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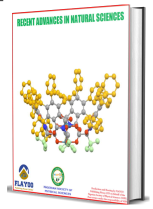

Pesticide handling practices and residue levels in yam and cassava across Nasarawa South, Nigeria

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ABSTRACT

The indiscriminate use of pesticides in agriculture poses serious health and environmental risks, especially in regions with weak regulatory enforcement. This study examines pesticide handling practices among farmers and assesses pesticide residues in yam (*Dioscorea spp.*) and cassava (*Manihot esculenta*) across Nasarawa South, Nigeria. Data were collected from 430 farmers using structured questionnaires and analysed with descriptive statistics and Chi-square tests. Additionally, yam and cassava samples were analyzed for pesticide residues using QuEChERS extraction and gas chromatography-mass spectrometry (GC-MS). Residue recovery ranged from 70% to 130%, confirming method reliability. Findings indicated poor adherence to safe storage and disposal practices, with household trash disposal being the most common method, posing environmental risks. Regional disparities were noted: Lafia exhibited better compliance in pesticide storage and disposal, while Awe lagged. Residue analysis revealed organochlorine, organophosphate, carbamate, and pyrethroid pesticides in food samples. Although no pesticide residues were detected in yam from Awe and cassava from Lafia, banned pesticides like Benzene Hexa Chloride (BHC) (0.000066 mg/kg) and Dichloro Diphenyl Trichloro Ethane (DDT) (0.00013 mg/kg) were found at varying concentrations in the cassava sample. However, mean residue levels remained below maximum residue limits. These findings underscore the urgent need for improved farmer education, stricter regulations, and sustainable pest management to mitigate health risks associated with pesticide exposure.

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1. INTRODUCTION

Pesticides play an important role in modern agriculture by protecting crops from pests and diseases [1, 2], thereby improving yields and ensuring food security [3]. However, improper handling, storage, and disposal of pesticides pose significant environmental and health risks, particularly in developing countries where regulatory oversight may be limited [4]. Unsafe storage, such as keeping pesticides in residential areas or near food supplies, increases the likelihood of accidental poisoning, particularly among children and farm workers [5]. Similarly, improper disposal of unused or expired pesticides, such as dumping them

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in open fields or water bodies, can result in soil and water contamination, affecting both human and ecological health [6, 7]. In many rural communities, farmers may have limited knowledge of best practices, leading to unsafe pesticide use and increased exposure risks. Pesticide residues in food crops have become a major concern due to their potential to cause acute and chronic health effects, including neurological disorders, endocrine disruption, and carcinogenicity [6, 8–10].

Several studies across Nigeria and other sub-Saharan African countries have reported pesticide contamination in staple crops such as maize, rice, vegetables, and fruits [11–14]. Ref. [13] found high levels of organochlorine residues in vegetables consumed in northern Nigeria, while Ref. [15] documented poor pesticide handling practices among rural farmers in Kano State. Despite these findings, there remains limited research focusing specifically on pesticide residues in root and tuber crops such as yam and cassava. Moreover, existing studies often focus either on residue analysis or farmer practices in isolation, but rarely integrate both aspects within a single study to provide a comprehensive risk profile. This represents a significant gap in understanding the full extent of pesticide exposure pathways in rural communities. To the best of our knowledge, there is currently a lack of data on both pesticide handling practices and residue levels in yam and cassava across Nasarawa South, Nigeria. As such, understanding farmers' pesticide handling practices and assessing pesticide residue levels in staple crops are critical for ensuring food safety and public health. A survey on pesticide uses in Nigeria reported that, between 1983 and 1990, the country imported approximately 15,000 metric tons of pesticides annually. These included around 135 active chemical substances marketed under more than 200 product brands and formulations, positioning Nigeria as one of the leading pesticide consumers in sub-Saharan Africa during that period [16, 17].

Yam (*Dioscorea rotundata*) and cassava (*Manihot esculenta*) are major staple crops in Nigeria, providing food and income for millions of people. It is a tropical tuber crop cultivated mainly for both local consumption and commercial purposes across Africa [18]. However, their cultivation often involves the application of pesticides to control pests and diseases, which may lead to the accumulation of pesticide residues in these crops [19]. The extent to which pesticide handling practices influence residue levels in food crops remains a subject of concern, particularly in regions with limited enforcement of pesticide regulations [20]. Nasarawa South, Nigeria, is an agrarian region where pesticide use is prevalent, yet there is limited empirical data on the safety practices of farmers and the resulting pesticide contamination in crops.

This study aimed to evaluate pesticide handling practices among farmers in Nasarawa South and assess pesticide residue levels in yam and cassava using QuEChERS extraction and Gas Chromatography-Mass Spectrometry (GC-MS) methods. Furthermore, a chi-square analysis was conducted to determine the association between pesticide storage and disposal practices and geographical location. The specific objectives were to:

1. Assess pesticide storage and disposal practices among farmers, agricultural extension workers, pesticide distributors, and pest control professionals in Nasarawa South, Nigeria.
2. Determine the association between pesticide handling practices and study locations (Awe, Doma, Lafia, Keana, and Obi) using chi-square analysis.
3. Quantify pesticide residue levels in yam and cassava from Awe, Doma, Lafia, Keana, and Obi using QuEChERS extraction and GC-MS methods.

Table 1. Chi-square test results for pesticide storage and disposal practices across different locations in Nasarawa South, Nigeria

Variables	Chi2 statistic	p-value	Degrees of freedom
storage	158.0065	0	12
disposal	215.2614	0	24

2. METHODOLOGY

2.1. STUDY AREA

This study was conducted in Nasarawa South, Nigeria, covering five selected locations: Awe, Doma, Lafia, Keana, and Obi.

2.2. STUDY DESIGN

A cross-sectional study design was employed to assess pesticide handling practices among farmers, agricultural extension workers, pesticide distributors, and pest control professionals, and to determine pesticide residue levels in yam and cassava.

3. DATA COLLECTION

3.1. SURVEY ON PESTICIDE HANDLING PRACTICES

3.1.1. Target Population and Sampling

The target population consists of farmers, agricultural extension workers, pesticide distributors, and pest control professionals in the five selected locations. The sample size was calculated using Eq. (1), as proposed in Ref. [21] and applied in the study by Ref.[22].

$$n = \frac{Z^2 \cdot \hat{p}(1-\hat{p})}{\varepsilon^2}, \tag{1}$$

where:

- n = sample size for an infinite population,
- Z = Z-value corresponding to the desired confidence level,
- $\hat{p}$ = estimated proportion of the population (if unknown, 0.5 is used as it provides the maximum sample size),
- ε = desired margin of error.

To ensure a high degree of confidence in the results, a Z-score of 1.96, corresponding to a 95% confidence level, was applied. A margin of error (ε) of 5% (0.05) was selected to maintain a balance between practicality and accuracy. The estimated proportion ($\hat{p}$) was set at 50% (0.5), a conservative assumption that maximizes the sample size and provides a robust upper bound for the number of participants needed.

By substituting these values into the formula, the required sample size for this study is calculated as follows:

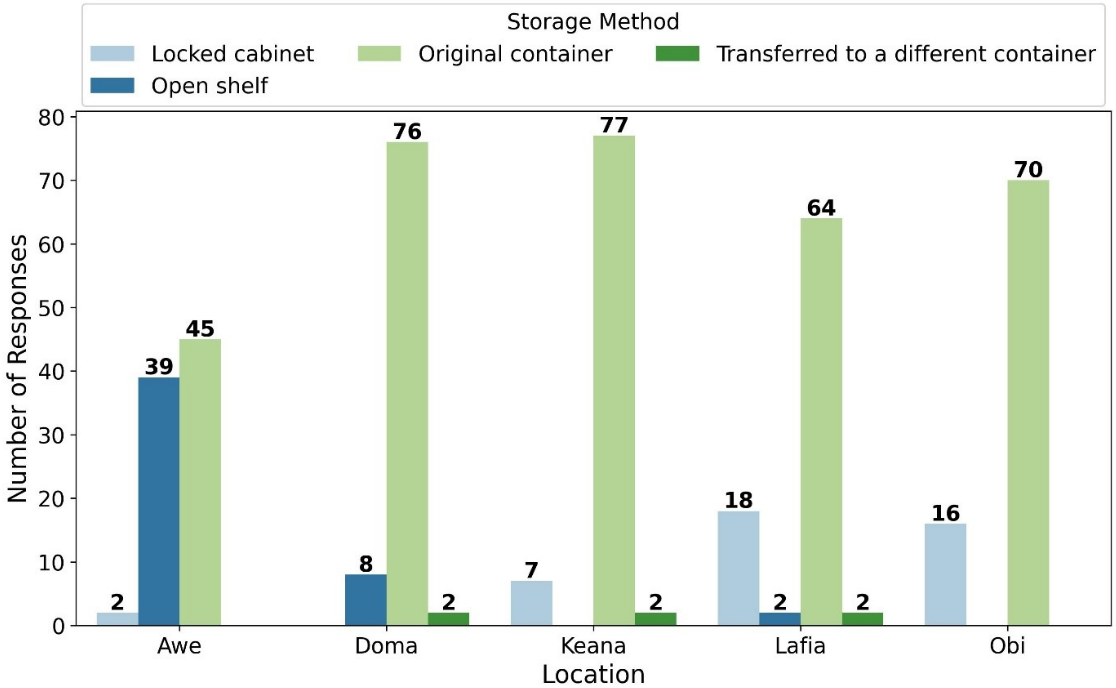

Figure 1. Distribution of responses to the question on the storage of pesticides.

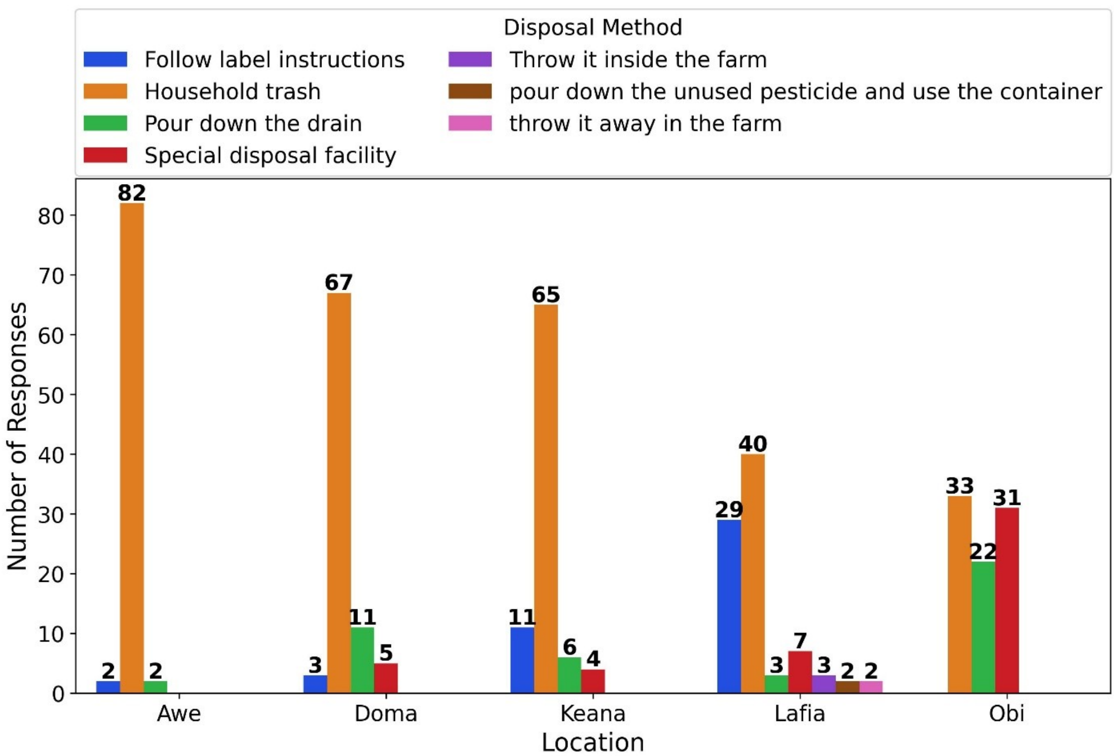

Figure 2. The disposal practices for unused or expired pesticides.

$$
\begin{aligned}
n &= \frac{(1.96)^2 \cdot (0.5)(1-0.5)}{(0.05)^2} \\
&= \frac{3.8416 \cdot 0.25}{0.0025} \\
&= \frac{0.9604}{0.0025} \\
&= 384.16.
\end{aligned}
$$

The estimated sample size for this study is 385 (rounded to the nearest whole number).

Due to the dispersed nature of farmers and potential literacy challenges, ensuring full questionnaire returns can be difficult. To account for non-responses, a 10% attrition rate was applied,

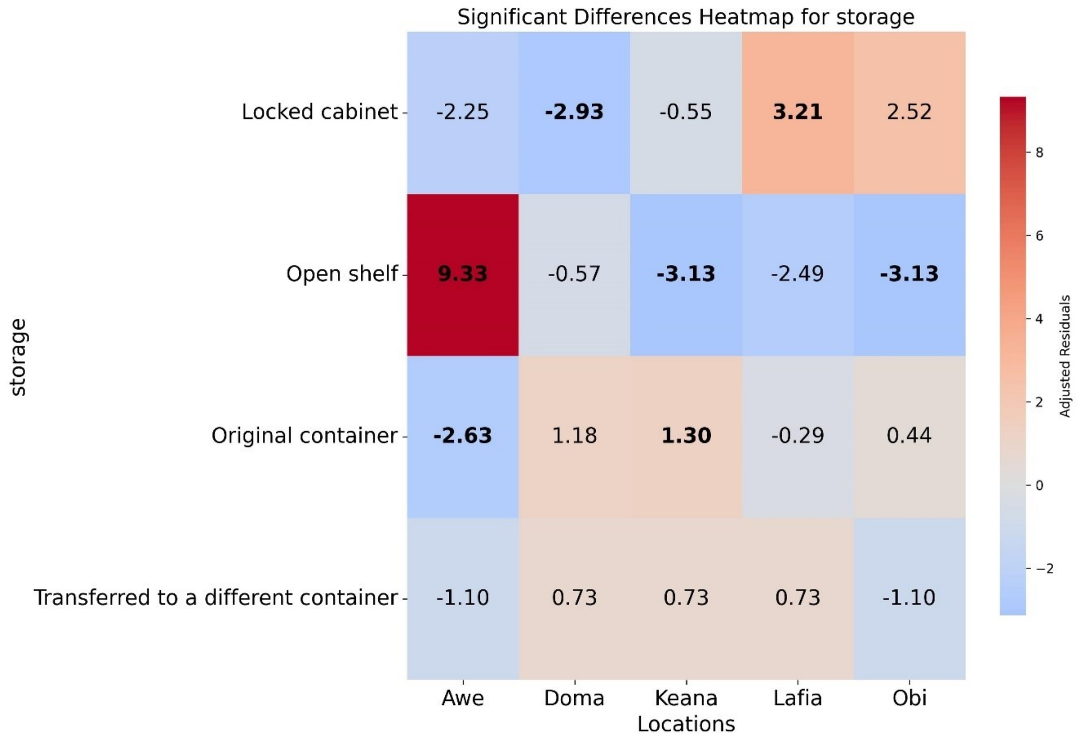

Figure 3. Heatmap visualization of the adjusted residuals for the storage categories, showing significant differences across Awe, Doma, Keana, Lafia, and Obi. Significant values in each category are highlighted in bold.

Table 2. P-values for post-hoc analysis of storage across Awe, Doma, Keana, Lafia, and Obi.

Storage	Awe	Doma	Keana	Lafia	Obi
Locked cabinet	1.598e-01	**1.096e-02**	1.000e+00	**3.167e-03**	5.882e-02
Open shelf	**3.176e-27**	1.000e+00	**4.011e-03**	6.164e-02	**4.011e-03**
Original container	**1.545e-08**	1.159e-01	**4.630e-02**	1.000e+00	1.000e+00
Transferred to a different container	1.000e+00	1.000e+00	1.000e+00	1.000e+00	1.000e+00

Table 3. P-values for post-hoc analysis of disposal across Awe, Doma, Keana, Lafia, and Obi

Disposal	Awe	Doma	Keana	Lafia	Obi
Follow label instructions	2.041e-01	6.342e-01	1.000e+00	**1.172e-13**	**1.375e-02**
Household trash	**1.075e-08**	4.908e-01	1.000e+00	**2.969e-04**	**1.493e-08**
Pour down the drain	2.390e-01	1.000e+00	1.000e+00	7.365e-01	**5.299e-06**
Special disposal facility	**9.840e-03**	1.000e+00	1.000e+00	1.000e+00	**2.470e-15**
Throw it inside the farm	1.000e+00	1.000e+00	1.000e+00	**4.166e-03**	1.000e+00
Pour down the unused pesticide and use the container	1.000e+00	1.000e+00	1.000e+00	2.676e-02	1.000e+00
Throw it away in the farm	1.000e+00	1.000e+00	1.000e+00	2.676e-02	1.000e+00

Significant p-values are highlighted in bold.

adjusting the sample size using Eq. (2):

$$n_{\text{adjusted}} = \frac{385}{1 - 0.10} \approx 428. \quad (2)$$

To ensure equal distribution across the five study locations, the final sample size was rounded to 430, with 86 participants per location. Questionnaires were randomly administered across the selected LGAs.

A structured questionnaire was designed to collect data on respondents' pesticide storage and disposal practices, among other variables.

4. DATA ANALYSIS

4.1. STATISTICAL ANALYSIS OF PESTICIDE HANDLING PRACTICES

A Chi-square (χ^2) test was used to determine the association between pesticide storage and disposal practices and the study locations. The test assessed whether respondents' safety practices differ significantly across the five locations.

The Chi-square statistic (χ^2) is calculated using Eq. (3):

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}, \quad (3)$$

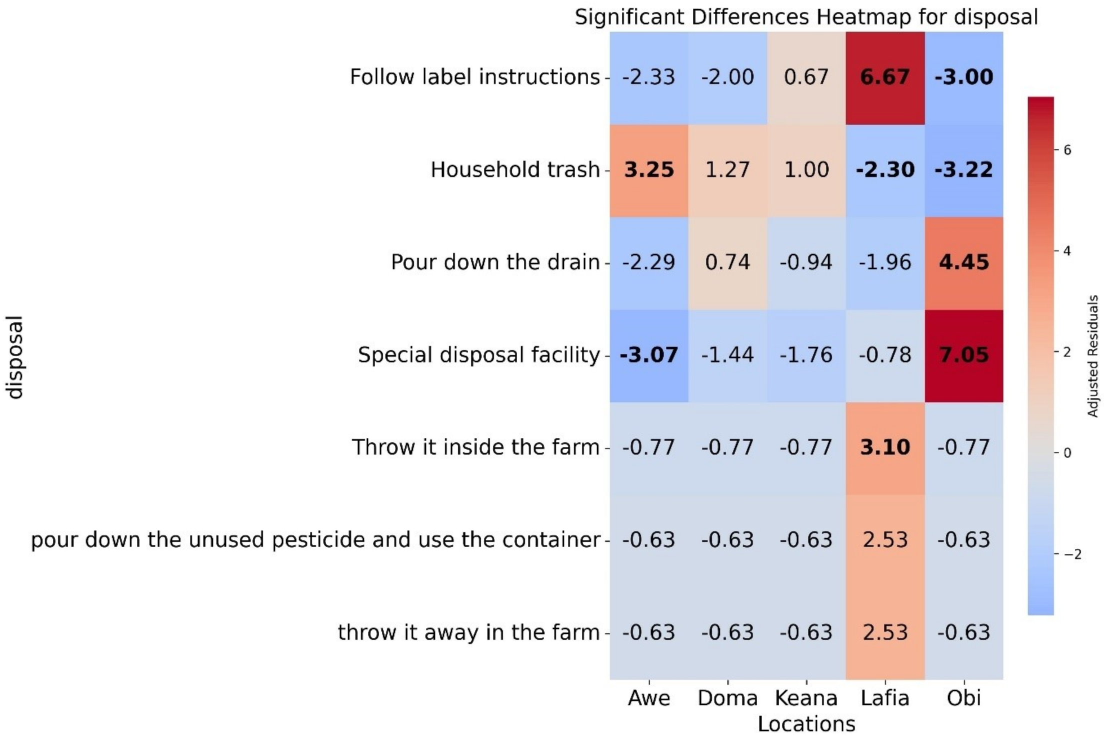

Figure 4. Heatmap visualization of the adjusted residuals for the disposal categories and their significant differences across Awe, Doma, Keana, Lafia, and Obi. The significant values in each category are highlighted in bold.

Table 4. Mean concentration, correlation coefficient, LOD, and LOQ of yam in Doma.

Pesticides	Mean concentration (mg/kg)	Mean ± SE	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Methoxychlor	5.00E-05	5.00E-05±0.00e+00	3.26E+01	9.98E-01	1.57E-11	4.77E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

Table 5. Mean concentration, correlation coefficient, LOD, and LOQ of yam in Lafia.

Pesticides	Mean concentration (mg/kg)	Mean ± SE	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Chlorpyrifos	5.00E-05	5.00E-05±9.43E-06	3.26E+01	9.98E-01	1.57E-11	4.77E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

where:

- O_i represents the observed frequency of the i-th category,
- E_i denotes the expected frequency of the i-th category under the null hypothesis, assuming no relationship between the variables.

A p-value less than 0.05 ($p < 0.05$) was considered statistically significant. Data analysis was conducted using Python version 3.10.9.

4.2. PESTICIDE RESIDUE ANALYSIS

4.2.1. Sample collection

Samples of selected food crops such as cassava and yam were sourced from the South Senatorial Districts in Nasarawa State, which include Awe, Doma, Keana, Lafia, and Obi. Yam and cassava samples were collected from farmers in the various locations, totaling 10 food crop samples, and identified in the Biology Laboratory at the Federal University of Health Sciences, Otukpo.

Samples were collected in sterilized poly bags to protect them from moisture and contamination. They were labelled and stored in a refrigerator at 4°C until ready for use.

4.2.2. Reagents and materials

The reagents used in this study include:

- Acetonitrile (GFS Chemicals, Columbus),
- Acetic acid (GFS Chemicals, Columbus),
- Silica gel 60–200 mesh (Labtech Chemicals),
- Anhydrous sodium sulphate (Merck, Germany).

Table 6. Mean concentration, correlation coefficient, LOD, and LOQ of Yam in Keana.

Pesticides	Mean concentration (mg/kg)	Mean ± SE	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Dichlorvos	1.20E-04	1.20E-04±1.89E-05	2.73E+01	9.96E-01	5.55E-11	1.68E-10
Parathion	3.67E-05	3.67E-05±2.72E-06	1.28E+01	9.97E-01	5.89E-12	1.79E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

Table 7. Mean concentration, correlation coefficient, LOD, and LOQ of yam in Obi.

Pesticides	Mean concentration (mg/kg)	Mean ± SE	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Dimethoate	6.67E-05	6.67E-05±2.72E-06	7.06E+00	9.97E-01	5.15E-12	1.56E-11
Methoxychlor	1.33E-05	1.33E-05±2.72E-06	3.54E+01	9.98E-01	6.35E-12	1.93E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

Table 8. Mean concentration, correlation coefficient, LOD, and LOQ of cassava in Awe.

Pesticides	Mean ± SE (mg/kg)	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Cypermethrin	9.00E-05±0.00e+00	2.00E+00	9.97E-01	1.00E-07	1.12E-07
Carbaryl	1.17E-04±2.72E-06	4.04E+00	9.97E-01	5.89E-12	1.79E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

These reagents were procured through various sales representatives of the producing companies based in Nigeria.

4.2.3. Pesticide standards

Reference pure pesticide standards (97–99%) for 6 organophosphates, 13 organochlorines, 2 pyrethroids, and 1 carbamate were used. These included dicofol, BHC, heptachlor epoxide, mirex, endosulfan I, chlordane, dichlorvos, ethion, parathion, dimethoate, diazinon, chlorpyrifos, heptachlor, aldrin, dieldrin, endrin, endosulfan II, DDT, methoxychlor, cypermethrin, deltamethrin, and carbaryl. All standards were purchased from Bristol Scientific Company Limited, a subsidiary of Sigma-Aldrich in Nigeria.

4.2.4. Sample extraction and clean-up

Extraction and clean-up procedures were conducted following a modified Quick, Easy, Cheap, Effective, Rugged, and Safe (QuEChERS) method [23], with slight adjustments by Ref. [24].

The sample was thoroughly mixed, and 2 mL was weighed into a 50 mL centrifuge tube. One gram of anhydrous sodium sulphate, pre-heated at 650°C for 1 hour and stored in a desiccator, was added to absorb any moisture.

Next, 20 mL of acetic acid–water–acetonitrile (1:5:94, v/v) was added to the tube. It was then closed and shaken vigorously by hand for 1 minute. A buffer–salt mixture (0.5 g sodium acetate and 3 g anhydrous $MgSO_4$) was added to induce phase separation and pesticide partitioning. The tube was closed, shaken for another minute, and centrifuged at 2500 rpm for 5 minutes.

The supernatant was carefully transferred into a clean flask. The residue was further extracted twice using the same procedure. The combined extract was then reduced to about 1 mL using a nitrogen evaporator at 36°C under a gentle stream of nitrogen gas.

4.2.5. Clean-up procedure

A clean-up column of about 15 cm (length) × 1 cm (internal diameter) was prepared. It was packed with glass wool at the base, followed by about 7.5 g of activated silica gel (prepared in a slurry form in acetonitrile), and topped with 5 g of anhydrous sodium sulphate to absorb moisture.

Pre-elution was carried out using 15 mL of acetonitrile, ensuring the sodium sulphate layer was not exposed to air to prevent drying of the silica gel. The reduced extract was run through the column and allowed to sink below the sodium sulphate layer. Elution was done using three 10 mL portions of acetonitrile.

The eluate was collected, dried with anhydrous sodium sulphate, and evaporated to dryness under a stream of analytical-grade nitrogen (99.99%) in preparation for GC-MS analysis.

GC-MS ANALYSIS AND CONDITIONS

Gas chromatography analysis was conducted using an Agilent 7890A system (Agilent, USA), hyphenated to a 5975C mass spectrophotometer with a triple-axis detector and equipped with an auto-injector (10 µL syringe). Helium was used as the carrier gas.

Chromatographic separation was carried out using capillary columns with the following specifications:

- Length: 30 m
- Internal diameter: 0.2 µm
- Film thickness: 250 µm
- Stationary phase: phenyl methyl siloxane

Additional GC-MS conditions were as follows:

- Ion source temperature: 250°C
- Internal temperature: 300°C

Table 9. Mean concentration, correlation coefficient, LOD, and LOQ of Cassava in Doma.

Pesticides	Mean ± SE (mg/kg)	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Dichlorvos	1.07E-04±2.72E-06	4.42E+00	9.96E-01	7.99E-12	2.42E-11
Parathion	8.67E-05±2.72E-06	5.43E+00	9.97E-01	5.89E-12	1.79E-11
Methoxychlor	1.50E-04±1.41E-05	1.63E+01	9.98E-01	3.31E-11	1.00E-10
Deltamethrin	6.00E-05±9.43E-06	2.72E+01	9.96E-01	2.77E-11	8.38E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

Table 10. Mean concentration, correlation coefficient, LOD, and LOQ of Cassava in Keana.

Pesticides	Mean ± SE (mg/kg)	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
BHC	6.33E-05±2.72E-06	7.44E+00	9.99E-01	3.27E-12	9.91E-12
Parathion	1.17E-04±2.72E-06	4.04E+00	9.97E-01	5.89E-12	1.79E-11
DDT	1.30E-04±1.89E-05	2.52E+01	9.98E-01	3.16E-11	9.57E-11
Dimethoate	1.20E-04±2.36E-05	3.40E+01	9.97E-01	4.46E-11	1.35E-10
Carbaryl	1.20E-04±9.43E-06	1.36E+01	9.97E-01	2.04E-11	6.18E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

Table 11. Mean concentration, correlation coefficient, LOD, and LOQ of Cassava in Obi.

Pesticides	Mean concentration (mg/kg)	Mean ± SE	RSD %	Linearity R^2	LOD (mg/kg)	LOQ (mg/kg)
Dichlorvos	9.00E-05	9.00E-05±0.00e+00	0.00E+00	9.96E-01	0.00E+00	0.00E+00
DDT	9.67E-05	9.67E-05±2.72E-06	4.87E+00	9.98E-01	4.55E-12	1.38E-11
Dimethoate	1.10E-04	1.13E-04±2.72E-06	4.16E+00	9.97E-01	5.15E-12	1.56E-11
Carbaryl	5.67E-05	5.67E-05±2.72E-06	8.31E+00	9.97E-01	5.89E-12	1.79E-11

SE- Standard Error, RSD- Relative Standard Deviation, LOD- Limit of Detection, LOQ- Limit of Quantification, 0.00e+00 - represents the mean of identical measurements, leading to a standard error of zero.

- Pressure: 16.2 psia
- Out time: 1.8 ms
- Injector: 1 µL in split mode (split ratio 1:50)
- Injection temperature: 300°C

PREPARATION OF CALIBRATION CURVES

Stock solutions of individual pesticides were prepared and serially diluted to concentrations ranging from 0.005 to 10.0 µg/L. The stock standard solutions were stored in amber-coloured bottles at 4°C in a refrigerator. Working standard solutions were freshly prepared before use.

These standard solutions were analyzed on the GC-MS under the specified chromatographic conditions. The mean peak areas obtained were plotted against their respective concentrations to generate calibration curves for each pesticide.

DETERMINATION OF LIMIT OF DETECTION (LOD)

The Limit of Detection (LOD) was determined by running the lowest concentration of pesticide standard six times and calculating the standard deviation, which was then multiplied by 3.3 as shown in Eq. (4), in line with Ref. [23]:

$$\text{LOD} = \frac{3.3 \times \sigma}{m}, \tag{4}$$

where σ is the standard deviation of the blank and m is the slope of the calibration curve.

DETERMINATION OF LIMIT OF QUANTIFICATION (LOQ)

The Limit of Quantification (LOQ) was calculated similarly, but by multiplying the standard deviation by 10, according to Ref. [24], as shown in Eq. (5):

$$\text{LOQ} = \frac{10 \times \sigma}{m}. \tag{5}$$

RESULTS AND DISCUSSION

PESTICIDE STORAGE AND DISPOSAL PRACTICES

Figure 1 presents the distribution of responses regarding pesticide storage methods across the five study locations: Awe, Doma, Keana, Lafia, and Obi.

Storing pesticides in their original containers was the most common method observed, with high adherence in Keana (77 responses), Doma (76), Obi (70), Lafia (64), and Awe (45). This reflects a general awareness of the importance of maintaining chemical stability and preventing contamination through proper storage.

Open shelf storage was notably high in Awe (39 responses) but much lower in other areas. This practice is hazardous due to the risk of accidental exposure, spillage, and potential poisoning, particularly in homes with children.

In Ref. [25], it was reported that 2.9% of respondents stored pesticides in the kitchen, 2.1% in the toilet, 22.8% hidden in rooms, and 65.6% in a dedicated store. However, locked cabinet storage, the safest method had low adoption across all sites, with Lafia (18) and Obi (16) recording the highest numbers.

Transferring pesticides to a different container, which can lead to accidental ingestion due to misidentification, was observed at minimal levels (2 responses) in each of the locations, suggesting that most individuals recognize the dangers associated with this practice.

In Figure 2, the distribution of responses regarding pesticide disposal methods across Awe, Doma, Keana, Lafia, and Obi is presented. Household trash disposal was the most frequently used method in all locations, posing significant environmental and health risks, as improperly discarded pesticides can leach into the soil and water systems, leading to contamination. In Lafia, 29 respondents followed label instructions, while in Obi, 31 respondents utilized special disposal facilities. This suggests that some awareness of proper disposal exists in these areas, although it remains relatively low in other locations. Pouring pesticides down the drain, which can lead to water pollution and ecological toxicity [26–28], was reported at low levels across all locations, with Obi (22 responses) showing the highest occurrence. This remains concerning, as pesticide residues in water bodies can harm aquatic life and enter the human food chain. Throwing pesticides inside farms or discarding unused chemicals while keeping the container was reported at minimal levels, but their presence suggests potential risks of pesticide residue accumulation in agricultural lands. Following label instructions, which represents the safest and most recommended practice, was relatively low across all locations. Lafia had the highest number of respondents adopting this practice (29 responses), indicating a better awareness level in this location.

4.3. ASSOCIATION BETWEEN PESTICIDE HANDLING PRACTICES AND STUDY LOCATIONS

The results of the Chi-square (χ^2) Test for pesticide storage and disposal practices among respondents across the study locations as shown in Table 1 revealed statistically significant associations between these practices and study locations. The Chi-square statistic for pesticide storage was 158.0065 with a p-value of 0.0000, while for pesticide disposal, the Chi-square statistic was 215.2614, also with a p-value of 0.0000. Since the p-values are below the significance level of 0.05, we reject the null hypothesis and conclude that pesticide storage and disposal practices significantly vary across the studied locations.

The high Chi-square values indicate substantial divergence in how respondents handle pesticides, suggesting that storage and disposal methods are not uniform across the sampled areas.

The Chi-square test confirms a significant association between pesticide handling practices and locations, but does not specify which locations differ in storage or disposal methods. Therefore, a post hoc analysis was conducted using pairwise Chi-square tests with Bonferroni correction to compare each pair of locations while adjusting for multiple comparisons. Also, adjusted standardized residuals were used to identify specific cells contributing to the overall significance, highlighting the locations responsible for the observed differences.

STORAGE METHODS

The post-hoc analysis of pesticide storage methods across various locations showed significant differences in practices. The results of the adjusted residuals for the storage categories are presented in Figure 3 and the associated P-values are in Table 2.

The significant positive residual for "Open shelf" (9.33) and negative residuals for "Locked cabinet" (-2.25) and "Original container" (-2.63), as shown in Figure 3, suggest that respondents from Awe are more likely to store pesticides on open shelves. The P-values (3.176e-27 for "Open shelf") support this statistical significance, indicating a prevalent improper storage practice in Awe. In Doma, the storage practices are less significantly varied, with a notable negative residual for "Locked cabinet" (-2.93) and a positive residual for "Original container" (1.18), indicating a tendency to use original containers rather than locked cabinets. In Keana, the significant negative residual for "Open shelf" (-3.13) and positive residuals for "Original container" (1.30) and "Transferred to a different container" (0.73) suggest a preference for storing pesticides in original or different containers rather than open shelves. The significant positive residual for "Locked cabinet" (3.21) and negative residuals for "Open shelf" (-2.49) indicate a strong adherence to proper storage practices in Lafia. The corrected p-value as presented in Table 2 (3.167e-03 for "Locked cabinet") confirms the statistical significance of this finding, reflecting a commendable compliance with recommended storage methods. Obi's results show significant positive residuals for "Locked cabinet" (2.52) and negative residuals for "Open shelf" (-3.13), indicating a preference for secure storage practices.

4.4. PESTICIDE DISPOSAL METHODS

The post-hoc analysis of pesticide disposal methods across Awe, Doma, Keana, Lafia, and Obi showed significant differences in practices. The adjusted residuals for the disposal categories are shown in Figure 4, with the corresponding P-values detailed in Table 3.

The significant positive residual for "Household trash" (3.25) and negative residuals for "Follow label instructions" (-2.33) and "Special disposal facility" (-3.07) as shown in Figure 4 suggest that respondents from Awe are more likely to dispose of pesticides in household trash. The P-values (1.075e-08 for "Household trash") support this statistical significance, indicating a prevalent improper disposal practice in Awe. The disposal practices in Doma are less significantly varied, with residuals indicating slight tendencies without strong deviations. This suggests that Doma's respondents have more mixed or moderate disposal habits without significant leaning towards any specific method. Similar to Doma, Keana's residuals do not show significant deviations, suggesting that disposal practices are relatively balanced and align with the overall sample trends. In Lafia, the significant positive residual for "Follow label instructions" (6.67) and negative residuals for "Household trash" (-2.29) indicate a strong adherence to proper disposal practices. The corrected p-value of 1.172e-13 for "Follow label instructions" as shown in Table 3 confirms the statistical significance of this finding, reflecting a commendable compliance with recommended disposal methods. The results for Obi showed significant positive residuals for "Special disposal facility" (7.05) and "Pour down the drain" (4.45), suggesting a mixed approach where respondents are utilizing special disposal facilities but also engaging in improper disposal methods. The P-values as shown in Table 3 (2.470e-15 for "Special disposal facility" and 5.299e-06 for "Pour down the drain") highlight these statistically significant practices.

4.4.1. Pesticide residue levels

Pesticide residue levels in yam from Doma, Lafia, Keana, and Obi

Methoxychlor is the only pesticide residue found in the yam samples with a mean concentration of 0.00005 mg/kg as shown in Table 4. According to the Environmental Protection Agency (EPA), levels of organochlorine pesticides above the maximum contaminant level of 0.04 mg/kg can cause central nervous system depression, diarrhea, and liver, kidney, and heart damage. Chronic exposure can lead to growth retardation [29]. In Refs. [12, 14, 30] studies, vegetable samples from South West Nigeria, Togo, and Kumasi, Ghana were analysed for pesticide residues. Among these, methoxychlor recorded the highest residue level in the samples from Ghana, although it remained within the permissible limit. In contrast, the residue levels detected in the samples from Togo and South West Nigeria were all below the maximum residue limits (MRLs), which aligns with the findings of the present study. The low residue levels observed may be attributed to the limited use of pesticides in those regions.

Chlorpyrifos an organophosphate was the only pesticide detected in the yam sample in Lafia with a concentration of 0.00005 mg/kg, as indicated in Table 5. The chlorpyrifos content found in Ref. [31] was 0.072 mg/kg which is very high compared to this study and also the MRL 0.05 mg/kg. High use of chlorpyrifos could lead to the poisoning of non-target species like humans and also the environment [31].

Dichlorvos and parathion, both organophosphate pesticides, are detected in small quantities in Keana yam samples, as shown in Table 6. Both pesticides are below the permissible residue limits, but contradict the study by [32], where the dichlorvos concentration is very high 9.615 mg/kg in the yam sample obtained from Wukari, Taraba State.

The pesticide residues detected in yam samples in Obi were residues of dimethoate and methoxychlor as given in Table 7. In Ref. [33], residues of BHC were also not detected in the yam samples. The concentrations found in the sample were both below MRL but in other studies [25, 34, 35] methoxychlor and dimethoate were not detected. The concentration of methoxychlor detected in Ref. [36] was higher than those detected in the yam samples from Obi.

Pesticide residue levels in cassava from Awe, Doma, Keana, and Obi

Residues of cypermethrin and carbaryl were found in cassava samples in Awe as indicated in Table 8. The analysis of cypermethrin showed a mean concentration of 0.00005 mg/kg with a highly consistent standard error of 9.00E-05 ± 0.00e+00. The relative standard deviation (RSD) is 2.000132, indicating some variability, while the coefficient of variation (CV) is 0.9968, reflecting high variability relative to the mean. With LOD and LOQ of 0.0000001 and 0.000000112 respectively this method demonstrates high sensitivity indicating high precisions. In a study done by Ref. [36] in Esa-oke farm settlements in Osun state, residues of cypermethrin and carbaryl were not found in the cassava samples studied, This may be due to differences in the types and constituents of pesticides used in various locations. Excessive exposure of animals to carbaryl can cause neuromyopathy, behavioural abnormalities, and reproductive toxicity [37–39]. In a recent study by Ref. [40] it was reported that exposure to carbaryl in pre-conception and first trimester can be associated with stillbirth. The carbaryl content found in the cassava sample in Awe is low when compared to the MRLs (0.000117 mg/kg to 0.020 mg/kg) respectively.

Dichlorvos (DDVP), parathion, methoxychlor, and deltamethrin in various concentrations were detected in cassava samples in Doma as given in Table 9. In a study by Ref. [36] residues of methoxychlor were found in the cassava sample which was higher at 0.00036 mg/kg than the residues found in the cassava sample in Doma 0.00015 mg/kg. It is one of the most commonly used organochlorine pesticides in developing countries and is classified by Ref. [20] as a class IB, 'highly hazardous chemicals' [41]. Parathion is an organophosphate compound that is highly toxic to non-target organisms including humans and environmental pollution (soil, water, and air) [42]. The detection of methoxychlor may be either a result of historical use of DDT of which technically methoxychlor contains about 88 % of the p,p'- isomer together with more than 50 structurally related contaminants, which might have been added to the actual amount of methoxychlor present [43]. Although the mean residue levels of detected pesticides were below the Codex, FAO/WHO maximum residue limits (MRLs), their presence particularly of banned compounds like DDT and BHC raises concern for chronic exposure. Long-term consumption of contaminated foods, especially among vulnerable populations, may lead to bioaccumulation and adverse health outcomes, including endocrine disruption and potential carcinogenic effects [8, 10, 20]. Additionally, the simultaneous presence of multiple pesticide residues may pose a cumulative risk, even if individual compounds remain within allowable limits.

Residues of BHC (Hexachlorobenzene), parathion, DDT, Dimethoate, and carbaryl were found in cassava samples in Keana as indicated in Table 10. The pesticide residues found in the samples did not exceed the permissible limits (MRL). BHC and DDT are persistent organochlorine pesticides, they are also banned pesticides [44]. Residues found in food samples indicate their usage even after being banned, which is a major concern for food safety. The detection of banned organochlorines such as BHC and DDT in this study, though within permissible limits, is consistent with findings by Ref. [45], who also reported traces of DDT and its metabolites in cereals, vegetables, and fruits in southwestern Nigeria despite its ban. Residues of BHC and DDT have also been found in several studies [35, 46], some above the MRL and some below the MRL. Parathion and dimethoate are organophosphate pesticides, and carbaryl is a carbamate pesticide.

Three various classes of pesticides (organochlorine, organophosphate, and carbamates) were detected in cassava samples in Obi which include dichlorvos, DDT, dimethoate, and carbaryl as given in Table 11. In a study by Ref. [34] 0.1007 mg/kg concentration of dichlorvos was found in the cassava sample, which is higher than that found in this study which is 0.00009 mg/kg. The maximum residue limits of dichlorvos were not exceeded in the cassava sample. DDT residue found in the cassava sample in Obi with the mean concentration of 0.00009 mg/kg is insignificant when compared to the MRL. In Refs. [11, 13], the level of DDT detected in the vegetable samples in Nasarawa and Pakistan were above MRL which may be as a result of variation in pesticide usage and sample intake. The analysis of dimethoate concentration revealed a mean level of 0.000113 mg/kg with a relative standard deviation (RSD) of 4.155895%, indicating low variability in measurements. The method demonstrated high sensitivity and precision with a limit of detection (LOD) of 5.15E-12 and a limit of quantification (LOQ) of 1.56E-11. Acute exposure to dimethoate can cause neurological symptoms such as headaches, dizziness, and respiratory distress, while chronic exposure may lead to prolonged neurological effects and impact liver and kidney function, with a potential increased risk of cancer [36]. The concentration of carbaryl residues present in cassava samples in Obi is below the permissible maximum residue limits, indicating food safety.

5. CONCLUSION

This study identified unsafe pesticide disposal practices and the presence of banned residues like BHC and DDT in yam and cassava across Nasarawa South, Nigeria. Despite awareness of pesticide risks, poor compliance especially in Doma, Awe, and Obi remains a concern. Lafia recorded better practices comparatively. Though residue levels were below safety limits, the detection of banned substances underscores ongoing health and environmental threats. Strengthening farmer education, enforcing regulations, and promoting safer pest control methods are essential for reducing exposure risks and ensuring food safety.

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