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Assessment of Organochlorine Pesticide Residues and Associated Health Risks in Some Vegetables Consumed in Yola, Adamawa State, Nigeria

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Abstract

The use of pesticides in agriculture can lead to the accumulation of residues in food commodities, posing potential health risks. The levels of organochlorine pesticide residues in selected vegetables (sorrel, spinach, okra, lettuce and sesame) consumed in Yola, Adamawa State, Nigeria were assessed. Vegetable samples were collected, extracted using the QuEChERS method and analysed by gas chromatography-mass spectrometry (GC-MS). Health risk assessment was conducted by estimating the estimated daily intake (EDI), hazard quotient (HQ), hazard index (HI) and lifetime cancer risk (LCR). Organochlorine pesticides, including lindane, aldrin, endosulfan and DDT, were detected in varying concentrations across vegetable samples. Spinach exhibited the highest levels, exceeding European Union Maximum Residue Levels for α-lindane (1.555 mg/kg), β-lindane (1.718 mg/kg), δ-lindane (1.556 mg/kg), aldrin (1.990 mg/kg), endosulfan I (1.960 mg/kg) and endosulfan II (5.209 mg/kg). The HI was 5.56, indicating potential non-carcinogenic health risks. Spinach posed a high cancer risk for α-lindane, β-lindane and p,p'-DDT. Organochlorine pesticide residues in vegetables consumed in Yola exceeded regulatory limits, with spinach posing the highest health risks. Effective monitoring, sustainable agricultural practices and strengthened regulatory frameworks are crucial to

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safeguard food safety and public health. Thus, consumption of vegetables in Yola should be done with caution.

Keywords: Pesticide residue, Health risk, Organochlorine pesticide, Nigeria, Vegetables

INTRODUCTION

The presence of pesticide residues in food commodities, particularly in fresh vegetables, has become a pressing issue due to the potential health risks associated with their consumption. Vegetables are an essential part of the human diet, providing essential nutrients, vitamins and minerals. However, their cultivation often involves the application of pesticides to control pests and diseases, leading to the potential accumulation of pesticide residues (Narenderan *et al.*, 2020).

Pesticides play a crucial role in modern agriculture, helping to protect crops from pests, diseases and weeds, thereby increasing yields and ensuring food security. However, the widespread use of pesticides has raised concerns about their potential adverse effects on human health and the environment (Ali *et al.*, 2021). Organochlorine pesticides (OCPs), a class of synthetic organic compounds containing chlorine atoms, have been widely used in agricultural practices due to their cost-effectiveness and broad-spectrum activity against various pests (Douass *et al.*, 2022). Despite their effectiveness, OCPs are known for their persistence in the environment, bioaccumulation in the food chain and potential toxic effects on humans and other organisms (Madiha *et al.*, 2021).

In Nigeria, the use of pesticides in agriculture has been increasing in recent years to meet the growing demand for food production. However, there is a lack of comprehensive data on the levels of pesticide residues in locally grown vegetables (Oyenpemi *et al.*, 2023). This lack of information hinders the proper assessment of potential health risks associated with the consumption of contaminated vegetables and the implementation of effective regulatory measures.

Organochlorine pesticides, such as DDT, lindane and endosulfan, have been extensively used in Nigeria for agricultural purposes due to their low cost and effectiveness against a wide range of pests (Sosan *et al.*, 2020). However, the persistent nature of these compounds and their tendency to bioaccumulate in the food chain have raised concerns about their

potential adverse effects on human health and the environment. Exposure to OCPs has been linked to various health problems, including reproductive disorders, endocrine disruption, neurotoxicity and an increased risk of certain cancers (Islam *et al.*, 2022).

Yola North Local Government Area in Adamawa State, Nigeria, is an important agricultural hub known for its vegetable production (Ahmad, 2023). However, there is limited data on the levels of pesticide residues in vegetables grown in this region. Assessing the presence and concentrations of pesticide residues in locally grown vegetables is crucial for identifying potential health risks and implementing appropriate measures to safeguard consumer safety.

The vegetables examined in this study have long histories of cultivation and use in various cultures around the world. Sorrel (*Rumex acetosa*) has been used since ancient times for its tangy leaves, acidic, sour-lemony flavor often in soups and salads (Korpelainen and Pietiläinen, 2020). Spinach (*Spinacia oleracea*) originated in Persia and spread to Europe in the Middle Ages, becoming a staple leafy green due to its nutritional value (Ferreira *et al.*, 2018). Okra (*Abelmoschus esculentus*) is believed to have originated in Ethiopia and was cultivated by the ancient Egyptians (Elkhalifa *et al.*, 2021); it is now a key ingredient in many African dishes. Lettuce (*Lactuca sativa*) has been grown since ancient Egyptian times and was prized by the Romans for its crisp texture and mild flavor (Qari *et al.*, 2016). Sesame (*Sesamum indicum*) is one of the oldest oilseed crops, with origins in Africa and India and has been valued for its seeds and oil for thousands of years (Dossa *et al.*, 2017). These vegetables have become integral parts of various cuisines worldwide and are now widely cultivated in Nigeria, including the Yola region, due to their nutritional value and adaptability to local growing conditions.

This study aims to determine the presence and concentrations of organochlorine pesticide residues in selected vegetables (sorrel, spinach, okra, lettuce and sesame) grown within Yola North of Adamawa State, Nigeria. By providing data on pesticide residue levels and their associated health risks, this study can contribute to the development of effective monitoring strategies and the implementation of appropriate regulatory measures to ensure food safety and protect public health in the region.

MATERIALS AND METHODS

Sampling Area

The sampling area for this study was selected from farms located in the Geriyo region of Yola North Local Government Area, Adamawa State, Nigeria. This area is situated at approximately 9°17'28.8" N latitude and 12°25'49.4" E longitude. The primary economic activities in the region include farming, grazing, mild administrative operations and small-scale industrial activities (Umaru and Arabo, 2021).

Sample Collection and Preparation

Fresh samples of selected vegetables, including *Spinacia oleracea* (Spinach), *Hibiscus esculentus* (Okro), *Rumex acetosa* (Sorrel), *Sesame indicum* (Sesame) and *Lectuca sativa* (Lettuce) were collected from farms in Geriyo, Yola North of Adamawa State, Nigeria. The samples were identified and authenticated at the Department of Plant Science, Modibbo Adama University, Yola. About 2kg of each fresh vegetable sample were collected from the farms. The collected vegetable samples were picked and washed immediately after collection and were stored at -4°C for further analysis.

Chemicals and Reagents

All solvents and chemicals used were of analytical grade. Organochlorine pesticide standards (Sigma-Aldrich, USA). Acetonitrile, n-hexane, acetone and acetic acid were obtained from Merck (Darmstadt, Germany). Anhydrous magnesium sulfate ($MgSO_4$) and sodium acetate ($C_2H_3NaO_2$) used for the extraction process were obtained from (SRL Pvt. Ltd., India).

Sample Preparation, Extraction and Clean Up

The sample was extracted and analysed using the AOAC Official method, as described by Lehotay (2007) and Ananda and Somashekar (2012). The multi-residue pesticide analysis technique was followed, which consists of the QuECHERS (quick, easy, cheap, effective, rugged and safe) based method. QuECHERS was developed using an extraction method for pesticides in fruits and vegetables, coupled with a cleanup method that removes sugars, lipids, organic acids, sterols, proteins, pigments and excess water.

For each vegetable sample, exactly 15g was taken and homogenized in a pestle and mortar. The homogenized sample was then transferred to a clean 50ml tube, to which 15ml of acetonitrile containing 1% acetic acid (v/v) was added. The sample was then shaken

vigorously for one minute. Exactly 6.0g of $MgSO_4$ anhydrous and 1.5g of sodium acetate anhydrous were added for sample drying and buffering. The mixture was then shaken vigorously, ensuring that the salts were not at the bottom of the tube. It was then centrifuged for four minutes at 3500rpm to separate the solid materials. The supernatant resulting from the phase separation stage of sample extract preparation was transferred to a vial tube. Exactly 150mg of $MgSO_4$ and 2.5mg of graphite carbon per sample were added to the extract and it was shaken using a vortex mixer for one minute. The extract was then centrifuged for four minutes at 3500rfc. After the centrifugation step, the supernatant was subjected to GC-MS for further analysis (Chen *et al.*, 2007).

Instrumental Analysis

All compounds were determined using a gas chromatograph equipped with a mass-selective detector (GC-MS), an auto-sampler and a split-splitless injector, as described in the study by Lehotay *et al.* (2005). The GC-MS was equipped with a DB-5 fused silica capillary column (30m x 0.25µm i.d. x0.25µm film thickness) coated with cross-linked 5% phenyldimethyl polysiloxane. The carrier gas used was helium (99.999% purity) at a flow rate of 1.0 ml/min. The oven temperature was programmed as follows: initially maintained at 40ºC for 1min, increased at 12ºC/min to 280ºC, then at 20ºC/min to 215ºC, at 100ºC/min to 265ºC and finally at 200ºC/min to 290ºC and held for 8min. The injection volume was 1µL, injected in splitless mode at an injection temperature of 250ºC. The mass spectrometer was operated in electron impact (EI) ionization mode with a detector voltage of 700V, ion source temperature of 200ºC, GC interface temperature of 320ºC and emission current of 150µV. The acquisition mode was selected ion monitoring (SIM). The identification of individual OCPs was done by comparing the retention time of standard OCPs with those in the samples. The quantification of each OCP was done by comparing the peak areas of the OCPs in the samples with those in the standard.

Health Risk Assessment

Health risk assessment involves evaluating the potential impact on consumer health posed by consuming vegetables contaminated with pesticides which was determined according to methods described by Sosan *et al.* (2020). This assessment encompasses both short-term (acute) and long-term (chronic) exposure to pesticides through consumption.

The Estimated Daily Intake (EDI) of Pesticide Residue

This was then calculated using the formula:

$$\mathrm{EDI} = \frac{\mathrm{hRL} \times \mathrm{IR}}{\mathrm{BW}} \quad (1)$$

where hRL is the highest residue level of pesticide residue in the vegetable (mg/kg), IR is the ingestion rate of the vegetable which is 0.13kg/day for an adult Nigerian as estimated by Raaijmakers *et al.* (2018) for urban Nigeria and BW is the body weight of adult consumer, established at 70kg.

The Hazard Quotient (HQ)

This was calculated to assess the non-carcinogenic risk. The HQ was calculated using the formula:

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \quad (2)$$

where RfD is the reference dose of the pesticide (mg/kg/day) as established by European Food Safety Authority *et al.* (2022).

The HQ was calculated for vegetables and organochlorines. The HQ was summed up to give the hazard index (HI) (Chen *et al.*, 2011).

$$\mathrm{HI} = \sum_{i=1}^{n} HQ_i \quad (3)$$

HQ and HI >1 suggest potential non-cancer health effects and could cause risk to the consumer. Values <1 is considered acceptable with unlikely adverse effects at estimated exposure levels (Saleem *et al.*, 2019).

The carcinogenic Risk

This was assessed by calculating the chronic daily intake (CDI) and lifetime cancer risk (LCR). The CDI and LCR was calculated using the formula:

$$\mathrm{CDI} = \frac{\mathrm{mRL} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{LE}} \quad (4)$$

$$\mathrm{LCR} = \mathrm{CDI} \times \mathrm{CSF} \quad (5)$$

where mRL is the mean residue level in vegetable, ED is the exposure duration (years), EF is the exposure frequency (days/year), CSF is the cancer slope factor of the pesticide $(\mathrm{mg/kg/day})^{-1}$ as listed in **Error! Reference source not found.** (Lee *et al.*, 2014; Qu *et al.*,

2015; Sosan *et al.*, 2020), LE is the life expectancy (days) estimated as 365 days × 70 years (Sosan *et al.*, 2020). LCR $<1\times10^{-6}$ poses no cancer risk; LCR $>1\times10^{-4}$ poses high cancer risk and LCR from 1×10^{-6} to 1×10^{-4} shows acceptable risk.

Statistical Analysis

The statistical analysis of the data was performed using the software SPSS (Statistical Package for the Social Sciences) version 27.0 (IBM Corp, Armonk, NY, USA). Values are expressed as mean ± S.E.M. One-way analysis of variance (ANOVA) was used to compare the mean pesticide residue levels among different vegetables, followed by Tukey's post-hoc test. The level of significance was set at $p < 0.05$.

RESULTS

Figure 1 presents the GC-MS chromatograms for the different vegetable samples, illustrating the characteristic peaks corresponding to the detected organochlorine compounds. The concentrations of organochlorine pesticide residues in five selected vegetables (*H. esculentus*, *L. sativa*, *S. oleracea*, *R. acetosa* and *S. indicum*) were analysed and compared to the European Union Maximum Residue Levels (EU MRLs) (**Error! Reference source not found.**) (European Food Safety Authority *et al.*, 2022). For α-lindane, spinach (*S. oleracea*) had the highest concentration (1.555 mg/kg), significantly ($P<0.05$) higher than the other vegetables and the EU MRL of 0.01 mg/kg. Spinach also recorded the highest β-lindane level (1.718 mg/kg), significantly ($P<0.05$) surpassing the EU MRL. Similarly, spinach had the greatest concentration of ɤ-lindane (0.956 mg/kg), significantly ($P<0.05$) higher than both other vegetables and the MRL. A similar trend was seen with δ-lindane, where spinach again had the maximum concentration (1.556 mg/kg), significantly ($P<0.05$) above the MRL.

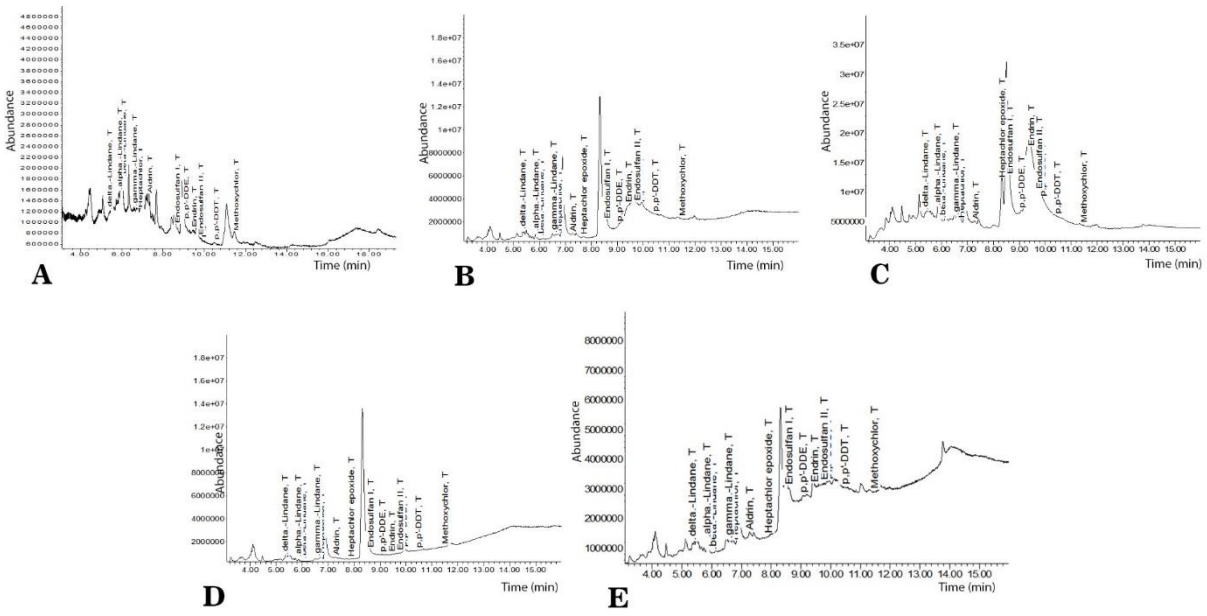

Figure 1: GC-MS Chromatogram of Organochlorine Levels in Selected Vegetables (A) *H. esculentus*, (B) *L. sativa*, (C) *S. oleracea,* (D) *R. acetosa* and (E) *S. indicum.*

Table 1: Concentration of organochlorine pesticide residue in selected vegetables.

Pesticide Residue	Concentration (mg/kg)					EU MRL
	H. esculentus	*L. sativa*	*S. oleracea*	*R. acetosa*	*S. indicum*	
α-lindane	0.111±0.01^{b}	0.325±0.14^{c}	1.555±0.22^{d}	0.064±0.03^{a}	0.265±0.10^{c}	0.01
β-lindane	0.354±0.12^{a}	0.451±0.02^{b}	1.718±0.11^{c}	0.301±0.04^{a}	0.434±0.11^{b}	0.01
ɤ-lindane	0.221±0.11^{b}	0.532±0.13^{c}	0.956±0.08^{d}	0.146±0.01^{a}	0.660±0.28^{c}	0.01
δ-lindane	0.073±0.02^{a}	0.224±0.05^{b}	1.556±0.03^{c}	0.093±0.02^{a}	0.217±0.01^{b}	0.01
Heptachlor	0.005±0.00^{a}	0.020±0.01^{b}	0.121±0.10^{c}	0.009±0.00^{a}	0.034±0.10^{b}	0.01
Heptachlor-epoxide	0.000±0.00^{a}	0.006±0.01^{b}	0.006±0.01^{b}	0.006±0.02^{b}	0.006±0.01^{b}	0.01
Aldrin	1.096±0.45^{b}	0.642±0.05^{a}	1.990±0.21^{c}	0.578±0.13^{a}	1.435±0.21^{bc}	0.01
Endrin	0.183±0.02^{c}	1.126±0.23^{c}	0.593±0.22^{b}	0.068±0.03^{a}	0.378±0.22^{b}	0.01
Endosulfan I	0.268±0.16^{a}	0.874±0.21^{b}	1.960±0.27^{c}	0.248±0.11^{a}	0.659±0.07^{b}	0.05
Endosulfan II	0.529±0.23^{a}	0.786±0.31^{a}	5.209±0.53^{b}	0.880±0.32^{a}	5.209±0.73^{b}	0.05
p,p'-DDE	0.003±0.01^{a}	0.011±0.00^{b}	0.034±0.01^{bc}	0.030±0.01^{bc}	0.054±0.01^{c}	0.05
p,p'-DDD	0.036±0.01^{a}	0.019±0.01^{a}	0.139±0.02^{b}	0.025±0.01^{a}	0.078±0.02^{a}	0.05
p,p'-DDT	0.035±0.01^{a}	0.076±0.01^{a}	0.248±0.03^{b}	0.026±0.03^{a}	0.054±0.03^{a}	0.05
Methoxychlor	0.025±0.01^{a}	0.016±0.00^{a}	0.047±0.01^{a}	0.025±0.01^{a}	0.014±0.00^{a}	0.01

Values with different superscript are significantly different ($p<0.05$), within a row; EU MRL: European Union Maximum residue level.

For heptachlor, spinach showed the highest residue (0.121 mg/kg), significantly ($P<0.05$) higher than the EU MRL of 0.01 mg/kg. Heptachlor-epoxide concentrations were uniform across all vegetables but within the regulatory limit. Aldrin was found at the highest concentration in spinach (1.990 mg/kg), significantly ($P<0.05$) exceeding the EU MRL. Endrin was most concentrated in lettuce (*L. sativa*) at 1.126 mg/kg, significantly ($P<0.05$) higher than in other vegetables and the MRL.

Endosulfan I was most concentrated in spinach (1.960 mg/kg), while endosulfan II showed equally high concentrations in spinach and sesame (*S. indicum*), both at 5.209 mg/kg, significantly ($P<0.05$) above the EU MRL of 0.05 mg/kg. Sesame had the highest level of p,p'-DDE (0.054 mg/kg), significantly ($P<0.05$) higher than other vegetables and close to the MRL. For p,p'-DDD and p,p'-DDT, spinach recorded the highest concentrations at 0.139 mg/kg and 0.248 mg/kg, respectively, both significantly ($P<0.05$) higher than other vegetables and the MRL. Methoxychlor concentrations were generally low, with no vegetable exceeding the EU limit.

Table 2 provides the estimated daily intake (EDI) and hazard risk assessment of organochlorine pesticide residues from selected vegetables, focusing on both reference doses (RfD) and hazard quotients (HQ). Spinach (*S. oleracea*) consistently exhibited the highest estimated daily intake across most organochlorines, notably α-lindane (0.00404 mg/kg), β-lindane (0.00447 mg/kg) and δ-lindane (0.00405 mg/kg), all significantly higher than the corresponding values in other vegetables. Spinach also had the highest EDI for aldrin (0.00517 mg/kg), which exceeded that of other vegetables, contributing to the highest hazard quotient for aldrin (HQ = 1.31). The EDI for endosulfan I and endosulfan II in spinach was also substantial at 0.00510 mg/kg and 0.01354 mg/kg, respectively, with the latter shared with sesame (*S. indicum*), both contributing to a hazard quotient of 0.66. For heptachlor and heptachlor-epoxide, spinach had a moderate EDI (0.00031 mg/kg and 0.00002 mg/kg, respectively), but these values were below hazardous levels (HQ = 0.05 and 0.01). The Hazard Index (HI) calculated across all pesticides was 5.56.

Table 2: Estimated daily intake (mg/kg) and hazard risk assessment of organochlorines from selected vegetables.

Pesticide Residue	*H. esculentus*		*L. sativa*		*S. oleracea*		*R. acetosa*		*S. indicum*		HQ
	RfD	EDI	RfD	EDI	RfD	EDI	RfD	EDI	RfD	EDI	
α-lindane	0.01	0.00029	0.01	0.00085	0.01	0.00404	0.01	0.00017	0.01	0.00069	0.60
β-lindane	0.01	0.00092	0.01	0.00117	0.01	0.00447	0.01	0.00078	0.01	0.00113	0.85
ɤ-lindane	0.01	0.00057	0.01	0.00138	0.01	0.00249	0.01	0.00038	0.01	0.00172	0.65
δ-lindane	0.01	0.00019	0.01	0.00058	0.01	0.00405	0.01	0.00024	0.01	0.00056	0.56
Heptachlor	0.01	0.00001	0.01	0.00005	0.01	0.00031	0.01	0.00002	0.01	0.00009	0.05
Heptachlor-epoxide	0.01	0.00000	0.01	0.00001	0.01	0.00002	0.01	0.00002	0.01	0.00002	0.01
Aldrin	0.01	0.00285	0.01	0.00167	0.01	0.00517	0.01	0.00150	0.02	0.00373	1.31
Endrin	0.01	0.00048	0.01	0.00293	0.01	0.00154	0.01	0.00018	0.01	0.00098	0.61
Endosulfan I	0.05	0.00070	0.05	0.00227	0.05	0.00510	0.05	0.00064	0.10	0.00171	0.19
Endosulfan II	0.05	0.00138	0.05	0.00204	0.05	0.01354	0.05	0.00229	0.05	0.01354	0.66
p,p'-DDE	0.05	0.00001	0.05	0.00003	0.05	0.00009	0.05	0.00008	0.05	0.00014	0.01
p,p'-DDD	0.05	0.00009	0.05	0.00005	0.05	0.00036	0.05	0.00006	0.05	0.0002	0.02
p,p'-DDT	0.05	0.00009	0.05	0.00020	0.05	0.00064	0.05	0.00007	0.05	0.00014	0.02
Methoxychlor	0.01	0.00007	0.01	0.00004	0.01	0.00012	0.01	0.00007	0.01	0.00004	0.03
Hazard Index (HI) =											**5.56**

RfD: Reference Dose, EDI: Estimated daily intake, HQ: Hazard quotient.

Error! Reference source not found. shows the EDI and hazard risk assessment of organochlorine pesticides for each individual vegetable sample. *S. oleracea* was found to have the highest mean residue level (16.13 mg/kg) and EDI (0.04194 mg/kg/day) as well as HQ (2.62), which is substantially higher than the acceptable level of 1, among the vegetables studied, indicating it poses the greatest health risk.

S. indicum also exhibited a relatively high mean concentration of organochlorine pesticide residues at 9.4970 mg/kg, resulting in an EDI of 0.02469 mg/kg and an HQ of 1.01 (**Error! Reference source not found.**). While the HQ for *S. indicum* is slightly above the acceptable level of 1, it suggests a potential risk for non-carcinogenic health effects, although lower than that associated with the consumption of spinach.

The remaining vegetable samples, *L. sativa*, *H. esculentus* and *R. acetosa*, exhibited lower HQs of 0.96, 0.58 and 0.40, respectively. While these values are below the acceptable level of 1, they still contribute to the overall HI and is being considered in the context of cumulative exposure to these pesticides from multiple sources.

Table 3: Estimated daily intake and hazard risk assessment of organochlorines for each vegetable.

Vegetable	Means (mg/kg)	ADI (mg/kg)	EDI (mg/kg)	HQ
H. esculentus	2.9390	0.34	0.00764	0.58
L. sativa	5.1077	0.34	0.01328	0.96
S. oleracea	16.1320	0.34	0.04194	2.62
R. acetosa	2.4986	0.34	0.00649	0.40
S. indicum	9.4970	0.40	0.02469	1.01
Hazard Index (HI) =				**5.56**

ADI: Acceptable daily intake, EDI: Estimated daily intake, HQ: Hazard quotient.

Error! Reference source not found. shows the estimated LCR of organochlorines for each vegetable for adults. For α-lindane, the LCR ranged from 7.18×10^{-4} for *R. acetosa* to 1.74×10^{-2} for *S. oleracea*. The highest cancer risk was observed for *S. oleracea*, while the lowest risk was observed for *R. acetosa*. Similarly, for β-lindane, the LCR ranged from 9.65×10^{-4} for *R. acetosa* to 5.51×10^{-3} for *S. oleracea*.

For ɤ-lindane, the LCR ranged from 3.38×10^{-4} for *R. acetosa* to 2.21×10^{-3} for *S. oleracea*, while for δ-lindane from 2.34×10^{-4} for *H. esculentus* to 4.99×10^{-3} for *S. oleracea*. For Heptachlor, the LCR ranged from 4.01×10^{-5} for *H. esculentus* to 9.70×10^{-4} for *S. oleracea*. For aldrin, the LCR ranged from 1.75×10^{-3} for *R. acetosa* to 6.02×10^{-3} for *S. oleracea*. For Heptachlor-epoxide, the LCR showed acceptable risk for all vegetables except *H. esculentus* where the risk was not available.

For p,p'-DDE, the LCR ranged from 1.82×10^{-6} for *H. esculentus* to 2.06×10^{-5} for *S. oleracea*. *H. esculentus* and *L. sativa* poses no risk while all the others showed acceptable risk. For

p,p'-DDD, the LCR ranged from 7.78×10^{-6} for *L. sativa* to 5.69×10^{-5} for *S. oleracea*. It poses no risk in *L. sativa* and acceptable risk in all other vegetables. For p,p'-DDT, the LCR ranged from 1.57×10^{-5} for *R. acetosa* to 1.50×10^{-4} for *S. oleracea*. *S. oleracea* showed high cancer risk while the other vegetables showed acceptable risks.

Table 4: Estimated lifetime cancer risk of organochlorines for each vegetable for adults.

Pesticide Residue	CSF	Lifetime Cancer Risk				
		H. esculentus	*L. sativa*	*S. oleracea*	*R. acetosa*	*S. indicum*
α-lindane	6.30	$1.25\times10^{-3\#}$	$3.65\times10^{-3\#}$	$1.74\times10^{-2\#}$	$7.18\times10^{-4\#}$	$2.97\times10^{-3\#}$
β-lindane	1.80	$1.13\times10^{-3\#}$	$1.45\times10^{-3\#}$	$5.51\times10^{-3\#}$	$9.65\times10^{-4\#}$	$1.39\times10^{-3\#}$
ɤ-lindane	1.30	$5.12\times10^{-4\#}$	$1.23\times10^{-3\#}$	$2.21\times10^{-3\#}$	$3.38\times10^{-4\#}$	$1.53\times10^{-3\#}$
δ-lindane	1.80	$2.34\times10^{-4\#}$	$7.18\times10^{-4\#}$	$4.99\times10^{-3\#}$	$2.98\times10^{-4\#}$	$6.96\times10^{-4\#}$
Heptachlor	4.50	$4.01\times10^{-5*}$	$1.60\times10^{-4\#}$	$9.70\times10^{-4\#}$	$7.21\times10^{-5*}$	$2.72\times10^{-4\#}$
Heptachlor-epoxide	9.10	-	$9.24\times10^{-5*}$	$9.72\times10^{-5*}$	$9.56\times10^{-5*}$	$9.72\times10^{-5*}$
Aldrin	1.70	$3.32\times10^{-3\#}$	$1.94\times10^{-3\#}$	$6.02\times10^{-3\#}$	$1.75\times10^{-3\#}$	$4.34\times10^{-3\#}$
Endrin	N.A	-	-	-	-	-
Endosulfan I	N.A	-	-	-	-	-
Endosulfan II	N.A	-	-	-	-	-
p,p'-DDE	0.34	1.82×10^{-6}	6.66×10^{-6}	$2.06\times10^{-5*}$	$1.82\times10^{-5*}$	$3.27\times10^{-5*}$
p,p'-DDD	0.23	$1.47\times10^{-5*}$	7.78×10^{-6}	$5.69\times10^{-5*}$	$1.01\times10^{-5*}$	$3.19\times10^{-5*}$
p,p'-DDT	0.34	$2.12\times10^{-5*}$	$4.60\times10^{-5*}$	$1.50\times10^{-4\#}$	$1.57\times10^{-5*}$	$3.27\times10^{-5*}$
Methoxychlor	N.A	-	-	-	-	-

CSF: Cancer slope factor; N.A: Not available; superscript '*' indicates acceptable risk; superscript '#' indicates high cancer risk.

DISCUSSION

The current study evaluated the levels of organochlorine pesticide residues in commonly consumed vegetables in Yola, Adamawa State, Nigeria. Spinach exhibited the highest concentrations of various OCPs, such as α-lindane, β-lindane, aldrin and endosulfan II, all of which exceeded the European Union's Maximum Residue Levels (MRLs). This finding is consistent with other studies that have found leafy vegetables like spinach to be particularly vulnerable to pesticide accumulation. For example, research conducted by Yuan *et al.* (2021) found that spinach, due to its large surface area and tendency to grow in close contact with soil, tends to accumulate higher levels of pesticide residues than other

vegetables. Similarly, Adeleye *et al.* (2019) reported that spinach in Nigeria had a significantly higher level of pesticide residues compared to other vegetables, reinforcing the current study's results.

However, studies conducted in other regions have reported lower pesticide residue levels in spinach. For instance, a study by Ibrahim *et al.* (2018) analyzing pesticide residues in vegetables in Nasarawa state, Nigeria reported that spinach contained OCPs at levels significantly below the MRLs, suggesting that environmental conditions, agricultural practices and pesticide regulations could account for these discrepancies. The higher residue levels found in the Yola region may be attributed to the continued illegal use of banned pesticides, as suggested by Olawale and Confidence (2021), as well as the environmental persistence of OCPs long after their application has ceased. Also, the common practice of wastewater irrigation with untreated municipal and agricultural wastewaters introduces additional pesticide loads into agricultural fields (Mishra *et al.*, 2023).

Ali *et al.* (2021) note that in many developing countries, farmers often lack proper training on the safe application of pesticides, resulting in the excessive use of hazardous chemicals, even when safer alternatives are available. In contrast, developed countries have implemented programs to educate farmers on integrated pest management (IPM) and the use of safer, more sustainable alternatives to OCPs, contributing to the reduced levels of pesticide residues in their food supply (Valcke *et al.*, 2017). This disparity in agricultural practices between regions is likely a key factor in the discrepancies observed between this study and others from regions with more advanced agricultural systems. For instance, research from Europe and North America has shown that the adoption of IPM practices and the use of modern, less persistent pesticides have led to a significant reduction in pesticide residues in food crops (EFSA, 2022). In Yola, however, the continued reliance on hazardous OCPs, combined with a lack of knowledge about safer alternatives, may be contributing to the elevated residue levels in the vegetables sampled.

The health risk assessment revealed non-carcinogenic and carcinogenic risks from chronic dietary exposure to pesticide residues through the consumption of contaminated vegetables. Of particular concern was spinach, which exhibited the highest EDI, HI and cancer risks, suggesting it poses the greatest threat to consumer health. The cumulative HI exceeding the safe level of 1 indicates potential adverse non-cancer effects, while cancer

risks for some pesticides/vegetables surpassed acceptable thresholds (Ogbeide *et al.*, 2016; Valcke *et al.*, 2017). These results are consistent with prior studies reporting health risks from pesticide residues in various foods (Odewale *et al.*, 2022; Ogbeide *et al.*, 2016).

The potential health impacts of OCP exposure are well-documented in the literature. OCPs like lindane, aldrin and DDT have been classified as probable human carcinogens by the International Agency for Research on Cancer (IARC) due to their links to various cancers, including breast cancer, leukemia and non-Hodgkin's lymphoma (Islam *et al.*, 2022). In addition to cancer risks, chronic exposure to OCPs has been associated with a range of non-carcinogenic health effects, including reproductive disorders, endocrine disruption and neurotoxicity (Madiha *et al.*, 2021). The elevated HQ values for aldrin, lindane and endosulfan in this study suggest that consumers in Yola are at risk of developing these adverse health effects, particularly from long-term exposure.

To address the discrepancies between this study's findings and those from other regions, several key interventions are needed. First, there must be stronger regulatory enforcement to limit the use of hazardous pesticides like OCPs in Nigeria. This could involve stricter penalties for the illegal use of banned pesticides, as well as more frequent monitoring of pesticide residues in food products (Zikankuba *et al.*, 2019). Additionally, efforts should be made to educate farmers on the dangers of OCPs and the benefits of adopting safer alternatives, such as biological pest control methods and modern, less persistent pesticides.

Public awareness campaigns are also crucial in reducing consumer exposure to pesticide residues. As recommended by Hashem and Qi (2021), educating the public on the importance of washing vegetables thoroughly before consumption and reducing the frequency of consuming high-risk vegetables like spinach could help mitigate the health risks associated with pesticide residues. Finally, improving access to clean, treated water for irrigation could significantly reduce the levels of pesticide contamination in agricultural soils, as shown by Mishra *et al.* (2023) in their review of wastewater irrigation practices.

CONCLUSION

The levels of organochlorine pesticide residues, particularly in spinach, exceeds the regulatory limits and may pose potential health risks to consumers in Yola, Adamawa State in North-Eastern Nigeria. The hazard risk assessment indicated a high hazard index and lifetime cancer risk, underscoring the need for implementing effective monitoring

strategies, promoting sustainable agricultural practices and strengthening regulatory frameworks to safeguard food safety and public health.

Conflict of Interests

The authors declare no potential conflicts of interest with respect to research, authorship and/or publication of this article.

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