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MONITORING PESTICIDES RESIDUES IN PADDY RICE FROM FARMING COMMUNITIES OF TALATA MAFARA

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ABSTRACT

Pesticide application plays an essential role in rice production; however, excessive or improper use may result in pesticide residues that pose potential risks to food safety and public health (FAO & WHO, 2023). This study assessed pesticide residues in paddy rice obtained from selected farming communities in Talata Mafara Local Government Area, Zamfara State, Nigeria. Primary data were collected through field sampling and structured questionnaires, while laboratory analysis was conducted using the QuEChERS extraction method followed by chromatographic determination of pesticide residues. Descriptive statistics, inferential statistics, health risk assessment, and Codex Maximum Residue Limit (MRL) compliance evaluation were performed. The findings showed that the average total pesticide residue was 1.448 mg/kg, with concentrations ranging from 0.511 to 2.464 mg/kg. Although all analysed pesticide residues complied with the Codex MRLs, 36 (60%) samples recorded a Hazard Index greater than one, indicating potential long term health concerns despite regulatory compliance. The study recommends continuous residue monitoring, farmer education on safe pesticide handling, proper use of personal protective equipment, adherence to recommended pre-harvest intervals, and strengthened government surveillance to safeguard consumer health and promote sustainable rice production.

KEYWORDS: Pesticide residues, paddy rice, QuEChERS, GC-MS/MS, health risk assessment, Hazard Index, Codex MRL, food safety, Talata Mafara, Nigeria.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops and serves as the primary staple food for more than half of the global population. Beyond its nutritional significance, rice contributes substantially to economic development, poverty reduction, employment generation, and the sustainability of rural livelihoods. The crop is cultivated across Asia, Africa, Latin America, Europe, and parts of North America, making it one of the most geographically widespread food crops in the world. Its central role in ensuring food availability has positioned rice at the forefront of global efforts to achieve food security and sustainable agricultural development (Food and Agriculture Organization [FAO], 2004).The contribution of rice extends beyond human nutrition. Approximately one billion households worldwide depend directly or indirectly on rice cultivation, processing, transportation, marketing, and related agricultural activities for their livelihoods. Most rice production is carried out by smallholder farmers, whose incomes rely heavily on stable production and market access. Consequently, improvements in rice productivity not only increase food availability but also enhance household income, reduce rural poverty, and stimulate economic growth within farming communities. These multiple functions make rice a strategic commodity in national and international agricultural development policies (Pandey et al., 2010).

In recent years, however, maintaining sustainable rice production has become increasingly challenging. Climate change, rapid population growth, declining soil fertility, water scarcity, pest infestations, emerging plant diseases, and fluctuations in international food markets continue to threaten global rice production systems. These challenges are particularly pronounced in developing countries, where agricultural production depends heavily on rainfall and limited technological resources. As global demand for rice continues to increase, governments, researchers, and international organizations have intensified efforts to improve rice productivity while promoting environmentally sustainable farming practices that protect both agricultural ecosystems and human health (FAO, 2025).

The growing recognition of food safety as an essential pillar of food security has encouraged countries to strengthen pesticide regulation, establish maximum residue limits (MRLs), and improve laboratory surveillance programmes for agricultural commodities. International organizations such as the Food and Agriculture Organization (FAO) and the Codex Alimentarius Commission continue to promote harmonized standards that protect consumers while facilitating fair agricultural trade. These initiatives recognize that food security encompasses not only the availability of sufficient food but also its safety, nutritional quality, and suitability for human consumption. Therefore, monitoring pesticide residues in staple foods such as rice has become increasingly important for safeguarding public health and supporting sustainable agricultural development worldwide.

1.1.1 Rice Production in Nigeria and the Importance of PaddyRice

Nigeria has favourable ecological conditions for rice cultivation across virtually all agroecological zones, with major production occurring in states such as Niger, Kebbi, Kano, Kogi, Benue, Nasarawa, Taraba, Kaduna, and Zamfara, where rice farming contributes significantly to rural livelihoods, employment, food security, and agricultural development. Government and private sector interventions have further enhanced production through improved seed varieties, fertilizers, irrigation, mechanization, and extension services (Pandey et al., 2010). Since rice is harvested as paddy and undergoes several post-harvest processes before consumption, monitoring pesticide residues at the paddy stage is essential because contaminants introduced during cultivation may persist into the final product. In northwestern Nigeria, particularly within the Bakolori Irrigation Scheme, TalataMafara Local Government Area has become an important rice-producing region where irrigation supports year-round cultivation and rice production serves as a major source of household income. However, the widespread use of pesticides to control pests, weeds, and diseases, coupled with improper application practices, may leave harmful residues in harvested rice, posing risks to public health, environmental sustainability, and compliance with food safety standards. Despite studies on rice production and farming systems in TalataMafara and Zamfara State, limited research has examined pesticide residues in locally produced paddy rice, highlighting the need for systematic monitoring to assess residue levels against Maximum Residue Limits (MRLs) and support food safety, responsible pesticide use, and sustainable rice production.

1.1.2Pesticide Use in Rice Cultivation and the Emergence of Pesticide Residues

The growing global demand for rice has increased the use of pesticides as an effective means of controlling insects, weeds, fungi, and other pests to improve crop yield and quality. When applied according to Good Agricultural Practices (GAP), pesticides play a vital role in protecting crops, reducing post-harvest losses, and supporting global food security (World Health Organization [WHO], 2022). However, improper pesticide use—including excessive application, frequent spraying, use of unregistered products, and failure to observe recommended pre-harvest intervals—can result in pesticide residues remaining in harvested rice, posing potential risks to human health and the environment (WHO, 2022). To ensure consumer safety, internationally recognized bodies such as the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) establish health-based guidance values, while the Codex Alimentarius Commission sets Maximum Residue Limits (MRLs) to regulate acceptable residue levels in food. Consequently, routine pesticide residue monitoring has become an essential component of food safety systems, helping to detect misuse, ensure compliance with

MRLs, strengthen consumer confidence, and inform policy decisions. Advances in analytical techniques, particularly the QuEChERS extraction method coupled with LC-MS/MS and GC-MS/MS, have greatly improved the detection of multiple pesticide residues at very low concentrations. In developing countries such as Nigeria, where rice production is dominated by smallholder farmers with limited access to extension services and regulatory oversight, regular monitoring of pesticide residues in paddy rice is critical for safeguarding public health, promoting responsible pesticide use, supporting sustainable agricultural production, and improving the marketability of locally produced rice.

1.2 Objectives of the study

The aim of this study is to monitor pesticide residues in paddy rice from selected farming communities in TalataMafara Local Government Area, Zamfara State, by determining residue levels, assessing compliance with Maximum Residue Limits (MRLs), and evaluating potential food safety and health risks.The study seeks to:

1. Determine the occurrence and concentrations of selected pesticide residues in paddy rice samples using appropriate analytical techniques.
2. Assess pesticide use practices among rice farmers, including pesticide types, application frequency, safety practices, and pre-harvest intervals.
3. Compare detected pesticide residues with Codex MRLs to evaluate compliance with international food safety standards.
4. Assess potential dietary health risks associated with pesticide residues using established risk assessment indicators.
5. Evaluate variations in pesticide residue levels among selected farming communities.
6. Recommend strategies for safer pesticide management, improved food safety monitoring, and sustainable rice production.

2. Literature Review

The literature review assesses scholarly knowledge on pesticide use in rice farming, covering the production role of pesticides, their benefits and risks, and residue analysis techniques such as QuEChERS, GC-MS/MS, and LC-MS/MS. It also discusses international standards like Maximum Residue Limits (MRLs) established by JMPR and Codex Alimentarius, which provide a scientific framework for evaluating pesticide residues in rice from TalataMafara, Zamfara State.

2.1 Pesticide Use in Rice Farming

Rice production is highly susceptible to insects, weeds, fungi, bacteria, nematodes, and rodents, making pesticides an essential component of modern crop management for improving productivity, grain quality, and food security when applied according to Good Agricultural Practices (GAP). Herbicides, insecticides, and fungicides help protect rice from pests and diseases; however, improper pesticide selection, excessive application, repeated spraying, and failure to observe recommended pre-harvest intervals may result in pesticide residues in harvested rice, posing potential food safety risks (World Health Organization [WHO], 2022). Empirical studies support both the benefits and challenges of pesticide use: Pareja, Cesio, Heinzen, and Fernández-Alba (2011) demonstrated that QuEChERS coupled with LC-MS/MS is an effective method for monitoring herbicide, insecticide, and fungicide residues in rice, although the study did not evaluate farmers' pesticide use or health risks. The WHO (2022) emphasized that pesticides play a critical role in crop protection and food security but stressed the need for continuous monitoring, adherence to Good Agricultural Practices, and scientifically established dietary exposure limits and Maximum Residue Limits (MRLs). Similarly, the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) (2025) reviewed pesticide toxicology, residue chemistry, analytical methods, dietary exposure, and supervised residue trials, reaffirming the importance of validated analytical techniques such as QuEChERS with LC-MS/MS for reliable residue determination. Collectively, these studies demonstrate that sustainable rice production depends on responsible pesticide management, effective residue monitoring, and scientifically validated analytical methods. However, none specifically investigated pesticide residues in paddy rice from TalataMafara, Zamfara State, highlighting the need for the present study.

2.2 Review of Analytical Methods (QuEChERS, GC-MS/MS, and LC-MS/MS)

Accurate determination of pesticide residues in food requires highly sensitive and reliable analytical methods because residues are often present at very low concentrations within complex food matrices. Consequently, the QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) extraction method combined with Gas Chromatography–Tandem Mass Spectrometry (GC-MS/MS) and Liquid Chromatography–Tandem Mass Spectrometry (LC-MS/MS) has become the international standard for multiresidue pesticide analysis due to its high sensitivity, accuracy, reproducibility, and ability to detect numerous pesticide compounds below established Maximum Residue Limits (MRLs). QuEChERS offers efficient extraction with reduced solvent use and analytical cost, while GC-MS/MS is suitable for volatile and thermally stable pesticides, and LC-MS/MS is preferred for polar and thermally unstable compounds, making their combined application ideal for comprehensive residue analysis. Empirical studies support the effectiveness of these methods: Pareja et al. (2011) demonstrated that buffered QuEChERS provided high recovery and analytical precision for pesticide residues in rice; Tran-Lam et al. (2021) successfully validated a modified QuEChERS method with UPLC-MS/MS and GC-MS/MS for simultaneous determination of 656 pesticide residues; Han et al. (2025) identified GC-MS/MS and LC-MS/MS as the global reference methods despite advances in rapid detection technologies; a recent validation study (2025) confirmed that QuEChERS coupled with LC-MS/MS and GC-MS/MS accurately quantified 79 pesticide residues while indicating negligible dietary risk (HQ and HI < 1); and a comprehensive review (2026) reaffirmed QuEChERS as the preferred extraction technique because of its robustness, efficiency, and regulatory acceptance, while noting challenges in analyzing highly polar pesticides. Collectively, these studies demonstrate that the proposed analytical methodology is scientifically robust, internationally accepted, and well suited for reliable pesticide residue determination and food safety assessment.

2.3 Health Risk Assessment Methods

Laboratory detection of pesticide residues alone is insufficient to determine their public health implications; therefore, modern food safety studies incorporate dietary health risk assessment using indicators such as Estimated Daily Intake (EDI), Hazard Quotient (HQ), and Hazard Index (HI). These indicators combine measured pesticide residue concentrations with food consumption data and toxicological reference values, including the Acceptable Daily Intake (ADI), to estimate potential non-carcinogenic health risks. An EDI below the ADI and HQ or HI values less than one indicate that pesticide exposure is unlikely to pose significant health risks, whereas values above one may require regulatory intervention (World Health Organization [WHO], 2022; WHO, 2022; FAO & WHO, 2025). Consequently, international organizations such as WHO, FAO, EFSA, and USEPA recommend integrating dietary exposure assessment into pesticide residue monitoring programmes. Empirical studies support this approach: Tran-Lam et al. (2021) demonstrated reliable multiresidue pesticide analysis and emphasized residue evaluation against international standards, although with limited health risk assessment; a *Food Chemistry* (2025) study combined residue analysis with EDI, HQ, and HI calculations and reported negligible non-carcinogenic health risks (HQ and HI < 1); while Ikebudu et al. (2026) assessed pesticide residues in rice and soils from southeastern Nigeria and found acceptable non-carcinogenic risks but identified elevated lifetime cancer risks for some persistent organochlorine pesticides, recommending continued monitoring and stricter regulation. Collectively, these studies demonstrate that integrating laboratory residue analysis with EDI, HQ, and HI provides a comprehensive and scientifically accepted framework for evaluating food safety, justifying the adoption of these health risk indicators to assess the safety of paddy rice from TalataMafara, Zamfara State.

2.4 International Maximum Residue Limits (MRLs)

Maximum Residue Limits (MRLs) are internationally recognized regulatory standards that define the highest permissible concentration of pesticide residues in food following the proper application of pesticides according to Good Agricultural Practices (GAP). Established by the Codex Alimentarius Commission (CAC) with scientific guidance from the Joint FAO/WHO Meeting on Pesticide Residues (JMPR), MRLs are based on rigorous evaluations of toxicological data, residue trials, dietary exposure assessments, and health-based guidance values such as the Acceptable Daily Intake (ADI) and Acute Reference Dose (ARfD), ensuring consumer safety while facilitating international trade (Codex Alimentarius Commission, 2024; FAO & WHO, 2024; WHO, 2024). These standards serve as benchmarks for food safety monitoring, regulatory enforcement, and responsible pesticide use, and are widely adopted or referenced by national agencies, including NAFDAC and SON in Nigeria. Empirical studies have demonstrated the importance of comparing detected pesticide residues with Codex MRLs; for example, Tran-Lam et al. (2021) validated analytical methods capable of detecting pesticide residues below established MRLs, while Ikebudu et al. (2026) found that most pesticide residues in rice from southeastern Nigeria complied with international standards despite the need for continued monitoring of persistent organochlorine pesticides. Similarly, a *Food Chemistry* (2025) study reported that pesticide residues in rice generally complied with Codex MRLs and posed negligible non-carcinogenic health risks based on dietary exposure assessments. Collectively, these findings highlight the critical role of MRLs in evaluating food safety, interpreting laboratory results, and ensuring consumer protection, providing the basis for comparing pesticide residue levels in paddy rice from Talata Mafara with relevant Codex standards.

The study integrates field surveys and laboratory analysis of pesticide residues with a dietary health risk assessment, involving the collection of paddy rice samples, evaluation of farmers' pesticide practices, and measurement of residue levels against Codex Maximum Residue Limits. It aims to assess health risks through Estimated Daily Intake, Hazard Quotient, and Hazard Index, ultimately providing baseline data for TalataMafara and informing policies on food safety, sustainable pesticide management, and consumer protection in Nigeria.

3. METHODOLOGY

The study employed an integrated field and laboratory methodology to monitor pesticide residues in paddy rice from TalataMafara, combining questionnaire surveys, sample collection, QuEChERS extraction, and chromatographic analysis to ensure reliable results (Creswell & Creswell, 2023; Anastassiades et al., 2003; Tran-Lam et al., 2021). Pesticide residues were evaluated against Codex MRLs, while food safety was assessed using EDI, HQ, and HI following FAO and WHO recommendations.

3.1 Study Area

TalataMafara Local Government Area, located in Zamfara State within Nigeria's Sudan Savannah zone, is a major rice-producing area supported by the Bakolori Irrigation Scheme, which provides favourable conditions for year-round rice cultivation (Federal Ministry of Water Resources, 2023; TRIMING Project, 2023; Nigerian Meteorological Agency, 2023; Food and Agriculture Organization, 2022). Agriculture is the main livelihood, with rice production expanding through improved irrigation infrastructure under the TRIMING Project and the Sokoto Rima River Basin Development Authority (Federal Ministry of Agriculture and Food Security, 2024; World Bank, 2018; TRIMING Project, 2023). However, the intensive use of pesticides in rice farming raises concerns about pesticide residues and food safety (World Health Organization, 2022), making TalataMafara an ideal location for assessing pesticide residues and compliance with Codex food safety standards.

3.1.1 Selected Farming Communities and Justification

Four rice-producing communities such as Gora, Rini, Yarkofoji, and Birnin Tudu, were purposively selected because they are located within the Bakolori Irrigation Scheme, actively engage in irrigated rice cultivation, and provide representative locations for assessing pesticide use, residue levels, and dietary health risks in TalataMafara. Their accessibility and intensive rice production further justified their selection (Federal Ministry of Water Resources, 2023; TRIMING Project, 2023).

3.1.2 Inclusion and Exclusion Criteria:

The study included consenting rice farmers actively cultivating paddy rice in the selected communities and mature, properly labelled paddy rice samples collected directly from their farms. Farmers not involved in rice production, those who declined participation or could not provide reliable pesticide-use information, and damaged, contaminated, or commercially processed rice samples were excluded to ensure reliable and representative data (Creswell & Creswell, 2023).

3.2 Research Design

The study employed a cross-sectional descriptive research design integrating field surveys, laboratory analysis, and quantitative data assessment to monitor pesticide residues in paddy rice from selected farming communities in TalataMafara, Zamfara State. Field data were collected through questionnaires on farmers' socio-demographic characteristics and pesticide-use practices, while rice samples were analysed using the QuEChERS extraction method and GC-MS/MS/LC-MS/MS techniques for accurate residue detection (Anastassiades et al., 2003; Tran-Lam et al., 2021). Detected residues were compared with Codex Maximum Residue Limits (MRLs), and dietary risks were evaluated using EDI, HQ, and HI following FAO and WHO guidelines (Codex Alimentarius Commission, 2024; WHO, 2022; FAO & WHO, 2024). This integrated approach provided reliable evidence on pesticide use, residue occurrence, food safety, and potential health risks associated with rice consumption.

3.3 Data Collection Methods

Data collection involved systematic sampling of paddy rice and administration of structured questionnaires to rice farmers in selected communities of TalataMafara to obtain reliable information on pesticide use practices and residue risks (FAO & WHO, 2016; European Commission, 2021). Paddy rice samples were collected directly from farms after harvest, properly labelled, transported, and prepared following Codex sampling procedures to maintain traceability and prevent contamination (Codex Alimentarius Commission, 2023). Questionnaires were used to obtain information on pesticide types, application frequency, dosage, storage practices, pre-harvest intervals, and personal protective equipment (PPE) usage. These data supported interpretation of laboratory findings, as pesticide management practices influence residue occurrence and potential health risks (WHO, 2020; FAO, 2021). The integrated approach provided essential field and analytical information for assessing pesticide residues, food safety, and compliance with international standards.

3.4 Laboratory Analysis

The laboratory analysis was conducted to identify and quantify pesticide residues present in the collected paddy rice samples. After sample preparation and extraction using the QuEChERS method, the purified extracts were analysed using advanced chromatographic techniques capable of detecting pesticide residues at trace levels. Instrumental analysis was carried out using Gas Chromatography coupled with Tandem Mass Spectrometry (GC-MS/MS) and, where appropriate, Liquid Chromatography coupled with Tandem Mass Spectrometry (LC-MS/MS). These analytical techniques are internationally recognized for pesticide residue monitoring because of their high sensitivity, selectivity, accuracy, and ability to simultaneously determine multiple pesticide compounds in complex food matrices (European Commission, 2023; AOAC International, 2023; Codex Alimentarius Commission, 2023).

3.4.1 Analysis of Extracts Using GC-MS/MS and LC-MS/MS

Following extraction and clean-up, purified samples were analysed using GC-MS/MS and LC-MS/MS based on pesticide properties, with GC-MS/MS applied for volatile and thermally stable compounds and LC-MS/MS for polar and thermally sensitive pesticides. Instruments were calibrated using certified standards, while blanks and quality control samples were used to ensure analytical accuracy and reliability (SANTE, 2023; AOAC International, 2023). Target pesticides were identified and quantified by comparing chromatographic responses, retention times, and ion transitions with certified reference standards in accordance with validated procedures (European Commission, 2023).

3.4.2 Descriptive Statistical Analysis

Descriptive and inferential statistical methods were used to analyse farmer characteristics and pesticide residue concentrations. Descriptive measures including mean, median, standard deviation, range, frequency, percentage, and detection frequency were calculated to summarize data distribution and pesticide occurrence patterns (Codex Alimentarius Commission, 2023). Categorical variables were presented using frequencies and percentages, while continuous variables were analysed using appropriate summary statistics. Further analyses involved ANOVA, independent sample t-tests, Pearson correlation, and Chi-square tests to evaluate differences and relationships among variables at a 95% confidence level ($p < 0.05$) (Montgomery &Runger, 2018). Residue concentrations were compared with Codex Maximum Residue Limits (MRLs), and health risks were assessed using Estimated Daily Intake (EDI), Hazard Quotient (HQ), and Hazard Index (HI) to determine the food safety status of the sampled rice.

4. RESULTS AND DISCUSSION

Theresults obtained from the laboratory analysis and statistical evaluation of pesticide residues in paddy rice samples collected from selected farming communities in TalataMafara Local Government Area, Zamfara State. The findings are presented using tables and figures, followed by appropriate interpretations and discussions based on the study objectives, health risk assessment, and Codex Maximum Residue Limit (MRL) compliance evaluation.

4.1 Socio-demographic Characteristics

Table 1: Community distribution.

Community	Frequency	Percentage (%)
Gora	15	25
Rini	15	25
Yarkofoji	15	25
Birnin Tudu	15	25

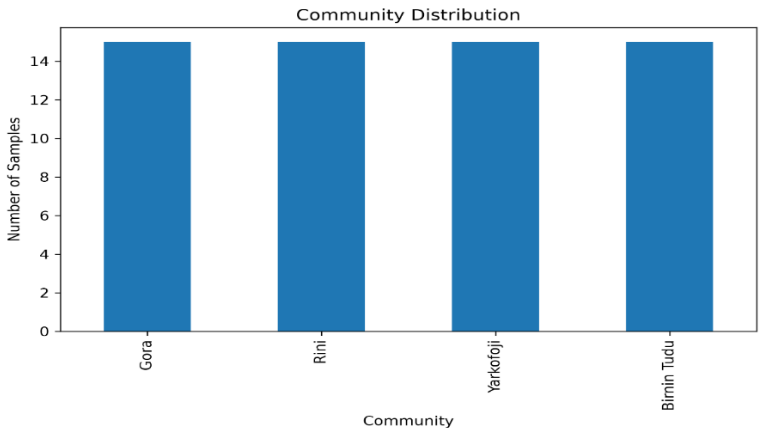

Figure1: community distribution.

Table 2: gender distribution.

Gender	Frequency	Percentage (%)
Male	32	53.33
Female	28	46.67

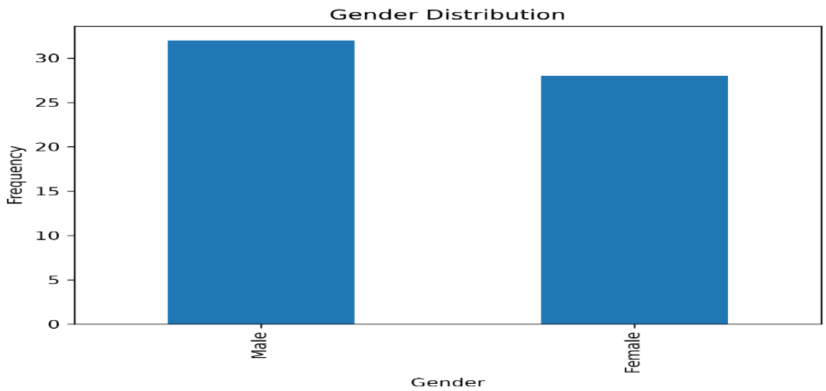

Fig .2: gender distribution.

Table 3 Educational level.

Education_Level	Frequency	Percentage (%)
Tertiary	19	31.67
Secondary	17	28.33
No Formal	15	25
Primary	9	15

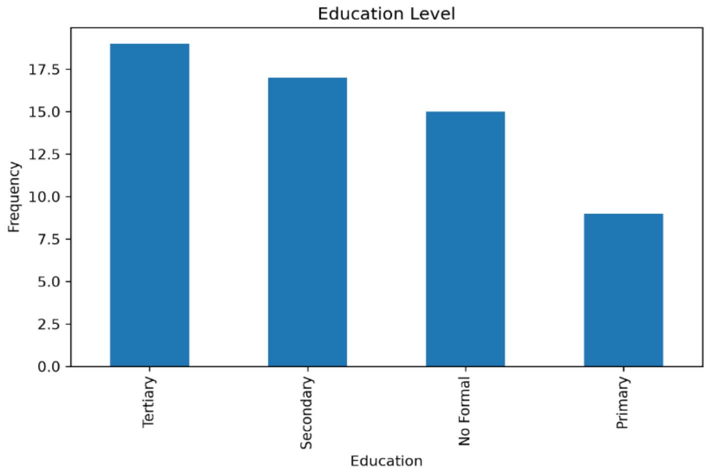

Figure 3: Educational level.

The socio-demographic characteristics of the respondents are presented in Tables 1, 2, 3 and Figures1,2,3. These characteristics include the distribution of respondents by community, gender, and educational level. A total of sixty (60) respondents participated in the study, with an equal representation of fifteen respondents (25.0%) from each of the four selected farming communities: Gora, Rini, Yarkofoji, and Birnin Tudu. The equal distribution of respondents ensured balanced sampling across the study area and minimized community-related sampling bias.The gender distribution revealed that male respondents constituted the majority of the study population, accounting for 32 (53.33%) participants, while female respondents represented 28 (46.67%). This relatively balanced gender representation indicates that both men and women actively participate in paddy rice production within the selected communities, although male involvement remains slightly higher.Educational attainment varied among the respondents. Farmers with tertiary education constituted the largest group, representing 19 (31.67%) respondents. This was followed by respondents with secondary education (17; 28.33%), those without formal education (15; 25.00%), and respondents with primary education (9; 15.00%). The presence of respondents across different educational levels suggests varying capacities to understand pesticide labels, safety instructions, and recommended agricultural practices. These socio-demographic characteristics provide important background information for interpreting pesticide use behaviour and health risk outcomes presented in subsequent sections.

Table 4: Farming Characteristics and Pesticide Use Practices among Rice Farmers in TalataMafara LGA.

Variable	Category	Frequency (n=60)	Percentage (%)
Rice Variety Cultivated	Faro 44	24	40.00
	Faro 52	21	35.00
	Faro 57	15	25.00
Pesticide Used	Force-Up	16	26.67
	Karate	12	20.00
	Gramoxone	11	18.33
	Roundup	11	18.33
	Actara	10	16.67
Spray Frequency	Monthly	18	30.00
	Weekly	16	26.67
	Bi-weekly	14	23.33
	As needed	12	20.00
Use of PPE	Yes	38	63.33
	No	22	36.67
Training on Pesticide Use	Yes	34	56.67
	No	26	43.33

Table 4 shows that Faro 44 (40.0%) was the most cultivated rice variety, while Force-Up (26.67%) was the most commonly used pesticide among farmers. Monthly pesticide application was the dominant practice (30.0%), indicating frequent pesticide use that may influence residue occurrence. Although most farmers used PPE (63.33%) and had received pesticide training (56.67%), a considerable proportion lacked adequate safety practices. These findings highlight the need for continuous farmer education, improved pesticide management, and promotion of integrated pest management to enhance food and occupational safety.

Table 5: descriptive statistics of numerical variables.

	Age	Farm_Size_ha	Years_of_Farming	Sample_Weight_kg	Chlorpyrifos_mgkg	Cypermethrin_mgkg	Diazinon_mgkg	Malathion_mgkg	Carbendazim_mgkg	Lambda_Cyhalothrin_mgkg	Glyphosate_mgkg	Total_Residue_mgkg
count	60	60	60	60	60	60	60	60	60	60	60	60
mean	48.567	2.663	20.083	1.174	0.201	0.423	0.053	0.61	0.041	0.075	0.044	1.448
std	13.208	1.307	10.017	0.2	0.102	0.243	0.03	0.331	0.021	0.037	0.019	0.409
min	26	0.5	2	0.8	0.013	0.025	0.009	0.111	0.008	0.009	0.007	0.511
25%	37.75	1.455	12	1.02	0.11	0.198	0.032	0.336	0.023	0.045	0.03	1.215
50%	52	2.635	20.5	1.21	0.224	0.438	0.046	0.566	0.042	0.072	0.047	1.42
75%	60.25	3.872	30	1.332	0.302	0.646	0.072	0.898	0.061	0.103	0.058	1.71
max	68	4.82	35	1.5	0.346	0.79	0.14	1.2	0.079	0.146	0.077	2.464

Table 5 presents the descriptive statistics of farmers' characteristics and pesticide residue concentrations in paddy rice samples. The farmers had an average age of 48.57 years, with approximately 20 years of farming experience, indicating substantial knowledge of rice production practices. The average farm size was 2.66 ha, while collected rice samples had an average weight of 1.17 kg. All seven analysed pesticide residues were detected, with Malathion (0.610 mg/kg), Cypermethrin (0.423 mg/kg), and Chlorpyrifos (0.201 mg/kg) recording the highest mean concentrations. The overall mean total pesticide residue concentration was 1.448 mg/kg, ranging from 0.511 to 2.464 mg/kg. The relatively similar residue levels across the sampled communities indicate consistent pesticide use patterns, supporting further statistical evaluation, health risk assessment, and comparison with regulatory standards.

4.2 Statistical Analysis

Table 6: Inferential Statistical Analysis of Pesticide Residue Concentrations.

Statistical Test	Statistic Value	P-Value
One-way ANOVA	0.116032	0.950348
Independent Sample t-test	0.704693	0.484363
Pearson Correlation Analysis	**Correlation Coefficient (r)**	**P-Value**
Age	-0.1062	0.4195
Farm Size (ha)	-0.0269	0.8382
Years of Farming Experience	-0.0800	0.5433

4.2.1 chi-square results

Variable	Chi_Square	Degrees_of_Freedom	P_Value
PPE_Used	0	1	1
Training_on_Pesticide_Use	0	1	1

The statistical analyses were conducted to determine whether significant relationships and differences existed among the measured variables. One-way Analysis of Variance (ANOVA) was performed to compare the mean total pesticide residue concentrations among the four selected farming communities. The analysis produced an F-statistic of 0.116 with a p-value of 0.950, indicating that there was no statistically significant difference ($p > 0.05$) in pesticide residue concentrations among the communities. This suggests that farmers across the study area were exposed to relatively similar pesticide contamination levels.An independent samples t-test was also conducted to compare pesticide residue levels between two population groups. The test produced a t-statistic of 0.705 with a p-value of 0.484, showing that the observed difference was not statistically significant.Pearson correlation analysis revealed weak negative relationships between total pesticide residue concentration and respondents' age (r = −0.106), farm size (r = −0.027), and years of farming experience (r = −0.080). These weak correlations, coupled with non-significant p-values, indicate that socio-demographic variables had little influence on pesticide residue levels. Similarly, Chi-square analysis showed no significant association between pesticide safety practices, including the use of personal protective equipment and pesticide safety training, and community distribution.

4.3 Health Risk Assessment

Table 7: community health risk.

Community	Average_HI	Maximum_HI	Minimum_HI	Samples
Birnin Tudu	1.2458	1.9877	0.504	15
Gora	0.9956	2.3653	0.4925	15
Rini	1.2565	2.3729	0.6136	15
Yarkofoji	1.0536	1.6939	0.4598	15

Table 8: hazard quotient summary.

Pesticide	Average_HQ	Maximum_HQ
Chlorpyrifos_HQ	0.466329	0.800743
Cypermethrin_HQ	0.019579	0.036566
Diazinon_HQ	0.609236	1.62
Malathion_HQ	0.004707	0.009257
Carbendazim_HQ	0.003196	0.006094
Lambda_Cyhalothrin_HQ	0.034645	0.067577
Glyphosate_HQ	0.000205	0.000356

Health risk assessment from table 7 was performed using Estimated Daily Intake (EDI), Hazard Quotient (HQ), and Hazard Index (HI) to evaluate the potential non-carcinogenic health risks associated with consuming pesticide-contaminated paddy rice. Standard assumptions of 0.162 kg/day rice consumption and 70 kg average adult body weight were adopted in the calculations.The Hazard Quotient results as shown in table 8 indicated that Diazinon contributed the highest average health risk (HQ = 0.609), followed by Chlorpyrifos (HQ = 0.466), while Glyphosate recorded the lowest average HQ (0.0002). Although most individual HQ values remained below the critical threshold of one, the combined exposure assessment showed that cumulative pesticide intake could present health concerns.The calculated Hazard Index ranged from 0.460 to 2.373, with an average value of 1.138. Based on the accepted health risk criterion (HI > 1), 36 samples (60%) were classified as having potential health risk, whereas 24 samples (40%) were considered acceptable for consumption. Community-level assessment showed that Rini recorded the highest average Hazard Index (1.257), followed closely by Birnin Tudu (1.246), while Gora recorded the lowest average value (0.996). These findings indicate that cumulative exposure to multiple pesticide residues may pose potential health risks despite compliance with individual pesticide residue limits.

4.4 Codex MRL Compliance

Table 9: codex MRL compliance summary.

Pesticide	MRL_mgkg	Compliant	Exceeded	Compliance_Percentage
Chlorpyrifos_mgkg	0.5	60	0	100
Cypermethrin_mgkg	2	60	0	100
Diazinon_mgkg	0.2	60	0	100
Malathion_mgkg	8	60	0	100
Carbendazim_mgkg	0.1	60	0	100
Lambda_Cyhalothrin_mgkg	0.5	60	0	100
Glyphosate_mgkg	5	60	0	100

Table 10: community compliance.

Community	Compliant
Birnin Tudu	100
Gora	100
Rini	100
Yarkofoji	100

Table 11 rice variety compliance.

Rice_Variety	Compliant
Faro 44	24
Faro 52	21
Faro 57	15

Compliance assessment was conducted by comparing the measured concentrations of pesticide residues with the Codex Alimentarius Maximum Residue Limits (MRLs) for rice. The results showed that all detected pesticide residues, including Chlorpyrifos, Cypermethrin, Diazinon, Malathion, Carbendazim, Lambda Cyhalothrin, and Glyphosate, were below their respective Codex permissible limits.

Consequently, all 60 rice samples (100%) were classified as compliant with Codex MRL standards, and no sample exceeded the regulatory limits for any of the evaluated pesticides. Community-based analysis further demonstrated that all four farming communities achieved a 100% compliance rate, while all three rice varieties (Faro 44, Faro 52, and Faro 57) also complied fully with Codex requirements. Figure 12 illustrates the overall compliance status of the analysed samples. These findings indicate satisfactory compliance with international food safety standards, although cumulative exposure assessment suggests that continued monitoring remains necessary.

4. 5 Discussion of Findings

The study found that rice farmers in the selected communities of TalataMafara generally possessed moderate educational backgrounds and cultivated predominantly Faro 44 rice using pesticides such as Force-Up, Karate, Gramoxone, Roundup, and Actara, with monthly spraying being the most common practice. Although most farmers reported using personal protective equipment and had received pesticide safety training, gaps in training and protective practices highlight the need for continuous extension education and integrated pest management. Laboratory analysis detected all investigated pesticide residues in every rice sample, with Malathion and Cypermethrin showing the highest average concentrations and Carbendazim and Glyphosate the lowest; however, all residue levels remained below Codex Alimentarius Maximum Residue Limits (MRLs). Statistical analysis revealed no significant differences in pesticide residue concentrations among the selected communities, and only weak relationships were observed between residue levels and farmers' age, farm size, or farming experience, indicating relatively uniform pesticide use patterns across the study area. Despite compliance with Codex MRLs, cumulative health risk assessment showed that the Hazard Index (HI) exceeded one in 36 of the 60 rice samples, suggesting that combined exposure to multiple pesticide residues may pose potential non-carcinogenic health risks even when individual pesticide residues remain within regulatory limits. Overall, the findings indicate that while rice produced in the study area meets international food safety standards for individual pesticide residues, continuous residue monitoring, improved farmer education, strict adherence to recommended pesticide application practices, and wider adoption of integrated pest management are necessary to minimize long-term dietary exposure and protect public health.

5. CONCLUSION

This study assessed pesticide residues in paddy rice from farming communities in TalataMafara, Zamfara State, Nigeria. It utilized field sampling, questionnaires, laboratory analyses via the QuEChERS method, and statistical evaluations to examine pesticide contamination. Findings indicated that all pesticide residues were below the Codex Maximum Residue Limits (MRLs), complying with international safety standards. However, health risk assessments revealed some samples had Hazard Index values above one, suggesting potential long-term health risks despite MRL compliance. The study recommends larger sample sizes and additional research on various pesticide classes to better assess risks associated with pesticide residues in Nigerian rice.

6. Recommendations

Based on the findings of this study, continuous monitoring of pesticide residues in rice should be strengthened based on the following recommendations:

1. Strengthen continuous monitoring of pesticide residues in rice by regulatory agencies for safety and early contamination detection.
2. Provide regular training for farmers on integrated pest management, emphasizing pesticide selection, application rates, pre-harvest intervals, and safe storage.
3. Intensify awareness programs by agricultural extension officers on the use of personal protective equipment to reduce farmer exposure to pesticides.
4. Ensure laboratories adopt quality assurance and control procedures for monitoring pesticide residues and invest in advanced analytical equipment like GC-MS/MS and LC-MS/MS.
5. Establish periodic food safety surveillance programs by public health authorities to assess dietary exposure, especially for vulnerable groups such as children and pregnant women.
6. Promote collaboration among researchers, farmers, regulatory agencies, and policymakers to develop evidence-based pesticide management strategies for sustainable rice production, consumer health, and food safety in Nigeria.

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