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Occurrence of Multi-Class Pesticide Residues in Soils of Selected Farmlands and Farmer's Household Surroundings in the Southwestern Part of Oyo State, Nigeria

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Abstract

The indiscriminate use of pesticides for crop production in Nigeria has led to contamination of the environment. Specifically, soil contamination from pesticide residues, including banned compounds raises serious public and environmental health concerns. However, very little is known about the occurrence of pesticides in Nigerian soils. Therefore, this study investigated the occurrence and concentration of organochlorine, organophosphate, carbamate and pyrethroid pesticide residues in farm and farmers' house compound soils at a depth of 0-20 cm. Soil pesticide residues were analyzed using gas chromatography-mass spectrometry (GC-MS). A total of 41 pesticides were detected including; 14 organochlorines, 15 organophosphates, 9 carbamates and 3 pyrethroids. In maize crop soil, heptachlor, chlorpyrifos, carbofuran and cypermethrin were found having the highest concentrations (0.257±0.006, 8.567±0.907, 5.100±1.127 and 0.173±0.021 µg/kg, respectively). In cassava crop soil, endosulfan, pirimiphos-methyl, carbofuran and permethrin had the highest concentrations (2.300±0.200, 3.567±0.569, 0.467±0.176 and 0.223±0.038 µg/kg, respectively). While in the farmers' house compound soil, heptachlor, pirimiphos-methyl, carbofuran and cypermethrin were found having the highest concentrations (0.165±0.007, 0.742±0.931, 0.225±0.050 and 0.076±0.020 µg/kg, respectively). Overall, the cumulative concentrations of the pesticides showed organochlorine and pyrethroid were higher in cassava crop soil while organophosphate and carbamate were higher in maize crop soil. This study revealed the use of highly (e.g., carbofuran) and moderately (e.g. chlorpyrifos) hazardous pesticides, as well as detection of extremely hazardous (e.g., oxamyl) and banned (e.g., endosulfan) pesticide residues. The results pointed out the use of multiple pesticides by farmers in this area. Overall, these findings underscore the need to restrict the use of highly hazardous pesticides in food crop production. The use of safer pesticide alternatives as well as remediation of the already contaminated soil environment are recommended.

Keywords: Soil contamination, Pesticide residues, Organochlorine pesticides, Carbofuran

1.0 Introduction

Although pesticides are beneficial for crop production and ensuring food security, the extensive use of pesticides raises serious environmental concerns due to the contamination of natural resources including, air, water and soil with adverse impact on the ecosystem and human health (Sharma et al. 2019; Riedo et al. 2021; Tudi et al. 2021; Alaoui et al. 2024). More specifically, the application of chemical pesticides to agricultural fields for the protection of crops leads to the formation of residues in soils (Riedo et al. 2023). As a result, pesticides can accumulate in soils directly by its application in agriculture and indirectly by aerial deposition, surface runoff or leaching from different sites or areas (Sharma et al. 2019; Riedo et al. 2023). Previous studies have reported large amounts of remaining pesticides after application penetrate or reach non-target plants and environmental media, including air, water and soil (Tudi et al. 2021). As a result, soil remains the largest reservoir of different classes of pesticides applied for agricultural purposes (Gill and Garg, 2014).

Pesticides can be widely classified based on different characteristics. However, in this study, four sub-classes including, organochlorines (OC), organophosphates (OP), carbamates, and pyrethroids widely used in agriculture are discussed. Of the pesticides classes mentioned above, organochlorines such as aldrin, endrin, chlordane, toxaphene, heptachlor, dieldrin, mirex, endosulfan, hexachlorocyclohexane (HCH), dichlorodiphenyltrichloroethane (DDT) and their degradation products, are classified as persistent organic pollutants (POPs) based on the global Stockholm Convention (Fitzgerald and Wikoff, 2014). POPs are characterized by environmental persistence, transboundary mobility, lipophilicity, and bioaccumulation that may induce fatality especially to top ranked biota due to biomagnification (Miraji et al. 2021). Upon exposure, POPs can lead to effects such as endocrine disruption, reproductive and immune dysfunction, genetic mutations, birth defects, neurological disorders, and cancer (Fitzgerald and Wikoff, 2014; Miraji et al. 2021). Among different classes of pesticides, organochlorine pesticides are the most harmful due to their slow rate of decomposition, greater stability and long half-life (Sharma et al. 2019).

Even more concerning is the widespread contamination of the soil environment with banned pesticides which are hazardous to ecosystems and humans (Alaoui et al. 2024). Previous studies have reported residue of banned pesticides in agricultural soils across Africa, including Kenya (Ndungu et al. 2019), South Africa (Degrendele et al. 2022), Ghana (Atitsogbey et al. 2023), Nigeria (Onuwa et al. 2017; Adeola et al. 2025) and Mexico (Sanchez-del Cid et al. 2025) and, in some countries in Europe (Alaoui et al. 2024),

Africa has become the dumping site for importing banned synthetic pesticides rejected by the European Union (Anaduaka et al. 2023). Nigeria accounts for more than a quarter of the share of total pesticides used in Africa, and their utilization in the agricultural sector has grown by 70%, from 33,968 tons in 2012 to 57,822 tons in 2022 (Yami et al. 2025). Many pesticides still widely used in Africa including Nigeria have been banned in developed countries (Anaduaka et al. 2023; Yami et al. 2025).

In southwestern Nigeria, different classes of pesticides including, endosulfan and lindane (organochlorines), chlorpyrifos and dichlorvos (organophosphates), carbofuran (carbamates), cypermethrin (pyrethroids), imidacloprid (neonicotinoids) are used by farmers on food crops including maize, yam, soybeans, tomato and a range of cash crops (Adeola et al. 2025). Similarly, lambda cyhalothrin and cypermethrin (pyrethroid), dichlorvos and profenofos (organophosphate), imidacloprid (neonicotinoids), and methomyl (carbamate) were the prevalent pesticides used among smallholder tomato farmers in Kano State in northwest Nigeria (Yami et al., 2025). These chemicals have been categorized as moderately hazardous to highly hazardous pesticides (WHO, 2019). Consequently, farmland soils can be considered the primary source of pesticide pollution where they are often applied with the possibility of soil to plant transfers and human uptake (Udoekpo et al. 2024). However, studies that determine pesticide residues in the soil compartment of the environment are scarce in Nigeria.

Again, owing to their persistent and ubiquitous nature, pesticides can be found at different sites. Riedo et al. (2023) detected pesticides at sites without a connection to previous applications. Pesticide residues in soils around farmer's households have been reported in limited studies (Klaimala et al. 2019). Although, pesticide exposure at households is mainly explained by spray-drift and take-home, via clothes and pets (Dereumeaux et al. 2020), pesticide storage in homes as well as mixing near home area (Klaimala et al. 2019) are relevant exposure pathways in developing countries. However, major gaps exist in our knowledge of pesticide concentrations in residential soils, especially around farmer's households in Nigeria. It is therefore pertinent to have information on status of pesticides in soils of farms and farmers' households due to extensive pesticide usage and more specifically, those of restricted or banned status.

Studies have been conducted in Oyo State on pesticides' knowledge, awareness and safety practices among farmers (Oshingbade et al. 2025). However, studies that quantify the pesticide concentrations in soils are lacking. Pesticide exposure threatens both human and environmental health, more so in areas with extensive usage and weak enforcement of regulations such as in Nigeria. In Oyo state, Nigeria, farming is a major occupation especially in agrarian communities like Ibarapa North Local Government Area where farmers depend heavily on chemical pesticides for improving crop production. To address these concerns, this study was designed to determine the occurrence of pesticide residues in soils of selected farms and farmer's household surroundings in a farming community in Oyo State, Nigeria.

2.0 Materials and Methods

2.1 Study area and soil sample collection

The study was conducted in Ayete (7°33′55″N and 3°13′37″E), a town in Ibarapa North Local Government Area of Oyo state, Nigeria, predominantly known for its agricultural activities. This area is characterized with a tropical climate having two distinct seasons of wet and dry periods (Akanbi, 2018). The dry season usually extends from November to March with an average monthly precipitation of < 25 mm while the wet season peaks around June and September with monthly rainfall > 100 mm (Akanbi, 2018). The total annual rainfall in the area ranges from 813 to 1853 mm while the annual temperature ranges from 24 to 29°C (Akanbi, 2018).

Sample collection was carried out in

November 2019. Soil samples were collected at 0 – 20 cm depth from three selected farms under cassava (*Manihot esculenta*) and maize (*Zea mays*) crops separately, and in two farmers house compounds. In each farm and residential compound, soil samples were collected separately from five sampling points comprising the center and north, south, west, east directions and homogenized into a composite sample per site. Soil samples were air-dried, sieved with a 2 mm sieve and finely ground for the organic carbon, total nitrogen and pesticide analyses.

2.2 Physicochemical soil analyses

Soil physicochemical properties were determined following standard procedures. Soil moisture was determined by the gravimetric method at 105°C and texture by particle size analysis according to the Bouyoucos hydrometer method (Bouyoucos, 1962). Soil pH and electrical conductivity were determined in distilled water at 1:2.5 soil:water ratio (Anderson and Ingram 1993). Organic carbon was determined by the Walkley-Black method (Walkley and Black, 1934) and total nitrogen by the kjeldahl method (Bremner, 1996).

2.3 Analysis of pesticides in soils

2.3.1 Pesticides extraction and clean-up

Pesticide extraction in soil samples was conducted using a modified ultrasonic-assisted extraction (UAE) adopted from EPA-600/8-80-038, where 2 g of soil was weighed into a beaker to which 10 mL of dichloromethane and n-Hexane (1:1) were added. The mixture was shaken vigorously on an orbital shaker for two hours and transferred for extraction into an ultrasonic bath at 30°C for 45 minutes. The extract was then filtered using Whatman filter paper under vacuum conditions. The clean-up of extract was done in a 10 mm chromatographic column using 3 g of activated silica gel, 2 g of anhydrous sodium sulphate and 5 mL of n-hexane. The sample extract was quantitatively transferred to a centrifuge tube, concentrated on a nitrogen evaporator to 2 mL and collected in a vial for further analysis on the GC-MS.

2.3.2 Gas chromatographic analysis

Pesticides were analyzed by GC-MS high performance quadrupole (HP 6890) powered with HP chemstation Rev A09.01 (1206) software. A capillary column (30m × 0.25m × 0.25μm) containing 5% diphenyl and 95% dimethyl polysiloxane HP-5MS was used. The samples were injected in splitless mode for 3 min followed by a 1:20 split ratio with the injector and detector set at a temperature of 250°C. A volume of 1 μL of the extract was injected and the separation was performed in the column. The flow rate was set at 1.0 mL/min with helium as the carrier gas. The oven temperature programme was set at 80°C held for 1 min, and raised to 200°C at a rate of 8°C/min, then ramped to 300°C at 30°C/min with holding time of 3 min. The mass spectrophotometer operates within the electron impact mode (EI) at 70 eV. The retention times of sample peaks were compared with that of the eternal standard to identify the pesticides compounds. Pesticide concentrations are presented in μg/kg.

2.4 Data analysis

Descriptive statistics including means and standard deviations of the data on pesticide residues in soil samples were computed. One way ANOVA was carried out to compare the means and Duncan multiple range test was used to separate the means at a significant level of $p < 0.05$. The data were processed using Excel 2021 (Microsoft Inc.,) and SPSS v.21.0 (SPSS Inc., Chicago, USA).

3.0 Results and Discussion

3.1 Some physicochemical characteristics of the soil

The results of the physicochemical characteristics of soils of farmlands and farmer's house compounds are presented in Table 1. The pH values across the study sites ranged between 7.08 ± 0.04 and 7.27 ± 0.01. The mean soil pH values were: 7.15 ± 0.08 (maize), 7.17 ± 0.04 (cassava) and 7.26 ± 0.02 (house compounds) indicating neutral conditions. In all the study sites, OC content ranged from 1.16 ± 0.10 to 1.62 ± 0.21 %, however, the mean soil OC contents were: 1.36 ± 0.24% (maize), 1.31 ± 0.06% (cassava) and 1.49 ± 0.07% (house compounds). Additionally, the mean electrical conductivity (µS/cm) of the soils across the study were: 49.17 ± 9.46 (maize), 30.83 ± 2.89 (cassava) and 102.50 ± 67.18 (house compounds).

3.2 Occurrence of multi-class pesticides residues

The results in this study demonstrated a widespread occurrence of pesticides in all the soil samples of farmlands and farmer's household surroundings. Pesticide residues comprising of four classes including; organochlorines (14), organophosphates (15), carbamates (9) and pyrethroids (3) were detected in the study (Tables 2 – 4). Overall, a total of 41 different pesticide residues were detected and their concentrations in the soils are presented in Tables 2 – 4. Interestingly, all 41 pesticide residues were found in all soils collected from the farms cultivated with maize and cassava as well from the farmer's houses in varying concentrations (Tables 2 – 4). Most of the pesticides found in this study have been reported to occur in various concentrations in agricultural soils (Onuwa et al. 2017; Froger et al. 2023) and in indoor dust of farmworker households (Navarro et al. 2023) in Nigeria and elsewhere. According to Adeola et al (2025), the most commonly used pesticides in Oyo State include; Dichlorvos > Cypermethrin > Chlorpyriphos > lindane, which fall under WHO class Ia (highly hazardous) and class II (moderately hazardous) chemicals (WHO, 2019). The occurrence of multiple pesticides in soils in this study could be attributed to the mixing of different pesticides commonly practiced by farmers in order to improve their effectiveness as the case in a recent study in Nigeria (Yami et al. 2025). Another study in Switzerland reported widespread contamination of agricultural soils with a variety of pesticides (Riedo et al. 2021). Pesticide mixture has been reported to induce higher risks in cultivated soils (Froger et al. 2023). Furthermore, the main reason for pesticide contamination of the soil around house compound of farmers could be due to storage of pesticides at home and via contaminated farm tools brought back to the house by the farmers.

Table 1. Soil physico-chemical characteristics of farmlands and farmer's house compounds

Properties	Maize			Cassava			House	
	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3	House 1	House 2
pH	7.08 ± 0.04	7.13 ± 0.06	7.23 ± 0.05	7.17 ± 0.05	7.13 ± 0.12	7.21 ± 0.06	7.24 ± 0.02	7.27 ± 0.01
MC (%)	53.37 ± 0.00	24.69 ± 0.00	12.61 ± 0.00	40.25 ± 0.00	21.80 ± 0.00	11.23 ± 0.00	45.56 ± 0.00	41.44 ± 0.00
EC (µS/cm)	42.50 ± 5.00	45.00 ± 10.00	60.00 ± 33.67	32.50 ± 5.00	27.50 ± 12.58	32.50 ± 5.00	55.00 ± 19.15	150.0 ±18.26
OC (%)	1.16 ± 0.10	1.30 ± 0.18	1.62 ± 0.21	1.37 ± 0.20	1.26 ± 0.22	1.30 ± 0.05	1.44 ± 0.05	1.54 ± 0.20
TN (%)	0.11 ± 0.01	0.10 ± 0.03	0.13 ± 0.03	0.11 ± 0.04	0.11 ± 0.01	0.13 ± 0.05	0.11 ± 0.04	0.10 ± 0.02
Sand (%)	67.18 ± 0.04	62.54 ± 4.65	62.88 ± 1.44	68.03 ± 5.86	59.44 ± 1.05	59.74 ± 4.55	66.40 ± 2.11	72.00 ± 3.47
Silt (%)	13.34 ± 1.53	14.29 ± 1.38	17.01 ± 2.48	13.15 ± 4.70	13.37 ± 0.04	16.25 ± 0.93	13.84± 0.55	12.05 ± 0.40
Clay (%)	19.49 ± 1.93	23.18 ± 3.27	20.12 ± 1.04	18.83 ± 1.16	27.1 ± 1.16	24.01 ± 0.93	19.72±1.56	15.95 ± 3.87
Texture	SL	SCL	SCL	SL	SCL	L	SL	SL

MC – moisture content; EC – electrical conductivity; OC – organic carbon; TN – total nitrogen; SL – sandy loam; SCL – sandy clay loam; L – loam; Mean (n=4) ± standard deviation

Table 2. Distribution of pesticide residue concentrations in the surface soils of maize farms

			Maize				
Organochlorine	µg/kg	Organophosphate	µg/kg	Carbamate	µg/kg	Pyrethroids	µg/kg
Heptachlor	0.257±0.006a	Dichlovors	0.023±0.017d	Aldicarb	0.045±0.005b	Permethrin	0.072±0.010b
Heptachlor Epoxide	0.032±0.004c	Trichlorfon	0.046±0.013d	Bendiocarb	0.060±0.013b	Cypermethrin	0.173±0.021a
Aldrin	0.018±0.005c	Fenithion	0.055±0.017d	Carbaryl	0.022±0.015b	Deltamethrin	0.054±0.006b
Endosulfan	0.066±0.007c	Methidathion	0.017±0.014d	Methiocarb	0.037±0.015b		
Endrin	0.243±0.006a	Diazinon	0.016±0.006d	Ethiofencarb	0.011±0.008b		
Endrin Aldehyde	0.040±0.005c	Pirimiphos-methyl	2.367±0.058b	Pirimicarb	0.010±0.010b		
Endrin-ketone	0.034±0.004c	Edifenphos	0.069±0.013d	Propoxur	0.160±0.017b		
Eldrin	0.082±0.025c	Chlorpyrifos	8.567±0.907a	Carbofuran	5.100±1.127a		
DDT	0.077±0.057c	Chlorpyrifos-methyl	1.100±0.000c	Oxamyl	0.130±0.017b		
2, 4-D	0.030±0.026c	Fenitrothion	0.067±0.003d				
2, 4, 5-T	0.042±0.010c	Ethion	0.290±0.010d				
Lindane	0.041±0.013c	Malathion	0.037±0.009d				
Dieldrin	0.149±0.114ab	Phosmet	0.177±0.025d				
Chlordane	0.193±0.116ab	Chlorfervinphos	0.016±0.002d				
		Carbophenothion	0.177±0.493d				
$\Sigma_{14OC\ pesticides}$	1.303±0.083	$\Sigma_{15OP\ pesticides}$	13.023±2.221	$\Sigma_{9Carbamates}$	5.574±1.681	$\Sigma_{3Pyrethroids}$	0.299±0.064

Mean (n) = 3±Standard deviation; Similar lowercase letters indicate no significant difference (p>0.05), while different lowercase letters indicate means are significantly different (p<0.05)

Table 3. Distribution of pesticide residue concentrations in the surface soils of cassava farms

Cassava							
Organochlorine	µg/kg	Organophosphate	µg/kg	Carbamate	µg/kg	Pyrethroids	µg/kg
Heptachlor	0.223±0.038b	Dichlovors	0.058±0.003c	Aldicarb	0.081±0.086b	Permethrin	0.223±0.038a
Heptachlor Epoxide	0.047±0.017cde	Trichlorfon	0.117±0.159c	Bendiocarb	0.037±0.006b	Cypermethrin	0.058±0.080c
Aldrin	0.009±0.004e	Fenithion	0.121±0.174c	Carbaryl	0.033±0.023b	Deltamethrin	0.042±0.006c
Endosulfan	2.300±0.200a	Methidathion	0.012±0.015c	Methiocarb	0.012±0.008b		
Endrin	0.223±0.045b	Diazinon	0.008±0.004c	Ethiofencarb	0.045±0.010b		
Endrin Aldehyde	0.054±0.017cde	Pirimiphos-methyl	3.567±0.569a	Pirimicarb	0.024±0.006b		
Endrin-ketone	0.500±0.052cde	Edifenphos	0.191±0.242c	Propoxur	0.055±0.074b		
Eldrin	0.062±0.008cde	Chlorpyrifos	1.367±0.058b	Carbofuran	0.467±0.176a		
DDT	0.106±0.061cde	Chlorpyrifos-methyl	1.567±0.306b	Oxamyl	0.091±0.021b		
2, 4-D	0.042±0.018cde	Fenitrothion	0.055±0.006c				
2, 4, 5-T	0.039±0.020de	Ethion	0.260±0.026c				
Lindane	0.039±0.034de	Malathion	0.021±0.006c				
Dieldrin	0.147±0.025bcd	Phosmet	0.133±0.021c				
Chlordane	0.160±0.026bc	Chlorfervinphos	0.062±0.027c				
		Carbophenothion	0.150±0.020c				
$\Sigma_{14OC\ pesticides}$	3.502±0.594	$\Sigma_{15OP\ pesticides}$	7.685±0.974	$\Sigma_{9Carbamates}$	0.844±0.142	$\Sigma_{3Pyrethroids}$	0.323±0.100

Mean (n) = 3±Standard deviation; Similar lowercase letters indicate no significant difference (p>0.05), while different lowercase letters indicate means are significantly different (p<0.05)

Table 4. Distribution of pesticide residue concentrations in the surface soils of farmer's house compounds

Residential Soils							
Organochlorine	µg/kg	Organophosphate	µg/kg	Carbamate	µg/kg	Pyrethroids	µg/kg
Heptachlor	0.165±0.007a	Dichlovors	0.046±0.004b	Aldicarb	0.025±0.001cde	Permethrin	0.027±0.010b
Heptachlor Epoxide	0.049±0.008cd	Trichlorfon	0.017±0.003b	Bendiocarb	0.005±0.003e	Cypermethrin	0.076±0.020a
Aldrin	0.007±0.002d	Fenithion	0.128±0.045b	Carbaryl	0.022±0.016de	Deltamethrin	0.007±0.006b
Endosulfan	0.064±0.014cd	Methidathion	0.023±0.004b	Methiocarb	0.065±0.003bc		
Endrin	0.140±0.014ab	Diazinon	0.005±0.003b	Ethiofencarb	0.047±0.003bcde		
Endrin Aldehyde	0.054±0.006cd	Pirimiphos-methyl	0.742±0.931a	Pirimicarb	0.018±0.004de		
Endrin-ketone	0.050±0.056cd	Edifenphos	0.047±0.001b	Propoxur	0.073±0.004b		
Eldrin	0.064±0.004cd	Chlorpyrifos	0.555±0.191ab	Carbofuran	0.225±0.050a		
DDT	0.082±0.007c	Chlorpyrifos-methyl	0.515±0.177ab	Oxamyl	0.060±0.004bcd		
2, 4-D	0.006±0.004d	Fenitrothion	0.044±0.003b				
2, 4, 5-T	0.043±0.002cd	Ethion	0.109±0.129b				
Lindane	0.053±0.016cd	Malathion	0.012±0.004b				
Dieldrin	0.096±0.020bc	Phosmet	0.068±0.019b				
Chlordane	0.061±0.070cd	Chlorfenvinphos	0.041±0.003b				
		Carbophenothion	0.047±0.050b				
$\Sigma_{14OC\ pesticides}$	0.931±0.044	$\Sigma_{15OP\ pesticides}$	2.397±0.237	$\Sigma_{9Carbamates}$	0.537±0.066	$\Sigma_{3Pyrethroids}$	0.110±0.036

Mean (n) = 2±Standard deviation; Similar lowercase letters indicate no significant difference (p>0.05), while different lowercase letters indicate means are significantly different (p<0.05)

3.3 Organochlorine pesticides

Of the 14 Organochlorine pesticide detected in the study, the highest concentrations (µg/kg) were the residues of heptachlor (0.257±0.006), endrin (0.243±0.006) and chlordane (0.193±0.116) in maize crop soil, contributing 20, 19 and 15%, respectively to the total concentration (Table 2). However, in the cassava crop soil, residue of endosulfan was significantly higher (2.300±0.200 µg/kg) than others and contributed 66% to the total concentration of organochlorine pesticides. Although banned in many countries due to its toxic nature and persistence, endosulfan are still commonly used in agriculture in developing countries (Berdowska and Bandurska, 2025). Despite its toxic nature, motivation for using endosulfan in developing countries like Nigeria with resource-poor farmers is mainly driven by its low cost and effectiveness, hence its detection in the soils of this study. However, safer alternatives are urgently required because endosulfan is not only an endocrine disruptor but has been reported to have adverse effect on the reproductive system and also associated with human cancers (Berdowska and Bandurska, 2025). Osuala et al. (2024) found higher concentrations of heptachlor epoxide than endosulfan compounds in soils of selected urban farms of vegetable crops in Lagos, Nigeria. Heptachlor epoxide, a by-product of heptachlor pesticide is more persistent and toxic than its parent compound (Osuala et al. 2024). Generally, heptachlor and heptachlor-epoxide have been reported to be found especially, in soils around the world (Purnomo et al. 2013). Although the production and use of heptachlor have been banned or restricted in some developed countries since the 1970s, a considerable number of developing countries have continued its usage in controlling pests of both agriculture and public health significance (Purnomo et al. 2013). Another study in southwestern Nigeria reported the presence of organochlorine pesticides with heptachlor epoxide, heptachlor and endosulfan having high concentrations in cassava crop (Oyinloye et al. 2021).

Also, the cumulative concentration of the 14 organochlorine pesticides was higher in soil of cassava crop than in soils of maize and house compounds. In accordance with this study, Udoekpo et al. (2024), recently reported higher cumulative levels of 13 organochlorine pesticides in farm soils in a major cassava-producing region in southern Nigeria. Although, it is important to mention that the soil sampling depth in their study was shallower (0 – 5 cm) than in this present study (0 – 20 cm). Overall, the presence of organochlorine pesticide residues, particularly those (e.g., aldrin, chlordane, DDT, dieldrin, heptachlor and lindane) that their use and production have been prohibited or severely restricted by the Stockholm Convention on persistent organic pollutants (WHO, 2019) is of great concern in this study.

3.4 Organophosphate pesticides

Table 2 – 4 presents the results of the organophosphate pesticide residues detected in soil samples from the study area. Based on the concentrations, three out of the 15 organophosphate pesticide residues namely, chlorpyrifos, chlorpyrifos-methyl and pirimiphos-methyl contributed the most (92%) to the total concentration in the maize crop soil. They were in the order: chlorpyrifos (8.567±0.907) > pirimiphos-methyl (2.367±0.058) > chlorpyrifos-methyl (1.100±0.000). Statistically, the concentration of chlorpyrifos in the maize crop soil were significantly ($p > 0.05$) higher than the other organophosphate pesticide residues (Table 2). Chlorpyrifos is among one of the most widely used organophosphate pesticide among farmers in Nigeria and specifically in Oyo State (Adeola et al. 2025) which explains the reason for its occurrence in the maize crop soil. Chlorpyrifos is a class II (moderately

hazardous) pesticide (WHO, 2019) and was recently banned in 2020 (Carvalho et al. 2025). The concentration of chlorpyrifos in soils of cacao crop in Ghana (Fosu-Mensah et al. 2016) and agricultural soils in Nigeria (Mohammed et al. 2025) was higher than that observed in the present study. However, in the cassava crop soil, pirimiphos-methyl (3.567±0.569 µg/kg) accounted for 46% of the total organophosphate pesticide residues and was significantly higher than chlorpyrifos-methyl (1.567±0.306 µg/kg) and chlorpyrifos (1.367±0.058 µg/kg). Although, having much lower concentrations, organophosphate pesticide residues in soil of the house compound followed the order: pirimiphos-methyl (0.742±0.931 µg/kg) > chlorpyrifos (0.555±0.191 µg/kg) > chlorpyrifos-methyl (0.515±0.177 µg/kg). Thus, indicating farmers use of hazardous pesticides, since the aforementioned pesticides fall under the WHO class II (moderately hazardous) and III (slightly hazardous) according to WHO hazard classification.

The cumulative concentration of the 15 organophosphate pesticide residues observed in soils from the study sites were: maize (13.023±2.221 µg/kg) > cassava (7.685±0.974 µg/kg) > house compounds (2.397±0.237 µg/kg), reflecting the prevalence of use in agricultural sector in the study area.

3.5 Carbamate Pesticides

Carbofuran significantly ($p < 0.05$) contributed the most to the total carbamate pesticide content (Tables 2 – 4), with mean concentrations of 5.100±1.127, 0.467±0.176 and 0.225±0.050 µg/kg in soils of maize crop, cassava crop and house compounds, respectively. Contributions of carbofuran accounted for 92, 55 and 42% of the total carbamate concentration. The prevalence of carbofuran in these soils could be due to its frequent application to control pests in many crop varieties (Umar Mustapha et al. 2020). According to WHO hazard classification, carbofuran fall under Class Ib which is highly hazardous and has the highest acute toxicity to humans than all groups of carbamate pesticides (WHO, 2019; Umar Mustapha et al. 2020). Together with its high mobility in soil and a half-life of 50 days (Umar Mustapha et al. 2020), the detection of carbofuran in the soils of this study makes it an increasing concern.

Additionally, aldicarb and oxamyl which are extremely hazardous (class Ia; WHO, 2019) were detected in all soil samples but at significantly ($p < 0.05$) lower concentrations than carbofuran. This points to the fact that extremely hazardous pesticides are widely used in this area with little or no regard for human health and environmental risks. A recent study in Pakistan suggested that yield maximization, easy availability and perceived effectiveness are among the important drivers for using highly hazardous pesticides among farmers (Mehmood et al. 2025).

3.6 Pyrethroid pesticides

Three widely used pyrethroid pesticide residues were detected in the soils in this study. Of the three, cypermethrin was the most detected with the highest contribution of 58 and 69% to the total concentration in soils of the maize crop and house compound, respectively. Conversely, permethrin had the highest concentration in the cassava crop soil, accounting for about 69% of the total concentration. Cypermethrin is one of the most widely used pyrethroid insecticides against different pests (Aioub et al. 2019). According to Ahamad and Kumar (2023), cypermethrin is the most utilized pyrethroids pesticide in India, followed by deltamethrin. Also, Yami, et al. (2025) reported the extensive use of cypermethrin by farmers in northern Nigeria and noted that it is usually mixed with other pesticides. In Oyo State, Nigeria, Adeola et al. (2025) found that 63% of farmers reportedly used cypermethrin solely and in combination with other pesticides such as profenofos (39%) and dimethoate (27%). The detection of cypermethrin in this study is indicative of soil contamination as previously reported (Aioub et al. 2019). Generally, Oyo State has been noted for its high usage of pesticides in farming (Adeola et al. 2025). This might explain the varieties of pesticides detected in the soils of the study. As noted, the pyrethroid pesticides detected in the soils in this study have been classified as moderately hazardous (Class II) by WHO hazard classification. Consequently, careful application of pesticides is required to reduce risks to humans and the environment.

4.0 Conclusion

This study investigated the occurrence and concentrations of pesticide residues in soils of maize and cassava crop farms and farmers' house compounds. A total of forty-one pesticides belonging to organochlorine, organophosphate, carbamate and pyrethroid classes were found in the soils of this study. The highest cumulative concentration of organophosphate was observed in the maize crop soil while that of organochlorine was found in the cassava crop soil. Of the organophosphate pesticides, chlorpyrifos and pirimiphos-methyl contributed the highest indicating their extensive use in this area, especially in maize crop production. On the other hand, banned endosulfan, a toxic organochlorine pesticide contributed the highest in cassava crop soil. Also, highly hazardous carbofuran was found to contribute the most among the carbamate pesticides. Similarly, but in lower concentrations, all pesticide residues were detected in the soil of the farmers' house compounds. This study highlights the ongoing usage of highly hazardous and even banned pesticides in farming. Based on the hazardous nature of many of the pesticides found in this study, it is necessary to restrict their usage, monitor their presence in the soil environment and substitute their use with safer alternatives to protect both human and environmental health.

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