kg in Kwara soil, 0.017 ± 0.00 mg/kg in Jigawa soil, 0.036 ± 0.00 mg/kg in Kano soil, and 0.016 ± 0.00 mg/kg in Edo soil. This compound was not detected in Ekiti and Ogun soils. The US EPA Maximum Residue Limit (MRL) for 4,4'-DDE is 0.02 mg/kg. The concentrations in Kwara and Kano soils exceed the permissible limit, while Jigawa and Edo soils are within the limit. Dieldrin concentrations were 0.216 ± 0.00 mg/kg in Kwara soil, 0.162 ± 0.00 mg/kg in Jigawa soil, 16.873 ± 0.00 mg/kg in Kano soil, and 0.083 ± 0.00 mg/kg in Edo soil. Ekiti and Ogun soils had similar concentrations of 0.070 ± 0.00 mg/kg and 0.069 ± 0.00 mg/kg, respectively. US EPA sets the permissible limit for Dieldrin at 0.04 mg/kg. All observed values exceed the permissible limit.

Endrin was detected at 0.474 ± 0.00 mg/kg in Kwara soil, 0.044 ± 0.00 mg/kg in Jigawa soil, 0.0458 ± 0.00 mg/kg in Kano soil, and 0.0452 ± 0.00 mg/kg in Edo soil. It was not detected in Ekiti and Ogun soils. The US EPA Maximum Residue Limit (MRL) for Endrin is 0.05 mg/kg. The concentrations in Jigawa, Kano, and Edo soils are within the limit, while Kwara soil exceeds the limit. 4,4'-DDD concentrations were 0.027 ± 0.00 mg/kg in Kwara soil, 0.082 ± 0.00 mg/kg in Jigawa soil, 0.047 ± 0.00 mg/kg in Kano soil, and 0.076 ± 0.00 mg/kg in Edo soil. It was found at 0.005 ± 0.00 mg/kg and 0.006 ± 0.03 mg/kg in Ekiti and Ogun soils, respectively. The US EPA Maximum Residue Limit (MRL) for 4,4'-DDD is 0.05 mg/kg. The concentrations in Jigawa, Kano, and Edo soils exceed the permissible limit, while Kwara, Ekiti, and Ogun soils are within the limit. Endrin aldehyde concentrations varied significantly, with 26.996 ± 0.12 mg/kg in Kwara soil, 1.743 ± 0.01 mg/kg in Jigawa soil, 83.633 ± 0.01 mg/kg in Kano soil, and 1.750 ± 0.06 mg/kg in Edo soil. Ekiti and Ogun soils had lower concentrations of 0.163 ± 0.00 mg/kg and 0.157 ± 0.02 mg/kg, respectively. The US EPA Maximum Residue Limit (MRL) for Endrin aldehyde is 0.05 mg/kg. All observed values exceed the permissible limit. 4,4'-DDT was found at 1.043 ± 0.00 mg/kg in Kwara soil, 0.444 ± 0.01 mg/kg in Jigawa soil, 0.494 ± 0.00 mg/kg in Kano soil, and 0.854 ± 0.00 mg/kg in Edo soil.

**Table 2:** Concentration of Pesticide Levels in Soil

| | Kwara Soil | Jigawa | Kano Soil | Edo Soil | Ekiti Soil | Ogun Soil |
|---|---|---|---|---|---|---|
| α-Lindane | 0.006±0.00[a] | 0.008±0.00[b] | 0.009±0.02[c] | 0.006±0.00[a] | ND | ND |
| β-Lindane | 0.114±0.00[a] | 0.034±0.00[b] | 0.062±0.00[d] | 0.058±0.00[c] | ND | ND |
| γ-Lindane | 0.041±0.00[b] | 0.010±0.00[a] | 0.105±0.00[c] | 0.035±0.00[b] | ND | ND |
| δ-Lindane | 0.234±0.00[a] | 0.030±0.00[b] | 0.071±0.00[c] | 0.087±0.00[d] | ND | ND |
| Endosulfan II | 17.156±0.00[b] | 24.350±0.02[c] | 30.517±0.01[d] | 36.644±0.02[e] | 1.828±0.05[a] | 1.834±0.04[a] |
| Heptachlor | 0.199±0.00[b] | 0.377±0.01[c] | 32.646±0.44[a] | 0.269±0.00[bc] | ND | ND |
| Aldrin | 0.074±0.00[b] | 0.139±0.00[d] | 0.530±0.00[e] | 0.100±0.00[c] | 0.019±0.00[a] | 0.019±0.00[a] |
| Heptachlor epoxide (Isomer B) | 0.575±0.00[b] | 0.758±0.00[c] | 1.259±0.01[e] | 0.930±0.00[d] | 0.238±0.00[a] | 0.251±0.38[a] |
| Endosulfan I | 0.885±0.00[d] | 0.720±0.00[c] | 28.315±0.00[e] | 0.315±0.00[b] | 0.105±0.00[a] | 0.105±0.00[a] |
| 4,4'-DDE | 0.031±0.00[d] | 0.017±0.00[c] | 0.036±0.00[a] | 0.016±0.00[b] | ND | ND |
| Dieldrin | 0.216±0.00[d] | 0.162±0.00[c] | 16.873±0.00[e] | 0.083±0.00[b] | 0.070±0.00[a] | 0.069±0.00[a] |
| Endrin | 0.474±0.00[a] | 0.044±0.00[b] | 0.0458±0.00[d] | 0.0452±0.00[c] | ND | ND |
| 4,4'-DDD | 0.027±0.00[b] | 0.082±0.00[e] | 0.047±0.00[c] | 0.076±0.00[d] | 0.005±0.00[a] | 0.006±0.03[a] |
| Endrin aldehyde | 26.996±0.12[c] | 1.743±0.01[b] | 83.633±0.01[d] | 1.750±0.06[b] | 0.163±0.00[a] | 0.157±0.02[a] |
| 4,4'-DDT | 1.043±0.00[e] | 0.444±0.01[b] | 0.494±0.00[c] | 0.854±0.00[d] | 0.129±0.01[a] | 0.124±0.00[a] |
| Endosulfan sulfate | 0.692±0.00[a] | 0.070±0.00[c] | 0.496±0.01[d] | 0.038±0.00[b] | ND | ND |
| Methoxychlor | 0.057±0.00[a] | 0.017±0.00[b] | 0.068±0.01[c] | 0.055±0.00[a] | ND | ND |

Data are represented as mean ± standard error (n=9). Values with different superscripts across the group (states) ([a,b,c,d,e,f,g,h,I,j,k]) are significantly different at $p < 0.05$; ND: Not detected.

The concentrations in Ekiti and Ogun soils were 0.129 ± 0.01 mg/kg and 0.124 ± 0.00 mg/kg, respectively. US EPA sets the permissible limit for 4,4'-DDT at 0.05 mg/kg. All observed values exceed the permissible limit.

Endosulfan sulphate concentrations were 0.692 ± 0.00 mg/kg in Kwara soil, 0.070 ± 0.00 mg/kg in Jigawa soil, 0.496 ± 0.01 mg/kg in Kano soil, and 0.038 ± 0.00 mg/kg in Edo soil. This compound was not detected in Ekiti and Ogun soils. The US EPA Maximum Residue Limit (MRL) for Endosulfan sulphate is 0.1 mg/kg. The concentration in Kwara soil exceeds the permissible limit, while Jigawa, Kano, and Edo soils are within the limit. Methoxychlor was detected at 0.057 ± 0.00 mg/kg in Kwara soil, 0.017 ± 0.00 mg/kg in Jigawa soil, 0.068 ± 0.01 mg/kg in Kano soil, and 0.055 ± 0.00 mg/kg in Edo soil. It was not detected in Ekiti and Ogun soils. The US EPA Maximum Residue Limit (MRL) for Methoxychlor is 0.01 mg/kg. All observed values exceed the permissible limit (Table 2).

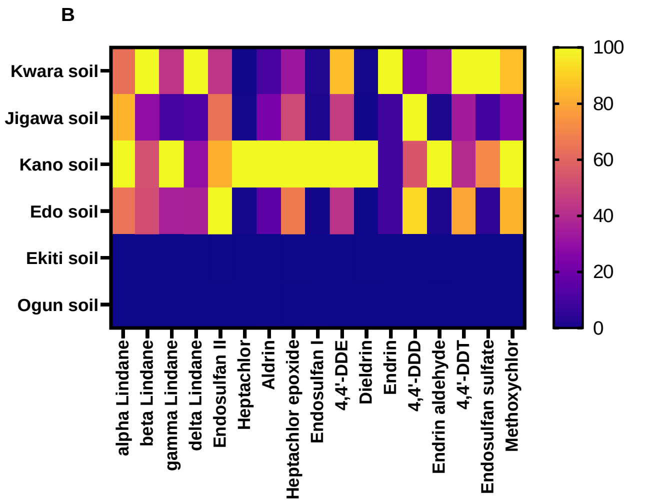


Table 3 illustrates the Estimated Daily Intake (EDI) values for organochlorine pesticides in local rice. Ogun has the highest EDI at 0.013348, indicating significant pesticide exposure risks, while Kwara and Jigawa show the lowest EDI values at 0.000054 mgkg$^{-1}$BW and 7.92E-05 mgkg$^{-1}$BW, respectively, suggesting comparatively lower pesticide contamination.

**Table 3:** Estimated Daily Intake (EDI) of Organochlorine Pesticides in Local Rice through Consumption of Rice by average Adult

| Pesticide | Ogun | Kwara | Jigawa | Kano Umza | Kano Costus | Edo | Ekiti | ADI |
|---|---|---|---|---|---|---|---|---|
| α-Lindane | 8.4E-06 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| β-Lindane | 8.4E-06 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| γ-Lindane | 1.08E-05 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| δ-Lindane | 0.000012 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| Endosulfan II | 0.013348 | 0.015637 | 0.005338 | 0.003323 | 0.024847 | 0.010904 | 0.002183 | 0.006 |
| Endosulfan I | 0.000295 | 0.000054 | 7.92E-05 | 6.36E-05 | 0.000716 | 0.000149 | 0.000114 | 0.03 |
| Heptachlor | 2.16E-05 | 0.0000 | 0.0000 | 0.000054 | 0.000894 | 0.0000 | 0.0000 | 0.000013 |
| Aldrin | 0.000269 | 2.64E-05 | 0.000155 | 1.92E-05 | 8.76E-05 | 7.68E-05 | 2.16E-05 | 0.00003 |
| Dieldrin | 0.000282 | 0.000161 | 3.48E-05 | 0.000054 | 0.000127 | 0.000103 | 7.92E-05 | 0.00005 |
| Endrin aldehyde | 0.001145 | 0.000385 | 0.00016 | 0.000166 | 0.000301 | 0.000397 | 0.000192 | 0.0003 |
| Heptachlor epoxide (Isomer B) | 0.000737 | 0.000328 | 0.000116 | 0.000667 | 0.000332 | 0.000218 | 0.000284 | 0.0005 |
| 4,4'-DDD | 8.88E-05 | 0 | 1.56E-05 | 1.92E-05 | 3.84E-05 | 2.52E-05 | 0.000006 | 0.0020 |
| 4,4'-DDT | 0.000594 | 0.000145 | 0.000114 | 0.000161 | 0.000989 | 0.000241 | 0.000149 | 0.0005 |
| Methoxychlor | 9.6E-06 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000006 | 0.0000 | 0.1000 |

EDI: Estimated Daily Intake, ADI: Acceptable Daily Intake; EDI and ADI measured in mgkg$^{-1}$BW day$^{-1}$; ADI Values (Shoiful *et al*., 2013; Kodavanti *et al*., 2014)

The Aceptable Daily Intake, ADI for Endosulfan II is set at 0.006 mg/kg body weight per day (WHO, 1999; Shoiful *et al.,* 2013), but Ogun's EDI of 0.013348 mg/kg exceeds this threshold, indicating a potential health risk. Similarly, Ogun's ADI for Aldrin (0.000269 mgkg$^{-1}$BW) was above its ADI of 0.00003 mgkg$^{-1}$BW (Shoiful *et al.,* 2013), the ADI for Dieldrin (0.000282 mgkg$^{-1}$BW) surpasses its ADI of 0.00005 mgkg$^{-1}$BW (Shoiful *et al.,* 2013), suggesting exposure risks; however, Kano's EDI for Heptachlor exceeds the safe limit, given its ADI of 0.000013 mgkg$^{-1}$BW (Shoiful *et al.,* 2013). Similarly, EDIs of samples in Ogun and Kano particularly, the Umza exceeded ADI of 0.0005 mgkg$^{-1}$BW. This regional variability emphasizes the need for ongoing monitoring and regulation of pesticide usage to protect public health and the environment, particularly in areas with higher contamination levels like Ogun.

Table 4 reveals significant non-carcinogenic risks associated with organochlorine pesticide (OCP) exposure from local rice consumption, particularly in Ogun and Kano. Notably, Heptachlor shows the highest Target Hazard Quotient (THQ) in Kano (Costus) at 8.94, indicating a substantial health risk. Aldrin poses a serious risk in Ogun (8.96) and Jigawa (5.16), both exceeding the safety threshold, with elevated values also observed in Kano Costus (2.92) and Edo (2.56). Dieldrin further highlights these risks, with THQ values above 1 in Ogun (5.64) and Kwara (3.216). Heptachlor Epoxide (Isomer B) has the highest overall THQ, reaching 56.68 in Ogun, underscoring a critical public health concern. Endrin aldehyde also presents risks, especially in Ogun (3.816) and Kwara (1.284). While 4,4'-DDD and 4,4'-DDT have lower THQ values, the latter exceeds the threshold in Kano (Costus) at 1.9776. Heptachlor epoxide (isomer B) accounts for 73.92% of the overall non-carcinogenic risk in Ogun, 81.63% in Kwara, 57.39% in Jigawa, 94.18% in Kano (Umza), 59.42% in Kano (Costus), 72.16% in Edo, and 87.05% in Ekiti. The HI values across all regions indicate potential health risks, with Ogun exhibiting the highest hazard index, underscoring the need for monitoring and regulatory actions to mitigate pesticide exposure risks in food sources.

**Table 4:** THQ of Exposure to Organochlorine Pesticides in Local Rice through Consumption of Rice by average Adult

| Pesticide | Ogun | Kwara | Jigawa | Kano Umza | Kano Costus | Edo | Ekiti |
|---|---|---|---|---|---|---|---|
| Heptachlor | 0.216 | 0.000 | 0.000 | 0.54 | 8.94 | 0.000 | 0.000 |
| Aldrin | 8.96 | 0.88 | 5.16 | 0.64 | 2.92 | 2.56 | 0.72 |
| Dieldrin | 5.64 | 3.216 | 0.696 | 1.08 | 2.544 | 2.064 | 1.584 |
| Endrin aldehyde | 3.816 | 1.284 | 0.532 | 0.552 | 1.004 | 1.324 | 0.640 |
| Heptachlor epoxide (Isomer B) | 56.67692 | 25.200 | 8.95385 | 51.3231 | 25.5692 | 16.800 | 21.8769 |
| 4,4'-DDD | 0.1776 | 0.000 | 0.0312 | 0.0384 | 0.0768 | 0.0504 | 0.012 |
| 4,4'-DDT | 1.188 | 0.2904 | 0.228 | 0.3216 | 1.9776 | 0.4824 | 0.2976 |
| Methoxychlor | 0.00192 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0012 | 0.000 |
| HI | 76.676 | 30.870 | 15.601 | 54.495 | 43.032 | 23.282 | 25.131 |

THQ: Target Hazard Quotient, HI: Hazard Index; THQ: Target Hazard Quotient, HI: Hazard Index; THQ>1 = Substantial non-carcinogenic risk; H1>1 = potential risk for non-carcinogenic health effects for multiple OCPs

The results in Table 5 reveal significant Lifetime Cancer Risk (LCR) values for organochlorine pesticide exposure through local rice consumption, with Ogun presenting the highest cumulative LCR at 0.016107, which far exceeds the safety threshold of 1 x $10^{-4}$ and indicates a substantial public health concern. This elevated risk is primarily attributed to Aldrin (0.00457) and Heptachlor epoxide (Isomer B) (0.006705), both of which significantly contribute to the overall LCR. In comparison, Kwara's LCR of 0.006052, while lower, still reflects notable risks, particularly from Dieldrin (0.002573) and Heptachlor epoxide (Isomer B) (0.002981).

Regions such as Jigawa (0.00429), Kano (Umza) (0.007564), and Kano (Costus) (0.010918) also demonstrate concerning LCR values, indicating that organochlorine pesticide exposure is a widespread issue. Although Edo (0.005032) and Ekiti (0.004274) show lower LCRs compared to Ogun and Kano, their values still signify potential health risks. Overall, the cumulative LCR values across all regions highlight an urgent need for enhanced monitoring and regulatory measures to mitigate the risks associated with pesticide residues in rice, particularly in areas where the LCR exceeds the acceptable limit.

## DISCUSSION

### Concentration of Pesticide Levels in Local Rice

All sampled rice varieties showed levels of endosulfan II, aldrin, dieldrin, endrin aldehyde, and

**Table 5:** Lifetime Cancer Risk (LCR) of Exposure to Organochlorine Pesticides in Local Rice through Consumption of Rice by average Adult

| Pesticide | Ogun | Kwara | Jigawa | Kano Umza | Kano Costus | Edo | Ekiti |
|---|---|---|---|---|---|---|---|
| Heptachlor | 9.72E-05 | 0 | 0 | 0.000243 | 0.004023 | 0 | 0 |
| Aldrin | 0.00457 | 0.000449 | 0.002632 | 0.000326 | 0.001489 | 0.001306 | 0.000367 |
| Dieldrin | 0.004512 | 0.002573 | 0.000557 | 0.000864 | 0.002035 | 0.001651 | 0.001267 |
| Heptachlor epoxide (Isomer B) | 0.006705 | 0.002981 | 0.001059 | 0.006072 | 0.003025 | 0.001987 | 0.002588 |
| 4,4'-DDD | 2.13E-05 | 0 | 3.74E-06 | 4.61E-06 | 9.22E-06 | 6.05E-06 | 1.44E-06 |
| 4,4'-DDT | 0.000202 | 4.94E-05 | 3.88E-05 | 5.47E-05 | 0.000336 | 8.2E-05 | 5.06E-05 |
| ∑LCR | 0.016107 | 0.006052 | 0.00429 | 0.007564 | 0.010918 | 0.005032 | 0.004274 |

LCR > 1 x $10^{-4}$ (1 in 10,000) = a significant concern for public health

heptachlor epoxide that exceeded their respective maximum residue limits (MRLs). Only the rice samples from Kano had heptachlor residues above the MRLs. In contrast, only Ofada rice samples from Ogun had α, β, γ, and D-lindane residues, and were considerably within their MRLs. Additionally, only rice samples from Ogun and Edo contained methoxychlor, and these levels were below their MRLs.

The detection of pesticide residues in rice varieties, particularly levels of endosulfan II, aldrin, dieldrin, and heptachlor epoxide exceeding their respective maximum residue limits (MRLs), raises significant health concerns. Chronic exposure to these pesticides has been linked to serious health issues, including endocrine disruption, reproductive problems, and an increased risk of cancers. For example, endosulfan is known to have neurotoxic effects, particularly on developing children, making its presence in staple foods like rice particularly alarming.

Furthermore, the fact that only certain regions, such as Kano and Ogun, show varying levels of pesticide residues suggests localized agricultural practices and regulatory oversight issues. This inconsistency highlights the need for improved monitoring and management of pesticide use to mitigate risks associated with bioaccumulation in the food chain. Ensuring that food sources remain safe for consumption is essential for protecting public health, particularly among vulnerable populations who may rely heavily on rice as a dietary staple.

Higher endosulfan II levels as observed in this present study especially in samples from Ogun, Kwara, Kano and Edo compared to Khammanee *et al*. (2020) were notably high, possibly due to intensive pesticide application. Contamination sources could include spray drift, root absorption during dry soil conditions, or improper storage and distribution practices. Importantly, many of the pesticides detected are banned by regulatory agencies like the National Agency for Food and Drug Administration and Control (NAFDAC), highlighting concerns over their presence in rice samples.

**Pesticide Levels in Soil**

The elevated levels of pesticides such as heptachlor, aldrin, heptachlor epoxide, endosulfan I, 4,4-DDE, dieldrin, endrin aldehyde, and methoxychlor found in Kano soil raise significant health concerns for local populations. OCPs such as DDE and DDTs detected in samples similarly matched with those reported in Khammanee *et al*. (2020). Prolonged exposure to these organochlorine pesticides (OCPs) can lead to severe health issues, including neurodevelopmental disorders, endocrine disruption, and increased cancer risk. Given that these chemicals can persist in the environment and bioaccumulate in the food chain, the risks extend beyond immediate exposure, potentially impacting the health of future generations who may consume contaminated crops.

In contrast, the lower levels of OCPs detected in Ekiti and Ogun soils may suggest a relatively safer agricultural environment (Jolodar *et al*., 2021). However, this does not eliminate the need for vigilant monitoring and management practices to ensure that pesticide use remains within safe limits. Even with lower residue levels, the potential for localized contamination and the cumulative effects of pesticide exposure over time underscore the importance of sustainable agricultural practices and strict regulatory oversight. Protecting soil health is essential not only for crop quality but also for safeguarding public health and maintaining a safe food supply (Gao *et al*., 2023).

**Estimated Daily Intake (EDI) Values of Sampled Rice Varieties across different Locations**

The disparities in Estimated Daily Intake (EDI) values for organochlorine pesticides, particularly in Ogun, can be attributed to various factors, including agricultural practices, types of crops grown, local regulatory enforcement, environmental conditions, economic circumstances of farmers, and consumer awareness. Research indicates that regions with intensive pesticide use, and less stringent regulations often exhibit higher uptake or EDI values (Damalas and Eleftherohorinos, 2011; Barański *et al*., 2014; Mohamed *et al*., 2019). Additionally, specific crop susceptibility to pesticides can lead to increased residue levels (Eddleston *et al*., 2002). Environmental factors, such as soil composition and climate, also significantly influence pesticide accumulation (Bhupander *et al*., 2011; Sharma *et al*., 2019; Pathak *et al*., 2022). Economic constraints can affect farmers' choices regarding pesticide use, pushing them toward cheaper, more hazardous options (de-Assis *et al*., 2022; Adesuyi *et al*., 2023). Together, these elements contribute to the significant differences in pesticide exposure observed across regions.

**Implication for Estimated Target Hazard Quotient (THQ) and Hazard Index (HI) Values**

The presence of organochlorine pesticides (OCPs) with high potential health risks, as indicated by the significant Target Hazard Quotient (THQ) values, has serious implications for public health, particularly in regions like Ogun and Kano. High THQ values for substances such as Heptachlor and Aldrin suggest that regular consumption of contaminated rice could lead to adverse health effects, including neurological and endocrine disruptions. The alarming levels of Heptachlor Epoxide (Isomer B), which accounts for a substantial portion of the overall non-carcinogenic risk, highlight the urgent need for comprehensive risk assessments and public health interventions.

Moreover, the elevated Hazard Index (HI) values across various regions point to the cumulative effects of multiple pesticide residues, underscoring a broader concern for food safety and long-term health consequences for consumers. These findings stress the necessity for improved regulatory frameworks and monitoring systems to ensure safer agricultural practices and minimize pesticide exposure. Ultimately, addressing these health risks is critical for protecting vulnerable populations, promoting food security, and ensuring sustainable agricultural practices.

**Implication of Lifetime Cancer Risks (LCR) Values in the Studied Samples**

This lifetime cancer risk, primarily driven by Aldrin and Heptachlor epoxide (Isomer B), underscores the critical need for immediate action to address pesticide contamination in food sources. Both Aldrin and Heptachlor epoxide (Isomer B) are associated with significant adverse health effects in humans, including neurotoxicity, endocrine disruption, and potential carcinogenicity (Honeycutt and Shirley, 2014). Chronic exposure to these pesticides can lead to symptoms such as tremors and dizziness, as well as increased risks of reproductive issues and various cancers.

The presence of notable LCR values in other regions, such as Kwara, Jigawa, and both areas of Kano, indicates that organochlorine pesticide exposure is not isolated to one location but is a widespread issue affecting multiple communities. Even regions with lower LCRs, like Edo and Ekiti, demonstrate potential health risks, suggesting a pervasive problem that requires attention across the board. These elevated LCR values emphasize the necessity for enhanced monitoring and regulatory measures to reduce pesticide residue in agricultural products, particularly rice, which is a staple food in these regions. Implementing stricter regulations on pesticide usage, promoting safer agricultural practices, and increasing public awareness about the risks of pesticide exposure are essential steps to mitigate these health risks. Additionally, further research into the long-term health effects of chronic exposure to these pesticides is critical for informing public health policies and ensuring the safety of food supplies.

## CONCLUSION

The health risk assessment of organochlorine pesticides (OCPs) in selected Nigerian rice grains and soils reveals significant contamination levels that pose serious health risks to consumers. This study identified various OCP residues, including Aldrin, Dieldrin, and Endosulfan, with concentrations frequently exceeding the European Union's Maximum Residue Limits (MRLs). Notably, Endosulfan II exhibited particularly high levels, especially in samples from Ogun, Kwara, Kano, and Edo, likely due to intensive agricultural practices and pesticide application. The findings indicate substantial non-carcinogenic risks associated with OCP exposure, particularly in Ogun and Kano, where the Target Hazard Quotient (THQ) values were significantly above the safety threshold. Furthermore, the Lifetime Cancer Risk (LCR) analysis highlighted Ogun as having the highest cumulative risk, driven primarily by Aldrin and Heptachlor epoxide concentrations. The results underscore the urgent need for enhanced monitoring and regulatory measures to address pesticide contamination in rice, particularly in regions where risk levels exceed acceptable limits. This comprehensive assessment provides a vital scientific basis for developing national food safety policies and environmental resilience strategies aimed at mitigating the adverse effects of pesticide use in agricultural practices across Nigeria.

**Recommendations**

Based on the observations of this study and the critical need to enhance agricultural sustainability, protect public health, and promote environmental stewardship in rice farming communities, this study recommends:

i. Investigate the impact of regional agricultural practices on contamination and implement systematic monitoring of banned metals and pesticide concentrations in rice and soil in regions such as Kano, Ogun, and Kwara.
ii. Strengthen regulatory frameworks for safety compliance, educate farmers on sustainable practices like bio-pesticides and Integrated Pest Management (IPM), and promote soil and water management techniques to improve soil health, water efficiency, and climate resilience.
iii. Promote PPE use among farmers, provide training on safe pesticide application, and address essential metal concentration variability through dietary supplementation and agronomic biofortification.
iv. Enhance environmental management to prevent soil contamination, engage communities in awareness programs about pesticide risks and sustainable farming, and support farmers with financial incentives, technical assistance, and access to eco-friendly alternatives.

**Data availability statement**

Data included in article/supplementary material/referenced in article.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Acknowledgments**

Authors expressed their heartfelt gratitude to Bukola Adebisi, Steven Aderemi, Motunrayo Omoyajowo, Dr. Victor Sobanke, Dr. Sunday Akintelu, Dr. Mela Danji, Abdufatai Bello, and many others whose invaluable support and encouragement played a crucial role in the successful completion of this study.

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