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Original Article

Evaluation of Pesticides and Heavy Metal Residues in Selected Vegetables sold in Abuja Nigeria.

[*1]Abioye, K. K. and [1,2]Abioye, O. P.

[1]Africa Centre of Excellence for Mycotoxin and Food Safety, Federal University of Technology, Minna,
[2]Department of Microbiology, Federal University of Technology, P.M.B 65, Minna, Nigeria.

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ABSTRACT

The presence of pesticide residues and toxic heavy metals in vegetables poses serious threats to food safety and public health. This study investigated the levels of selected pesticide residues and heavy metals in four commonly consumed vegetables cabbage (Brassica Oleracea var. capitata), carrot (Daucus carota subsp. Sativus), cucumber (Cucumis sativus), and tomato (Solanum lycopersicum) collected from Dutse, Wuse, Kado, and Utako markets in Abuja, Nigeria. A total of 64 vegetable samples were collected and analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) for pesticide residues, and Atomic Absorption Spectroscopy (AAS) for heavy metal detection. The findings revealed several pesticide residues, including aldrin (1.46 $\pm$ 1.86mg/kg), chlorpyrifos (0.46 $\pm$ 0.36mg/kg) in cabbage, γ-lindane, diazinon (0.54$\pm$ 0.01mgkg) in carrot, carbaryl (1.03$\pm$0.04mg/kg) in cucumber, Dichlorodiphenyl dichloroethane (1.12 $\pm$ 1.44mg/kg) in cabbage and (0.60 $\pm$ 0.00mg/kg in tomatoes were present in concentrations that, in some cases, exceeded internationally accepted Maximum Residue Limits (MRLs). Similarly, heavy metals such as lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), and mercury (Hg) were detected, with lead concentrations in some vegetable samples significantly surpassing safe limits. Cabbage (2.03$\pm$1.10mg/kg) and carrot (0.42$\pm$0.01mg/kg) samples from Dutse and Kado showed notably high contamination levels of lead (Pb). These findings highlight an urgent need for regular monitoring and stricter enforcement of food safety regulations to reduce public exposure to chemical contaminants through diet. The study calls for improved agricultural practices, enhanced consumer awareness, and the establishment of effective surveillance mechanisms to ensure the safety of vegetables consumed in Abuja.

Keywords: Pesticides Residues, DDD (Dichlorodiphenyldichloroethane), Maximum Residua Limit (MRL). Contaminant.

***Corresponding author's email**: karimat.ac2117275@st.futminna.edu.ng, +2348039508172

INTRODUCTION

Vegetables are essential component of a balanced diet, providing key nutrients such as vitamins, minerals, and antioxidants necessary for human health. Among these, carrots, cabbage, cucumber, and tomatoes are widely consumed due to their health benefits and culinary versatility. However, the safety of these vegetables has increasingly become a concern due to the potential contamination of pesticide residues and heavy metals. These contaminants enter the food supply chain primarily through agricultural practices, where pesticides are used to control pests and increase yield, and through exposure to environmental pollution from industrial activities, contaminated water, and soil [29,17].
Pesticides such as cyanazine, chlorpyrifos, aldrin, carbofuran, g-chlordane, chlorpyrifos, chlorobiphenyl, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyltrichloroethane (DDT), dichlorvos, endosulfan, heptachlor, hexachlorobenzene (HCB), isopropylamine, lindane, t-nonachlor, and profenofos are toxicologically significant given the residues they leave behind, and together with heavy metals, they find their way through the agrofood processing and supply chain, and eventually cause various human illnesses and organ dysfunction [25]. Therefore, pesticides applied to agricultural crops must adhere to all applicable regulations, which ensure the remaining post-harvest chemical residues are within the consumer permissible/safe ranges [14].

Pesticides, when applied improperly or excessively, can leave residues on vegetables that remain even after harvest. The consumption of such contaminated produce can pose serious health risks, including neurological, reproductive, and developmental effects, and in extreme cases, cancer [33].
High levels of these metals are hazardous to the environment because they are absorbed by plants and accumulate in food crops consumed by humans and animals, posing health risks. There are many known sources of hazardous metals, including emissions from soil to food, air, water, agricultural fertilizers, pesticides and herbicides, and human activities such as irrigation. Other sources include automobile exhaust fumes, paints, tobacco smoking, industry, sewage and waste disposal.

Evidence suggests that vegetables and other food crops consumed in Nigeria are contaminated with heavy metals, which are linked to health problems such as cancer, which are currently on the rise in the country. It is therefore vital that communities with high levels of heavy metal pollution avoid eating large quantities of these food items [25].
Heavy metals such as lead (Pb), cadmium (Cd), Arsenic (As) and mercury (Hg), commonly found in contaminated water and soil, are also of particular concern. These metals are non-biodegradable, can bioaccumulate in plants, and pose long-term health risks, including kidney dysfunction, cardiovascular disease, and immune system impairment [28] including developmental delays in children, kidney damage, and cardiovascular diseases [4].
Both pesticide residues and heavy metals have been identified as significant food safety hazards due to their potential toxicity, persistence, and bioaccumulation in the human body [1].
In Abuja, Nigeria's capital, the demand for fresh vegetables such as carrots, cabbage, cucumber, and tomatoes are high due to urbanization and changing dietary habits. However, the regulatory monitoring of pesticide and heavy metal contamination in vegetables remains limited. Consequently, there is a lack of comprehensive data on contamination

levels, leaving consumers vulnerable to potential health risks [22]. Studies in other parts of Nigeria have detected pesticide residues and heavy metals in vegetables, sometimes exceeding the maximum residual limits (MRLs) set by food safety authorities such as the Codex Alimentarius Commission as reported by Odoh *et al.* [23].

Therefore, understanding the contamination levels of pesticides and heavy metals in vegetables in Abuja markets is critical for assessing public health risks and developing guidelines for safe agricultural practices.

MATERIALS AND METHODS

The study adopted an experimental design involving the collection, preparation, and laboratory analysis of vegetable samples.

Study Area

The study area, Abuja metropolis lies between latitudes 8º 25' N and 9º25' N of the Equator and longitudes 6º 45' E and 7º39' E of the Greenwich Meridian. Abuja is a planned city located in Northcentral and the Federal Capital Territory (FCT) of Nigeria.

The average annual temperature is 26.1ºC, while the average annual rainfall is 2750mm. This site was chosen for the collection of these samples because it is the gateway or entry point through which fruits and vegetables from the other northern part are brought into city for sales within the metropolis.

Sample Collection

Sampling was done using the method of Ndubbuike and Egbe [19] with some modifications. Samples were collected from Open market and Wholesale Shops. Samples were collected from four major markets in Abuja Federal Capital Territory (Dutse, Wuse, Kado, and Utako, markets) because these are the major markets were most of the people living in Abuja buys their vegetables. The different samples were pooled into separate and labelled polyethylene bags zip lock and stored appropriately.

Samples: Carrot, cabbage, cucumber and tomato vegetables were considered representative of the commonly consumed vegetables in Abuja. At each market, vegetable samples were collected from four randomly selected sellers.

A total of 64 vegetable samples were collected from four selected markets. For each of the vegetable type, one sample was purchased from each of the four different seller per market, this procedure was repeated for all four vegetables types across the four markets resulting in a total of sixty-four 64 samples. All the samples were pooled into separate and labelled polyethylene bags and kept in the refrigerator overnight and transported to Afe Babalola University (ABUAD) Ado Ekiti maintaining cool temperature and kept refrigerated as soon as it arrived Ado Ekiti for analysis of pesticides residues and heavy metals analysis.

Analysis and Quantification of Pesticides Residues

Reagents for residue analysis

Reference standards of pesticides were purchased from Sigma-Aldrich (Germany) with purity between 98% - 99%. Acetone, dichloromethane, n-hexane were obtained from Sharlau (Barcelona, Spain) and anhydrous sodium sulfate was acquired from Merck (Germany). Stock solutions of each pesticide standard with concentration of 100 mg/kg were prepared in n-hexane and stored in a freezer at –18°C. A mixture from stock solution of all pesticide standards was prepared by transferring 1 ml of each stock solution to a 100 ml volumetric flask and diluted up to the mark with n-hexane (5 mg·kg^{1}).

Determination of pesticide residue

The determination of pesticide residue followed the multiresidue pesticide analysis technique consisting of the QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) sample preparation method by AOAC Method (2007) with slight modifications for number of analytes spiking was adopted. The method was adopted with minor adjustment to the specific list and number of targeted analytes included in the recovery spiking experiments. Specifically, the number and type of target analytes used in the recovery spiking experiments were adjusted to match the pesticides relevant to the study samples ensuring accurate and reliable quantification. During method validation, known number of pesticides are spiked into blank samples to assess recovery efficiency.

According to the procedure 1 ml of methanol and 2 ml of extracted vegetable sample was taken in 20 ml screw capped vial. Extraction of pesticides was carried out with 10 ml of solvent system containing n-hexane and acetone in the ratio of 9:1. The mixture was shaken for 1 min on vortex mixer. After addition of anhydrous sodium sulfate the vial was placed in an ultrasonic bath for 2 min, and then centrifuged at 3000 RPM for 5 min. The cleanup procedure was carried out using solid phase extraction (SPE) cartridge containing octadecyl (C_{18}) resin. Gradient system was used to elute pesticides initially with 6 ml of pure n-hexane and then with 6 ml of a mixture of n-hexane and dichloromethane in the ratio of 5:1. The combined eluates were concentrated under the gentle stream of nitrogen, and an aliquot of the final concentrated extract was analyzed by GC-MS, respectively.

Instrumentation and methodology of Gas Chromatography-Mass Spectrometry (GC-MS) analysis

GC-MS is a unique analysis technique used for identification and quantification which is limited to analytes that are not only volatile and thermally labile but can also withstand the harsh partitioning conditions of the gas chromatograph. A representative spectral output of all the ascertainable compounds from the empirical sample is displayed by this technique. The Gas-chromatography device has an injection port from where the process is initiated by injecting the sample to that port. After this, evaporation and separation of the components take place one by one and finally this equipment identifies the components present in the corresponding sample. A specific spectral pick is produced for each component which is recorded on a paper chart electronically.

Analysis was done using a Varian 3800/4000 gas chromatograph mass spectrometer. The capillary column was AT-1, length was 30 m, ID was 0.25 mm and film thickness was 0.25 μm. Nitrogen gas was used as carrier and make up gas The GC column oven temperature was programmed from 70 ^{0}C to 300 ^{0}C. The initial temperature was 70 ^{0}C (hold time 2min) and it rose to 300 ^{0}C (hold time 7min) at the rate of 10 ^{0}C min^{-1}. The total run time was 32.0 min. Nitrogen with 99.9995% purity was used as carrier gas with a constant flow of 1.51ml/min. The GC-MS interface temperature was at 280 ^{0}C. Injector and detector temperatures were set at 250 ^{0}C, flow control mode: linear velocity;.1μl of sample was injected in split ratio of 30:0. The MS scan range was set from 40-800 Da. The identification of suspected pesticide was performed by peak retention times in samples to those of peaks in the pure analytical standards. and with the spectral data obtained from data library of the corresponding compounds. Quantities of the compounds are represented as relative area percentage in derived from the integrator. Identification of phytochemical components was conducted using the database of National Institute Standard and Technology MS library (NIST- MS library comparing the spectrum obtained through GC – MS compounds present in the samples were identified. No response factors were calculated.

All the samples and replicates were continuously injected as one batch in random order to discriminate technical from biological variations.

Prior to the injection of the sample extract, standard solutions of different concentrations of each pesticide group were prepared and injected with suitable instrument parameters. The samples were calibrated (retention time, peak area etc.) against five-pointed calibration curve of standard solution of concerned pesticide. Each peak was characterized by its retention time. Sample results were expressed in mg/kg automatically by the GC software.

Additionally, the prepared pooled samples were used as quality controls (QCs), which were injected at regular intervals throughout the analytical run to provide a set of data from which the repeatability can be assessed.

Determination of Heavy Metals Concentration

Sample preparation

In order to remove lipids, each of the analysed samples (5 g) was triturated with n-hexane (3 × 30 mL) at room temperature for 30 min. To evaporate organic solvent residues, degreased samples were air-dried for 24 h The defatted samples (1 g) were extracted three times with 10 mL of acetone-water-hydrochloric acid mixture (80:19.5:0.5%, v/v/v). Afterward, the samples were centrifuged at 4000× (TD4A-WS Benchtop Low-speed centrifuge, Shanghai, China) for 10 min, and the collected supernatants were evaporated (Heidolph, Rotary Evaporator, HB digit, Scwabach, Germany), transferred into a flask and filled up with extraction mixture acetone-water-hydrochloric acid, 80:19.5:0.5% (v/v/v) to obtain 10 mL of extract.

Determination of metals concentration by Atomic Absorption Spectroscopy (AAS)

The composition of Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb), and Mercury (Hg) in the sample were determined by the AOAC, [5] method. After preparative steps, which included mashing 5 grams of the samples dissolving the ash in 100 ml of 0.05 N nitric acid solution followed by a series of filtration, the minerals were quantified using Shimadzu (N1100A model) double beam digital Atomic Absorption Spectrophotometer (AAS). Mineral standards were used to quantify the minerals in the samples. Mineral determinations were done in triplicate for each sample type.

Data Analysis

Descriptive statistics was used to summarize the results (mean, standard deviation). ANOVA was used to compare contamination levels between markets and vegetables.

RESULTS AND DISCUSSION

Pesticides Residues level in Cabbage Across the Markets (mg/kg)

The detection of multiple pesticide residues in cabbage from the selected markets reflects common agricultural practices in vegetable farming in Nigeria. The presence of organochlorine pesticides like Dieldrin, Aldrin, and Heptachlor suggests that these banned or restricted chemicals are still in use, likely due to poor regulation and lack of awareness among farmers. This is similar to findings by Odewale *et al* [21], who reported persistent organochlorine residues in cabbage from local markets in Southwest Nigeria. The observed variation in pesticide levels across markets may be attributed to differences in farming practices, pesticide types used, and levels of regulatory enforcement. According to El-Sheikh *et al [10]*, markets located in areas with more commercial farming activities tend to have higher pesticide residues due to intensive chemical use. The detection of pesticides like Metalaxyl and Diazinon aligns with their widespread application for pest and fungal control [7,16]. High values of Aldrin and Dieldrin in certain markets exceed the maximum limits set by WHO [34], posing health risks to consumers. The mixture of pesticides within samples reflects a practice where farmers combine different chemicals to boost pest control efficiency, but often without observing safe pre-harvest intervals [16]. These findings raise concerns about food safety and the need for improved farmer education, regulatory control, and consistent monitoring to minimize health risks.

Table 1: Pesticides Residues level in Cabbage Across the Markets (mg/kg)

Pesticides Residues	Dutse	Kado	Utako	Wuse	MRL
Carbaryl	0.34 ± 0.11^{a}	0.24 ± 0.01^{b}	0.30 ± 0.06^{ab}	0.25 ± 0.04^{b}	0.5
γ- Lidane	0.04 ± 0.23^{c}	0.21 ± 0.13^{b}	0.22 ± 0.11^{b}	0.31 ± 0.02^{a}	0,01
β-Hexachlorocyclohexane	0.06 ± 0.07^{c}	0.08 ± 0.04^{bc}	0.13 ± 0.08^{a}	0.09 ± 0.00^{ab}	0.01-0.02
Triphenylmethan	0.06 ± 0.06^{b}	0.08 ± 0.03^{b}	0.07 ± 0.04^{b}	0.30 ± 0.11^{a}	0.01-0.1
p,p'-DDE	0.48 ± 0.35^{a}	0.13 ± 0.08^{c}	0.41 ± 0.18^{b}	0.51 ± 0.46^{a}	0.01-0.1
Metalaxyl	0.19 ± 0.01^{ab}	0.14 ± 0.08^{b}	0.26 ± 0.03^{a}	0.20 ± 0.13^{ab}	0.06
Diazinon	0.10 ± 0.04^{b}	0.37 ± 0.25^{a}	0.27 ± 0.23^{ab}	0.16 ± 0.08^{b}	0.01
Pirimiphos methyl	0.22 ± 0.10^{ab}	0.16 ± 0.16^{b}	0.36 ± 0.16^{a}	0.16 ± 0.16^{b}	0.1
Fenpropathrin	0.15 ± 0.00^{b}	0.10 ± 0.05^{c}	0.16 ± 0.02^{b}	0.23 ± 0.06^{a}	0.1-0.3
Dichlorodiphenyl dichloroethylene	0.47 ± 0.21^{b}	0.14 ± 0.14^{c}	0.58 ± 0.42^{a}	0.56 ± 0.11^{a}	0.1
Permethrine	0.27 ± 0.23^{b}	0.48 ± 0.40^{a}	0.29 ± 0.06^{b}	0.28 ± 0.13^{b}	0.1
Cyclopropanecarboxylic acid	0.04 ± 0.01^{c}	0.10 ± 0.08^{a}	0.06 ± 0.03^{bc}	0.08 ± 0.02^{ab}	0.01
Dichlorodiphenyl dichloroethane	0.31 ± 0.04^{b}	1.12 ± 1.44^{a}	0.30 ± 0.07^{b}	0.18 ± 0.13^{b}	0.01-0.2
Aldrin	0.11 ± 0.07^{b}	1.46 ± 1.86^{a}	0.12 ± 0.08^{b}	0.08 ± 0.01^{b}	0.05
Dieldrin	0.60 ± 0.11^{a}	0.30 ± 0.03^{b}	0.11 ± 0.01^{c}	0.11 ± 0.08^{c}	0.05
Chlorpyrifos	0.08 ± 0.02^{c}	0.46 ± 0.36^{a}	0.23 ± 0.04^{b}	0.27 ± 0.01^{b}	0.1
Propargite	0.21 ± 0.08^{a}	0.18 ± 0.16^{a}	0.19 ± 0.16^{a}	0.17 ± 0.18^{a}	0.2
Heptachlor	0.38 ± 0.13^{ab}	0.28 ± 0.34^{b}	0.46 ± 0.26^{a}	0.32 ± 0.11^{ab}	0.01
α-Endosulfan	0.24 ± 0.21^{a}	0.10 ± 0.08^{bc}	0.16 ± 0.04^{ab}	0.07 ± 0.02^{c}	0.02
β-Endosulfan	0.04 ± 0.00^{c}	0.14 ± 0.06^{b}	0.17 ± 0.04^{ab}	0.18 ± 0.01^{a}	0.05
Fenvalerate 1	0.08 ± 0.00^{b}	0.09 ± 0.06^{b}	0.17 ± 0.16^{a}	0.32 ± 0.06^{a}	0.05-0.1
Endosulfan sulfate	0.22 ± 0.01^{ab}	0.11 ± 0.08^{c}	0.35 ± 0.04^{a}	0.23 ± 0.00^{b}	0.01-0.5

Superscript across the row indicate significant differences at $p < 0.05$

Keywords: Regulatory Framework, Organochlorine, Organophosphate, Dichlorodiphenyldichloroethane DDD, Maximum Residue Limit (MRL)

Pesticide Residues Concentration in Carrot from the Various Markets (mg/kg)

The detection of pesticide residues in carrot samples from the markets reflects the common application of pesticides during carrot production, especially in urban and peri-urban farming systems. The presence of organochlorines such as Aldrin and Dieldrin in some samples is concerning because these compounds are banned or highly restricted due to their persistence and potential health hazards [34]. Similar reports have documented the continued detection of such pesticides in carrots and other root crops in Nigeria, highlighting regulatory gaps and farmers' poor knowledge of chemical restrictions. [26,24]. The differences in pesticide concentrations across markets may result from variations in pesticide usage, accessibility, and compliance with recommended application rates. High levels of Cyclopropanecarboxylic acid and Metalaxyl indicate the use of synthetic pyrethroids and fungicides, which are common in carrot production c

to control insect pests and fungal diseases, as noted by Nyandwi [20]. The presence of multiple residues within the same sample also aligns with the practice of mixed pesticide application to increase pest control effectiveness, as reported by Liu *et al.* [15]. The consistent detection of pesticides, some of which exceed recommended limits, points to weak enforcement of food safety standards and insufficient monitoring. These findings emphasize the need for educating farmers on proper pesticide use and strengthening regulatory frameworks to ensure safe levels of residues in carrots consumed by the publi

Table 2: Pesticide Residues Concentration in Carrot from the Various Markets (mg/kg)

Pesticides Residues	Dutse	Kado	Utako	Wuse	MRL
Carbaryl	0.01 ± 0.01^{a}	0.01 ± 0.00^{a}	0.00^{b}	0.01 ± 0.01^{a}	0.5
γ- Lidane	0.01 ± 0.01^{c}	0.07 ± 0.06^{b}	0.01 ± 0.01^{c}	0.11 ± 0.00^{a}	0.01
β-Hexachlorocyclohexane	0.05 ± 0.05^{c}	0.17 ± 0.06^{a}	0.16 ± 0.07^{a}	0.12 ± 0.00^{b}	0.01 to 0.2
Triphenylmethane	0.13 ± 0.01^{a}	0.15 ± 0.04^{a}	0.00^{b}	0.00^{b}	0.01-0.1
p,p'-DDE	0.00^{b}	0.00^{b}	0.00^{b}	0.23 ± 0.18^{a}	0.1
Metalaxyl	0.32 ± 0.01^{b}	0.34 ± 0.13^{b}	0.42 ± 0.09^{a}	0.33 ± 0.12^{b}	0.02
Diazinon	0.21 ± 0.30^{c}	0.42 ± 0.01^{b}	0.44 ± 0.04^{b}	0.54 ± 0.01^{a}	0.05
Pirimiphos methyl	0.40 ± 0.17^{a}	0.07 ± 0.08^{b}	0.06 ± 0.07^{b}	0.07 ± 0.08^{b}	0.1
Fenpropathrin	0.14 ± 0.01^{b}	0.08 ± 0.06^{c}	0.15 ± 0.21^{b}	0.28 ± 0.04^{a}	0.1-0.3
Dichlorodiphenyl dichloroethylene	0.33 ± 0.02^{a}	0.30 ± 0.04^{a}	0.26 ± 0.11^{b}	0.12 ± 0.09^{c}	0.1
Permethrine	0.16 ± 0.02^{a}	0.05 ± 0.06^{c}	0.13 ± 0.01^{ab}	0.11 ± 0.06^{bc}	0.1
Cyclopropanecarboxylic acid	0.57 ± 0.06^{d}	0.62 ± 0.01^{c}	0.69 ± 0.10^{b}	0.70 ± 0.06^{a}	0.01
Dichlorodiphenyl dichloroethane	0.64 ± 0.08^{a}	0.10 ± 0.01^{c}	0.12 ± 0.00^{b}	0.06 ± 0.08^{d}	0.01-0.2
Aldrin	0.12 ± 0.01^{c}	0.10 ± 0.04^{c}	0.40 ± 0.07^{b}	0.47 ± 0.01^{a}	0.05
Dieldrin	0.53 ± 0.01^{b}	0.55 ± 0.02^{ab}	0.48 ± 0.01^{c}	0.21 ± 0.00^{d}	0.05
Chlorpyrifos	0.19 ± 0.04^{c}	0.27 ± 0.14^{ab}	0.27 ± 0.02^{ab}	0.23 ± 0.07^{b}	0.1
Propargite	0.16 ± 0.04^{a}	0.12 ± 0.01^{b}	0.12 ± 0.01^{b}	0.13 ± 0.01^{b}	0.2
Heptachlor	0.13 ± 0.02^{b}	0.16 ± 0.07^{a}	0.13 ± 0.01^{b}	0.12 ± 0.02^{b}	0.01
α-Endosulfan	0.22 ± 0.04^{a}	0.15 ± 0.05^{b}	0.13 ± 0.01^{bc}	0.11 ± 0.00^{c}	0.02
β-Endosulfan	0.04 ± 0.06^{c}	0.12 ± 0.01^{b}	0.10 ± 0.04^{b}	0.28 ± 0.08^{a}	0.05
Fenvalerate 1	0.32 ± 0.01^{c}	0.34 ± 0.02^{b}	0.38 ± 0.06^{a}	0.33 ± 0.05^{bc}	0.02
Endosulfan sulfate	0.15 ± 0.04^{b}	0.16 ± 0.02^{b}	0.11 ± 0.01^{c}	0.17 ± 0.06^{a}	0.01-0.5

Superscript across the row indicate significant differences at $p < 0.05$

Pesticide Residues Concentration in Cucumber from the Various Markets

The occurrence of pesticide residues in cucumber samples from the selected markets shows that pesticide application is a common practice in cucumber farming. This agrees with previous studies by Omoyajowo *et al [2*6] and Ogah *et al* (24), who reported high pesticide usage among vegetable farmers in Nigeria. The presence of organochlorine residues such as Dieldrin and β-Endosulfan suggests the use of banned or restricted chemicals, likely due to weak regulatory enforcement and farmers' limited awareness of pesticide bans, as also stated by Ogah *et al.* [24]. The relatively high levels of Carbaryl in cucumber from Wuse may be linked to the use of this pesticide for pest control during storage or on farms, which is common due to its broad-spectrum effectiveness [3]. The detection of multiple residues in the same samples suggests that farmers often apply pesticide mixtures to increase pest management success, though this practice may lead to residue accumulation beyond acceptable limits [34]. Differences in pesticide levels across markets may be explained by variations in farming intensity, pesticide availability, and adherence to recommended practices. High values of Diazinon and Metalaxyl are consistent with their use to control insects and fungi in cucumber production. These findings raise concerns about consumer safety and underline the need for improved farmer training, strict market surveillance, and regular residue monitoring to reduce health risks.

Table 3: Pesticide Residues Concentration in Cucumber from the Various Markets (mg/kg)

Pesticides Residues	Dutse	Kado	Utako	Wuse	MRL
Carbaryl	0.08 ± 0.02^{b}	0.08 ± 0.04^{b}	0.06 ± 0.01^{b}	1.03 ± 0.04^{a}	0.5
γ- Lidane	0.12 ± 0.01^{a}	0.12 ± 0.02^{a}	0.13 ± 0.01^{a}	0.12 ± 0.03^{a}	0.01
B-Hexachlorocyclohexane	0.17 ± 0.03^{a}	0.16 ± 0.02^{a}	0.15 ± 0.00^{a}	0.14 ± 0.01^{a}	0.01-0.2
Triphenylmethane	0.15 ± 0.02^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.01-0.1
p,p'-DDE	0.00^{c}	0.42 ± 0.02^{a}	0.43 ± 0.04^{a}	0.39 ± 0.04^{b}	0.01-0.1 0.3-0.5
Metalaxyl	0.38 ± 0.01^{b}	0.49 ± 0.08^{a}	0.43 ± 0.03^{ab}	0.50 ± 0.05^{a}	0.05
Diazinon	0.49 ± 0.02^{a}	0.47 ± 0.05^{a}	0.00^{b}	0.00^{b}	0.1
Pirimiphos methyl	0.52 ± 0.01^{a}	0.51 ± 0.07^{a}	0.49 ± 0.02^{a}	0.55 ± 0.01^{a}	0.1-0.3
Fenpropathrin	0.12 ± 0.02^{a}	0.12 ± 0.03^{a}	0.12 ± 0.01^{a}	0.13 ± 0.00^{a}	0.01-0.1
Dichlorodiphenyl dichloroethylene	0.65 ± 0.04^{b}	0.64 ± 0.02^{b}	0.66 ± 0.03^{b}	0.71 ± 0.03^{a}	0.5
Permethrine	0.12 ± 0.01^{ab}	0.13 ± 0.03^{a}	0.11 ± 0.01^{b}	0.13 ± 0.01^{a}	0.01
Cyclopropanecarboxylic acid	0.49 ± 0.03^{ab}	0.48 ± 0.08^{b}	0.50 ± 0.05^{a}	0.47 ± 0.00^{b}	0.01
Dichlorodiphenyl dichloroethane	0.29 ± 0.01^{a}	0.30 ± 0.05^{a}	0.24 ± 0.05^{b}	0.25 ± 0.05^{b}	0.05
Aldrin	0.11 ± 0.01^{d}	0.12 ± 0.02^{c}	0.13 ± 0.01^{b}	0.14 ± 0.01^{a}	0.05
Dieldrin	0.12 ± 0.01^{d}	0.13 ± 0.01^{c}	0.16 ± 0.01^{b}	0.21 ± 0.06^{a}	0.05
Chlorpyrifos	0.16 ± 0.04^{a}	0.12 ± 0.01^{b}	0.12 ± 0.01^{b}	0.13 ± 0.01^{b}	0.1
Propargite	0.56 ± 0.03^{a}	0.52 ± 0.10^{a}	0.46 ± 0.01^{b}	0.46 ± 0.00^{b}	1.0
Heptachlor	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.01
α-Endosulfan	0.13 ± 0.01^{b}	0.15 ± 0.02^{a}	0.13 ± 0.00^{b}	0.12 ± 0.00^{b}	0.02
β-Endosulfan	0.22 ± 0.02^{a}	0.23 ± 0.04^{a}	0.13 ± 0.01^{c}	0.14 ± 0.01^{b}	0.05
Fenvalerate 1	0.12 ± 0.01^{a}	0.13 ± 0.01^{a}	0.11 ± 0.01^{b}	0.11 ± 0.01^{b}	0.05
Endosulfan sulfate	0.15 ± 0.02^{b}	0.15 ± 0.03^{b}	0.16 ± 0.01^{b}	0.21 ± 0.07^{a}	0.5

Superscript across the row indicate significant differences at $p < 0.05$
Keywords: Dichlorodiphenyldichloroethane DDD, Organochlorine. Organophosphate, Maximum Residue Limit MRL, Bioaccumulation.

Concentration of pesticide residues in tomato from the various markets

The detection of pesticide residues in tomato samples reflects the heavy use of agrochemicals in tomato cultivation in Nigeria, as supported by studies such as those by Momoh [18] and Fabiyi and Olatunji [12]. The absence of certain pesticides like Carbaryl and γ-Lindane in all markets may indicate some level of awareness or reduced usage of these chemicals in tomato farming. However, the presence of organochlorine compounds like β-Hexachlorocyclohexane, Aldrin, and Dieldrin in tomatooes indicates that banned pesticides are still in use, possibly due to their effectiveness and availability in informal markets, as suggested by Ogah *et al [24]*. The high levels of p,p'-DDE and Dichlorodiphenyl dichloroethane may also point to environmental persistence from previous agricultural use, which aligns with findings by Sun *et al* [30]. The detection of other pesticides like Metalaxyl, Permethrine, and Diazinon reflects their application to manage insect pests and fungal diseases, especially in tomato cultivation, where pest infestation is a major challenge [6]. The variation in residue levels across markets could be attributed to differences in farmers' knowledge, pesticide handling practices, and enforcement of pre-harvest intervals. The detection of multiple residues within single samples aligns with reports by Elgueta *et al.* [11] on the common practice of pesticide mixing among farmers. These findings highlight the urgent need for targeted farmer education, stricter enforcement of pesticide regulations, and consistent residue monitoring to protect public health

Table 4: Concentration of pesticide residues in tomato from the various markets

Pesticides Residues	Dutse	Kado	Utako	Wuse	MRL
Carbaryl	0.00^a	0.00^a	0.00^a	0.00^a	1
γ- Lidane	0.00^a	0.00^a	0.00^a	0.00^a	0.01
β-Hexachlorocyclohexane	0.16 ± 0.02^b	0.18 ± 0.08^b	0.14 ± 0.01^c	0.26 ± 0.02^a	0.01-0.2
Triphenylmethane	0.00^a	0.00^a	0.00^a	0.00^a	0.01-0.1
p,p'-DDE	0.39 ± 0.01^c	0.38 ± 0.05^c	0.36 ± 0.07^c	0.47 ± 0.01^a	0.01
Metalaxyl	0.45 ± 0.01^c	0.45 ± 0.05^c	0.50 ± 0.06^b	0.62 ± 0.02^a	0.3
Diazinon	0.50 ± 0.08^a	0.00^c	0.00^c	0.12 ± 0.00^b	0.05
Pirimiphos methyl	0.13 ± 0.01^c	0.06 ± 0.07^d	0.18 ± 0.01^b	0.31 ± 0.07^a	0.1
Fenpropathrin	0.22 ± 0.08^b	0.28 ± 0.01^a	0.25 ± 0.07^{ab}	0.00^c	0.01-0.5
Dichlorodiphenyl dichloroethylene	0.14 ± 0.02^c	0.06 ± 0.08^d	0.16 ± 0.01^b	0.54 ± 0.04^a	0.1
Permethrine	0.54 ± 0.04^c	0.64 ± 0.01^a	0.63 ± 0.11^a	0.62 ± 0.04^{ab}	0.1
Cyclopropanecarboxylic acid	0.00^d	0.05 ± 0.07^c	0.12 ± 0.01^b	0.16 ± 0.01^a	0.01
Dichlorodiphenyl dichloroethane	0.56 ± 0.01^b	0.58 ± 0.01^{ab}	0.60 ± 0.04^a	0.60 ± 0.00^a	0.01-0.2
Aldrin	0.58 ± 0.02^a	0.24 ± 0.02^c	0.25 ± 0.01^c	0.23 ± 0.03^c	0.05
Dieldrin	0.28 ± 0.01^c	0.25 ± 0.02^c	0.86 ± 0.03^a	0.85 ± 0.01^a	0.05
Chlorpyrifos	0.17 ± 0.02^{bc}	0.23 ± 0.03^a	0.12 ± 0.01^c	0.20 ± 0.11^{ab}	0.1
Propargite	0.19 ± 0.01^b	0.23 ± 0.01^a	0.18 ± 0.06^b	0.10 ± 0.01^c	0.5-1.0
Heptachlor	0.11 ± 0.03^d	0.19 ± 0.00^c	0.24 ± 0.08^b	0.41 ± 0.02^a	0.01
α-Endosulfan	0.36 ± 0.00^a	0.30 ± 0.01^b	0.30 ± 0.07^b	0.00^c	0.02
β-Endosulfan	0.00^a	0.00^a	0.00^a	0.00^a	0.05
Fenvalerate 1	0.05 ± 0.07^c	0.07 ± 0.10^{bc}	0.13 ± 0.01^b	0.15 ± 0.02^a	0.1
Endosulfan sulfate	0.17 ± 0.06^c	0.19 ± 0.08^{bc}	0.26 ± 0.01^b	0.30 ± 0.02^a	0.1-0.5

Superscript across the row indicate significant differences at $p < 0.05$

Heavy Metals Concentrations in Vegetables from Different Markets (mg/kg)

The presence of heavy metals in vegetables, as seen in this study, is a public health concern, and similar patterns have been reported in other research works. Studies have shown that vegetables grown or sold in urban areas often contain elevated levels of heavy metals due to environmental contamination [13]. One major source is the use of contaminated water for irrigation, which is common in urban and peri-urban farming. This may explain the high levels of arsenic and lead observed in cabbage and carrots from Dutse and Utako markets. Another possible reason is atmospheric deposition of heavy metals from traffic emissions and industrial activities near market locations. According to Boahen [9] vegetables sold near busy roads or industries tend to accumulate more heavy metals due to air pollution. Similarly, contaminated soils in urban farmlands contribute significantly to the accumulation of cadmium and lead in vegetables [8]. The variations observed across the different markets in this study could be linked to differences in the source of vegetables, handling practices, and the environmental conditions around the markets. Some studies have reported that vegetables like cabbage, tomatoes, carrots, and cucumbers easily absorb heavy metals from the soil due to their fibrous root systems [32]. The differences in heavy metal levels among these vegetables also reflect their varied ability to accumulate metals, a factor supported by recent findings by Xiang *et al. [36]*. The presence of mercury, although generally low, aligns with reports that mercury contamination in vegetables is often minimal unless there is severe environmental pollution [31] Overall, the results are consistent with previous studies, suggesting that environmental factors, agricultural practices, and market locations play a critical role in the heavy metal content of vegetables

Table 5: Heavy Metals Concentrations in Vegetables from Different Markets (mg/kg)

Crop Type	Market	As	Cd	Cr	Pb	Hg
Cabbage	Dutse	0.54 ± 0.51^{a}	0.07 ± 0.02^{ab}	0.19 ± 0.02^{a}	2.03 ± 1.10^{a}	0.03 ± 0.01^{a}
	Kado	0.07 ± 0.04^{b}	0.06 ± 0.02^{b}	0.17 ± 0.02^{a}	0.13 ± 0.03^{c}	0.03 ± 0.01^{a}
	Utako	0.07 ± 0.01^{b}	0.06 ± 0.03^{b}	0.15 ± 0.02^{b}	0.21 ± 0.02^{b}	0.02 ± 0.01^{ab}
	Wuse	0.06 ± 0.02^{b}	0.08 ± 0.03^{b}	0.16 ± 0.03^{ab}	0.20 ± 0.02^{b}	0.01 ± 0.01^{b}
Tomato	Dutse	0.04 ± 0.02^{c}	0.04 ± 0.02^{b}	0.29 ± 0.03^{a}	0.38 ± 0.06^{a}	0.00^{c}
	Kado	0.05 ± 0.02^{b}	0.05 ± 0.02^{ab}	0.22 ± 0.03^{c}	0.34 ± 0.02^{b}	0.01 ± 0.01^{b}
	Utako	0.06 ± 0.02^{ab}	0.04 ± 0.02^{b}	0.28 ± 0.02^{a}	0.37 ± 0.04^{a}	0.02 ± 0.00^{a}
	Wuse	0.08 ± 0.01^{a}	0.07 ± 0.01^{a}	0.20 ± 0.03^{d}	0.33 ± 0.01^{c}	0.01 ± 0.01^{b}
Carrot	Dutse	0.06 ± 0.02^{a}	0.05 ± 0.05^{ab}	0.23 ± 0.11^{b}	0.28 ± 0.17^{b}	0.02 ± 0.01^{a}
	Kado	0.05 ± 0.02^{b}	0.00^{c}	0.40 ± 0.03^{a}	0.42 ± 0.01^{ab}	0.02 ± 0.00^{a}
	Utako	0.06 ± 0.02^{a}	0.06 ± 0.03^{a}	0.19 ± 0.05^{b}	0.44 ± 0.01^{a}	0.02 ± 0.01^{a}
	Wuse	0.03 ± 0.01^{c}	0.04 ± 0.02^{b}	0.23 ± 0.02^{b}	0.43 ± 0.02^{a}	0.00^{b}
Cucumber	Dutse	0.07 ± 0.01^{b}	0.08 ± 0.04^{ab}	0.20 ± 0.07^{a}	0.15 ± 0.04^{c}	0.01 ± 0.01^{a}
	Kado	0.07 ± 0.03^{b}	0.11 ± 0.03^{a}	0.19 ± 0.02^{a}	0.38 ± 0.06^{a}	0.00^{b}
	Utako	0.08 ± 0.01^{a}	0.07 ± 0.04^{b}	0.19 ± 0.02^{a}	0.35 ± 0.02^{b}	0.00^{b}
	Wuse	0.08 ± 0.03^{a}	0.08 ± 0.02^{ab}	0.19 ± 0.03^{a}	0.35 ± 0.03^{b}	0.00^{b}
WHO/FAO	MRL	0.2	0.05-0.1	0.1	0.2	0.01-0.03

Superscript across the row indicate significant differences at $p < 0.05$
Keywords=As-Arsenic, Cd-Cadmium, Cr-Chromium, Pb-Lead, Hg-Mercury.

C

ONCLUSION

This research provides evidence of the presence of both pesticide residues and heavy metals in vegetables sold across major markets in Abuja. The data shows that while some of the contaminant levels were within permissible limits, several others exceeded safe thresholds, especially in cabbage and carrots from Dutse and Kado markets. These findings confirm that consumers are at risk of chronic exposure to toxic substances through commonly consumed vegetables. The situation is aggravated by weak enforcement of food safety standards and lack of awareness among farmers and sellers. Therefore, without immediate intervention, these contaminants could continue to threaten public health, particularly among vulnerable populations.

Authors' Contribution

AKK and AOP conceptualized the study. AKK and AOP designed the study. AKK participated in fieldwork and data collection. AKK, AAO performed the data analysis; AKK interpreted the data and prepared the first draft of the manuscript, reviewed by AOP and OCJF, AKK and AOP contributed to the development of the final manuscript and approved its submission.

Disclosure of Conflict of Interest

None

Ethics Approval and Informed Consent

This study did not use human or animal subjects. Therefore, ethical consideration was not applicable.

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