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Health Risk Assessment of Pesticide Residue in Millet, Maize, Sorghum and Rice Cultivated in Wukari, Nigeria

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Abstract

The widespread application of pesticides in agriculture has raised global concerns about the accumulation of chemical residues in staple food crops and their implications for human health. This study quantitatively assessed the health risks associated with pesticide residues in millet, sorghum, and rice cultivated in Wukari, Nigeria. Using a cross-sectional design, grain samples were systematically collected from local farms and analyzed through gas chromatography–mass spectrometry (GC-MS) to identify and quantify residual pesticides. Detected compounds included organophosphates, carbamates, and pyrethroids, with variable concentrations across crop types. Health risk assessments were conducted by calculating the Estimated Daily Intake (EDI), Hazard Quotient (HQ), and Health Risk Index (HRI) for each pesticide, and comparing these values with the Maximum Residue Limits (MRLs) established by international regulatory bodies such as the FAO/WHO Codex Alimentarius. The results indicated that multiple pesticide residues exceeded

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permissible thresholds, with HQ and HRI values surpassing 1 in several cases, suggesting potential non-carcinogenic health risks, especially for sensitive groups including children and pregnant women. These elevated values are likely attributable to the extensive and often unregulated use of pesticides during cultivation and post-harvest storage, leading to bioaccumulation in the grains. The findings underscore the urgent need for regulatory enforcement, public health surveillance, and farmer education to mitigate dietary exposure to hazardous residues in commonly consumed cereals.

Keywords: Pesticide Residues; Gas Chromatography–mass Spectrometry; Health Risk Assessment; Organophosphates; Wukari Cereals; Hazard Quotient

INTRODUCTION

Numerous common meals and drinks, such as prepared foods, water, wine, fruit juices, snacks, and animal feed, include pesticide residues (Witczak et al., 2014; Chourasiya et al., 2015). It should be mentioned that the residues cannot be entirely eliminated by washing and peeling. The increasing use of pesticides in agricultural operations has made the presence of pesticide residues in food products a serious issue. Cereals such as millet, maize, sorghum, and rice are staple foods for a large portion of the population in Wukari, and their safety is paramount for public health. The amounts of pesticide residues in these grains in particular Wukari locations, however, are not well documented. Pesticide residues can have adverse health effects, including acute poisoning, long-term chronic illnesses, and developmental issues (Reiler et al., 2015).

In most instances, pesticide concentrations remain within levels deemed safe by regulatory standards (Chourasiya et al., 2016; Blaznik et al., 2015). However, these established safety thresholds might not fully account for the actual health risks, particularly in scenarios involving simultaneous exposure to multiple chemical substances. Such combined exposures, which are common in real-life situations, can produce synergistic effects that amplify potential harm (Kortenkamp, 2017). Global pesticide production has grown dramatically, from 0.2 million tons in the 1950s to over 5 million tons in 2000, or over 11% annually (Carvalho, 2017). A substantial portion of these pesticides, rather than targeting pests, disperses into unintended areas, contaminating non-target plants and various environmental media. In addition to harming ecosystems, this pervasive pollution has seriously endangered human health (Hernández et al., 2013; Bernardes et al., 2015).

In Wukari, agricultural methods frequently involve the usage of pesticides. Chonku, Bantaje, Gindin Dorowa, and Rafinkada are among the rural settlements that make up Wukari, a local government area in Taraba State. Because of their reputation for producing cereals, these regions are essential to local consumption and economic activity. To protect public health, guarantee food safety, and advance sustainable agriculture, it is essential to identify pesticide residues in grains like millet, maize, sorghum, and rice from certain Wukari regions. In order to reduce possible health hazards and environmental effects, this project intends to measure and analyze these residues in order to give crucial data that may guide agricultural practices and regulatory laws. This research aim at assessing the health risk associated to pesticide residues millet, maize, sorghum and rice cultivated in Wukari, Nigeria.

METHODOLOGY

Study Area

Wukari is located in Taraba State, Northeastern Nigeria, at latitude 7° 51'N and longitude 9° 47'E. The region's vegetation predominantly reflects the savannah zone, with two distinct climatic seasons: the dry season, lasting from November to March or April, and the wet or rainy season, spanning from March or April to October. Wukari, a traditional state known for its rich cultural diversity, customs, and values, had an estimated population of approximately 241,546 according to the 2006 census. It has an area of 4,308 km². The people's main occupations include farming, fishing, and trade.

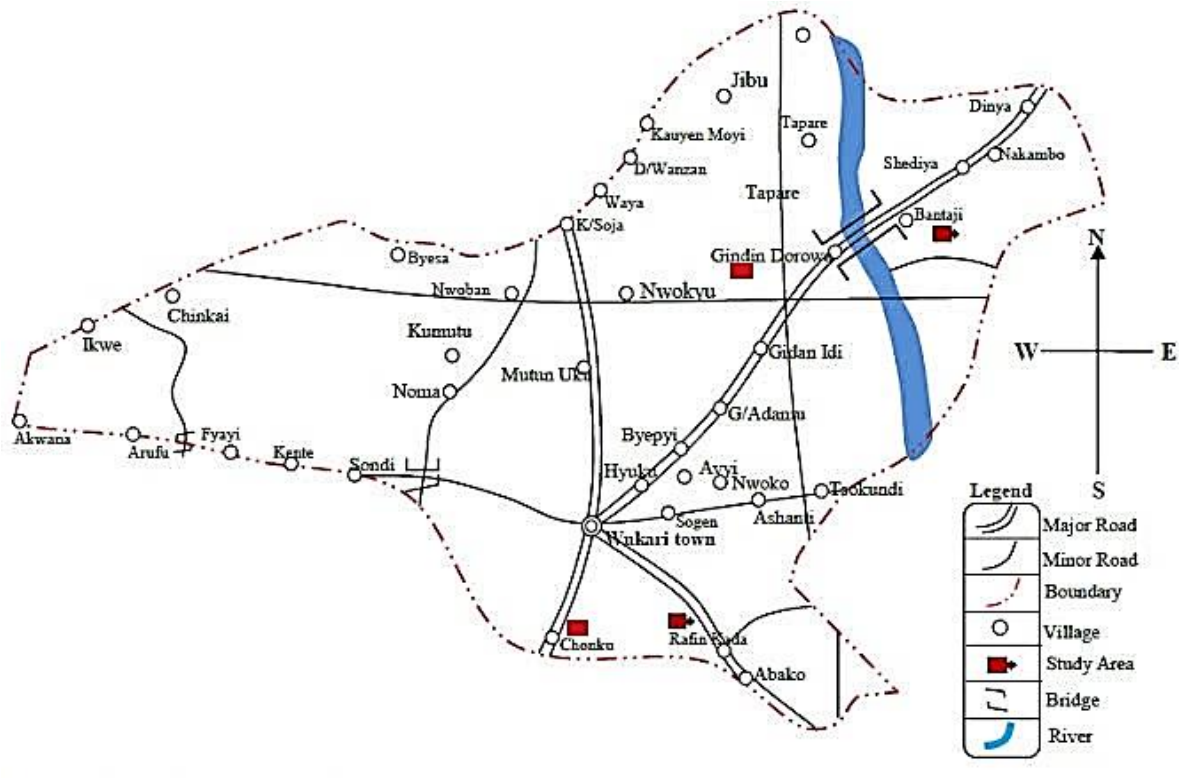


Fig. 1 Map of Nigeria and Taraba showing the location of Wukari, study area

Sample Collection

Samples were procured directly from local vendors in four wholesale marketplaces in Wukari local government area. Maize samples were gathered from four distinct stores and stored in sterile plastic bags to prevent contamination and moisture damage. Until it came time to utilize it, the sample was tagged and kept in a refrigerator at 4°C. The same procedure was used for the collection of millet, sorghum and rice samples. The sources of the samples (Bantaje, Chonku, Gindin Dorowa and Rafinkada) were sought and recorded.

Sample Preparation

Cereal grains (maize, sorghum, millet, and rice) were cleaned by removing stones, dirt, chaff, weevils, and other impurities. Each sample was then processed individually, first using a mortar and pestle, followed by a hand-grinding machine. Since the bean samples were already dry, no more drying was necessary. To hinder cross-contamination of the samples both before and after milling, precautions were taken. Before being analyzed, the processed samples were kept at room temperature in polythene bags.

Extraction

A 1:20 combination of acetonitrile and n-hexane was made using a measuring cylinder. The extraction solvent was made in a 1000 ml beaker. Pesticide standard mixtures were serially diluted (0.05, 0.5, 1.0, 2.0, 4.0, and 8.0µg/ml) for recovery and calibration purposes. The extraction procedure used by Oyeyiola et al. (2017) was slightly modified. A 10g aliquot of each powdered material was weighed into a 250 mL beaker using an electronic weighing balance. The weight of the beaker containing the sample was recorded as Wb+s, while the original weight of the beaker was recorded as Wb. Ten grams of the powdered material were placed in the beaker with thirty milliliters of extraction solvent. After securing the mixture with tape and foil, it was left to extract for 48 hours. Following the extraction process, the components were filtered using a funnel and filter paper before being concentrated by evaporation for 24 to 72 hours at room temperature. To avoid evaporating heat-sensitive pesticide residues, heating using a rotating evaporator was avoided. After that, the organic residue was diluted with one milliliter of n-hexane and put in reagent bottles for analysis using gas chromatography-mass spectrometry (GC-MS).

Clean Up

Methanol, distilled water, and acetonitrile were used to condition the solid-phase extraction cartridges. After applying the sample extract to the solid-phase extraction column, the column was cleaned with the eluting solvent and eluted using a 50:50 n-hexane and acetonitrile combination into a receiving glass tube. The eluate was collected for GC/MS analysis after being reconstituted to 1 ml with n-hexane and evaporated using a mild stream of nitrogen gas.

GC/MS Analysis

The study was performed using a gas chromatography system connected with a mass spectrometer (GC-MS) that included an auto-injector (10 µl syringe) and a triple-axis detector. The carrier gas was helium. A capillary column that satisfied the following requirements—length of 30 m, internal diameter of 0.2 µm, thickness of 250 µm, and treatment with phenyl methyl silox—was used for the chromatographic separation. A 1 µl injector in split mode with a split ratio of 1:50 at 300°C, an ion source temperature of 250°C, an internal temperature of 300°C, a pressure of 16.2 pa, and an out time of 1.8 minutes were all parts of the GC-MS configuration. A single µl of the material was administered. After five minutes at 35°C, the temperature program rose to 150°C at a pace

of 4°C per minute. At a rate of 20°C per minute, the temperature was raised to 250°C and maintained there for five minutes. Elution took 47.5 minutes in total.

Identification and Quantification

The retention durations, peak areas, and peak heights of the sample were compared to those of the respective standards in order to detect pesticide residues. The external standard approach, which compared the sample's peak areas to the pesticide standards under the same conditions, was used to quantify the discovered pesticides. The final data was calculated by averaging the findings of the analysis of each sample.

The pesticide content of each sample was calculated as

$$\text{Pesticide content} = \frac{A_S \times V_f}{Wt_2 \times C_f} \quad (1)$$

Where,

A_b = Peak area of sample

V_f = Final volume of clean extract

Wt_2 = Weight of sample extracted

C_f = Calibration factor

Risk Exposure

Health risk estimates

For each pesticide and each individual (adult) consumer, the anticipated daily intake or probable daily exposure was determined using the following Equation 2 formula:

$$EDI = \frac{\text{Cereals consumption}\left(\frac{kg}{day}\right) * \text{Pesticide concentration in cereals}\left(\frac{mg}{kg}\right)}{\text{Body weight}} \quad (2)$$

Estimation of health risk from pesticides

The possible health risk index for non-carcinogenic chemicals was used to quantify the risk of pesticide exposure for an individual (adults with an average body weight of 60 kg) using the following Equation 3 formula (Arowora et al., 2020):

$$HRI = \frac{EDI}{ADI} \quad (3)$$

Where HRI stands for health risk index, EDI stands for estimated daily intake, acceptable daily intake (ADI) stands for acceptable daily intake. A lifetime consumption of cereals

containing the detected amount of pesticide may be harmful to one's health if the HRI is larger than one (US EPA, 2000; Arowora et al., 2020).

Carcinogenic risk

The cancer slope factor was used to quantify each pesticide's carcinogenic risk. The following equation was applied (Danladi and Akoto, 2021).

$$R = CDI \times SF \quad -(4)$$

Where R is carcinogenic risk, CDI is the chronic daily intake and SF is the slope factor.

Data Analysis

SPSS version 20 was used to do the statistical analysis. Mean ± standard deviation was used to present the findings. The study's generated data was shown in tables. Calculations and tabulations were made of the various pesticide concentrations and their health risk index.

RESULTS

Pesticide Residue in Maize at Different Sampling Locations

The result of pesticide residue in maize obtained from the different sampling locations is presented in Figure 2

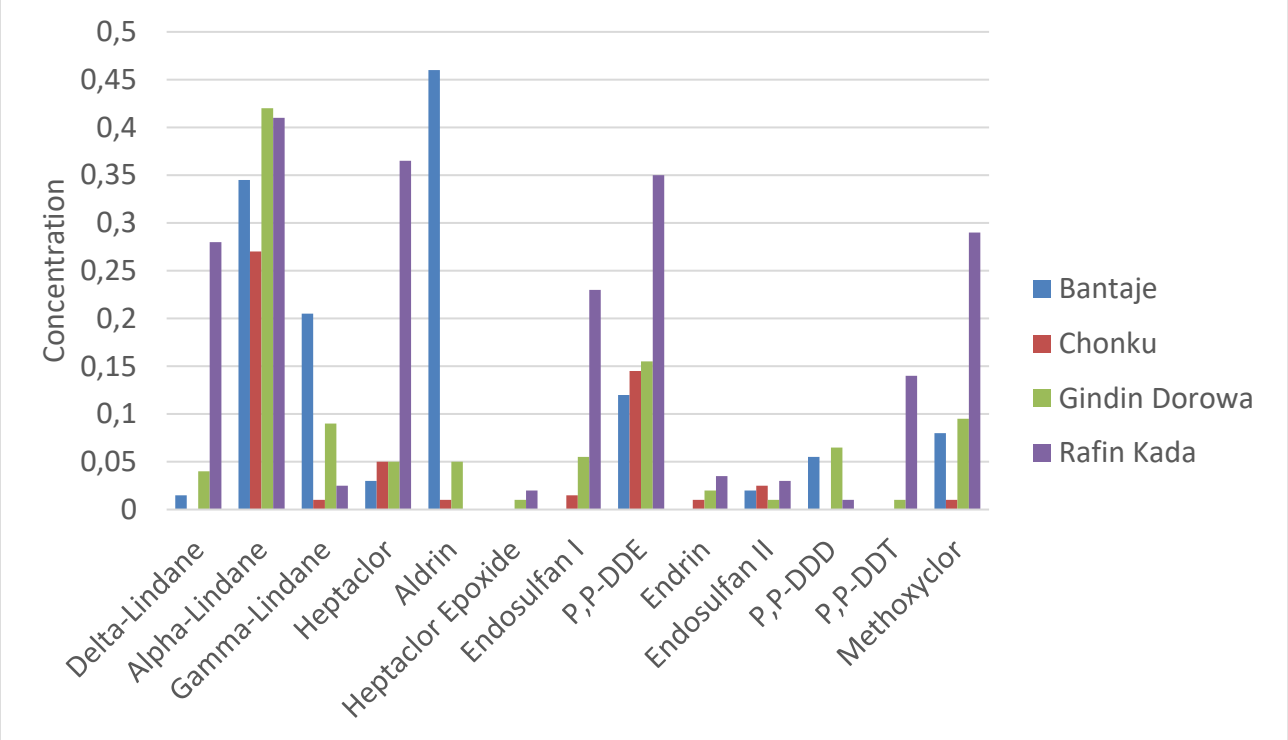


Figure 2: Pesticide Residue in Maize at Different Sampling Locations

In the maize samples obtained from the four location Wukari, delta-lindane, alpha-lindane, gamma-lindane, heptaclor, aldrin, heptaclor epoxide, endosulfan I, P,P-DDE, endrin, endosulfan II, P,P-DDD, P,P-DDT and methoxyclor ranged from 0.0150 to 0.2800, 0.2700 to 0.4200, 0.0100 to 0.2050, 0.0300 to 0.3650, 0.0100 to 0.4600, 0.0100 to 0.0200, 0.0150 to 0.2300, 0.1200 to 0.3500, 0.0100 to 0.0350, 0.0100 to 0.0300, 0.0100 to 0.0650, 0.0100 to 0.1400 and 0.0100 to 0.2900 ppm, respectively. The maize from Bantaje has the highest concentration of gamma-lindane (0.2050), aldrin (0.4600). Maize from Gindin Dorowa has the highest concentration of alpha-lindane (0.4200), P,P-DDD (0.0650). Maize from Rafin Kada has the highest concentration of delta-lindane (0.2800), heptaclor (0.3650), heptaclor epoxide (0.0200), endosulfan I (0.2300), P,P-DDE (0.3500), endrin (0.03500), endosulfan II (0.0300), P,P-DDT (0.1400) and methoxyclor (0.2900).

Pesticide Residue in Millets at Different Sampling Locations

Pesticide residues were present in millet obtained within Wukari LGA. The result is shown in Figure 3.

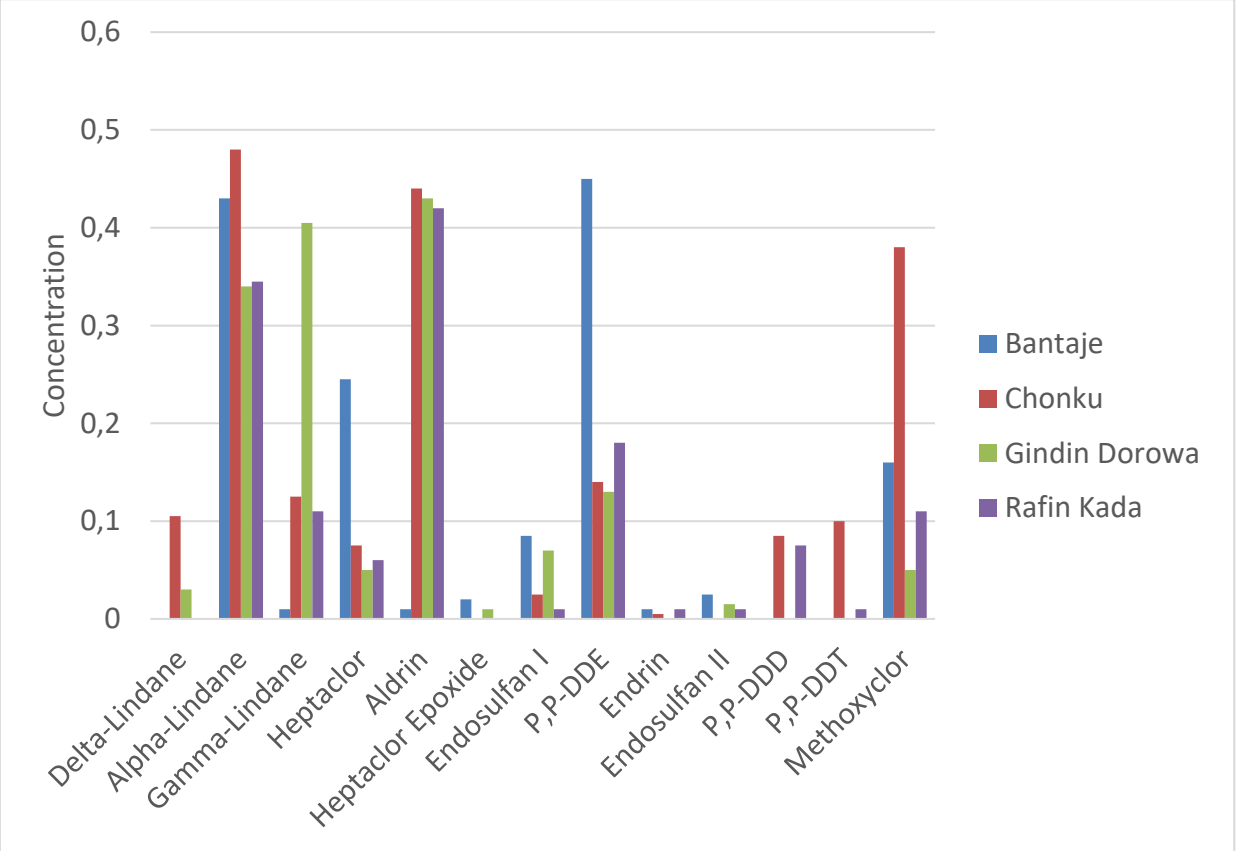


Figure 3: Pesticide Residue in Millets at Different Sampling Locations

The millet samples had delta-lindane, alpha-lindane, gamma-lindane, heptaclor, aldrin, heptaclor epoxide, endosulfan I, P,P-DDE, endrin, endosulfan II, P,P-DDD, P,P-DDT and methoxyclor concentrations ranging from 0.1050 to 0.0300, 0.3450 to 0.4800, 0.0100 to 0.4050, 0.0500 to 0.2450, 0.0100 to 0.4400 , 0.0100 to 0.0200, 0.0100 to 0.0850, 0.1300 to 0.4500, 0.0050 to 0.0100, 0.0100 to 0.0250, 0.0750 to 0.0850, 0.0100 to 0.1000 and 0.0500 to 0.3800 ppm, respectively. The highest concentration of delta-lindane (0.0300) and gamma-lindane (0.4050) was observed in millet from Gindin Dorowa. Millet from Bantaje had the highest heptaclor (0.2450), heptaclor epoxide (0.0200), endosulfan I (0.0850), P,P-DDE (0.4500), endrin (0.0100), endosulfan II (0.0250). Those obtained from Chonku had highest alpha-lindane (0.4800), aldrin (0.4400), P,P-DDD (0.0850), P,P-DDT (0.1000) and methoxyclor (0.3800).

Pesticide Residue in Sorghum at Different Sampling Locations

The result of pesticide residue in sorghum at the different sampling locations is presented in Figure 4.

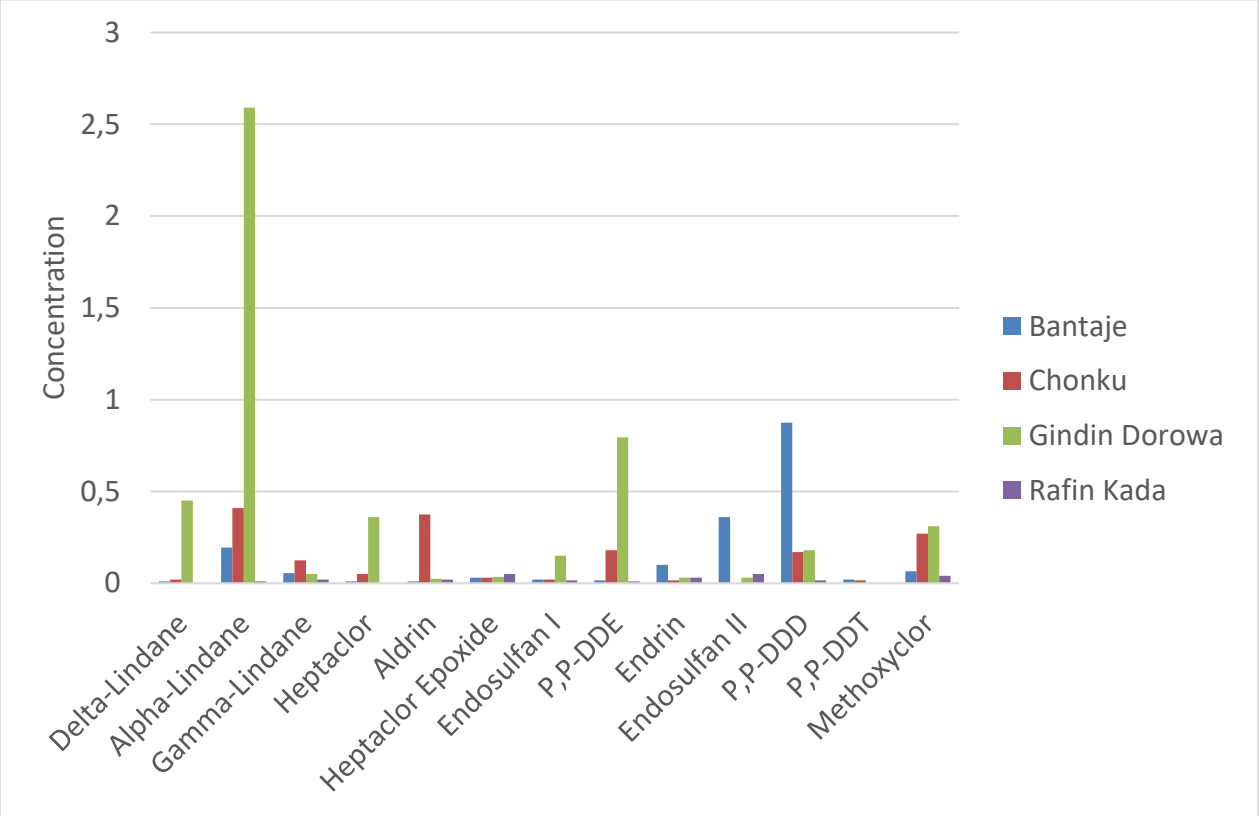


Figure 4: Pesticide Residue in Sorghum at Different Sampling Locations

In the sorghum samples obtained from the four location Wukari, delta-lindane, alpha-lindane, gamma-lindane, heptaclor, aldrin, heptaclor epoxide, endosulfan I, P,P-DDE, endrin, endosulfan II, P,P-DDD, P,P-DDT and methoxyclor ranged from 0.0100 to 0.4500, 0.0100 to 2.590, 0.0200 to 0.1250, 0.0100 to 0.3600, 0.0100 to 0.3750, 0.0300 to 0.0500, 0.0150 to 0.1500, 0.0150 to 0.7950, 0.0150 to 0.1000, 0.0300 to 0.3600, 0.0150 to 0.8750, 0.0150 to 0.0200 and 0.0400 to 0.3100 ppm, respectively. Sorghum sample from Gindin Dorowa had the highest concentration of delta-lindane (0.4500), alpha-lindane (2.590), heptaclor (0.3600), aldrin (0.3750), endosulfan I (0.1500), P,P-DDE (0.7950) and methoxyclor (0.3100). Gamma-lindane (0.1250) was highest in sorghum from Chonku. Heptaclor epoxide (0.0500) was highest in sorghum from Rafin Kada. Sorghum from Bantaje had highest level of endrin (0.100), endosulfan II (0.3600), P,P-DDD (0.8750) and P,P-DDT (0.0200).

Pesticide Residue in Rice at Different Sampling Locations

Pesticide residues were present in rice obtained within Wukari LGA. The result is shown in Figure 5.

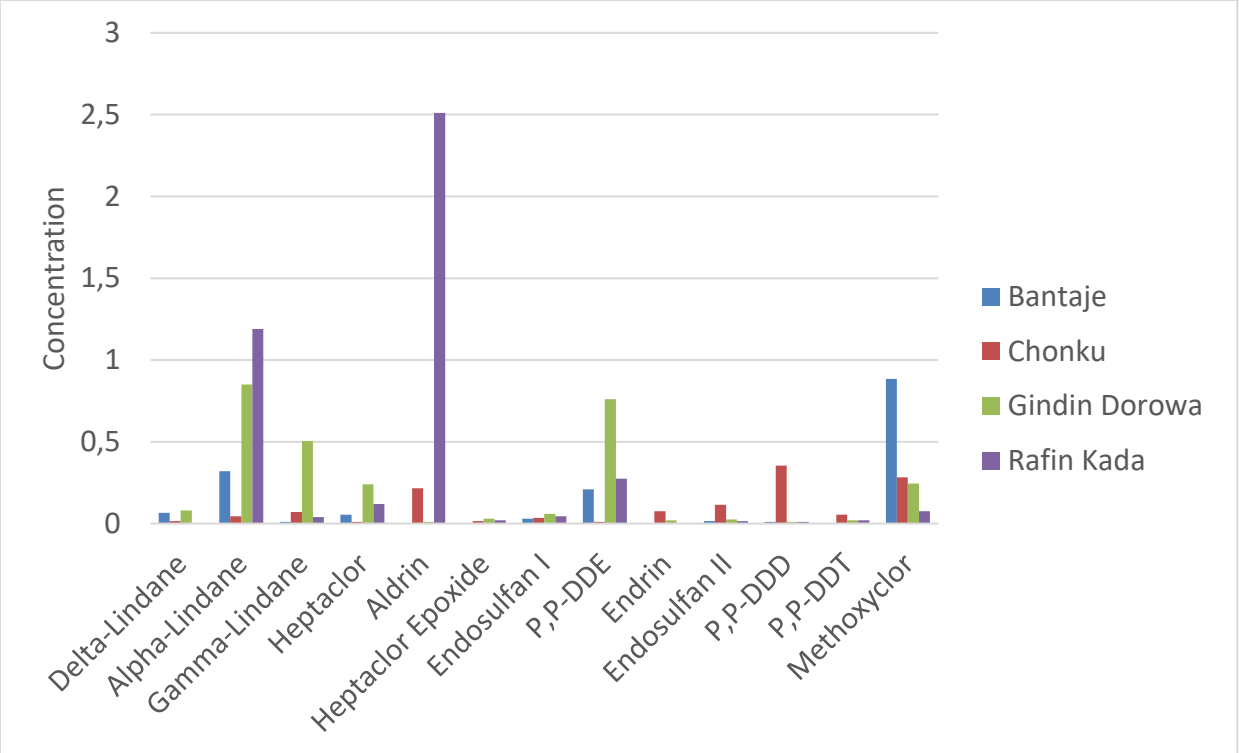


Figure 5: Pesticide Residue in Rice at Different Sampling Locations

The rice samples had delta-lindane, alpha-lindane, gamma-lindane, heptaclor, aldrin, heptaclor epoxide, endosulfan I, P,P-DDE, endrin, endosulfan II, P,P-DDD, P,P-DDT and methoxyclor concentrations ranging from 0.0150 to 0.080, 0.0450 to 1.1900, 0.0100 to 0.5050, 0.0100 to 0.2400, 0.0100 to 2.5100 , 0.0150 to 0.0300, 0.0300 to 0.0600, 0.0100 to 0.7600, 0.0200 to 0.0750, 0.0150 to 0.1150, 0.0100 to 0.3550, 0.0200 to 0.0550 and 0.0750 to 0.8850 ppm, respectively. The highest concentration of delta-lindane (0.0800), gamma-lindane (0.5050), heptaclor (0.2400), heptaclor epoxide (0.0300), P,P-DDE (0.7600) was recorded in rice from Gindin Dorowa. Endrin (0.0750), endosulfan II (0.1150), P,P-DDD (0.3550), P,P-DDT (0.0550) was highest in rice from Chonku. The highest alpha-lindane (0.8500) and aldrin (2.5100) levels were recorded in rice from Rafin Kada. Methoxyclor (0.8850) was highest in rice from Bantaje.

Hazard Index and Hazard Quotient

Hazard Index and Hazard Quotient in Adult from Grains Obtained from Bantaje

The result of hazard index and hazard quotient in adult from grains obtained from Bantaje is presented in Table 1.

Table 1: Hazard Index and Hazard Quotient in Adult from Grains Obtained from Bantaje

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	0.0205	ND	0.0137	0.0888
Alpha-Lindane	0.4715	0.5877	0.2665	0.4373
Gamma-Lindane	0.2802	0.0137	0.0752	0.0137
Heptaclor	0.2050	1.6742	0.0683	0.3758
Aldrin	3.1433	0.0683	0.0683	ND
Heptaclor Epoxide	ND	0.1367	0.2050	ND
Endosulfan I	ND	0.0968	0.0228	0.0342
P,P-DDE	0.0820	0.3075	0.0103	0.1435
Endrin	ND	0.3417	3.4167	ND
Endosulfan II	0.0228	0.0285	0.4100	0.0171
P,P-DDD	0.0376	ND	0.5979	0.0068
P,P-DDT	ND	ND	0.0137	ND
Methoxyclor	0.0547	0.1093	0.0444	0.6048
Hazard Quotient (HQ)	4.3175	3.3643	5.2127	1.7220

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The hazard index of the evaluated pesticide residue in the grains sampled from Bantaje reveals; the calculated hazard index for the evaluated pesticides residues in maize for adults were below 1 except aldrin which had a hazard index above 1 (3.1433). the calculated hazard index for the evaluated pesticides residue in millet for adults were below 1 except for heptaclor which had a hazard index slightly above 1 (1.6742). The hazard index for the evaluated pesticide residues in sorghum were below 1 except for endrin with a hazard index of 3.4167. The hazard index of the evaluated pesticide residue in rice was below one. The hazard quotient for all evaluated pesticide residues in the evaluated samples were all above the agreed/acceptable value of 1. Rice had the lowest hazard quotient while sorghum had the highest hazard quotient of 5.2127.

Hazard Index and Hazard Quotient in Adult from Grains Obtained from Chonku

The result of Hazard Index (HI) and Hazard Quotient (HQ) in adult from grains obtained from Chonku is presented in Table 2.

Table 2: Hazard Index and Hazard Quotient in Adult from Grains obtained from Chonku

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	ND	0.1435	0.0273	0.0205
Alpha-Lindane	0.3690	0.6560	0.5603	0.0615
Gamma-Lindane	0.0137	0.1708	0.1708	0.0957
Heptaclor	0.3417	0.5125	0.3417	0.0683
Aldrin	0.0683	3.0067	2.5625	1.4692
Heptaclor Epoxide	ND	ND	0.2050	0.1025
Endosulfan I	0.0171	0.0285	0.0228	0.0399
P,P-DDE	0.0991	0.0957	0.1230	0.0068
Endrin	0.3417	0.1708	0.5125	2.5625
Endosulfan II	0.0285	ND	ND	0.1310
P,P-DDD	ND	0.0581	0.1162	0.2426
P,P-DDT	ND	0.0683	0.0103	0.0376
Methoxyclor	0.0068	0.2597	0.1845	0.1927
Hazard Quotient (HQ)	1.2858	5.1706	4.8369	5.0307

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The hazard index of the evaluated pesticide residue in the grains sampled from Chonku reveals; the Hazard Index of all the evaluated pesticide residue in maize sampled were below 1. The calculated HI for evaluated pesticide residue in millet and sorghum and were below 1 except for aldrin with millet and sorghum having 3.0067 and 2.5625 HI's respectively. For rice, the HI for the evaluated/studied pesticide residues was below 1 except for aldrin and endrin with 1.4692 and 2.5625 respectively. The Hazard Quotient (HQ) in the evaluated grains were above 1 however, maize had the lowest HQ values while millet had the highest HQ value in Chonku.

Hazard Index and Hazard Quotient in Adult from Grains obtained from Gindin Dorowa

The result of Hazard Index (HI) and Hazard Quotient (HQ) in adult from grains obtained from Gindin Dorowa is presented in Table 3.

Table 3: Hazard Index and Hazard Quotient in Adult from Grains obtained from Gindin Dorowa

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	0.0547	0.0410	0.6150	0.1093
Alpha-Lindane	0.5740	0.4647	3.5397	1.1617
Gamma-Lindane	0.1230	0.5535	0.0683	0.6902
Heptaclor	0.3417	0.3417	2.4600	1.6400
Aldrin	0.3417	2.9383	0.1708	0.0683
Heptaclor Epoxide	0.0683	0.0683	0.2392	0.2050
Endosulfan I	0.0626	0.0797	0.1708	0.0683
P,P-DDE	0.1059	0.0888	0.5433	0.5193
Endrin	0.6833	ND	1.0250	0.6833
Endosulfan II	0.0114	0.0171	0.0342	0.0285
P,P-DDD	0.0444	ND	0.1230	0.0068
P,P-DDT	0.0068	ND	ND	0.0137
Methoxyclor	0.0649	0.0342	0.2118	0.1674
Hazard Quotient (HQ)	2.4828	4.6273	9.2011	5.3619

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The hazard index of the evaluated pesticide residue in the grains sampled from Gindin Dorowa reveals; the hazard index pesticide residue in maize sampled from Gindin Dorowa were below 1. The calculated HI for evaluated pesticide residue in sorghum and rice were below 1 except for alpha lindane and heptaclor with HI's above 1 respectively. The HI of the pesticide residues in millet were below 1 except aldrin with a HI above 1 (2.9383). The Hazard Quotient (HQ) in the evaluated grains was above 1 however. However, maize and sorghum had the lowest and highest HI's with 2.4828 and 9.2011 respectively.

Hazard Index and Hazard Quotient in Adult from Grains obtained from Rafin Kada

The result of Hazard Index (HI) and Hazard Quotient (HQ) in adult from grains obtained from Rafin Kada is presented in Table 4.

Table 4: Hazard Index and Hazard Quotient in Adult from Grains obtained from Rafin Kada

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	0.3827	ND	ND	ND
Alpha-Lindane	0.5603	0.4715	0.0137	1.6263
Gamma-Lindane	0.0342	0.1503	0.0273	0.0547
Heptaclor	2.4942	0.4100	ND	0.8200
Aldrin	ND	2.8700	0.1367	1.1517
Heptaclor Epoxide	0.1367	ND	0.3417	0.1367
Endosulfan I	0.2619	0.0114	0.0171	0.0513
P,P-DDE	0.2392	0.1230	0.0068	0.1879
Endrin	1.1958	0.3417	1.0250	ND
Endosulfan II	0.0342	0.0114	0.0569	0.0171
P,P-DDD	0.0068	0.0513	0.0103	0.0068
P,P-DDT	0.0957	0.0068	ND	0.0137
Methoxyclor	0.1982	0.0752	0.0273	0.0513
Hazard Quotient (HQ)	5.6398	4.5225	1.6628	4.1173

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The Hazard Index of the evaluated pesticide residue in the grains sampled from Rafin Kada reveals; the Hazard Index of all the evaluated pesticide residue in maize sampled from Rafin Kada were below 1 except for heptaclor (2.4942) and endrin (1.1958) with HI's above 1 respectively. The calculated HI for evaluated pesticide residue in millet were below 1 except for aldrin (2.8700) with HI above 1. The HI of the pesticide residues in sorghum were below 1 except endrin with a HI above 1 (1.0250). The HI for the evaluated pesticide residues in rice were below 1 except alpha lindane (1.6263) and aldrin (1.1517) with HI's above 1. The Hazard Quotient (HQ) in the evaluated grains were above 1 however. However, sorghum and maize had the lowest and highest HI's with 1.6628 and 5.6398 respectively.

Hazard Index and Hazard Quotient in Children from Grains obtained from Bantaje

The result of Hazard Index (HI) and Hazard Quotient (HQ) in children from grains obtained from Rafin Kada is presented in Table 5.

Table 5: Hazard Index and Hazard Quotient in Children from Grains obtained from Bantaje

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	0.0341	ND	0.0228	0.1479
Alpha-Lindane	0.7850	0.9784	0.4437	0.7281
Gamma-Lindane	0.4665	0.0228	0.1251	0.0228
Heptaclor	0.3413	2.7874	0.1138	0.6257
Aldrin	5.2335	0.1138	0.1138	ND
Heptaclor Epoxide	ND	0.2275	0.3413	ND
Endosulfan I	ND	0.1612	0.0379	0.0569
P,P-DDE	0.1365	0.5120	0.0171	0.2389
Endrin	ND	0.5689	5.6886	ND
Endosulfan II	0.0379	0.0474	0.6826	0.0284
P,P-DDD	0.0626	ND	0.9955	0.0114
P,P-DDT	ND	ND	0.0228	ND
Methoxyclor	0.0910	0.1820	0.0740	1.0069
Hazard Quotient	7.1885	5.6014	8.6789	2.8671

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The Hazard Index of the evaluated pesticide residue in the grains sampled from Rafin Kada reveals; the Hazard Index of all the evaluated pesticide residue in maize sampled from Rafin Kada were below 1 except for aldrin (5.2335) with HI value above 1. The calculated HI for evaluated pesticide residue in millet was below 1 except for heptaclor (2.7874) with HI above 1. The HI of the pesticide residues in sorghum were below 1 except endrin with a HI above 1 (5.6886). The HI for the evaluated pesticide residues in rice were below 1 except methoxyclor (1.0069) and aldrin (1.1517) with HI's above 1. The Hazard Quotient (HQ) in the evaluated grains were above 1 however. However, rice and sorghum had the lowest and highest HI's with 2.8671 and 8.6789 respectively.

Hazard Index and Hazard Quotient in Children from Grains obtained from Chonku

The result of Hazard Index (HI) and Hazard Quotient (HQ) in children from grains obtained from Chonku is presented in Table 6.

Table 6: Hazard Index and Hazard Quotient in Children from Grains obtained from Chonku

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	ND	0.2389	0.0455	0.0341
Alpha-Lindane	0.6144	1.0922	0.9329	0.1024
Gamma-Lindane	0.0228	0.2844	0.2844	0.1593
Heptaclor	0.5689	0.8533	0.5689	0.1138
Aldrin	0.1138	5.0060	4.2665	2.4461
Heptaclor Epoxide	ND	ND	0.3413	0.1707
Endosulfan I	0.0284	0.0474	0.0379	0.0664
P,P-DDE	0.1650	0.1593	0.2048	0.0114
Endrin	0.5689	0.2844	0.8533	4.2665
Endosulfan II	0.0474	ND	ND	0.2181
P,P-DDD	ND	0.0967	0.1934	0.4039
P,P-DDT	ND	0.1138	0.0171	0.0626
Methoxyclor	0.0114	0.4323	0.3072	0.3208
Hazard Quotient	**2.1408**	**8.6088**	**8.0532**	**8.3759**

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

Hazard Index and Hazard Quotient in Children from Grains obtained from Gindin Dorowa

The result of Hazard Index (HI) and Hazard Quotient (HQ) in children from grains obtained from Gindin Dorowa is presented in Table 7.

Table 7: Hazard Index and Hazard Quotient in Children from Grains obtained from Gindin Dorowa

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	0.0910	0.0683	1.0240	0.1820
Alpha-Lindane	0.9557	0.7737	5.8934	1.9341
Gamma-Lindane	0.2048	0.9216	0.1138	1.1491
Heptaclor	0.5689	0.5689	4.0958	2.7305
Aldrin	0.5689	4.8922	0.2844	0.1138
Heptaclor Epoxide	0.1138	0.1138	0.3982	0.3413
Endosulfan I	0.1043	0.1327	0.2844	0.1138
P,P-DDE	0.1763	0.1479	0.9045	0.8647
Endrin	1.1377	ND	1.7066	1.1377
Endosulfan II	0.0190	0.0284	0.0569	0.0474
P,P-DDD	0.0740	ND	0.2048	0.0114
P,P-DDT	0.0114	ND	ND	0.0228
Methoxyclor	0.1081	0.0569	0.3527	0.2787
Hazard Quotient	**4.1337**	**7.7043**	**15.3195**	**8.9273**

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The hazard index of the evaluated pesticide residue in the grains sampled from Dorowa reveals; the hazard index of all the evaluated pesticide residue in maize sampled from Gindin Dorowa were below 1 except endrin (1.1377) with HI above 1. The calculated HI for evaluated pesticide residue in millet was below 1 except for aldrin (4.8922) with HI above 1. The HI of the pesticide residues in sorghum were below 1 except delta-lindane (1.0240), alpha-lindane (5.8934), heptaclor (4.0958) and endrin (1.7066) with a HI above 1. The HI for the evaluated pesticide residues in rice were below 1 except alpha-lindane (1.9341), gamma-lindane (1.1491), heptaclor (2.7305) and endrin (1.7066) with HI's above 1. The Hazard Quotient (HQ) in the evaluated grains was above 1. However, maize and sorghum had the lowest and highest HI's with 4.1337 and 15.3195 respectively.

Hazard Index and Hazard Quotient in Children from Grains obtained from Rafin Kada

The result of Hazard Index (HI) and Hazard Quotient (HQ) in children from grains obtained from Rafin Kada is presented in Table 8.

Table 8: Hazard Index and Hazard Quotient in Children from Grains obtained from Rafin Kada

Pesticide residue	Maize	Millet	Sorghum	Rice
Delta-Lindane	0.6371	ND	ND	ND
Alpha-Lindane	0.9329	0.7850	0.0228	2.7078
Gamma-Lindane	0.0569	0.2503	0.0455	0.0910
Heptaclor	4.1527	0.6826	ND	1.3653
Aldrin	ND	4.7784	0.2275	2.5569
Heptaclor Epoxide	0.2275	ND	0.5689	0.2275
Endosulfan I	0.4361	0.0190	0.0284	0.0853
P,P-DDE	0.3982	0.2048	0.0114	0.3129
Endrin	1.9910	0.5689	1.7066	ND
Endosulfan II	0.0569	0.0190	0.0948	0.0284

P,P-DDD	0.0114	0.0853	0.0171	0.0114
P,P-DDT	0.1593	0.0114	ND	0.0228
Methoxyclor	0.3299	0.1251	0.0455	0.0853
Hazard Quotient	**9.3900**	**7.5298**	**2.7685**	**7.4946**

Note; Hazard Index (HI) and Hazard Quotient (HQ) >1 implies health risk, ND = Not detected

The hazard index of the evaluated pesticide residue in the grains sampled from Rafin Kada reveals; the hazard index of all the evaluated pesticide residue in maize sampled from Rafin Kada were below 1 except endrin (1.9910) and heptaclor (4.1527) with HI above 1. The calculated HI for evaluated pesticide residue in millet was below 1 except for aldrin (4.7784) with HI above 1. The HI of the pesticide residues in sorghum were below 1 except endrin (1.7066) with a HI above 1. The HI for the evaluated pesticide residues in rice were below 1 except alpha-lindane (2.7078), heptaclor (1.3653) and aldrin (2.5569) with HI's above 1. The Hazard Quotient (HQ) in the evaluated grains was above 1. However, sorghum and maize had the lowest and highest HI's with 2.7685 and 9.3900 respectively.

DISCUSSION

According to the current investigation, the majority of the assessed grains from the various sample sites have residual concentrations higher than the MRL established by WHO (2018). The results of this investigation do not support the findings of Emmanuel et al.'s 2023 report, which found that DDT and DDD were below the maximum residual levels specified by the WHO. The results of this investigation are similar with those of Adeyemi et al. (2020), who found 0.037 ppb of heptachlor in their investigations. One kind of pesticide that is frequently seen is endosulfan sulfate. Endosulfan was identified as the most prevalent pesticide species in water, solids, and nutrients in Europe. According to the current investigation, endosulfan residual concentrations were higher than the WHO (2018) recommended MRL in the majority of the sample locations. The results are consistent with those of Iliya et al. (2012), who similarly found that grains samples tested in Adamawa had significant levels of endosulphan.

Around the world, aldrin is extensively utilized in agricultural settings. Both substances are hazardous, bioaccumulative, and extremely persistent in the environment. The substance is still in use because to its cheap cost and availability, even though NAFDAC prohibited the majority of dieldrin and aldrin's applications in 2018 due to the persistent pesticide's toxicity, which presented an immediate threat to human health. Aldrin has a limited ability to be eaten and eliminated from the body, and it is not readily metabolized in water. However, it is readily absorbed and carried by vertebrate blood and invertebrate hemolymph (Yakubu, 2018).

Furthermore, a comprehensive investigation is essential to understand the long-term exposure to a combination of pesticides in real-life scenarios, which may have additive or synergistic effects. Iornenge et al. (2024) highlight the complexity of the issue, noting the scientific uncertainties, the exposure risks to vulnerable populations, and the numerous potential pesticide combinations involved. When chemicals that are likely to cause cancer or affect hormones are combined, unidentified negative health consequences may result. Because of this, determining "safe" limits of exposure to individual pesticides may understate the true health impacts, excluding long term exposure to several chemicals. Given the detrimental consequences chemical pesticides have on both the environment and human health, it is clear that a new concept in agriculture is sorely required.

If the pesticide was used according to the guidelines for its safe use, it is not anticipated that the MRL would be exceeded in any food (Ogar et al., 2012). A food product is hazardous to eat if a residue in a sample of food above the MRL because it includes an unhealthy or unlawful level of the residue. This implies that organochlorine pesticides are often used in agricultural cultivation and/or storage.

Hazard Quotient (HQ) and cumulative Hazard Index (HI) are used to calculate the non-carcinogenic danger of hazardous chemicals. Multiple chemical exposures may raise the hazards to one's health. HI, a gauge of cumulative risk, is therefore calculated. HI, which may be calculated using an equation, is the total potential for non-carcinogenic effects that several pollutants may offer through ingestion or the skin (Vetrimurugan et al., 2017). The interactions are considered because multiple toxicants are present. It is assumed that the toxic risks from potentially harmful substances in the same medium are additive, meaning their combined effect may be greater than the sum of their individual effects.

The Hazard Index (HI) was calculated by summing the Hazard Quotients (HQs) (Zheng et al., 2010). The exposure pathways analyzed included ingestion and dermal absorption for both adult and pediatric populations. The receptors were categorized as either adult (>30 years old) or child (<6 years old). There is no evident risk to the public when HQ and HI levels are less than 1, but if these values are greater than 1, there may be worries about possible non-carcinogenic consequences (United State Environmental Protection Agency, 2020).

Since the majority of the pesticide residues were found to be above the critical Health Risk Index (HRI > 1), the calculated Health Risk Index (HRI) for all the pesticide residues evaluated in the cereal samples from all sampling locations indicates significant non-carcinogenic health risks for both adults and children. These results are in contrast to those of Otituju and Lewis, who assessed the risk of eating beans sold in Wukari (Otitoju and Lewis, 2019). Similar research by Adeoluwa et al. (2019) also suggests that organochlorine residues in vegetables consumed in southwest Nigeria provide a non-carcinogenic health risk. The non-carcinogenic risk linked to long-term bean eating by adults in the research location is shown by the presence of certain residues found in this investigation with an HRI > 1. The current study's Hazard Quotient (HQ) evaluation showed that the cumulative hazard index was significantly higher than one (HQ>1).

CONCLUSION

This study has demonstrated that staple grains such as rice, maize, sorghum, and millet contain pesticide residues at concentrations exceeding internationally recognized maximum residue limits. The detection of multiple organochlorine compounds across all grain types and locations underscores the widespread and persistent nature of pesticide contamination in staple food sources. The associated Health Risk Index and Hazard Quotient values, consistently above the safety threshold, highlight a potential public health concern, particularly with regard to chronic, non-carcinogenic outcomes from long-term dietary exposure.

These findings contribute to a growing body of evidence emphasizing the need for more stringent regulation and monitoring of pesticide use in agricultural production and post-harvest storage. The study advances both methodological and empirical understanding by applying validated risk assessment models to real-world food systems in a context where

data have historically been limited. In doing so, it addresses a critical gap in the literature on food safety in grain-consuming populations and reinforces the importance of integrating environmental and public health perspectives into food policy frameworks.

Future research should focus on identifying safer pest control alternatives and evaluating the effectiveness of current regulatory practices. Additionally, longitudinal studies examining health outcomes in affected populations would offer deeper insights into the long-term implications of dietary pesticide exposure. These directions are essential to informing evidence-based interventions and ensuring the protection of vulnerable consumer groups.

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