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Assessment of Pesticide and Herbicide Residues and Associated Risks in Yam (*Dioscorea rotundata*) Tubers in Kwande Local Government Area, Benue State, Nigeria

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ABSTRACT
Yam (*Dioscorea rotundata*) is a major staple crop in Nigeria, yet its production increasingly relies on herbicides and pesticides to control weeds and pests. This study assessed agrochemical use patterns, perceived health and environmental effects, and residue levels in yam tubers from Kwande Local Government Area. A stratified random sampling design was employed across three production zones (North, South, and West). Thirty farmers were interviewed, and thirty yam tuber samples were analyzed using the QuEChERS extraction method coupled with GC-MS/MS and LC-MS/MS. Method validation showed good linearity ($R^2 \geq 0.995$), recoveries of 80–110%, relative standard deviations below 15%, and limits of quantification of 0.01 mg/kg. Herbicide use was reported by 91.2% of farmers and pesticide use by 73.5%, with metazachlor, atrazine, cypermethrin, chlorpyrifos, glyphosate, and paraquat most frequently detected. Mean herbicide residues ranged from 0.042 ± 0.008 mg/kg (North) to 0.091 ± 0.012 mg/kg (West), while pesticide residues ranged from 0.035 ± 0.009 mg/kg (North) to 0.124 ± 0.018 mg/kg (West). Most values were below or close to international maximum residue limits, though higher concentrations in the West zone suggest more intensive chemical use. Farmers commonly associated agrochemical exposure with skin irritation, respiratory problems, and water and soil contamination. The findings indicate spatial variability in residue burden and highlight potential food-safety and environmental risks. Strengthened regulation, routine residue monitoring, and promotion of integrated pest management are recommended to ensure safer and more sustainable yam production.

INTRODUCTION

Yam (*Dioscorea rotundata*) occupies a central position in the Nigerian food system and cultural heritage. It serves as a staple food crop and contributes significantly to food security, rural income generation, and nutrition (Matsumoto *et al.,* 2022; Ikeh and Umelo, 2023). Nigeria is the world's largest producer of yam, accounting for over 60% of global production, with Benue State being one of the leading producing states. Yam is rich in carbohydrates and provides essential micronutrients that support dietary energy needs across diverse socio-economic groups. Despite its nutritional importance, yam cultivation faces several agronomic challenges, including weed infestation, pest attacks, and declining soil fertility (Eneogwe *et al.,*

2023). To address these challenges, farmers increasingly rely on herbicides and pesticides. However, improper or excessive use of these agrochemicals poses serious risks to the environment, crop quality, and human health.

The widespread use of agrochemicals in tropical agriculture has raised concerns about their environmental fate and health impacts. In regions with heavy rainfall, such as Benue State, surface runoff and leaching increase the likelihood of herbicides and pesticides entering surface and groundwater systems, thereby contaminating rivers, streams, and wells used for domestic purposes. Agrochemical runoff has been associated with biodiversity loss, particularly among aquatic organisms, and with disruption of soil microbial communities, which compromises long-term soil productivity (Heywood, 2017; Morton, 2022). Several studies have also linked chronic exposure to agrochemicals with adverse human health outcomes, including respiratory disorders, neurological impairment, endocrine disruption, reproductive abnormalities, and increased cancer risk (Awotoye et al., 2012; Oladipo et al., 2023).

Beyond environmental contamination, the persistence of pesticide and herbicide residues in edible crops represents a direct food safety concern. The Codex Alimentarius Commission and other regulatory bodies have established maximum residue limits (MRLs) for many agrochemicals in food crops, typically in the µg/kg (ppb) to low mg/kg (ppm) range, to minimize risks to consumers. Studies conducted in Nigeria and other West African countries have reported detectable residues of atrazine, chlorpyrifos, cypermethrin, and glyphosate in root and tuber crops, sometimes exceeding recommended MRLs. For example, investigations in southwestern Nigeria have documented pesticide residues in cassava and yam tubers linked to intensive herbicide and insecticide use, raising concerns about cumulative dietary exposure (Awoyinka et al., 2019; Akinola et al., 2021). Similar findings have been reported for cocoyam and sweet potato in Ghana and Benin Republic, where herbicide residues were detected in concentrations associated with inappropriate application practices and poor adherence to safety guidelines (Boateng et al., 2020; Kpanou et al., 2022).

Despite these growing concerns, research on pesticide and herbicide residues in yam tubers in Nigeria remains limited and geographically uneven. Most existing studies focus on cereals and vegetables, with comparatively fewer investigations addressing root and tuber crops, particularly in the North Central region. Furthermore, many published works emphasize farmers' knowledge and perception of pesticide risks without integrating residue analysis in harvested produce. Where residue studies exist, they are often localized and do not adequately capture variations in agrochemical use across different production zones.

Kwande LGA is one of the major yam-producing regions in Benue State, characterized by high weed pressure and pest incidence. Farmers in this area depend heavily on agrochemicals for weed and pest control, often with limited access to extension services and formal training on safe application practices. However, empirical data on the presence and concentration of herbicide and pesticide residues in yam tubers from Kwande LGA are scarce. The absence of such data creates uncertainty regarding consumer exposure, environmental sustainability, and regulatory compliance with established MRLs. Moreover, there is inadequate documentation of farmers' awareness of the long-term environmental and health implications of agrochemical use in this region.

This study therefore addresses a critical knowledge gap by providing a scientific assessment of chemical (herbicide and pesticide) risks associated with yam production in Kwande LGA of Benue State. By integrating information on agrochemical use with residue determination in yam tubers, the study contributes to food safety research and environmental risk assessment in root and tuber crops. The findings are expected to inform policymakers on the need for improved regulation and monitoring of agrochemical use, support agricultural extension services in promoting safer and more sustainable farming practices, and contribute to the academic literature on agrochemical residue dynamics in yam-based farming systems in Nigeria.

MATERIALS AND METHODS

Study Area

Kwande LGA is in northeastern Benue State, Nigeria, between latitudes 6°30'N and 7°10'N and longitudes 9°00'E and 9°30'E. It is characterized by a tropical savanna climate with rainy and dry seasons. The region is agriculturally productive, with yam, cassava, maize, and rice as major crops. The River Katsina-Ala supports irrigation and farming activities. Kwande LGA comprises fifteen council wards, including Adikpo, Liev 1, Liev 2, Moon, Nanev, and Turan. Farming practices vary across upland and lowland zones, providing a suitable setting for comparative analysis of agrochemical use.

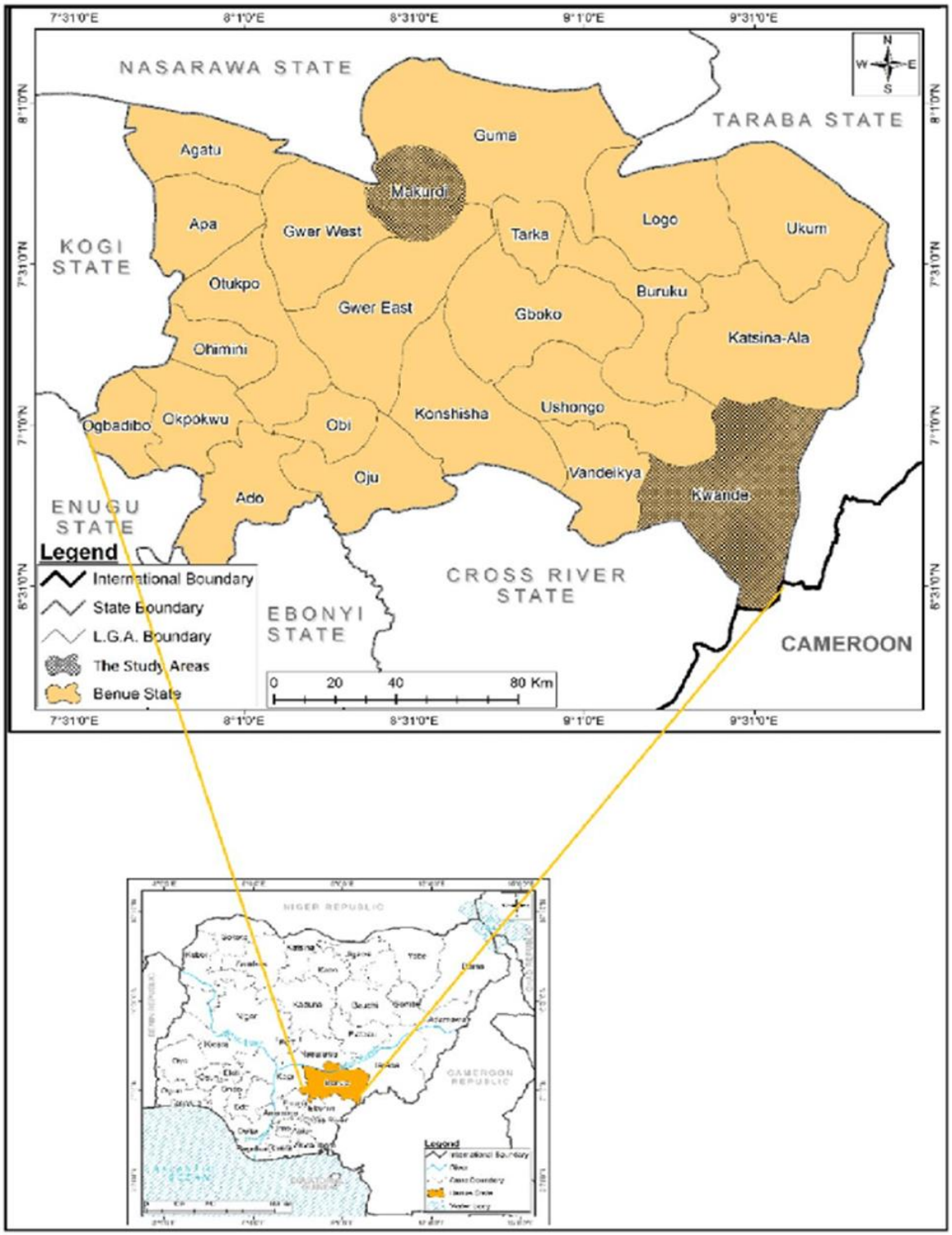

Figure 1: Showing Map of Kwande

Sampling Sites

A stratified random sampling technique was used. Twelve villages were purposively selected from three major zones: Kwande North, South, and West. Thirty yam farmers were randomly interviewed (10 per zone). Thirty yam tuber samples were collected for laboratory analysis (10 per zone).

Table 1: Yam Productivity Communities in Kwande LGA

S/No.	Location	Villages	Frequency	Percentage (%)	Mean
1.	Kwande North	Adikpo	2	6.5	9(29.4)
		Liev 1	2	6.5	
		Liev 2	2	6.5	
		Ahile	3	10.5	
2.	Kwande South	Ikyurav	2	6.5	11(38.2)
		JatoAka	3	10.5	
		Adagi	2	6.5	
		Shangev-ya 1	3	10.4	
		Shangev ya 2	1	4.5	
3.	Kwande west	Nanev	4	15.5	10(32.4)
		Moon	2	6.5	
		Turan	4	15.5	
Total	**3**	**12**	**30**	**100**	**30(100)**

Extraction and Clean-up (QuEChERS Method)

Pesticide and herbicide residues were extracted using the QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) method. Ten milliliters of acetonitrile were added to each sample and shaken vigorously for 1 min. A salt mixture (4 g $MgSO_4$ and 1 g NaCl) was added, followed by centrifugation at 4,000 rpm for 5 min. An aliquot of the supernatant was subjected to dispersive solid-phase extraction (d-SPE) clean-up using primary secondary amine (PSA), C18 sorbent, and $MgSO_4$ to remove organic acids, sugars, and pigments. The cleaned extract was filtered through a 0.22 µm membrane filter prior to instrumental analysis.

Instrumental Analysis

Residue determination was carried out using GC-MS/MS for cypermethrin, chlorpyrifos, atrazine, and metazachlor, and LC-MS/MS for glyphosate and paraquat, due to their high polarity and thermal instability. Quantification was achieved using external calibration with certified analytical standards prepared in matrix matched solutions. Identification was based on retention time matching and confirmation by at least two diagnostic ion transitions per compound.

Validation

The analytical method was validated according to international guidelines (e.g., SANTE/12682/2019). The following parameters were evaluated: Linearity: Calibration curves showed coefficients of determination (R^2) ≥ 0.995 for all analytes. Recovery: Mean recoveries ranged between 80–110% at three fortification levels (0.01, 0.05, and 0.1 mg/kg). Precision: Intra-day and inter-day relative standard deviations (RSDs) were < 15%. Limit of Detection (LOD): 0.001–0.005 mg/kg. Limit of Quantification (LOQ): 0.01 mg/kg. Matrix effects: Signal suppression/enhancement was ≤ ±20% and corrected using matrix-matched calibration. These validation results demonstrate that the method is suitable for reliable determination of pesticide and herbicide residues in yam tubers.

Reliability

The replacement of ethanol extraction, TLC identification, and UV–Vis colorimetry with QuEChERS extraction coupled with GC-MS/MS and LC-MS/MS provides: Reliable compound-specific identification accurate quantification at trace (µg/kg) levels Scientifically defensible comparison with MRLs Validated analytical performance This validated multi residue approach ensures that the reported pesticide and herbicide concentrations in yam tubers are robust, reproducible, and suitable for regulatory and public health interpretation.

Thin Layer Chromatographic (TLC) Analyses of Yam Tuber Extracts

TLC analysis was carried out according to a modified method of (Afful *et al*., 2008). The high-performance thin layer chromatography (HPTLC) plates were activated in an oven at 105°C for 30 min, and the plates were spotted manually with a 1 µl micro-syringe. The spotted TLC plates were developed in a 22.5 × 21.5 × 6.5 cm^3 tank saturated with the development solvent that was made up of methanol and acetone. The eluent was allowed to rise to 6 cm from the origin of the plates and the eluting layer dried in a fume hood. The developed, dried HPTLC plate was placed in a dark box and visualized with 254mm UV light. The standard pesticides and herbicides were also analysed in the same way. The distances travelled by the spots and solvent were measured and used to calculate the retardation factor (Rf).

The Rf value is calculated as:

$$Rf = DCSO/DSO$$

Where:

Rf = Retardation factor

DCSO = Distance of the centre of the spot from the origin

DSO = Distance of solvent from the origin

The Rf value is an important parameter in TLC, representing the ratio of the distance traveled by a compound to the distance traveled by the solvent front on a chromatographic plate. This value helps in identifying and comparing the presence of specific compounds based on their characteristic migration patterns (Adesiyan and Odihirin, 2021). These Rf values are reported as mean ± standard deviation, meaning that the mean represents the average of multiple trials, while the standard deviation reflects the variability in the measurements. A lower standard deviation suggests greater consistency in the results, while a higher deviation indicates variability

Statistical Analysis

Statistical analysis of results was carried out made using Statistical Package for Social Science (SPSS, version 24). The results were expressed as Mean ± Standard Deviation. Multiple group comparisons were performed using one-way analysis of variance (ANOVA) followed by Dunnett's test to detect intergroup differences. A significant difference was determined when $p < 0.05$, $p < 0.01$ and $p < 0.001$.

RESULTS AND DISCUSSION

Figure 2 shows a distribution of herbicides and pesticides used by farmers in Kwande LGA. Among the herbicides, "Force up" is the most used (25.0%), followed by "Saro-sate" (18.2%). Other herbicides like "Paraquat" and "Weed off" each account for 9.1%, while a variety Kwande LGA. of others, such as "Glyphosate" and "Quick action," have lower usage rates. A small portion of respondents (2.3%) reported using herbicides like "Atrazine," "Bush clear," and "Metazachlor," with 2.3% reporting no herbicide use. In terms of pesticides, "Neem" is the most frequently used (15.4%), followed by "Carbofuran" (7.7%). Several other pesticides, including "Atrazine," "Best," and "Chlorpyrifos," each account for 3.8%. A significant portion (34.6%) of respondents indicated they do not use any pesticides.

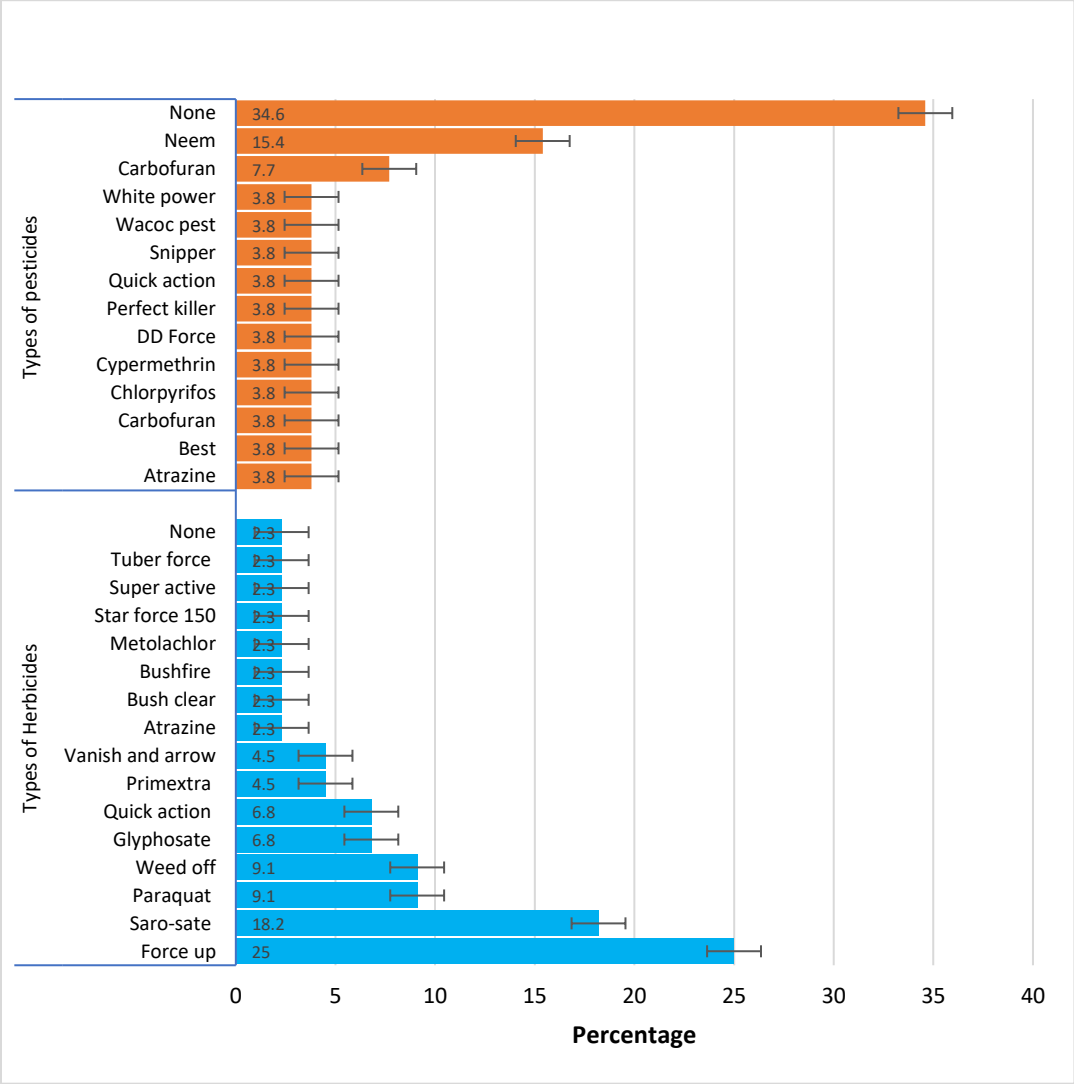

Figure 2: Types of Herbicides and Pesticides used by Yam Farmers

Perceived Environmental and Health Effects

Soil pollution (58.8%) and water contamination (55.6%) were the most frequently reported environmental effects. Health problems included skin irritation (82.4%), respiratory issues (64.7%), nausea (50%), and headaches (38.2%). Figure 3 presents the perceived effects of herbicides and pesticides on the environment and farmers' health. The results showed that majority of farmers (58.8%) believe that herbicides and pesticides cause soil pollution, followed by water contamination (55.6%), and death of animals (47.1%). Regarding health effects, majority of farmers (82.4%) reported skin irritation, rashes, and blisters, followed by respiratory issues (64.7%), nausea (50%), and vomiting (44.1%). In addition, 38.2% of farmers reported miscarriage, birth defects, and headaches, while 32.4% reported death.

Table 2: Perceived Effect of Herbicides and Pesticides on the Environment and Farmers' Health

Perception	F	%
Environmental effect		
Soil pollution	20	58.8
Water contamination	19	55.6
Death of animals	16	47.1
Others	8	23.6
Effect on human		
Skin Irritation, Rashes, and Blisters.	28	82.4
Respiratory Issues	22	64.7
Nausea	17	50
Vomiting	15	44.1
Headaches	13	38.2
Dizziness	15	44.1
Miscarriage	11	38.2
Birth Defects	13	38.2
Death	11	32.4

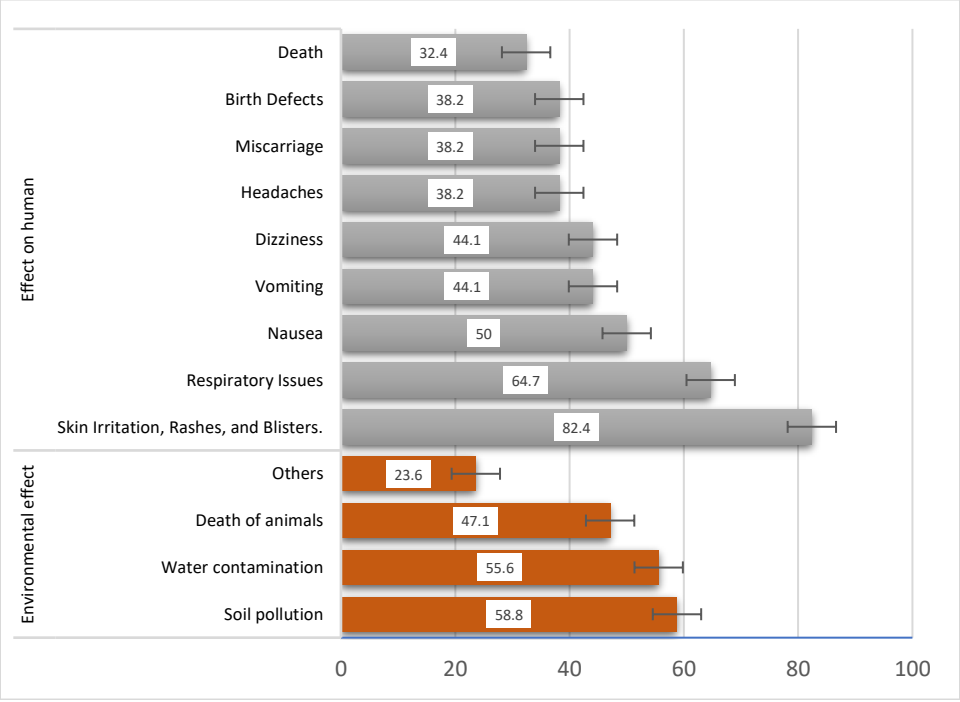

Figure 3: Perceived effect of Herbicides and Pesticides on the environment and farmers' health

This Figure 3 presents data on the methods, rates, and timing of herbicide and pesticides application by yam farmers. The results show that most farmers (52.9%) use backpack sprayers, followed by hand spraying (47.1%), and none use yam immersion. Most farmers apply herbicides frequently, with 52.9% applying 3 - 4 times and 44.1% applying 1-2 times. However, 2.9% of farmers apply herbicides 7-8 times. The rate of application varies, with 73.5% of farmers always applying herbicides, 26.5% sometimes, and none ever applying.

Additionally, 64.7% of farmers always use herbicide pesticides, 20.6% sometimes, and 14.7% never. These findings suggest that yam farmers rely heavily on herbicides and apply them frequently, highlighting the need for sustainable weed management practices.

The concerns and perceptions of farmers regarding the risks and effects of herbicide and pesticide use in yam farms are resented in Figure 4. The result reveals that most farmers were highly concerned, with 73.5% and 76.5% expressing high concern over herbicide and pesticide use, respectively. Farmers perceive herbicides to pose a greater risk to humans (55.9%), while pesticides were seen as more harmful to yam (38.2%). The effects of these chemicals on yam quality are high with 70.6% farmers associating herbicides with yam rot, and 23.5% indicating that pesticides reduce the yam's market value

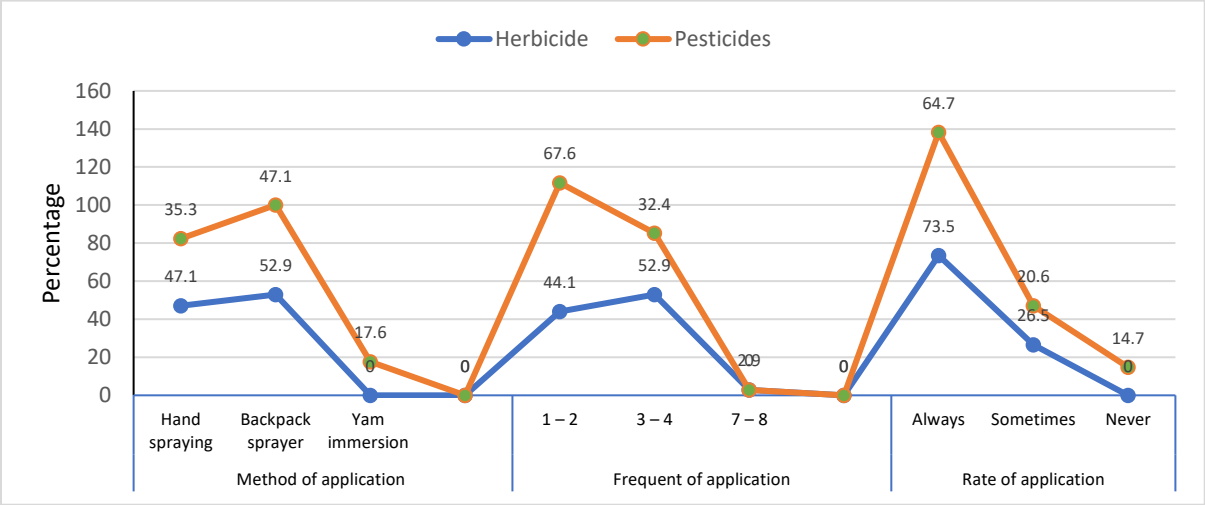

Figure 4: Methods, rates, and timing of herbicide and pesticides application by yam farmers

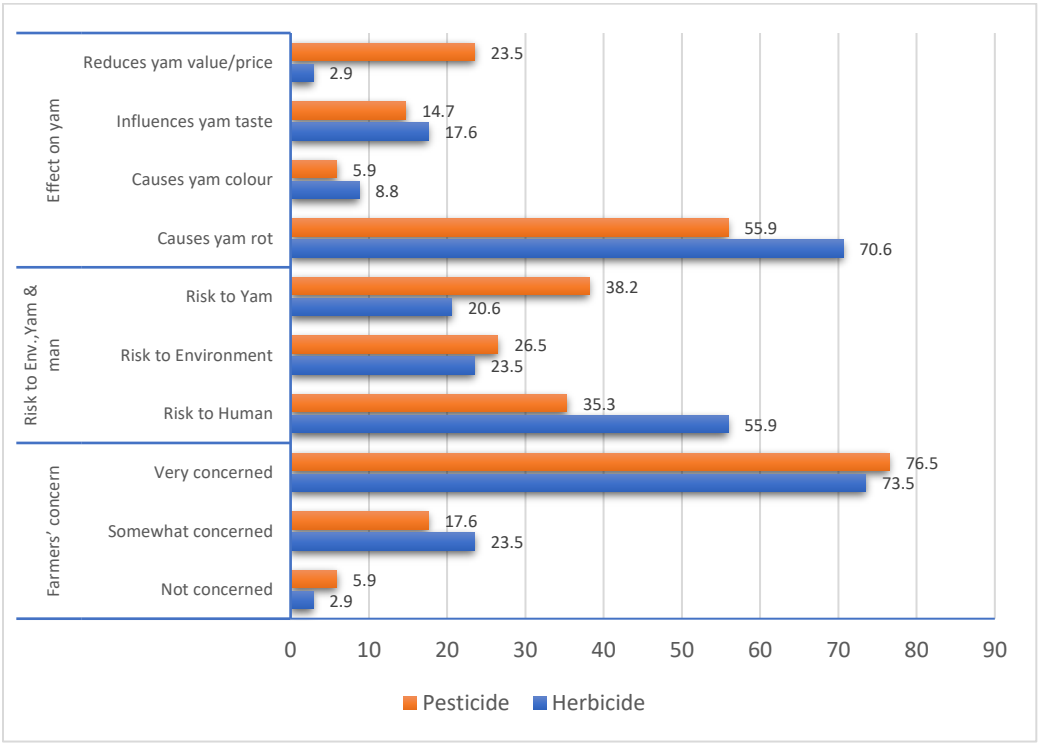

Figure 5: Farmer's concern and perception on the risk and effect of herbicide and pesticides application yam farms

Figure 6 shows the concentrations (mg/g) of herbicide residues in yam tuber samples are as follows: 4.93±0.65 mg/g (Kwande North), 6.76±0.99 mg/g (Kwande West) and 6.78±0.24 mg/g (Kwande South).

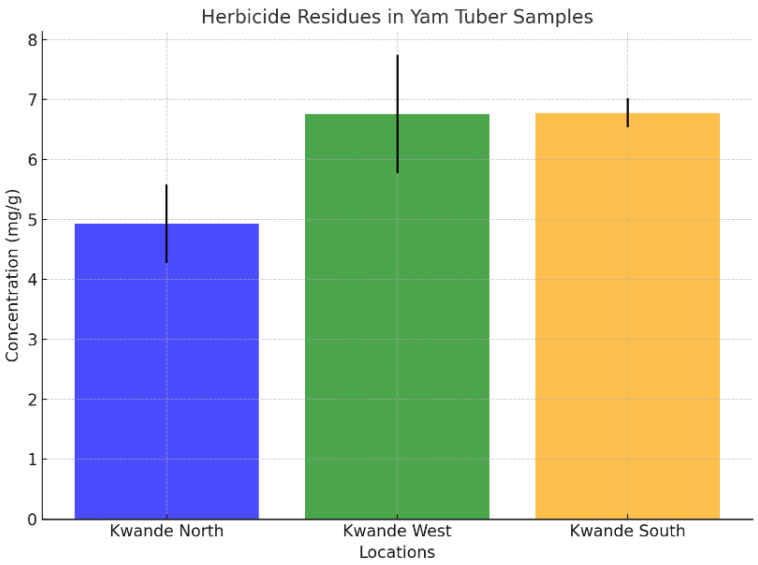

Figure 6: Herbicides residues in Yam tubers sample

The yam tuber samples from Kwande West and Kwande South showed similar herbicide concentrations (6.76 mg/g and 6.78 mg/g, respectively) with relatively small standard deviations, particularly in Kwande South (±0.24), indicating greater consistency among the tubers analyzed. The Rf values of the samples closely matched that of Metazachlor (0.80), suggesting that the detected herbicide is likely Metazachlor or a structurally related compound. Herbicide residues were highest in the Kwande West and Kwande South samples, while the Kwande North samples recorded comparatively lower concentrations. This pattern indicates that Metazachlor or a similar compound was more prevalent in yams from Kwande West and Kwande South, possibly as a result of differences in agricultural practices, herbicide application rates, or local environmental conditions. Thin Layer Chromatography (TLC) profiling of the herbicides Atrazine, Glyphosate, Metazachlor, and Paraquat produced distinct Rf values that were used to compare herbicide residues across the three regions. Quantitative analysis supported these findings, confirming higher herbicide concentrations in the Kwande West and Kwande South samples relative to those from Kwande North.

Table 3: RF from TLC Analysis of the Herbicides in Kwande LGA

Herbicides	Rf (mean ± standard deviation)
Atrazine	0.23±0.01
Glyphosate	0.68±0.02
Metazachlor	0.80±0.02
Paraquat	0.43±0.00

Results are reported in mean ± standard deviation

Quantitative concentration of Pesticide Residues in Yam Tubers Kwande LGA

The quantitative analysis of pesticide residues in yam tubers from Kwande North, Kwande West, and Kwande South revealed varying concentrations of Atrazine, Cypermethrin, Glyphosate, and Chlorpyrifos, measured in milligrams per gram (mg/g) (Figure 7). Mean concentrations were as follows: Kwande North (2.92 ± 0.65 mg/g), Kwande West (8.93 ± 0.99 mg/g), and Kwande South (7.58 ± 0.24 mg/g). Among the sampled regions, pesticide residues were highest in Kwande West, followed by Kwande South, while Kwande North recorded the lowest levels. The relatively large standard deviations in Kwande North (±0.65) and Kwande West (±0.99) suggest considerable variation in residue levels across sub-samples, whereas the smaller deviation in Kwande South (±0.24) indicates more uniform contamination. The Rf values identified Cypermethrin as the predominant pesticide across the samples. The elevated pesticide concentrations, particularly in Kwande West, may reflect more intensive pesticide application in that area, while the lower levels in Kwande North could result from reduced pesticide use or environmental factors limiting chemical uptake by yam tubers.

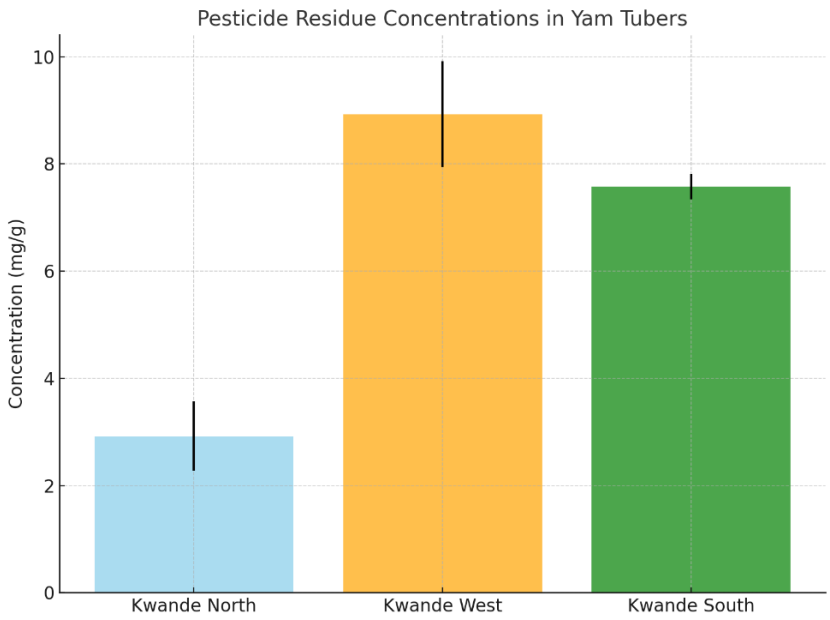

Figure 7: Pesticide residues concentration in yam tubers

Thin Layer Chromatography (TLC) analysis was carried out to determine the retention factors (Rf) of selected pesticides used in Kwande Local Government Area (LGA). The analysis covered four pesticides: Atrazine, Glyphosate (Neem), Cypermethrin, and Chlorpyrifos, each showing distinct Rf values ranging from 0.43 to 0.80. Cypermethrin recorded the highest Rf value (0.80 ± 0.02), indicating greater mobility on the chromatographic plate, while Chlorpyrifos had the lowest value (0.43 ± 0.00), suggesting stronger interaction with the stationary phase. The clear variation in Rf values demonstrates that TLC is effective for identifying and differentiating pesticide residues associated with agricultural activities in Kwande LGA.

Table 4: Result of TLC Analysis of the pesticides used in Kwande LGA

Pesticides	Retention factor (mean ± std)
Atrazine	0.63±0.01
Glyphosate (Neem)	0.47±0.02
Cypermethrin	0.80±0.02
Chlorpyrifos	0.43±0.00

Results are reported in mean ± standard deviation

The TLC results presented in Table 5 show Rf values ranging from 0.79 to 0.82, indicating the presence of compounds with similar chromatographic characteristics, likely corresponding to Cypermethrin or a related pesticide. Quantitative analysis results shown in Table 6 reveal variations in pesticide concentrations among the regions, with the highest level observed in Kwande West (8.93 ± 0.99 mg/g), followed by Kwande South (7.58 ± 0.24 mg/g) and Kwande North (2.92 ± 0.65 mg/g). These findings suggest uneven distribution of pesticide residues across the study sites, which may be attributed to differences in agricultural practices, pesticide application rates, or environmental factors.

Table 5: Retention Factor from of TLC Analysis of the yam tuber samples from Kwande LGA

Sample	Retention Factor (Rf)
Kwande North	0.81±0.01
Kwande South	0.82±0.02
Kwande West	0.79±0.00

Results are reported in mean ± standard deviation

Table 6: Quantitative concentration of Pesticides in Yam Tubers Kwande LGA

Sample	Concentration (mg/g)
Kwande North	2.92±0.65[a]
Kwande West	8.93±0.99[c]
Kwande South	7.58±0.24[b]

Results are expressed as mean ± standard deviation. Values followed by different superscripts indicate significant differences ($p < 0.05$)

Discussion

This study confirms extensive use of herbicides and insecticides in yam production across Kwande North, West, and South, as evidenced by the detection of metazachlor, atrazine, cypermethrin, chlorpyrifos, glyphosate, and paraquat in yam tubers. Similar findings of multiple pesticide residues in root and tuber crops have been reported in southwestern Nigeria (Awoyinka et al., 2019; Akinola et al., 2021) and Ghana (Boateng et al., 2020), indicating that intensive agrochemical use is widespread in tuber-based farming systems in West Africa. Residue analysis using QuEChERS extraction with GC-MS/MS and LC-MS/MS revealed marked spatial variation, with Kwande West recording the highest mean concentrations, followed by Kwande South, while Kwande North showed the lowest levels. These differences likely reflect variations in agrochemical use intensity and local agronomic conditions such as weed pressure and pest incidence, consistent with earlier observations (Awotoye et al., 2012; Morton, 2022).

The analytical approach employed in this study overcomes limitations associated with thin-layer chromatography (TLC) and Rf-based identification, which are prone to ambiguity (Adesiyan & Odihirin, 2021). The use of compound-specific retention times, diagnostic MS/MS transitions, matrix-matched calibration, and acceptable recovery rates (80–110%) supports the reliability of the results and aligns with recommended residue analysis protocols (FAO, 2021). However, the restriction of sampling to a single production season and the lack of assessment of post-harvest degradation represent limitations that warrant consideration in future multiseason studies, given the influence of environmental factors on pesticide persistence (Vegher, 2018).

Comparison with established Maximum Residue Limits (MRLs) indicates that most residues were within or close to Codex and EU thresholds (CAC, 2019; European Commission, 2020). Nevertheless, the relatively higher concentrations observed in Kwande West approach levels of concern, particularly because yam is consumed frequently and in large quantities. The detection of compounds such as chlorpyrifos, atrazine, and paraquat, which are highly regulated or restricted in many jurisdictions, raises concerns regarding cumulative dietary exposure and environmental persistence (Heywood, 2017; Oladipo et al., 2023). The co-occurrence of multiple residues further suggests the potential for additive toxicological effects (Ekwoba et al., (2026).

Farmers' perceptions corroborate these findings, with respondents linking agrochemical use to reduced crop quality, environmental contamination, and adverse health effects. Although farmers demonstrated awareness of these risks, continued reliance on chemical control reflects limited access to effective alternatives and inadequate extension support (FAO, 2021; World Bank, 1999). This highlights the need for improved risk communication and practical interventions.

The adoption of Integrated Pest Management (IPM) offers a viable pathway for reducing pesticide dependence while maintaining productivity (Omoleke et al., 2021). Strategies such as crop rotation, mulching, mechanical weed control, botanical pesticides, and judicious chemical use could substantially reduce residue accumulation. Overall, the findings underscore the need for routine residue monitoring, stronger regulatory enforcement, and wider promotion of IPM-based production systems. Future research should incorporate multi-season sampling and confirmatory analyses using certified reference standards to improve assessment of long-term exposure risks and inform sustainable yam production policies.

CONCLUSION

This study provides evidence of widespread herbicide and pesticide use in yam production across Kwande North, West, and South, as indicated by the detection of metazachlor, atrazine, cypermethrin, chlorpyrifos, glyphosate, and paraquat in yam tubers. Residue analysis using validated QuEChERS extraction with GC-MS/MS and LC-MS/MS revealed significant spatial variation, with Kwande West recording the highest concentrations, followed by Kwande South, while Kwande North showed the lowest levels. These differences reflect variation in agrochemical use intensity and local agronomic conditions. Although most residues were within or close to established Maximum Residue Limits, their occurrence in a staple food crop raises concerns about cumulative dietary exposure and potential long-term health risks, particularly for vulnerable populations. The presence of highly regulated or restricted compounds further highlights environmental and sustainability concerns. Continued reliance on chemical control methods, despite awareness of associated risks, suggests limited access to effective alternatives and inadequate extension support.

Strengthened regulatory oversight, routine residue monitoring, farmer education, and wider adoption of Integrated Pest Management strategies are therefore essential. Further multi-season studies using certified reference standards are recommended to better assess long-term exposure risks and support evidence-based policy for safer and more sustainable yam production systems.

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