ORIGINAL ARTICLE

Ecotoxicological assessment of pesticide residues in *Thryonomys Swinderianus* (grasscutters) in Nigeria

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ABSTRACT

The increase in the usage of pesticides and the persistence of their residues in the environment present significant risks to both wildlife and public health. This study investigated the presence, distribution and potential toxicological implications of pesticide residues in *Thryonomys swinderianus* (grascutter) harvested from three ecological zones of Nigeria. Tissue samples (liver, kidney and flesh) were analyzed for nineteen pesticide residues; including fifteen organochlorines, two pyrethroids (α- and β-cypermethrin) and one each from the triazine (atrazine) and organophosphate (glyphosate) classes. Results revealed widespread contamination, particularly in the liver and kidney, with several residues such as heptachlor, DDT and its metabolites (p,p'-DDT, p,p'-DDE, o,p'-DDE), aldrin, dieldrin and endosulfan exceeding or approaching international Maximum Residue Limits (MRLs). Organochlorine pesticides were the most dominant, with regional variations in concentration levels reflecting differences in pesticide application practices and environmental dynamics. Flesh samples contained the lowest residue levels, though detectable traces of persistent compounds like DDT and its metabolites were present. Atrazine and glyphosate were largely undetected. The findings underscore the persistence use of banned and restricted pesticides in the Nigerian environment and highlight the potential public health risks associated with the consumption of contaminated bushmeat.

Keywords: *Thryonomys swinderianus*, residues, ecotoxicology, liver, kidney

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INTRODUCTION

Pesticides have been central to agricultural and public health advancement over the past two centuries. These chemical substances are designed to either prevent, destroy, repel or suppress harmful organisms. They are broadly classified into insecticides, herbicides, fungicides, rodenticides, algaecides and bactericides [1]. While their benefits are widely acknowledged, increasing concern surrounds their formulation and long-term ecological impact.

Most commercial pesticides comprise active ingredients. These include the so-called "inert" components or adjuvants, which make up approximately 90–95% of the formulation. These adjuvants, often undisclosed due to proprietary protections, may possess toxicological properties more harmful than the active ingredients themselves [2-3]. Consequently, the environmental and health risks posed by such complex mixtures remain incompletely understood and insufficiently regulated.

Among the most persistent and globally scrutinized classes of pesticides are the organochlorines. These compounds are chemically stable, resistant to degradation and highly lipophilic. These traits facilitate their accumulation in animal tissues and enable biomagnification across trophic levels [4-5].

The consumption of bushmeat, particularly *Thryonomys swinderianus*, commonly known as the grasscutter or cane rat, is integral to local diets and economies in many African communities [6]. However, increasing reliance on chemical baits and poisoned forage to kill wild animals for bushmeat, particularly with the use of highly toxic pesticides, introduces severe food safety concerns [7]. These practices expose non-target wildlife to hazardous chemicals, which may accumulate in edible tissues and subsequently impact human health.

Therefore, this study aimed to conduct an ecotoxicological assessment of pesticide residues in the liver, kidney and flesh of *Thryonomys swinderianus* collected from three ecological zones in Nigeria. Specifically, the study sought to identify the types and concentrations of pesticide residues including organochlorines, pyrethroids, triazines and organophosphates present in these tissues. Then also, compare residue distribution across regions and evaluate their implications for environmental safety and human consumption risks.

MATERIALS AND METHODS

Study Area and Sampling Design

A multistage sampling approach was employed for this study, with consideration given to Nigeria's major ecological zones. Out of the seven ecological zones in the country, three were purposively selected based on the following criteria: abundance and diversity of wildlife species, intensity of wildlife trade and concentration of wildlife product vendors. The selected zones and corresponding states were: Mangrove Zone - Akwa Ibom State; Rainforest Zone - Oyo State and Guinea Savanna Zone - Nasarawa State. From each state, five local government areas (LGAs) were purposively selected and within each LGA, one market was targeted for sample collection resulting in a total of fifteen markets. The geographical representation of the sampled ecological zones is illustrated in Figure 1.

Wildlife Sampling and Tissue Collection

Wild animal specimens were opportunistically sampled based on availability within the selected markets. The study focused on the grasscutter/cane rat (*Thryonomys swinderianus*), a commonly traded bushmeat species. Tissue samples including liver, kidney, lung, heart, spleen and muscle were excised from each carcass and immediately preserved in ice packs to maintain sample integrity pending laboratory analysis. In total, 90 tissue samples were obtained from 15 cane rat carcasses, comprising 30 samples each of liver, kidney, and muscle tissues, which were selected for detailed pesticide residue analysis. Ethical approval for the collection of animal specimens was granted by the University of Ibadan Animal Care and Use Research Ethics Committee (UI-ACUREC), with approval number UI-ACUREC/18/0024.

Assessment of Pesticide Residues

Samples were screened for 19 pesticide compounds, including: Organochlorines: α-BHC, β-BHC, γ-HCH (Lindane), δ-BHC, Heptachlor, Aldrin, Heptachlor epoxide, Dieldrin, Endosulfan I & II, o,p'-DDE, p,p'-DDT; Herbicides: Atrazine, Glyphosate; Chlorothalonil, PCB 153, α-Cypermethrin, β-Cypermethrin.

Chemical Reagents and Analytical Standards

All solvents and reagents used were of analytical grade, obtained from Merck (Germany) and distilled using a packed column setup in accordance with Schwarzbauer [8].

Sample Preparation and Analytical Procedure

The analytical process involved four primary stages: extraction, sample cleanup, quality control and data analysis. For each batch of 6–8 samples, quality assurance/quality control (QA/QC) protocols were followed, including the inclusion of procedural blanks and standard-spiked samples. Approximately 3 g of homogenized tissue was mixed with 20 g of anhydrous sodium sulfate, pre-heated at 140 °C overnight, for moisture removal.

The extracts were analyzed using Gas Chromatography (GC) equipped with an Electron Capture Detector (ECD) (Hewlett Packard GC 5890 Series II). The instrument was operated in splitless mode with varying temperature.

Quantification was performed using five-point calibration curves ($r^2 \geq 0.999$), developed from reference standards obtained from ACCU standards (USA). Pesticide residues were identified by matching the retention times of analyses with those of standards and quantified using the area response factors. Instrument precision and accuracy were validated using randomly repeated samples, maintaining a standard deviation < 5%.

Statistical Analysis

Descriptive statistics (frequencies and percentages) and inferential analysis was conducted using IBM SPSS Version 20.0, with significance considered at $p < 0.05$.

RESULTS

A total of nineteen pesticide residues were detected across the tissue samples of grasscutters, comprising fifteen organochlorine pesticides (OCPs), two pyrethroids (α- and β-cypermethrin), and one compound each from the triazine (atrazine) and organophosphate (glyphosate) classes. This is in agreement with the findings of Olisah *et al*. [9]. As shown in Figure 2, the liver samples revealed significant variations in pesticide contamination. Among the three ecological zones assessed, Nasarawa State, located in the Guinea Savanna zone, exhibited the highest levels of pesticide residues in liver tissues. This aligns with previous reports documenting extensive pesticide use in agricultural activities within Nasarawa State [10-12].

Heptachlor was the most prevalent residue identified in the liver samples from Nasarawa, with a concentration of 4.00 µg/kg. This was closely followed by p,p'-DDT, recorded at 3.90 µg/kg. These findings corroborate earlier studies by Fatoki and Awofolu [13] and Olisah *et al*. [14], which similarly reported high heptachlor levels in environmental and biological samples. In Akwa Ibom State, situated in the Mangrove zone, the third highest concentration was observed, with Dieldrin detected at 3.70 µg/kg. This aligns with the observations of Moses *et al*. [15], who reported the predominance of Dieldrin in fish samples collected from aquatic environments in Akwa Ibom.

Interestingly, PCB 153 and β-cypermethrin were exclusively detected in liver tissues from Nasarawa and Oyo States, respectively, suggesting region-specific pesticide application practices or exposure sources. Atrazine and glyphosate were not detected in any of the liver samples across the ecological zones. This absence may be indicative of limited or discontinued use of these compounds in the sampled regions or may reflect their rapid degradation and inability to bioaccumulate in liver tissues. However, earlier work by Akinyemi [11] ranked atrazine as the fourth most common active ingredient among 11 active components found in 20 tested pesticides in Nasarawa State.

As illustrated in Figure 3**,** kidney tissues of *Thryonomys swinderianus* revealed significant spatial variation in both the diversity and concentration of pesticide residues across the ecological zones. Akwa Ibom State recorded the highest diversity and levels of contamination in kidney samples. Notably, seven pesticide compounds exhibited elevated concentrations in this region: Heptachlor (3.80 µg/kg), Aldrin (3.50 µg/kg), Dieldrin (3.20 µg/kg), PCB 153 (2.60 µg/kg), Delta (Δ)-BHC (2.50 µg/kg), β-BHC (2.40 µg/kg), and γ-HCH (Lindane) (2.20 µg/kg). These findings are consistent with the report of Udousung *et al*. [16], who documented widespread use of these chemical compounds by farmers in Akwa Ibom for pest control. In contrast, Oyo State demonstrated peak concentrations in five different pesticide residues: α-BHC, β-BHC, Chlorothalonil, o,p'-DDE and Endosulfan II.

Nasarawa State (Guinea Savanna), however, displayed a more limited contamination profile in kidney tissues, with p,p'-DDT being the dominant residue detected. This singular dominance may reflect restricted pesticide use or a shift in chemical preference by local farmers. The detection of DDT is supported by the findings of Omotehinwa *et al*. [12], who reported its presence in cassava samples from Nasarawa State.

Additionally, α-cypermethrin and β-cypermethrin, both pyrethroids, were exclusively identified in kidney samples from Oyo State, suggesting region-specific application practices of these insecticides. Glyphosate remained undetected in kidney tissues across all ecological zones. This observation aligns with the earlier results from liver samples. Nevertheless, Babarinsa *et al*. [17] noted that glyphosate ranks as the second most commonly used herbicide in Nigeria.

Of particular note, p,p'-DDE was the only pesticide residue consistently detected at similar concentrations across all ecological zones. Samsel and Seneff [18] previously associated glyphosate exposure with a range of chronic health conditions in humans, but in this study, the concern appears to shift toward persistent organochlorines like p,p'-DDE, which maintain detectable levels in wildlife tissues across geographically distinct regions.

The presence of multiple pesticide residues, particularly organochlorines such as heptachlor, dieldrin and DDT, underscores their continued environmental persistence despite global restrictions and regulatory bans. These findings align with Akinyemi [11], who highlighted that each class of pesticide presents distinct environmental risks, leading to the prohibition of several compounds and stricter controls on others. The detection of PCB 153, a persistent organic pollutant (POP), further suggests potential industrial or agrochemical runoff into grasscutter habitats. The localized occurrence of cypermethrin residues in Oyo State may reflect region-specific pest control strategies and raises concerns regarding the rate and method of application, as previously reported by Babarinsa *et al*. [17].

Table 1 provides a detailed overview of the mean concentrations of 19 pesticide residues detected in the liver samples of *T. swinderianus* from Akwa Ibom (TSLAK), Nasarawa (TSLNA) and Oyo (TSLOY) States. Of these, 17 residues were detected in at least one of the three states, with atrazine (ATRZ) and glyphosate (GLYS) undetected across all liver samples. Organochlorines (OCPs) dominated the residue profile, with Dieldrin, p,p'-DDT (pDDT), endosulfan I and delta-BHC (ΔBHC) occurring at relatively high concentrations. Akwa Ibom samples showed the highest levels of ΔBHC (3.00 µg/kg), endosulfan I (3.10 µg/kg), Deldrin (3.70 µg/kg), and pDDT (3.60 µg/kg), reflecting significant contamination by persistent pollutants. This finding is consistent with Olisah *et al*. [14], who reported elevated levels of OCPs in various environmental matrices including biota, soil, sediment and food items—despite bans under the Stockholm Convention [19].

In Nasarawa State, heptachlor (4.00 µg/kg) and pDDT (3.90 µg/kg) were the most abundant residues, indicating recent or historical use of these compounds. Conversely, liver samples from Oyo State exhibited relatively elevated levels of βBHC (2.80 µg/kg), γ-HCH (2.60 µg/kg), and ΔBHC (2.60 µg/kg), though lower or undetectable concentrations were recorded for PCB 153, cypermethrins, and DDT derivatives, suggesting localized patterns of pesticide usage or exposure. These geographic disparities in residue levels were statistically significant ($p < 0.05$) for several compounds.

Table 2 presents the mean concentrations (µg/kg) of pesticide residues identified in the kidney tissues of *Thryonomys swinderianus* collected from Akwa Ibom (TSKAK), Nasarawa (TSKNA), and Oyo (TSKOY) States, representing three distinct ecological zones in Nigeria. Of the 19 pesticide compounds analyzed, organochlorine pesticides (OCPs) were the most frequently detected across all locations, although concentrations varied by region and compound.

Heptachlor was notably prevalent, with the highest concentration observed in Akwa Ibom (3.80 ± 1.25 µg/kg), followed by Oyo (3.20 ± 1.89 µg/kg) and Nasarawa (2.80 ± 1.60 µg/kg), reflecting its environmental persistence and potential for bioaccumulation. Other OCPs such as Aldrin, Dieldrin and both Endosulfan I and II were also detected at concentrations exceeding 2 µg/kg in several samples, particularly in Akwa Ibom and Oyo States. These findings are consistent with the work of Omotehinwa *et al*. [12], who reported similar pesticide residues in yam and cassava samples across Nasarawa State, indicating the persistence of these compounds in the food chain and environment.

Polychlorinated Biphenyl (PCB 153), a known industrial pollutant, was detected at its highest in Akwa Ibom (2.60 ± 2.51 µg/kg), with markedly lower concentrations in Nasarawa (0.50 ± 1.12 µg/kg) and Oyo (0.30 ± 0.67 µg/kg), suggesting possible point-source pollution or regional industrial discharge. Pyrethroids (α- and β-cypermethrin), atrazine (ATRZ), and glyphosate (GLYS) were either absent or present at trace levels.

The detection of both parent (p,p'-DDT) and metabolite forms (p,p'-DDE and o,p'-DDE) of DDT suggests past usage and ongoing degradation. Notably, p,p'-DDE and o,p'-DDE were detected at moderate concentrations across all three zones, indicating the long-term environmental stability of these compounds. Ibrahim *et al*. [10] also reported p,p'-DDT presence in all their environmental samples, reinforcing the compound's persistence. Despite the national ban on DDT use since 2008, its continuous detection may be due to illegal use, as highlighted by Akan *et al*. [20], and its classification by NAFDAC as a probable human carcinogen further raises health concerns.

Table 3 presents the mean concentrations (µg/kg) of pesticide residues detected in the flesh samples of *Thryonomys swinderianus* from Akwa Ibom (TSFAK), Nasarawa (TSFNA), and Oyo (TSFOY) States. In general, pesticide residue levels in the flesh were minimal across all locations, with the majority of compounds either undetectable or present at trace levels. Several compounds, including β-BHC, Heptachlor, Heptachlor epoxide, Aldrin, Endosulfan II, PCB 153, α- and β-cypermethrin, atrazine (ATRZ), and glyphosate (GLYS), were not detected in any of the samples, indicating either their absence in the environment or rapid degradation and limited tissue accumulation.

In Akwa Ibom, α-BHC, o,p′-DDE, Endosulfan I, Dieldrin, and p,p′-DDT were detected at concentrations ranging between 0.01 and 0.02 µg/kg, although statistical analysis indicated no significant differences when compared with values from other zones ($p > 0.05$). Meanwhile, Oyo State recorded significantly higher concentrations ($p < 0.05$) of Δ-BHC (0.01 ± 0.02 µg/kg) and p,p′-DDE (0.01 ± 0.02 µg/kg) compared to the other zones, suggesting potential site-specific contamination.

The exclusive detection of DDT and its metabolites; namely p,p′-DDT, p,p′-DDE and o,p′-DDE—in some samples highlights the long-term persistence of organochlorine pesticides in the environment. It is noteworthy that all detected pesticide concentrations in the flesh samples were well below the Maximum Residue Limits (MRLs) set by the FAO/WHO for meat products. This contrasts with earlier findings by Moses *et al*. [15], who reported significantly elevated pesticide levels in fish from the Nwaniba River in Akwa Ibom State and by Ibrahim *et al*. [10], who found multiple residues in vegetables exceeding international safety thresholds. Despite the relatively low concentrations observed in the current study, chronic exposure to organochlorine compounds known for their endocrine-disrupting, immunotoxic, and carcinogenic properties, remains a potential public health concern, particularly among populations that rely on bushmeat as a dietary staple [12; 21-22].

Table 4 presents the mean concentrations (µg/kg) of pesticide residues detected in the liver and kidney tissues of *Thryonomys swinderianus* collected from Akwa Ibom, Nasarawa, and Oyo States; representing the mangrove, guinea savanna and rainforest ecological zones of Nigeria. The findings reveal varying levels of organochlorine and other persistent pesticide residues, with some concentrations approaching or exceeding international Maximum Residue Limits (MRLs). These observations align with earlier reports, such as Ibrahim *et al*. [10], who found that pesticide levels in vegetables frequently exceeded the European Union's general MRL threshold of 0.05 mg/kg for produce.

Among the most concerning compounds was gamma-HCH, which was detected in all samples, reaching a peak of 3.75 µg/kg in kidney tissues from Oyo (OYTSK). While this is well below the Japan Food Chemical Research Foundation (JFCRF) MRL of 1000 µg/kg, it approaches the 20 µg/kg permissible limit set by the European Union Pesticide Database (EUPDB), suggesting chronic exposure through environmental or dietary sources. Other hexachlorocyclohexane (HCH) isomers - namely αBHC, βBHC, and ΔBHC were also identified, particularly in Oyo, where αBHC reached 2.7 µg/kg and ΔBHC recorded a maximum of 3.0 µg/kg. These results may indicate historical pesticide application and persistence in the local ecosystem.

Aldrin residues were highest in kidney tissues from Akwa Ibom (3.5 µg/kg) and liver samples from Nasarawa (3.0 µg/kg). Dieldrin, another persistent organochlorine, peaked at 3.7 µg/kg in liver samples from Akwa Ibom, further supporting concerns about the enduring presence of banned pesticides in the region. Endosulfan I and II were consistently detected across all tissues and zones. Maximum concentrations reached 3.1 µg/kg in the liver (AKTSL) and 2.3 µg/kg in the kidney (OYTSK). Although these values are below international safety thresholds (ranging from 50 to 100 µg/kg), their documented toxicity and potential to induce harmful effects even at low exposure levels warrant attention [23].

The presence of DDT and its metabolites; p,p'-DDT (pDDT), p,p'-DDE and o,p'-DDE provides further evidence of either recent or historical application of this now-banned compound. pDDT was most prominent in liver samples from Nasarawa (3.9 µg/kg) and Akwa Ibom (3.6 µg/kg).

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FIGURES AND TABLES

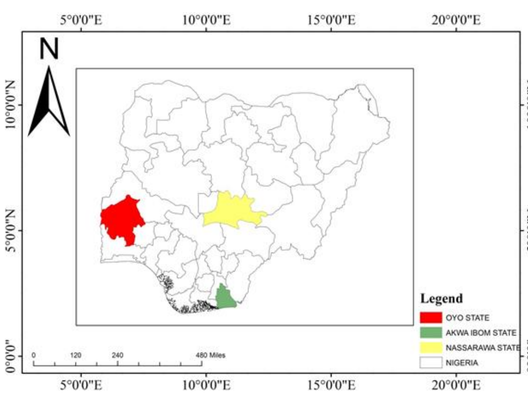

Figure 1: Map of Nigeria showing selected ecological zones for the study

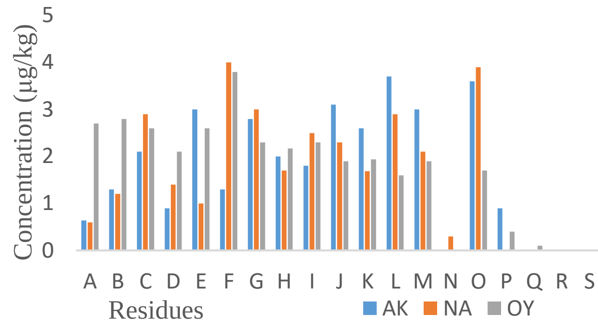

Figure 2: Mean Concentrations (µg/kg) of Pesticide Residues in Grasscutter (*Thryonomys swinderianus*) Liver

A(alpha(α) BHC) B (beta(β) BHC) C (gamma (ϒ)-HCH (Lindane) D (Chlorothalonil) E (delta (Δ) BHC) F (Heptachlor) G (Aldrin) H (Heptachlor epoxide (B) I (o, p'-DDE) J (Endosulfan I) K (p, p'-DDE) L (Deldrin) M (Endosulfan II) N (PCB 153) O (p, p'-DDT) P (alpha (α) cypermethrin) Q (beta (β) cypermethrin) R (Atrazine) S (Glyphosate)

AK- Akwa Ibom State NA-Nasarawa State OY-Oyo State

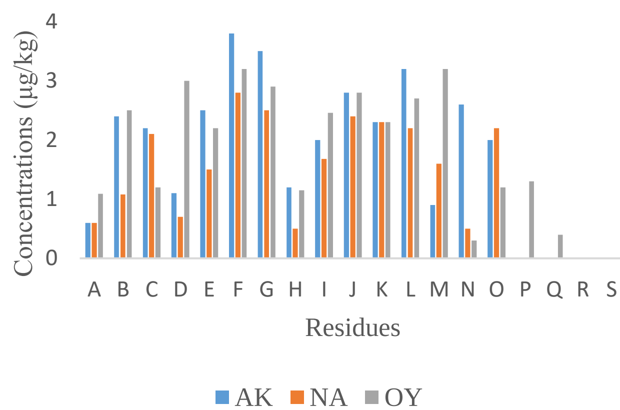

Figure 3: Mean Concentrations (µg/kg) of Pesticide Residues in Grasscutter (*Thryonomys swinderianus*) Kidney

A(alpha(α) BHC) B (beta(β) BHC) C (gamma (ϒ)-HCH (Lindane) D (Chlorothalonil) E (delta (Δ) BHC) F (Heptachlor) G (Aldrin) H (Heptachlor epoxide (B) I (o, p'-DDE) J (Endosulfan I) K (p, p'-DDE) L (Deldrin) M (Endosulfan II) N (PCB 153) O (p, p'-DDT) P (alpha (α) cypermethrin) Q (beta (β) cypermethrin) R (Atrazine) S (Glyphosate)

AK- Akwa Ibom State NA-Nasarawa State OY-Oyo State

Table 1: Concentrations in mean (µg/kg) of residues of pesticide in the liver of Grasscutters (*Thryonomys swinderianus*) in the three ecological zones in Nigeria

Pesticide residue	TSLAK	TSLNA	TSLOY
αBHC	0.64 ± 0.60^{ab}	0.60 ± 0.22^{abc}	2.70 ± 1.75^{bc}
βBHC	1.30 ± 0.84^{abcd}	1.20 ± 1.35^{abcd}	2.80 ± 2.28^{c}
ϒHCH	2.10 ± 1.85^{abcde}	2.90 ± 1.71^{de}	2.60 ± 1.78^{bc}
Chloro	0.90 ± 0.89^{abc}	1.40 ± 0.82^{abcd}	2.10 ± 1.75^{abc}
ΔBHC	3.00 ± 1.30^{cde}	1.00 ± 1.22^{abcd}	2.60 ± 1.78^{bc}
Heptac	1.30 ± 0.84^{abcd}	4.00 ± 1.37^{e}	3.80 ± 1.25^{c}
Aldrin	2.80 ± 2.02^{cde}	3.00 ± 1.70^{de}	2.30 ± 1.79^{abc}
Heptac	2.00 ± 2.12^{abcde}	1.70 ± 1.15^{abcd}	2.17 ± 1.61^{abc}
oDDE	1.80 ± 1.57^{abcde}	2.50 ± 2.35^{cde}	2.30 ± 2.54^{abc}
Endosul	3.10 ± 1.98^{de}	2.30 ± 1.72^{bcde}	1.90 ± 1.08^{abc}
pDDE	2.60 ± 1.64^{bcde}	1.69 ± 1.90^{abcd}	1.94 ± 2.03^{abc}
Deldr	3.70 ± 1.86^{e}	2.90 ± 1.95^{de}	1.60 ± 1.56^{abc}
Endosu	3.00 ± 2.12^{cde}	2.10 ± 1.88^{abcde}	1.90 ± 1.75^{abc}
PCB	0.00 ± 0.00^{a}	0.30 ± 0.67^{ab}	0.00 ± 0.00^{a}
pDDT	3.60 ± 1.78^{e}	3.90 ± 2.19^{e}	1.70 ± 1.72^{abc}
α cyper	0.90 ± 2.01^{abc}	0.00 ± 0.00^{a}	0.40 ± 0.65^{ab}
β cyper	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.10 ± 0.22^{a}
ATRZ	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
GLYS	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}

NB: Means with the same superscript alphabets in the same column are not significantly different at $p<0.05$

TSLAK – *Thryonomys swinderianus* Liver from Akwa Ibom state;

TSLNA – *Thryonomys swinderianus* Liver from Nasarawa state;

TSLOY – *Thryonomys swinderianus* Liver from Oyo state

KEY: **αBHC** – Alpha(α)BHC; **βBHC** – beta(β)BHC; **ϒHCH** – Gamma (ϒ)HCH (Lindane); **Chloro** – Chlorothalonil; **ΔBHC** – Delta (Δ) BHC; **Heptac** – Heptachlor); **Aldrin** – Aldrin; **Heptac** – Heptachlor epoxide (B); **oDDE** – o,p'-DDE; **Endosul** – Endosulfan I; **pDDE** – p,p'-DDE; **Deldr** – Deldrin; **Endosu** - Endosulfan II; **PCB** – PCB 153; **pDDT** – p,p'-DDT; **α cyper** – alpha (α) cypermethrin; **β cyper** – beta (β) cypermethrin; **ATRZ** – Atrazine; **GLYS** – Glyphosate

Table 2: Concentrations in mean (µg/kg) of residues of pesticide in the kidney of grasscutters (*Thryonomys swinderianus*) in the three ecological zones in Nigeria

Pesticide residue	TSKAK	TSKNA	TSKOY
αBHC	0.60 ± 0.42^{ab}	0.60 ± 0.22^{abc}	1.09 ± 0.67^{abcd}
βBHC	2.40 ± 2.43^{bcde}	1.08 ± 0.98^{abc}	2.50 ± 1.77^{cd}
ϒHCH	2.20 ± 1.30^{abcde}	2.10 ± 2.25^{abc}	1.20 ± 0.91^{abcd}
Chloro	1.10 ± 0.74^{abc}	0.70 ± 0.97^{abc}	3.00 ± 1.54^{d}
ΔBHC	2.50 ± 2.35^{bcde}	1.50 ± 1.00^{abc}	2.20 ± 2.17^{bcd}
Heptac	3.80 ± 1.25^{e}	2.80 ± 1.60^{c}	3.20 ± 1.89^{d}
Aldrin	3.50 ± 2.12^{de}	2.50 ± 1.91^{bc}	2.90 ± 1.95^{d}
Heptac	1.20 ± 0.76^{abcd}	0.50 ± 0.87^{ab}	1.15 ± 0.82^{abcd}
oDDE	2.00 ± 1.54^{abcde}	1.68 ± 1.91^{abc}	2.46 ± 2.14^{cd}
Endosul	2.80 ± 2.20^{bcde}	2.40 ± 2.22^{bc}	2.80 ± 2.05^{d}
pDDE	2.30 ± 1.99^{abcde}	2.30 ± 2.31^{bc}	2.30 ± 1.04^{bcd}
Deldr	3.20 ± 1.89^{cde}	2.20 ± 2.08^{abc}	2.70 ± 1.25^{d}
Endosu	0.90 ± 1.34^{abc}	1.60 ± 1.19^{abc}	3.20 ± 2.08^{d}
PCB	2.60 ± 2.51^{bcde}	0.50 ± 1.12^{ab}	0.30 ± 0.67^{ab}
pDDT	2.00 ± 1.90^{abcde}	2.20 ± 2.41^{abc}	1.20 ± 1.44^{abcd}
α cyper	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	1.30 ± 1.30^{abcd}
β cyper	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.40 ± 0.65^{abc}
ATRZ	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
GLYS	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}

NB: Means with the same superscript alphabets in the same column are not significantly different at $p<0.05$

TSKAK - *Thryonomys swinderianus* Kidney from Akwa Ibom state

TSKNA - *Thryonomys swinderianus* Kidney from Nasarawa state

TSKOY - *Thryonomys swinderianus* Kidney from Oyo state

KEY: **αBHC** – Alpha(α)BHC; **βBHC** – beta(β)BHC; **ϒHCH** – Gamma (ϒ)HCH (Lindane); **Chloro** – Chlorothalonil; **ΔBHC** – Delta (Δ) BHC; **Heptac** – Heptachlor); **Aldrin** – Aldrin; **Heptac** – Heptachlor epoxide (B); **oDDE** – o,p'-DDE; **Endosul** – Endosulfan I; **pDDE** – p,p'-DDE; **Deldr** – Deldrin; **Endosu** - Endosulfan II; **PCB** – PCB 153; **pDDT** – p,p'-DDT; **α cyper** – alpha (α) cypermethrin; **β cyper** – beta (β) cypermethrin; **ATRZ** – Atrazine; **GLYS** – Glyphosate

Table 3: Concentrations in mean (µg/kg) of residues of pesticide in the flesh of grasscutters (*Thryonomys swinderianus*) in the three ecological zones in Nigeria

Pesticide residue	TSFAK	TSFNA	TSFOY
αBHC	0.01 ± 0.02^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
βBHC	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a

ϒHCH	0.00 ± 0.01a	0.00 ± 0.00a	0.00 ± 0.00a
Chloro	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
ΔBHC	0.00 ± 0.00a	0.00 ± 0.00a	0.01 ± 0.02b
Heptac	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
Aldrin	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
Heptac	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
oDDE	0.01 ± 0.01a	0.00 ± 0.01a	0.00 ± 0.00a
Endosul	0.01 ± 0.01a	0.00 ± 0.01a	0.00 ± 0.00a
pDDE	0.00 ± 0.00a	0.00 ± 0.00a	0.01 ± 0.02b
Deldr	0.01 ± 0.02a	0.00 ± 0.00a	0.00 ± 0.00a
Endosu	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
PCB	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
pDDT	0.01 ± 0.01a	0.00 ± 0.00a	0.00 ± 0.00a
α cyper	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
β cyper	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
ATRZ	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
GLYS	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a

NB: Means with the same superscript alphabets in the same column are not significantly different at p<0.05
TSFAK - *Thryonomys swinderianus* Flesh from Akwa Ibom state
TSFNA - *Thryonomys swinderianus* Flesh from Nasarawa state
TSFOY - *Thryonomys swinderianus* Flesh from Oyo state

KEY: **αBHC** – Alpha(α)BHC; **βBHC** – beta(β)BHC; **ϒHCH** – Gamma (ϒ)HCH (Lindane); **Chloro** – Chlorothalonil; **ΔBHC** – Delta (Δ) BHC; **Heptac** – Heptachlor); **Aldrin** – Aldrin; **Heptac** – Heptachlor epoxide (B); **oDDE** – o,p'-DDE; **Endosul** – Endosulfan I; **pDDE** – p,p'-DDE; **Deldr** – Deldrin; **Endosu** - Endosulfan II; **PCB** – PCB 153; **pDDT** – p,p'-DDT; **α cyper** – alpha (α) cypermethrin; **β cyper** – beta (β) cypermethrin; **ATRZ** – Atrazine; **GLYS** – Glyphosate

Table 4: Pesticide Residues in the Liver and Kidney of Grasscutters (*Thryonomys swinderianus*) in Average Concentrations (µg/kg) from Three Ecological Zones of Nigeria with Recommended Maximum Residual Levels (MRL)

Pesticide residue	AKTSL	AKTSK	NATSL	NATSK	OYTSL	OYTSK	FAO/WHO	EUPDB	JFCRF
αBHC	0.64	0.6	0.6	0.6	2.7	1.09	-	-	-
βBH	1.	2.4	1.	1.0	2.	2.5	-	-	-
ϒHC	2.	2.2	2.	2.1	2.	3.7	-	20	10
Chlor	0.	1.1	1.	0.7	2.	3	-	-	-
ΔBH	3	2.5	1	1.5	2.	2.7	-	-	-
Hept	1.	3.8	4	2.8	3.	3.6	200	20	20
Aldri	2.	3.5	3	2.5	2.	1.1	200	20	20
Hept	2	1.2	1.	0.5	2.	2.4	200	20	20
oDD	1.	2	2.	1.6	2.	2.8	-	-	20
Endo	3.	2.8	2.	2.4	1.	2.3	100	50	20
pDD	2.	2.3	1.	2.3	1.	2.7	500	-	20
Deldr	3.	3.2	2.	2.2	1.	3.2	200	20	20
Endo	3	0.9	2.	1.6	1.	0.3	100	50	20
PCB	0	2.6	0.	0.5	0	2	-	-	-
pDD	3.	2	3.	2.2	1.	2.1	500	-	20
α	0.	0	0	0	0.	1	-	-	-
β cyper	0	0	0	0	0.1	3.2	-	-	-
ATRZ	0	0	0	0	0	0			
GLYS	0		0			0			

NB: MRL adapted from FAO/WHO, Japan Food Chemical Research Foundation (JFCRF) and European Union Pesticide Data Base (EUPDB)
AKTSL-*Thryonomys swinderianus* Liver from Akwa Ibom
NATSL - *Thryonomys swinderianus* Liver from Nasarawa
OYTSL - *Thryonomys swinderianus* Liver from Oyo

KEY: **αBHC** – Alpha(α)BHC; **βBHC** – beta(β)BHC; **ϒHCH** – Gamma (ϒ)HCH (Lindane); **Chloro** – Chlorothalonil; **ΔBHC** – Delta (Δ) BHC; **Heptac** – Heptachlor); **Aldrin** – Aldrin; **Heptac** – Heptachlor epoxide (B); **oDDE** – o,p'-DDE; **Endosul** – Endosulfan I; **pDDE** – p,p'-DDE; **Deldr** – Deldrin; **Endosu** - Endosulfan II; **PCB** – PCB 153; **pDDT** – p,p'-DDT; **α cyper** – alpha (α) cypermethrin; **β cyper** – beta (β) cypermethrin; **ATRZ** – Atrazine; **GLYS** – Glyphosate