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Health-risk assessment of organochlorine pesticides and heavy metals in selected staple foods from Abeokuta, Southwestern Nigeria

Adekola, M. B.[1], *Taiwo, A. M.*[1], *Towolawi, A. T.*[2], *Oyebanji, F. F.*[1], *Olatunde, K. A.*[1], *Iyanda, C. T.*[1], *Ajayi, O. E.*[1], *Uwajeh, N. L.*[1], *Agbaje, A. B.*[1], *Osho, S. A.*[1], *Adeyemi, T. V.*[1]

Address

[1]*Department of Environmental Management and Toxicology, Federal University of Agriculture, Abeokuta, PMB 2240, Ogun State, Nigeria*

[2]*Department of Environmental Health Science, Fountain University Osogbo, Osun State, Nigeria*

*Corresponding Author:*Adekola, Mukaila Babatunde*, **e-mail:** adekolamb@funaab.edu.ng

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ABSTRACT

This study examined the levels and health threat assessment of organochlorine pesticides (OCPs) and heavy metal (HM) residues in five selected foodstuffs—sorghum, maize, rice, garri (processed fried cassava), and beans—randomly collected from three markets within the Abeokuta metropolis in southwestern Nigeria. Gas chromatography-mass spectrometry (GC-MS) and atomic absorption spectrometry (AAS) methods were used to analyze the foodstuffs for OCPs and HMs, respectively. The collected data were analyzed using simple descriptive and inferential statistics. Health risk indices, including non-carcinogenic and carcinogenic effects, were estimated for organochlorine pesticides (OCPs) and heavy metals (HMs) in food samples. The findings revealed that the concentrations of OCPs and HMs in many food samples exceeded the recommended dietary allowances. The risk index values of OCPs and estimated HMs in each foodstuff exceed the permissible limit of 1.0, indicating potential negative health impacts, although not cancer-causing. Dieldrin was the largest contributor to adverse health effects, ranging from 10 to 98%, while Pb had the highest contribution, with values between 43 and 54%. The combined cancer risk of OCPs and HMs was above the allowable limit of 1×10^{-4}, suggesting a potential risk for cancer development. The data on OCPs and HMs in the analyzed foodstuffs represent direct threats to public health.

Keywords: Food toxicity; Pesticides; Metals; Health risk; Staple foods; Food composition; Food Analysis

INTRODUCTION

In agriculture, pesticides are primarily employed to prevent pest invasion and reproduction, thereby increasing crop yields. Organochlorine pesticides (OCPs) are a class of chemicals used to eradicate and prevent pests and diseases that affect agricultural production in the field or at retail outlets (Jayaraj *et al.,* 2016; Taiwo, 2019; Tagne-Fotso *et al.,* 2023). Dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexanes (HCHs) are OCPs frequently applied in agriculture and public health to lessen the destructive activities of pests and diseases (Hu *et al.,* 2010). The production and use of OCPs have been outlawed due to their distinctive traits such as persistence, toxicity, and lipophilicity (Ahmed *et al.,* 2015; Bai *et al.,* 2015; Taiwo, 2019; Taiwo *et al.,* 2020; Wang *et al.,* 2022).

In a previous study from Borno State in the northern part of Nigeria, the occurrence of organochlorine pesticides (OCPs) such as aldrin and lindane in post-harvest bean samples, as well as DDT and endrin in both pre- and post-storage samples, was reported by Ogah and Coker (2012). Garshin *et al.* (2023) assessed the risk factors associated with exposure to OCPs among the population of Kazakhstan. The health implications, ranging from acute to chronic disorders, and environmental impacts of OCPs have been reported in several published studies (Kumar *et al.,* 2011; Sun *et al.,* 2016; Taiwo, 2019; Taiwo *et al.,* 2020). High levels of pesticide residues in food products have been linked to incidences of food poisoning and fatalities in Nigeria due to the repeated and improper application of pesticides on farms and in stores (Oyeyiola *et al.,* 2017).

The National Agency for Food and Drug Administration and Control (NAFDAC), a Nigerian organization that regulates the importation, exportation, manufacture, sale, and use of food, drugs, cosmetics, and related products, conducted an investigation. Through laboratory analyses, NAFDAC determined that the food poisoning incident was caused by consuming beans exposed to pesticides, which directly led to fatalities (Oyeyiola *et al.,* 2017). Metals with high density and toxicity can have health effects; however, some are necessary for healthy metabolic growth and development. Increased concentrations can have harmful health consequences.

Heavy metals (HMs) such as Pb, Cd, Ba, and Ti exhibit no known physiological activities in biological systems and can be deleterious, regardless of their quantity (Taiwo *et al.,* 2019). Both natural and anthropogenic sources contribute to the mobilization of HMs into the environment; these include industrial and household waste, landfill leaching, storm runoff, automobile exhaust, and shipping (Swaroop *et al.,* 2021). The three main entry points for HMs into the human body are food, air, and drinking water (Singh Sankhla *et al.,* 2020). Due to their persistent nature, inability to degrade, and propensity to biomagnify throughout the food chain, heavy metals (HMs) pose a problem for ecosystems (Hong *et al.,* 2020). They can have harmful consequences for biological systems. Furthermore, it has been noted that under certain circumstances, HMs can interact with biomolecules and convert them into more dangerous metal-organic complex pollutants.

They have been linked to an increase in medical diseases such as cancer, diabetes, and Alzheimer's disease (Ara-Marini *et al.,* 2020; Taiwo *et al.,* 2023a). Different metals exhibit distinctive toxicity signs, with effects that may be acute, chronic, sub-acute, or sub-chronic. Additionally, they might have carcinogenic, mutagenic, teratogenic, hepatologic, neurotoxic, or other harmful effects (Swaroop *et al.,* 2021; Taiwo *et al.,* 2023b). An evaluation of the potential health h risks associated with human exposure to toxicants, including toxic metals and organochlorine pesticides (OCPs), in food and the environment was required due to their harmful effects (Liu *et al.,* 2010). Few studies have investigated the health effects of OCPs and heavy metals (HMs) on Nigerian staple foods. Research by Ogah and Coker (2012), Taiwo (2019), Taiwo *et al.* (2019), Taiwo *et al.* (2020), and Taiwo *et al.* (2023a) has reported the health hazards posed by OCPs and metals in foods. The current research determined the concentrations and potential health effects of organochlorine pesticides (OCPs) and heavy metals (HMs) in five common foods—sorghum, rice, maize, garri, and beans—randomly selected from Abeokuta city in Ogun State, Nigeria.

MATERIALS AND METHODS

Study location:

The location of the research is Abeokuta, the capital of the southwest Nigerian state of Ogun. It is situated 130 kilometers north of Lagos by boat or 77 kilometers by railroad. Abeokuta is positioned between latitudes 7° 5′ and 7° 20′ N, and longitudes 3° 17′ and 3° 27′ E. The region experiences a climate with multiple rainy and dry seasons. The average annual temperature is around 28 °C, with an average rainfall of 1,270 mm and potential evaporation of 1,100 mm (Olabisi *et al.,* 2008). The sampling locations are indicated in Fig. 1.

Samples collection and preparation:

Six samples of each of the five staple foods—sorghum, maize, rice, garri, and beans—were randomly selected from various markets in Abeokuta, Ogun State, southwest Nigeria. Markets for garri and maize were located in Osiele and Adatan, while those for beans and rice were in Kuto and Osiele. Sorghum was obtained from Adatan and Kuto. To avoid contamination, the samples were collected in pre-cleaned bottles that were tightly sealed. The samples were clearly labeled using masking tape.

Sample Preparation:

To clean the samples, stones and other foreign objects were removed. Using an electric blender, the samples (100 g each) were turned into a fine powder. The milled samples were properly labeled and stored in glass bottles to avoid cross-contamination both during and after the milling procedures.

Reagents and Materials:

Mallinckrodt supplied pesticide-grade (99.9%) acetonitrile, toluene, and isooctane from Phillipsburg, NJ, USA. J.T. Baker provided acetic acid, sodium acetate (99.0%), and magnesium sulphate (98.0%) from Xalostoc, Mexico. Primary-secondary amine (PSA) is a dispersive sorbent used for extraction in solid-phase clean-up, and octadecylsilane (C18) is a sorbent from Varian, Middelburg, Netherlands. Acetone, dichloromethane, n-hexane, alumina, methylene chloride, sodium sulphate, anhydrous potassium hydroxide, HNO_3 (purity: 70%), H_2SO_4 (purity: 97%), and $HClO_4$ (purity: 70%) are the chemicals obtained from reliable sources with high purity levels.

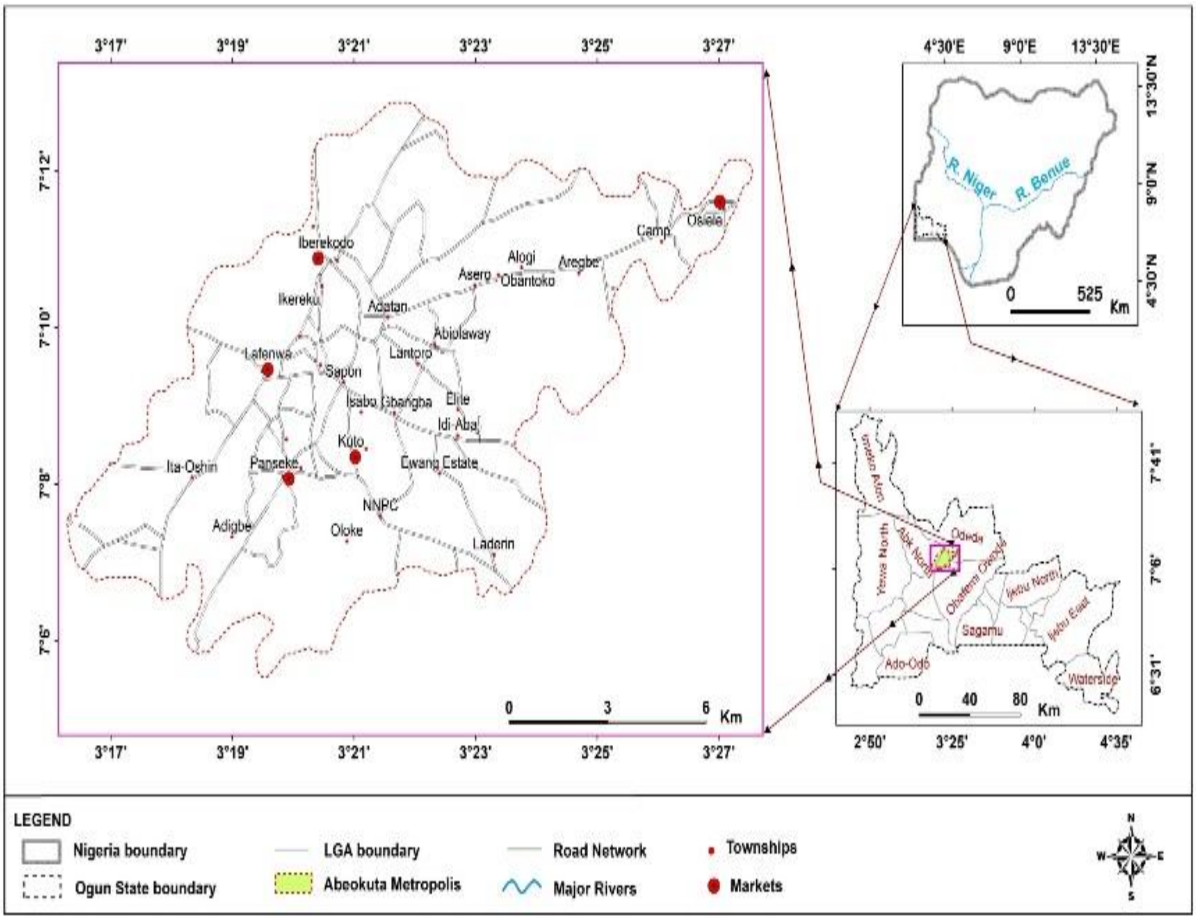


Fig. 1. The map of the study location with sample collection sites (Taiwo et al., 2022)

Preparation of Extraction Solvent:

In a 1000-mL beaker, a mixture of acetonitrile and hexane was prepared in a 1:20 ratio. Organochlorine pesticide stock standard solutions (Varian, Middelburg, Netherlands) were prepared, and multiple concentrations (0.05, 0.5, 1.0, 2.0, 4.0, and 8.0 µg mL-1) of each pesticide were created for use in the recovery procedure and calibration curves.

Extraction and Clean-up Procedure:

Anhydrous sodium sulfate was mixed with 10 g of finely ground sample after it had been individually and thoroughly milled. The samples and mixtures were placed in a beaker, which was then filled with 40 mL of a one-to-one (1:1) hexane and acetone solution and sonicated for at least 20 minutes. After allowing the mixture to settle, the solvent layer was decanted and concentrated to 2 mL using a rotary evaporator.

Analysis of HMs and OCPs:

Atomic absorption spectrophotometer (AAS) analysis:

One gram of the powdered food samples was weighed and digested with mixed acids according to the procedure of the AOAC (2000) and Taiwo et al. (2022). The mixed acids consisted of 10 mL of HNO_3, 5 mL of H_2SO_4, and 2 mL of $HClO_4$. The mixture was heated to 95 °C for 10 minutes in a fume cupboard (Taiwo et al., 2017). It was then diluted with 20 mL of deionized water and filtered into clean bottles before analysis for metals (Pb, Zn, Ni, Fe, Cr, and Cd) using AAS (Bulk Scientific, 210/211VGp, CT, USA) at the Central Laboratory at the University of Ibadan, Nigeria. The AAS instrument was calibrated using various standard solutions ranging from 0 to 10 mg/L. Background details regarding the AAS instrument are displayed in Table S1 (Supplementary Information). All extracting reagents were of analytical grade (Sigma-Aldrich Chemie GmbH, Darmstadt, Germany). A sample blank was also carried out to nullify the background matrix of the extracting solvents.

Gas chromatography-mass spectrometry (GC-MS) analysis:

Sample analyses were carried out on a Varian gas chromatograph 450-GC coupled to a Bruker 320-MS/MS triple quadrupole mass spectrometer (Walnut Creek, CA, USA). The 450-GC was equipped with a CP-8400 autosampler and a programmable temperature vaporizer 1079 injector containing an inert glass inlet liner (3.4 mm i.d., 54 mm length) packed with carbofrit. Injections were conducted in a large-volume injection mode.

The conditions were as follows: injection volume, 5 µL; injector temperature, 80 °C for 0.1 min and then increased at 200 °C min^{-1} to 300 °C and kept at this temperature until 31 min. The split time/valve position was as follows: initial, on; 0.10 min, off; 1.75 min, on. Pesticide separation was conducted on a Varian fused-silica capillary column (VF-5ms stationary phase; 0.25 µm film thickness; 30 m × 0.25 mm i.d.).

The column oven temperature programme started at 80 °C (held for 1 min), followed by 25 °C min−1 to 180 °C (held for 5 min), 5 °C min^{-1} to 280 °C (held for 5 min), and 10 °C min^{-1} to 300 °C (held for 5 min). The total run time was 37 minutes. Helium (99.99% purity) was used as carrier gas at a constant flow rate of 1 mL min^{-1} oxygen, and moisture gas filters (Restek, Bellefonte, PA, USA) were installed in the gas line.

The triple quadrupole MS/MS was operated in electron ionisation mode and multiple reaction monitoring modes. The temperatures of the transfer line, source, and manifold were set to 275, 265, and 50 °C, respectively. The detector voltage was 1300 volts. The filament (50 µA current) was switched off during a delay time of 3.6 minutes and switched on for 29 minutes. Data acquisition and processing were realised with the MS Workstation 6.9.3 software (Bruker, USA).

Health risk assessment:

The health effects of OCPs and metals in foods were evaluated for Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI), and Cancer Risk (CR) according to the formulae shown in equations 1–4 (USEPA, 2007).

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

Where, ADD = Average daily dose (mg kg^{-1} day^{-1})

C = Concentration of OCPs and metals in foods (mg kg^{-1}),

IR = Ingestion rate of foods (24.7 g day^{-1}) (FAO, 2008),

ED = Exposure duration (years) = 30 years for carcinogenic effects for adults,

EF = Exposure frequency (day/year) = 350 days $year^{-1}$,

AT = Averaging time or life expectancy = 54.5 years (WHO, 2015), AT = ED for non-carcinogenic effects,

BW = Body weight (kg); 60 kg for an adult (Taiwo *et al.,* 2021).

$$HI = \sum_{i=1}^{n} HQ \qquad i=1 \ldots n \quad (2)$$

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

Where, ADD =Average daily dose (mg kg^{-1} day^{-1}),

RfD =Reference dose (mg kg^{-1} day^{-1}) (USEPA, 2007),

n =numbers of observed elements.

HQ > 1 denotes adverse health effects; HQ < 1 indicates no adverse effects,

$$\text{Cancer Risk} = ADD \times CSF \quad (4)$$

Where, ADD = Average daily intake (mg kg^{-1} day^{-1}),

SF = Cancer slope factor (mg^{-1} kgday)

Data analysis:

Data obtained were analyzed for descriptive (Mean and Standard deviation) and inferential (Analysis of Variance and Duncan Multiple Range Test) statistics using the SPSS for Windows (version 21.0).

RESULTS

Levels of OCPs and HMs in foodstuffs:

The levels of OCPs and HMs found in dietary foodstuffs are shown in Table 1. The OCP levels were established in the following order: maize > rice > sorghum > beans > garri. Figure S1 (in the supplementary information) shows chromatograms of OCPs found in dietary samples. Except for p,p'-DDE, endrin aldehyde, endosulfan sulfate, dieldrin, endrin ketone, and methoxychlor, most OCP congeners in beans showed values below the detection limit (0.001 mg kg^{-1}). Aldrin and p,p'-DDD were also measured below the detection limit of the analytical equipment in rice and sorghum. DDT, the highest observed OCP in the foodstuffs, ranged from <0.001 mg kg^{-1} in beans to 18.54±12.60 mg kg^{-1} in maize, while endrin aldehyde varied from 0.004±0.005 mg kg^{-1} in garri to 0.77±0.50 mg kg^{-1} in rice.

The heavy metals data are presented in Table 1. Fe content of the food samples varied from 960 ± 159.17 mg kg^{-1} in maize to 1297 ± 175.84 mg kg^{-1} mg kg^{-1} in garri. Zn levels in all the foodstuffs were above the recommended value of 9.5 mg kg^{-1} according to the Institute of Medicine (IOM, 2001), except for garri (7.89 ± 1.18 mg kg^{-1}). Cd was not up to the recommended value in rice, maize, garri, and beans; only sorghum had a slightly higher level (0.11 ± 0.13 mg kg^{-1}) than the recommended level of 0.1 mg kg^{-1} as stated by FAO/WHO (2015). Ni showed values above the permissible limit in sorghum (1.65 ± 1.20 mg/kg), garri (2.26 ± 1.71 mg kg^{-1}), and beans (4.45 ± 1.41 mg kg^{-1}). The level of HMs in the foodstuffs followed the trend: garri > beans > sorghum > rice > maize.

Table 1 Levels of Organochlorine (OCPs) and Heavy metals (HMs) in the foodstuff (n = 30):

OCP (mg kg^{-1})	Sorghum	Rice	Maize	Garri	Beans	Permissible standards
Heptachlor	0.34^{ab}±0.32	1.35^{b}±0.42	1.76^{b}±0.89	0.006^{a}±0.001	<0.001^{a}	0.3$^{\#}$
Aldrin	1.27^{b}±0.00	1.65^{b}±0.00	<0.001^{a}	0.001^{a}±0.003	<0.001^{a}	0.3$^{\#}$
Heptachlor Epoxide	2.00^{b}±0.79	2.99^{b}±1.85	2.08^{b}±1.29	0.067^{a}±0.15	<0.001^{a}	0.3$^{\#}$
Endosulfan I	1.18^{b}±0.22	2.23^{b}±1.39	1.43^{b}±0.26	0.009^{a}±0.01	<0.001^{a}	0.5
p,p'-DDE	2.07^{b}±0.71	3.75^{b}±3.47	3.61^{b}±4.01	0.010^{a}±0.002	0.72ab±0.04	5$^{\#}$
Endrin	2.62^{b}±0.62	2.97^{b}±1.39	3.19^{b}±1.96	0.060^{a}±0.10	<0.001^{a}	0.3$^{\#}$
Endosulfan II	1.36^{b}±0.83	3.14^{c}±2.32	1.15^{b}±0.09	0.013^{a}±0.02	<0.001^{a}	0.5
p,p'-DDT	15.06^{b}±17.35	13.50^{b}±14.1	18.54^{b}±12.6	0.011^{a}±0.01	<0.001^{a}	5$^{\#}$
Endrin Aldehyde	0.59^{ab}±0.41	0.77^{b}±0.50	0.38^{ab}±0.11	0.004^{a}±0.01	0.31ab±0.10	0.3$^{\#}$
Endosufan Sulfate	1.67^{b}±0.00	3.08^{b}±2.49	2.04^{b}±0.00	0.025^{a}±0.05	1.12a±0.00	0.3$^{\#}$
Dieldrin	2.77^{b}±2.39	2.46^{b}±1.96	2.71^{b}±3.99	0.005^{a}±0.01	0.92ab±0.39	0.3$^{\#}$
p,p'-DDD	<0.001^{a}	<0.001^{a}	5.95^{b}±5.40	0.003^{a}±0.01	<0.001^{a}	5$^{\#}$
Endrin Ketone	5.67^{c}±5.19	2.58^{bc}±2.00	5.04^{c}±5.17	0.008^{a}±0.01	4.43bc±2.49	0.3$^{\#}$
Methoxychlor	3.23^{bc}±3.20	5.11^{c}±4.98	1.51^{b}±0.80	0.011^{a}±0.01	2.25b±1.52	0.3$^{\#}$
Metals (mg kg^{-1})						
Pb	8.01^{ab} ±4.19	9.22^{b} ±4.53	9.60^{ab} ±4.35	10.76^{b} ±3.81	11.77^{b} ±3.56	0.1-0.2^{+}
Cd	0.11^{a} ±0.13	0.05^{a} ±0.04	0.06^{a} ±0.04	0.05^{a} ±0.04	0.03^{a} ±0.05	0.1^{+}
Ni	1.65^{a} ±1.20	0.91^{a} ±0.45	1.26^{a} ±1.30	2.26^{a} ±1.71	4.45^{ab} ±1.41	1.5$^{¥}$
Cr	2.52^{ab} ±1.45	1.95^{ab} ±0.91	2.21^{ab} ±0.84	1.57^{a} ±0.99	3.24^{ab} ±1.79	0.1^{+}
Fe	1247^{c} ±297	1138^{c} ±359	960^{c} ±159	1297^{c} ±176	1269^{c} ±176	425$^{¥}$
Zn	20.87^{b} ±2.68	10.13^{a} ±3.39	18.12^{b} ±2.42	7.89^{b} ±1.18	25.67^{b} ±1.92	9.5*

Similar superscripted alphabets across the columns are not significant at p>0.05 according to Duncan Multiple Range Test, *IOM, 2001; +FAO/WHO, 2015; ¥ – FAO/WHO, 2001; #FDA (2001)

Health risk assessment of OCPs in the foodstuffs:

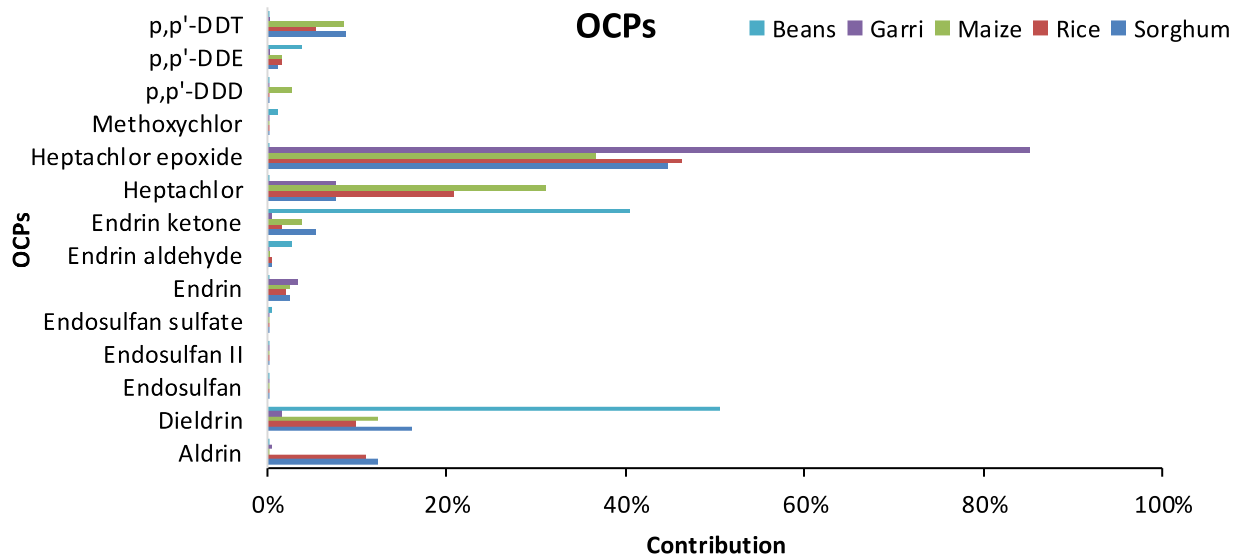
The average daily dose (ADD) levels of organochlorine pesticides (OCPs) and heavy metals (HMs) in foodstuffs are presented in Table S1 (in the supplementary information). The highest dose of OCP found in food was p,p'-DDT at 0.032 mg kg^{-1} day^{-1} in maize. Sorghum and rice also showed high p,p'-DDT dosages, with 0.025 and 0.023 mg kg^{-1} day^{-1}, respectively. Table 2 presents the hazard quotient and hazard index values for OCPs and metals in foodstuffs. The HQs of aldrin in sorghum, dieldrin, and endrin aldehyde in all foodstuffs except 'garri', endrin, heptachlor, p,p'-DDT in sorghum, rice, and maize, heptachlor epoxide in all the food samples, and methoxychlor in sorghum and rice were above the permissible limit of 1.0. The HQs were assessed to be greater than 1.0 for Pb and Fe in all the foodstuffs, as well as Cr in sorghum, rice, and maize.

Figure 2 illustrates the contributions of organochlorine pesticides (OCPs) to the total hazard index (HI). Dieldrin contributed the largest HI in beans (51%), while heptachlor exhibited the highest percentage in maize (31%). Heptachlor epoxide accounted for the majority of the overall HI of OCPs in 'garri' (88%). The figure also shows the contributions of foodstuffs to HI in meals. Lead (Pb), with values ranging from 43% in sorghum to 54% in 'garri', and iron (Fe), with values ranging from 27% in 'garri' and beans to 34% in sorghum, made the largest contributions to the HI. Table 3 presents the cancer risk (CR) data for OCPs in the food samples. Most of the observed OCPs had CRs (except p,p'-DDD) greater than the threshold limit of 1.0 x 10^{-4} in sorghum and rice. Furthermore, the CRs of all OCP congeners were also higher than the permissible limit in maize. The OCPs of carcinogenic concern were heptachlor epoxide in 'garri,' and dieldrin and p,p'-DDE in beans.

The cancer risks (CRs) for heavy metals indicated that cadmium (Cd), nickel (Ni), and chromium (Cr) had carcinogenic potentials exceeding the permissible level of 1.0 x 10^{-4} (Table 3). The distribution of CRs was in the following order: bean > sorghum > 'garri' > maize > rice for heavy metals (HMs), and rice > sorghum > maize > beans > 'garri' for organochlorine pesticides (OCPs). Figure 3 illustrates the contribution of each individual OCP and metal to the overall cancer risk, with values ranging from 38% in rice to 68% in beans. Nickel and heptachlor epoxide were primarily responsible for the overall cancer risk in food samples. Ni is the only metal of carcinogenic concern in the bean samples, while heptachlor epoxide was the organochlorine pesticide (OCP) of health concern in 'garri'.

Table 2. Hazard quotient and hazard index values of OCPs and metals in foodstuffs.

OCPs	fD (mg kg^{-1} day^{-1})	Sorghum Mean	SD	Rice Mean	SD	Maize Mean	SD	Garri Mean	SD	Beans Mean	SD
Aldrin	0.00003	70.63	0.00	91.77	0.00	0.03	0.00	0.06	0.17	0.03	0.00
Dieldrin	0.00005	92.43	79.75	82.09	65.40	90.43	133.15	0.17	0.00	30.70	10.01
Endosulfan	0.006	0.33	0.00	0.62	0.69	0.40	0.00	0.00	0.01	0.00	0.00
Endosulfan II	0.006	0.38	0.06	0.87	0.39	0.32	0.07	0.00	0.02	0.00	0.00
Endosulfan sulphate	0.006	0.46	0.38	0.86	0.65	0.57	0.03	0.01	0.01	0.31	0.00
Endrin	0.0003	14.57	14.57	16.52	7.73	17.74	10.90	0.33	0.51	0.00	0.00
Endrin aldehyde	0.0003	3.28	2.22	4.28	2.78	2.11	0.61	0.02	0.28	1.72	0.56
Endrin ketone	0.0003	31.53	28.86	14.35	11.12	28.03	28.75	0.04	0.00	24.64	13.35
Heptachlor	0.000013	43.64	41.07	173.27	53.91	225.89	114.23	0.77	1.28	0.06	0.06
Heptachlor epoxide	0.000013	256.69	101.39	383.75	237.44	266.96	165.57	8.60	19.77	0.06	0.00
Methoxychlor	0.005	1.08	1.07	1.71	1.66	0.50	0.27	0.00	0.00	0.75	0.51
p,p'-DDD	0.0005	0.00	0.00	0.00	0.00	19.86	18.02	0.01	0.00	0.00	0.00
p,p'-DDE	0.0005	6.91	2.37	12.51	11.58	12.05	13.38	0.03	0.07	2.40	0.13
p,p'-DDT	0.0005	50.26	57.90	45.05	47.18	61.87	42.05	0.04	0.04	0.00	0.00
	HI	572.20		827.65		726.75		10.09		60.69	
Metals	fD (mg kg^{-1} day^{-1})										
Pb	0.0035	3.82	2.00	4.40	2.16	4.58	2.07	5.13	1.82	5.61	1.70
Cd	0.0005	0.37	0.43	0.17	0.13	0.20	0.13	0.17	0.13	0.10	0.17
Ni	0.02	0.14	0.10	0.08	0.04	0.11	0.11	0.19	0.14	0.37	0.12
Cr	0.003	1.40	0.81	1.08	0.51	1.23	0.47	0.87	0.55	1.80	1.00
Fe	0.7	2.97	0.71	2.71	0.86	2.29	0.38	3.09	0.42	3.02	0.42
Zn	0.3	0.12	0.01	0.06	0.02	0.10	0.01	0.04	0.01	0.14	0.01
	HI	8.81		8.49		8.50		9.49		11.05	



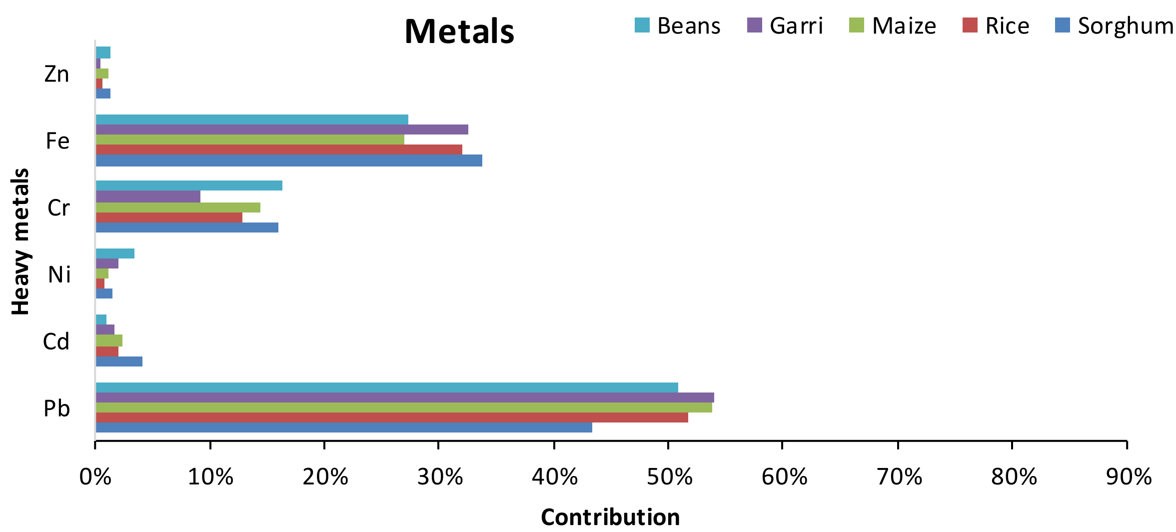
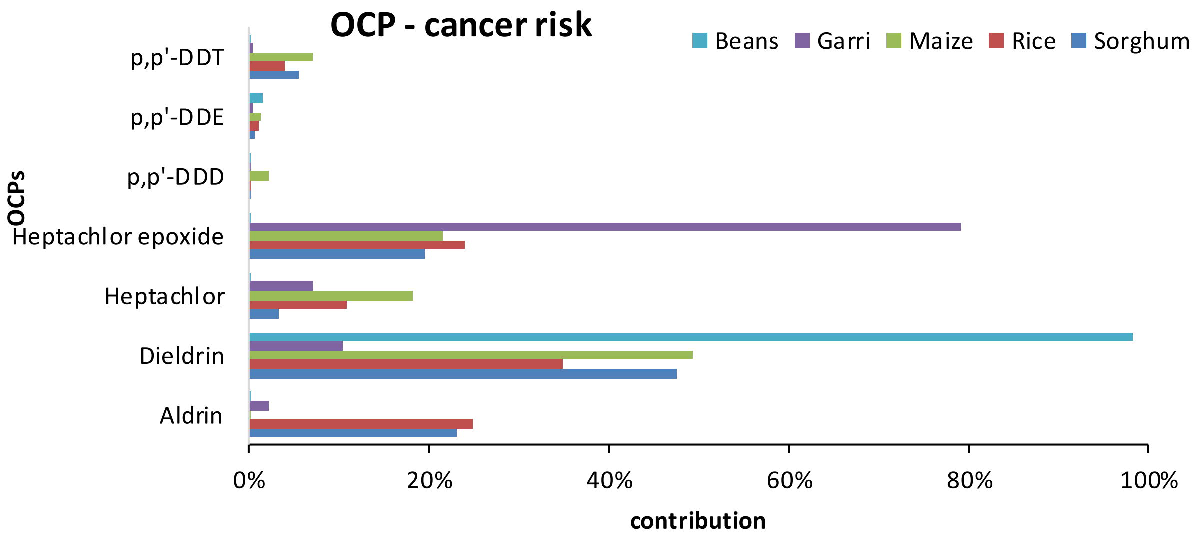


Fig. 2. Contributions of individual OCP and HM to total non-carcinogenic effects

Table 3 Cancer risk values of OCPs and HMs in foodstuffs:

		Sorghum		Rice		Maize		Garri		Beans	
	CSF (mg^{-1} kg day)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aldrin	17	2.0E-02	0.0E+00	2.6E-02	0.0E+00	7.8E-06	0.0E+00	1.6E-05	4.7E-05	7.8E-06	0.0E+00
Dieldrin	16	4.1E-02	3.5E-02	3.6E-02	3.5E-02	4.0E-02	5.9E-02	7.3E-05	0.0E+00	1.4E-02	4.4E-03
Heptachlor	9.1	2.8E-03	2.7E-03	1.1E-02	2.7E-03	1.5E-02	7.4E-03	5.0E-05	8.4E-05	4.2E-06	4.2E-06
Heptachlor Epoxide	9.1	1.7E-02	6.6E-03	2.5E-02	6.6E-03	1.7E-02	1.1E-02	5.6E-04	1.3E-03	4.2E-06	0.0E+00
p,p'-DDD	0.34	1.6E-07	0.0E+00	1.6E-07	0.0E+00	1.9E-03	1.7E-03	9.4E-07	0.0E+00	1.6E-07	0.0E+00
p,p'-DDE	0.34	6.5E-04	2.2E-04	1.2E-03	2.2E-04	1.1E-03	1.3E-03	3.1E-06	6.2E-06	2.2E-04	1.2E-05
p,p'-DDT	0.34	4.7E-03	5.4E-03	4.2E-03	5.4E-03	5.8E-03	3.9E-03	3.4E-06	4.1E-06	1.6E-07	0.0E+00
	∑CR	8.5E-02		1.0E-01		8.1E-02		7.1E-04		1.4E-02	
Metals	CSF (mg^{-1} kg day)										
Pb	0.0085	6.3E-05	3.3E-05	7.2E-05	3.5E-05	7.5E-05	3.4E-05	8.4E-05	3.0E-05	9.2E-05	2.8E-05
Cd	6.1	6.2E-04	7.3E-04	2.8E-04	2.2E-04	3.4E-04	2.2E-04	2.8E-04	2.2E-04	1.7E-04	2.8E-04
Ni	0.91	1.4E-03	1.0E-03	7.6E-04	3.8E-04	1.1E-03	1.1E-03	1.9E-03	1.4E-03	3.7E-03	1.2E-03
Cr	0.5	1.2E-03	6.7E-04	9.0E-04	4.2E-04	1.0E-03	3.9E-04	7.2E-04	4.5E-04	1.5E-03	8.2E-04
HI	**∑CR**	**3.2E-03**		**2.0E-03**		**2.5E-03**		**3.0E-03**		**5.5E-03**	

SD- standard deviation, CSF – Cancer slope factor



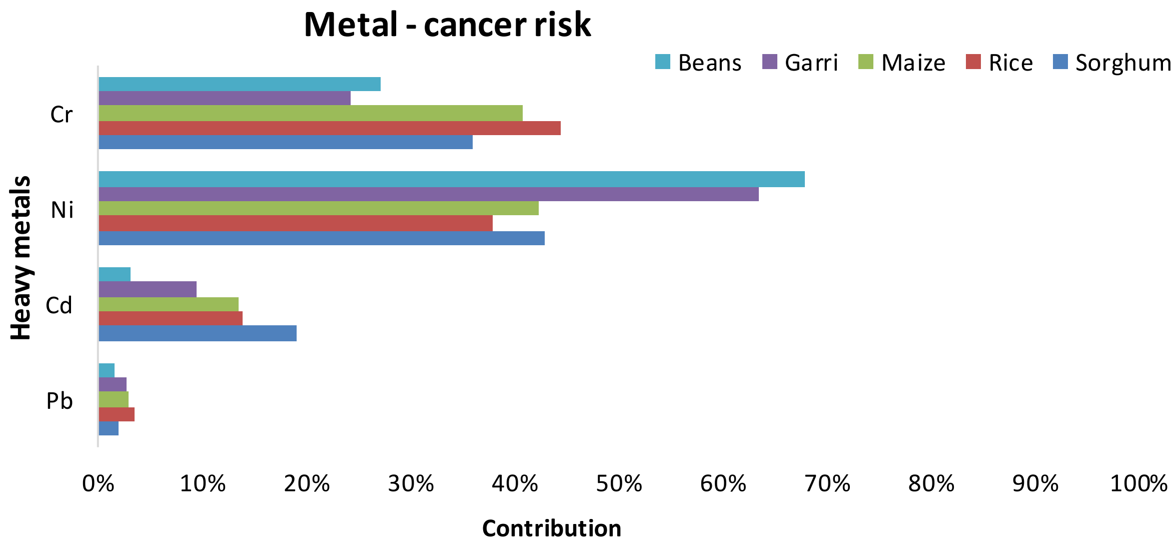


Fig. 3. Contribution to cancer risk by OCPs and HMs in foodstuffs

DISCUSSION

Levels of OCPs and HMs in foodstuffs:

The OCP levels observed in this study appear to be above those previously reported in food samples from past studies in Nigeria (Ogah *et al.,* 2012; Sosan *et al.,* 2015; Taiwo, 2019; Taiwo *et al.,* 2019). For example, Sosan *et al.* (2015) documented varying OCP levels of 0.007 to 0.044 mg kg^{-1} for α-BHC, 0.011 to 0.144 mg kg^{-1} for β-BHC, and 0.019 to 0.125 mg kg^{-1} for γ-BHC in cowpeas from Ile-Ife, Nigeria. Similarly, Ogah *et al.* (2012) reported levels of aldrin, DDT, dieldrin, endosulfan, and endrin at 0.0098, 0.0351, 0.0058, 0.0225, and 0.0078 mg kg^{-1} respectively in bean samples from Lagos. The concentrations of OCPs measured in staple foods from Nigeria indicate the presence of OCPs despite the ban on their production and usage in many countries, including Nigeria (Amdany *et al.,* 2014; Taiwo, 2019; Taiwo *et al.,* 2020).

The levels of heavy metals (HMs) observed in the present study were above those reported by Taiwo *et al.* (2019) in staple foods from Lagos and Ogun states, Nigeria. The occurrence of HMs in food materials can be associated with different sources, including the soils where the crops are planted, possible contamination during processing, and at the point of sale. Pb, Cd, Cr, Fe, and Ni levels exceeded the recommended dietary allowances in all five food samples (IOM, 2001; FAO/WHO, 2001; FAO/WHO, 2015). The toxic effects of Pb, Cd, and Cr have been documented by Jarup (2003). The toxic effects of chromium (Cr) are deleterious to human health at high concentrations. Repeated exposure to Cr can damage hepatic cells, lungs, and kidneys (Mekassa and Chandravanshi, 2015).

Cadmium (Cd) is typically stored in various tissues within the body, including the blood, spleen, liver, and kidneys, where it can cause mild to moderate toxicity in humans (LiverTox, 2012). Lead (Pb) has more harmful impacts on the human body than any benefits. People are exposed to Pb through air, water, and food. It is often stored in bones and substitutes for calcium in the body. Health issues related to Pb exposure include sleep difficulties, fatigue, and weight loss (Udochukwu et al., 2014; Gebrelibanos et al., 2016). Due to the slow pace of absorption by the body, Ni does not frequently harm humans (Wagesho and Chandravanshi, 2015).

Metal metabolism requires essential elements such as iron (Fe) and zinc (Zn). Zinc is crucial for the body due to its significant role in diets rich in protein and carbohydrates. It has biological importance for living organisms and is used in medicine to treat conditions like athlete's foot, dandruff, rashes, and acne (Okwulehie and Ogoke, 2013; Isiloglu *et al.,* 2001). Numerous enzymatic systems rely on iron, including the synthesis of hemoprotein (Taiwo *et al.,* 2021). When present in modest amounts, nickel (Ni) has positive effects on certain bodily processes, particularly by activating certain enzyme systems.

Health risk assessment of OCPs in the foodstuffs:

p,p'-DDT was the highest dosed OCP in the staple food samples. Taiwo *et al.* (2020) showed ADD values greater than 0.001 mg kg^{-1} in fish samples from Abeokuta and Lagos. HQs greater than 1.0 observed for Pb, Fe, and Cr imply negative health impacts. In rice samples from Bangladesh, Proshad *et al.* (2020) discovered HQs above 1.0 for Pb and Cr. Similarly, HQs of OCPs greater than the permissible limit of 1.0 are indicative of non-carcinogenic harmful health implications. According to Taiwo et al., In 2020, the hazard quotient (HQ) exceeded 1.0 for dieldrin, aldrin, and methoxychlor in pork, as well as for heptachlor, heptachlor epoxide, endrin ketone, and endrin aldehyde in protein-containing food items. Wang *et al.* (2022) reported organochlorine pesticides (OCPs) surpassing the maximum residue limits in various vegetables from the suburbs of Changchun, China.

The HI (∑HQs) values for each congener of OCP in the foodstuffs were more than 1.0, indicating dangerous consumption. The highest incidence of HI for OCPs in food samples was in the order of rice > maize > sorghum > beans. All the HIs of HMs found in samples exceeded 1.0, suggesting non-carcinogenic detrimental effects. In food samples, the distribution of HI for HMs was as follows: beans > 'garri' > sorghum > maize > rice. Armah *et al.* (2023) reported that the HI of HMs was greater than the permissible limit of 1.0 in infant food sold in Wa, Ghana. All the OCP congeners' cancer risks (CR) exceeded the USEPA's allowable limit of 1.0 x 10^-4 (USEPA, 2007), except for p,p'-DDT in sorghum and rice, and aldrin in maize. This indicates a potential correlation between the consumption of common foods and the incidence of cancer. The USEPA's permissible limit was also exceeded by the CRs of heptachlor epoxide in 'garri', dieldrin, and p,p'-DDE.

The abundance of total CRs for OCPs in foods followed the decreasing order: rice > sorghum > maize > beans > 'garri'. The contribution of each individual OCP to the overall cancer risk revealed dieldrin as having the highest portion. In a related study by Taiwo *et al.* (2020) on OCP levels in aquatic protein meals from Abeokuta and Lagos, Nigeria, dieldrin was found to dominate the overall cancer-related issues in the foodstuffs, ranging from 10% in 'garri' to 89% in beans. Additionally, OCPs have been identified as carcinogenic in groundwater samples from Ghana, according to Bolor *et al.* (2018). Ni is the only metal of carcinogenic concern in bean samples from Abeokuta and Lagos, according to previous work by Taiwo *et al.* (2019). Similarly, Fan *et al.* (2017) observed Cd concentrations higher than the acceptable limit in rice samples collected from central Chinese mining sites.

CONCLUSION

The current investigation evaluated the levels and potential dangers to human health from organochlorine pesticides (OCPs) and heavy metals (HMs) in a variety of common foodstuffs in Abeokuta, Nigeria. The study found that many staple foods analyzed contained high quantities of HMs and OCPs, with values exceeding the allowable limits. The highest observed OCP congener in staple foods, particularly sorghum, rice, and maize, was p,p'-DDT, while iron (Fe) was the most measured HM. Due to hazard quotients (HQs) and cancer risks (CRs) above the allowable limits of 1.0 and 1.0 x 10^-4 respectively, the health risk assessment indicated that consuming these staple foods was unsafe. Various adverse health effects, including non-carcinogenic and carcinogenic risks, may result from exposure to foodstuffs through ingestion. OCPs are still commonly used in research areas, as evidenced by the OCP levels found in common foods. It is advised that residues of OCPs and HMs in staple foods be continuously and routinely assessed.

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Data availability statement:
The corresponding author, [AMB], is willing to provide the data necessary to substantiate the study's conclusions upon reasonable request.

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