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Preliminary assessment of organochlorine pesticide residues and associated health risks in locally processed rice after Nigeria's 2022 importation ban

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How to cite this article: Iniaghe, P. O.; Osioma, E.; Ekwutoziam, P. Preliminary assessment of organochlorine pesticide residues and associated health risks in locally processed rice after Nigeria's 2022 importation ban. *J. Environ. Expo. Assess.* 2025, 4, 17. <https://dx.doi.org/10.20517/jeea.2025.23>

Received: 3 Apr 2025 **First Decision:** 30 Apr 2025 **Revised:** 5 May 2025 **Accepted:** 15 May 2025 **Published:** 18 Jun 2025

Academic Editor: Stuart Harrad **Copy Editor:** Pei-Yun Wang **Production Editor:** Pei-Yun Wang

Abstract

Rice is a staple food consumed globally. In Nigeria, a ban on rice importation was implemented in 2022 to reduce overdependence on foreign rice and boost local production. This policy shift led to increased cultivation of local rice and the introduction of new products into the Nigerian markets. However, despite this increase, the availability of a variety of locally processed rice products in Bayelsa State remains limited, posing a challenge for comprehensive sampling. Hence, this preliminary study - based on five rice products purchased from Swali Market, Bayelsa State - assessed the level of organochlorine pesticide (OCP) residues and associated health risks. Sixteen target OCPs were analyzed, and the detected concentration ranged from 2.11-4.78 $\mu\text{g}\cdot\text{kg}^{-1}$, with the average levels following the order: endrin > endrin aldehyde > heptachlor epoxide > dieldrin > β -HCH > aldrin. β -HCH was the only detected hexachlorocyclohexane, while dichlorodiphenyltrichloroethane (DDT) and its degradation products were not detected. All detected OCPs were within their respective maximum residue limits (MRLs) for cereals. Deterministic health risk assessments revealed that non-cancer risks were negligible (HQ and $\text{HI} < 1$), and total cancer risk values were within the acceptable range (10^{-6} - 10^{-4}). The Monte Carlo simulation showed that simulated exposures were within the recommended safety thresholds. Although the findings suggest that locally processed rice is relatively safe regarding OCP contamination, the small sample size limits the generalization of the results. Future large-scale studies are recommended to provide a more comprehensive evaluation. Additionally, promoting non-chemical pest



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control methods, such as biological control and organic farming, can help reduce reliance on synthetic pesticides and further enhance food safety.

Keywords: Organochlorine pesticides, maximum residue limit, food safety, dietary exposure, health risk assessment

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple crop consumed globally. In third-world countries, population growth and economic expansion have led to an increased demand for rice^[1]. Over the years, local rice production in Nigeria has been unable to keep up with this rising demand, resulting in a heavy reliance on rice imports. However, the influx of imported rice products has negatively impacted the nation's economy and local farming^[2,3]. To boost local rice production, enhance food security, and reduce the nation's dependence on imported rice, the Federal Government of Nigeria banned the importation of parboiled rice through seaports in January 2022, following an earlier ban in March 2016 on rice importation through land borders^[4-6]. This shift may compel local farmers to increase pesticide use to meet the growing demand for rice. However, concerns remain regarding agricultural practices, particularly pesticide usage among local farmers.

The primary reason for using pesticides in rice farming is to combat pest infestations, weeds, and pathogens across large agricultural areas while increasing rice productivity^[7]. Pesticides are also applied to eradicate disease vectors in homes, contributing to improved public health^[8]. While many pesticides can eliminate a broad range of pests or weeds, some are specifically designed to target particular pests or pathogens^[9]. Despite their importance in agriculture and their role in increasing crop yields, pesticide residues in harvested rice - resulting from misuse or overuse - are a major source of contamination and concern, as they pose significant risks to human health. Organochlorine pesticides (OCPs), in particular, are of environmental concern due to their resistance to degradation, high lipid solubility, low aqueous solubility, bioaccumulation potential, long half-life, and ability to undergo long-range transport^[9]. Due to their lipophilic nature, these compounds accumulate in fatty tissues of animals and humans, posing significant health risks^[10]. Toxic effects associated with excessive OCP exposure include neurological disorders, endocrine disruption, reproductive issues, and carcinogenicity^[11]. These concerns have led to the establishment of tolerance limits, such as the maximum residue limit (MRL)^[12], for various pesticides in food and water.

The use of OCPs has been prohibited in many developed countries since the 1980s due to the health risks they pose. In Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) banned OCPs in 2008^[13]. However, many OCPs, such as dichlorodiphenyltrichloroethane (DDT), aldrin, and hexachlorocyclohexanes (HCHs), are still in use. This continued use is driven by several factors: the low cost and high efficacy of OCPs compared to modern alternatives; poor enforcement of existing pesticide regulations, which allow banned products to circulate freely; the proliferation of informal markets where mislabeled products are sold under unregulated trade names; and limited farmer awareness of OCP toxicity and safer substitutes^[14,15].

The presence of OCPs in agricultural farmlands across Nigeria has been reported^[16-19], raising concerns about their potential transfer into food crops. Given rice's status as a widely consumed staple food, it is crucial to evaluate OCP residue levels in locally processed rice to assess its safety for consumption and compliance with the Codex Alimentarius' MRLs. This study provides a preliminary assessment of OCP

residues in locally processed rice following Nigeria's 2022 importation ban. Given the limited data on OCP residues in rice production post-ban, this study aims to establish baseline contamination levels and associated health risks, serving as a foundation for future large-scale studies. However, the study was constrained by the limited availability of a variety of locally processed rice products at the time of sampling, which influenced the sample size. Findings from this study will also contribute to an initial understanding of OCP residues in locally processed rice.

EXPERIMENTAL

Collection and preparation of rice samples

Rice samples were purchased from retail outlets in Swali Market, Bayelsa State, Nigeria - a major trading hub for various food products, including both locally processed and imported rice. Swali Market was strategically selected as it serves as the primary distribution point for agricultural commodities in the state. It attracts a wide range of rice products, making it a suitable location for evaluating the safety of processed rice available to consumers in the state.

Based on the rice types available and those most frequently purchased by consumers, five rice samples were selected. These included four samples originating from Northern Nigeria - a major rice-producing region - and one sample from Southeastern Nigeria, another rice-growing area. All samples were locally processed and produced in 2023, with foreign brands deliberately excluded from the study. The rice samples were coded and stored in ziplock bags. In the laboratory, they were size-reduced using a porcelain mortar and pestle, sieved through a 2 mm mesh, and stored in ziplock bags for further analysis.

Extraction and quantification of OCPs from rice

The Soxhlet extraction method, previously reported^[20] but with slight modifications, was utilized for the extraction of OCPs from the samples. A 10.0 g sample was combined with an equal mass of anhydrous Na_2SO_4 and subjected to Soxhlet extraction for 4 h using a 100 mL aliquot of a 1:1 dichloromethane (DCM)/n-hexane mixture. The extract was then concentrated to 2 mL using a Senco rotary evaporator, and cleanup was performed using a column packed with 1 g each of Florisil, anhydrous Na_2SO_4 , acidified copper powder, and silica gel. The OCPs were eluted with 15 mL each of hexane and DCM into a flask, concentrated to about 2 mL using a rotary evaporator, and transferred into a vial for analysis.

A gas chromatograph (6890N Agilent Technologies) coupled with a mass selective detector (Agilent 5975B) (GC-MS), fitted with an Agilent HP-5 GC column (30 m $\times$ 320 μm $\times$ 0.25 μm film thickness, operating at 60–325 °C), was used for the quantification of OCPs in the concentrated extracts. The initial oven temperature was maintained at 100 °C for 2 min, then ramped to 180 °C at 15 °C/min, followed by an increase to 300 °C at 3 °C/min, where it was held for 9 min. The carrier gas was helium at a flow rate of 0.8 mL/min. The sample injection volume in splitless mode was 1 μL . The mass spectrometer operated in electron impact ionization mode with automatic gain control. The storage window was programmed for full scan mode in the m/z range of 200–500, while the selected ion monitoring (SIM) mode was employed for data acquisition using Agilent ChemStation software.

The final concentration of OCPs was evaluated as follows:

$$\text{Concentration } (\mu\text{g} \cdot \text{kg}^{-1}) = \frac{\text{concentration of OCP in sample } (\mu\text{g/L}) \times \text{final volume (L)}}{\text{initial weight of sample (kg)}} \quad (1)$$

Quality control/ statistical analysis

Procedural blanks were prepared to detect any impurities in reagents and reaction vessels. Analytical-grade reagents were used throughout the analysis. The extraction efficiency of the chosen method was evaluated using matrix-spiked samples. In this method, known OCP standards were added to previously analyzed sample aliquots and reanalyzed. The percentage recovery of OCPs from the spiked samples ranged from 90.1% to 93.7%.

The limits of detection (LODs) and quantification (LOQs) were determined as three and ten times the signal-to-noise ratio of the blanks, respectively. The LODs and LOQs for the OCPs ranged from 0.01 to 0.05 ng·g⁻¹ and 0.03 to 0.15 ng·g⁻¹, respectively.

A one-way analysis of variance (ANOVA) was conducted to determine whether there were statistically significant differences in the concentrations of the target OCPs among the rice samples. This test assessed variability within and between the rice samples and identified any significant differences in OCP levels. Following a significant ANOVA result, Tukey's Honestly Significant Difference (HSD) test was applied for post-hoc pairwise comparisons to determine which specific OCP concentrations differed significantly between rice samples. The statistical significance level was set at $P < 0.05$.

Human health risk assessment

To evaluate the health risks associated with human exposure to OCPs in rice through dietary consumption, this study employed both deterministic and probabilistic approaches. The assessment comprised the estimated dietary intake (EDI), non-cancer risk (CR) [hazard quotient (HQ)], CR, and a Monte Carlo simulation to account for exposure variability.

EDI

The EDI for each OCP was evaluated using the equation^[21]:

$$\text{EDI (mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}) = \frac{C \times \text{RCR}}{\text{Bw}} \quad (2)$$

Where RCR is the rice consumption rate (33.4 kg per year as of 2022, which is equivalent to 0.092 kg per day)^[22], C is the concentration of OCPs in rice samples (LOD/√2 for OCPs below the detection limit), and Bw is the body weight of an adult (60 kg)^[23].

Non-CR assessment

The non-CR was evaluated using the HQ^[24]:

$$\text{HQ} = \frac{\text{EDI}}{\text{RfD}} \quad (3)$$

Where RfD is the oral reference dose (the RfD is defined as the estimated daily exposure to a substance that is unlikely to cause harmful effects to an individual over a lifetime). The following RfD values (mg·kg⁻¹·day⁻¹) were used in this study: β-HCH - 0.00002, aldrin - 0.00003, endrin - 0.0003, dieldrin - 0.00005, heptachlor - 0.0005, heptachlor epoxide - 0.000013, α-HCH - 0.00008, δ-HCH - 0.0003, and γ-HCH - 0.003^[25].

A hazard index (HI), the sum of individual HQs, was used to evaluate the risk of exposure to mixtures of detected pesticides belonging to the same chemical group^[26]. It is expressed as:

$$HI = \sum_i^n HQ_i \quad (4)$$

When the HQ and HI values are greater than 1, the food product is deemed unacceptable and may pose a health risk to humans; conversely, values below 1 indicate minimal risk^[24].

CR

The CR was calculated for OCPs with known carcinogenicity using the expression:

$$CR = EDI \times CSF \quad (5)$$

Where CSF is the cancer slope factor ($\text{mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$). The CSF values used in this study were - 9.1 for β -HCH, 17 for aldrin, 16 for dieldrin, 9.1 for heptachlor epoxide, 0.34 for DDT, and 4.5 for heptachlor^[27].

The total cancer risk (TCR) is the sum of the CR values of all target OCPs, and it was evaluated as follows:

$$\text{Total CR} = CR_1 + CR_2 + CR_3 + \dots + CR_n \quad (6)$$

If the TCR is less than 1×10^{-6} , the risk is negligible. If the TCR lies between 1×10^{-6} and 1×10^{-4} , the risk is within the tolerable range. If the TCR is greater than 1×10^{-4} , it suggests elevated CR and may require interventions^[24]. The maximum and minimum acceptable risk levels of 1×10^{-4} and 1×10^{-6} imply a risk of one in a million resulting from lifetime exposure to OCPs^[28].

Monte Carlo simulation

To account for variability in exposure and risk, a Monte Carlo simulation was conducted using Python (version 3.10). The simulation randomly sampled concentrations from observed data and computed the EDI and HQ using the same expressions earlier described^[29]. Through simulations, the repetitive number for each HQ was 10,000 and the 95th percentile was considered the health risk benchmark.

RESULTS AND DISCUSSION

Concentration of OCPs in rice residue samples

The concentrations of OCPs in the studied rice samples are presented in Table 1. Out of the 16 targeted OCPs, only six - β -HCH, heptachlor epoxide, dieldrin, endrin, endrin aldehyde, and aldrin - were detected. The total concentration of these detected OCPs ($\Sigma_o\text{OCPs}$) ranged from 2.11 to $4.78 \mu\text{g} \cdot \text{kg}^{-1}$, with an average concentration of $3.35 \mu\text{g} \cdot \text{kg}^{-1}$ across the rice samples. Significant differences ($P < 0.05$) were observed in the total concentration of OCPs across the rice samples and among the detected OCPs. The average OCP levels in the rice samples followed the order: endrin > endrin aldehyde > heptachlor epoxide > dieldrin > β -HCH > aldrin. The presence of these OCPs in rice suggests their bioavailability in the environment, raising concerns regarding rice safety, public health, and environmental contamination.

Aldrin was detected in only one rice sample at a concentration of $0.07 \mu\text{g} \cdot \text{kg}^{-1}$. In the environment, it breaks down into the more toxic metabolite, dieldrin^[30]. The presence of dieldrin in all analyzed rice samples highlights its toxicity, the environmental persistence of aldrin, and possibly recent usage. β -HCH was the only detected isomer of the HCHs, with concentrations ranging from 0.08 to $0.77 \mu\text{g} \cdot \text{kg}^{-1}$. It is the most environmentally persistent isomer of the HCHs, with the lowest water solubility and the greatest stability^[31]. Earlier studies have reported this isomer as the predominant one in cultivated rice^[1,32]. Its presence in rice in this study suggests that rice fields were likely cultivated with technical grade HCH (i.e., a mixture of all HCH isomers), and due to the high stability of β -HCH in soil, it could be absorbed by rice plants. DDT and

Table 1. Concentration of OCP residues in locally cultivated rice in Nigeria

S/N	OCPs	Concentration ($\mu\text{g}\cdot\text{kg}^{-1}$)					MRL
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	
1	α -HCH	< LOD	< LOD	< LOD	< LOD	< LOD	NL
2	Heptachlor	< LOD	< LOD	< LOD	< LOD	< LOD	20
3	β -HCH	0.08 ± 0.014^a	0.08 ± 0.01^a	0.77 ± 0.03^b	0.18 ± 0.03^c	0.25 ± 0.007^c	NL
4	Aldrin	< LOD	< LOD	0.07	< LOD	< LOD	20
5	δ -HCH	< LOD	< LOD	< LOD	< LOD	< LOD	NL
6	γ -HCH	< LOD	< LOD	< LOD	< LOD	< LOD	10
7	Heptachlor epoxide	0.29 ± 0.028^a	1.40 ± 0.007^b	1.54 ± 0.01^b	0.13 ± 0.03^c	0.19 ± 0.03^c	NL
8	Endosulfan	< LOD	< LOD	< LOD	< LOD	< LOD	NL
9	Dieldrin	0.16 ± 0.007^a	0.38 ± 0.028^b	0.19 ± 0.003^a	0.72 ± 0.04^c	0.24 ± 0.03^a	20
10	Endrin	1.03 ± 0.01^a	1.73 ± 0.04^b	1.40 ± 0.006^c	0.99 ± 0.01^a	1.25 ± 0.01^c	NL
11	m,p'-DDD	< LOD	< LOD	< LOD	< LOD	< LOD	NL
12	Endosulfan II	< LOD	< LOD	< LOD	< LOD	< LOD	NL
13	p,p'-DDT	< LOD	< LOD	< LOD	< LOD	< LOD	100
14	Endrin aldehyde	0.56 ± 0.04^a	0.95 ± 0.01^b	0.81 ± 0.02^c	0.58 ± 0.03^a	0.77 ± 0.04^b	NL
15	Endosulfan sulfate	< LOD	< LOD	< LOD	< LOD	< LOD	NL
16	Endrin ketone	< LOD	< LOD	< LOD	< LOD	< LOD	NL
ΣOCPs		2.11^a	4.54^b	4.78^b	2.60^a	2.70^a	

Within each row, concentration values with different superscript letters differ significantly ($P < 0.05$). OCP: Organochlorine pesticide; MRL: maximum residue limit; < LOD: below limit of detection; NL: not listed for the indicated OCP^[43].

one of its biodegradation products, DDD, were not detected in any of the studied samples, indicating its restricted use and possibly improved agricultural practices among rice farmers in Nigeria. However, elevated levels of permethrin, DDT, β -HCH, and other OCPs were reported in stored grains - rice, beans, wheat, and maize - from Ondo, Nigeria, prior to 2022^[33]. Low levels of OCPs were also reported in rice sold in Anambra markets in southeastern Nigeria following the rice importation ban^[34], but these levels were relatively higher than those in this study. Similarly, it has been shown that OCP residues in foods grown on agricultural farmlands in Lagos were generally below the limit of detection by the measuring equipment in one study^[35], while p,p'-DDE was reported to have the highest concentration, which was still within safe limits in another study^[36]. Elevated levels of DDT and other OCPs were also reported in cocoa beans and beans obtained from Ondo/Ile-Ife and Lagos, Nigeria^[15,37], as well as in maize-based complementary breakfast food products in Nigeria^[28].

Beyond Nigeria, DDT and HCH were reported in Chinese rice, with maximum concentrations of 39 and $53 \mu\text{g}\cdot\text{kg}^{-1}$, respectively^[1], while DDT and HCHs were also reported as the predominant OCP residues in rice cultivated in paddy farms in China and Thailand^[32]. In a related study, elevated levels of DDT and lindane were found in rice cultivated in agricultural pockets in Eastern India, with concentrations exceeding MRLs^[38]. Rice processing treatments, such as milling, parboiling, and storage conditions, are reported to significantly decrease pesticide residue in rice grains^[39,40]. Milling reduces the concentration of lipophilic pesticides, as most pesticides are found in the rice bran^[41]. The low level of OCP residues in rice samples in this study could also be partly attributed to their replacement with organophosphate pesticides, which are reported to exhibit limited environmental persistence^[42,43].

Food safety standards are designed to ensure consumer safety by establishing limits. A MRL is the highest concentration of pesticide residue legally allowed in food commodities and animal feeds^[44]. It is not expected to be exceeded if the pesticide is applied according to the recommended guidelines for its safe

Table 2. EDI of OCPs in rice samples

OCPs	EDI (mg·kg ⁻¹ ·day ⁻¹)				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
α-HCH	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸
Heptachlor	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸
β-HCH	1.22 × 10 ⁻⁷	1.22 × 10 ⁻⁷	1.18 × 10 ⁻⁶	2.76 × 10 ⁻⁷	3.83 × 10 ⁻⁷
Aldrin	1.53 × 10 ⁻⁸	1.53 × 10 ⁻⁸	1.07 × 10 ⁻⁷	1.53 × 10 ⁻⁸	1.53 × 10 ⁻⁸
δ-HCH	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸
γ-HCH	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	4.60 × 10 ⁻⁸	1.99 × 10 ⁻⁷	1.99 × 10 ⁻⁷
Heptachlor epoxide	4.45 × 10 ⁻⁷	2.15 × 10 ⁻⁶	2.36 × 10 ⁻⁶	2.36 × 10 ⁻⁶	2.91 × 10 ⁻⁷
Dieldrin	2.45 × 10 ⁻⁷	5.83 × 10 ⁻⁷	2.91 × 10 ⁻⁷	1.10 × 10 ⁻⁶	3.68 × 10 ⁻⁷
Endrin	1.57 × 10 ⁻⁶	2.65 × 10 ⁻⁶	2.14 × 10 ⁻⁶	1.52 × 10 ⁻⁶	1.92 × 10 ⁻⁶
p,p'-DDT	1.53 × 10 ⁻⁸	1.53 × 10 ⁻⁸	1.53 × 10 ⁻⁸	1.53 × 10 ⁻⁸	1.53 × 10 ⁻⁸

EDI: Estimated dietary intake; OCPs: organochlorine pesticides.

use^[37]. In this study, the concentration of all detected OCPs was within their respective MRLs, indicating that the locally processed rice is safe for consumption, based on safety guidelines for pesticide residues in food^[44]. Although this study is preliminary in nature, the findings suggest that locally processed rice may contain residual levels of OCPs, warranting further large-scale monitoring to ensure consumer safety.

Human health risk assessment

EDI

In Table 2, the results for dietary exposure to OCPs (expressed as the EDI) are presented. The calculated values of EDI for OCPs in rice were all within their respective RfDs. This suggests that the level of OCP residues in the studied rice samples does not pose a significant potential health risk to consumers. The RfD refers to the amount of a contaminant that a person could be exposed to daily over a lifetime without significantly increasing the likelihood of harm^[45]. Hence, with EDI values within the limits of their respective RfDs, the rice samples can be considered safe for consumption from a toxicological perspective.

Non-CR

The results for non-CR exposure due to ingestion of OCPs in rice are shown in Table 3. The HI values of OCPs in the rice samples ranged from 0.057 to 0.25. The highest HI values were found in samples 2 and 3, with significant contributions from aldrin and heptachlor epoxide. The computed values were all less than 1, suggesting that there is negligible risk associated with OCPs in locally processed rice available in local markets in Bayelsa State. The HI values obtained in this study are very low compared to an earlier report^[21], with HI values ranging from 14.5 to 15.3 and 1.76 to 3.08 for rice from China and Thailand, respectively. However, they are similar to a later report, where HI values were less than 1^[34].

CR

The results for CR due to OCP residues in rice are shown in Table 4. The values ranged from 9.60 × 10⁻⁶ to 3.90 × 10⁻⁵. Rice sample 3 had the highest TCR values. These values suggest a wide variation in the CR contributions from different OCPs detected in the rice samples. All computed TCR values were within the US EPA's risk range of 1.00 × 10⁻⁶ to 1.00 × 10⁻⁴ for carcinogens, with heptachlor epoxide contributing the most to the TCR.

Monte Carlo simulation

The mean HQ, median HQ, and 95th percentile exposure values for the detected OCPs are presented in

Table 3. Non-CR of OCP residue in rice samples

OCPs	HQ				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
α -HCH	0.00057	0.00057	0.00057	0.00057	0.00057
Heptachlor	0.000092	0.000092	0.000092	0.000092	0.000092
β -HCH	0.0061	0.0061	0.059	0.013	0.019
Aldrin	0.00051	0.00051	0.0035	0.0015	0.0015
δ -HCH	0.00015	0.00015	0.00015	0.00015	0.00015
γ -HCH	0.00015	0.00015	0.00015	0.00015	0.00015
Heptachlor epoxide	0.034	0.16	0.18	0.015	0.022
Dieldrin	0.0049	0.012	0.0058	0.022	0.0073
Endrin	0.0052	0.0088	0.0072	0.0051	0.0063
p,p'-DDT	0.000031	0.000031	0.000031	0.000031	0.000031
HI	0.050	0.19	0.25	0.058	0.057

CR: Cancer risk; OCP: organochlorine pesticide; HQ: hazard quotient; HI: hazard index.

Table 4. CR of OCP residues in rice

OCPs	CR				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Heptachlor	2.07×10^{-7}	2.07×10^{-7}	2.07×10^{-7}	2.07×10^{-7}	2.07×10^{-7}
β -HCH	1.16×10^{-6}	1.11×10^{-6}	1.07×10^{-5}	2.51×10^{-6}	3.48×10^{-6}
Aldrin	2.61×10^{-7}	2.61×10^{-7}	1.82×10^{-6}	7.87×10^{-7}	7.82×10^{-7}
γ -HCH	5.98×10^{-8}	5.98×10^{-8}	5.98×10^{-8}	5.98×10^{-8}	5.98×10^{-8}
Heptachlor epoxid	4.04×10^{-6}	1.95×10^{-5}	2.15×10^{-5}	1.81×10^{-6}	2.65×10^{-6}
Dieldrin	3.92×10^{-6}	9.32×10^{-6}	4.66×10^{-6}	1.76×10^{-5}	5.88×10^{-6}
p,p'-DDT	5.21×10^{-9}	5.21×10^{-9}	5.21×10^{-9}	5.21×10^{-9}	5.21×10^{-9}
TCR	9.62×10^{-6}	3.05×10^{-5}	3.90×10^{-5}	2.34×10^{-5}	1.38×10^{-5}

CR: Cancer risk; OCP: organochlorine pesticide; TCR: total cancer risk.

Table 5. The Monte Carlo simulation confirmed the result of the deterministic analysis, indicating that exposure to the detected OCPs via rice consumption poses negligible non-cancer health risks. All HQ values were well below 1, even at the 95th percentile, indicating that variations in OCP concentrations do not result in significant health threats.

Limitations of the study

Despite providing valuable insights into OCP residues in locally processed rice in Nigeria, this study has some limitations. First, the small sample size ($n = 5$) limits the generalizability of the results. The small sample size was partly due to the focus of this study on locally processed rice and the exclusion of foreign brands, which reduced available varieties in the selected market. Second, the study's scope was limited to the Swali Market in Bayelsa State. Although the market is a major distribution point, it may not fully represent rice products sold in other parts of Nigeria. Lastly, this study focused exclusively on OCPs and did not include other classes of pesticides, which may also be in use and pose additional health risks.

CONCLUSION

This preliminary study provides valuable insights into OCP residues in locally processed rice in Nigeria, particularly following the 2022 rice importation ban. All detected OCP concentrations were within the

Table 5. Monte Carlo simulation results for non-CR of OCPs in rice

OCPs	Mean HQ	Median HQ	95th percentile HQ	Exceedance probability (HQ > 1)
β-HCH	0.0000	0.0000	0.0001	0.0%
Aldrin	0.0000	0.0000	0.0000	0.0%
Heptachlor epoxide	0.0000	0.0000	0.0000	0.0%
Dieldrin	0.0000	0.0000	0.0000	0.0%
Endrin	0.0000	0.0000	0.0000	0.0%

CR: Cancer risk; OCPs: organochlorine pesticides; HQ: hazard quotient.

MRLs set by the Codex Alimentarius, indicating that at the time of sampling, locally processed rice posed minimal risk with respect to OCP contamination. Health risk assessments - based on EDI, HQ and HI models, and Monte Carlo simulation - indicated negligible risks to consumers. These findings suggest that dietary exposure to OCPs through rice consumption is currently not a significant health concern. To strengthen future investigations, studies should incorporate a larger sample size, broaden regional coverage, and compare local and imported rice products. In addition, continuous monitoring, stricter enforcement of pesticide regulations, and the promotion of non-chemical pest control methods - such as biological control and organic farming - will be essential for enhancing food safety, promoting sustainable agricultural practices, and reducing reliance on synthetic pesticides.

DECLARATIONS

Acknowledgments

The effort of Miss Tare and Messrs Christian Ogegere and Favour Ifeanyi in the course of this research is highly appreciated.

Authors' contributions

Made substantial contributions to the conception and design of the study and performed data analysis and interpretation: Iniaghe, P. O.; Osioma, E.

Performed data acquisition, as well as providing administrative, technical, and material support: Iniaghe, P. O.; Ekwutoziam, P.

Availability of data and materials

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Financial support and sponsorship

None.

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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