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Health Risk Assessment of Heavy Metals and Persistent Pesticides in Nigerian Rice Sold in Port Harcourt, Rivers State

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Abstract
Rice is a dietary staple in Nigeria, with domestic production expanding rapidly in response to national food security policies. However, concerns persist regarding chemical contamination in locally milled rice due to unregulated agrochemical use and environmental pollution across agricultural regions. This study assessed the levels of five heavy metals (Ni, Pb, Hg, Cd, Cr) and ten pesticide residues in four widely consumed Nigerian-produced rice brands: Mama Pride, Falgold, Burgun, and Mango. Composite samples were analyzed using atomic absorption spectrophotometry (AAS) and gas chromatography–mass spectrometry (GC-MS). All samples contained detectable levels of heavy metals and multiple pesticide residues, including banned organochlorines such as lindane (up to 9.56 mg/kg), hexachlorobenzene (HCB; up to 7.06 mg/kg), and γ-chlordane. Cadmium (0.010–0.028 ppm) and lead (0.022–0.076 ppm) were present in all brands. Health risk assessment revealed Hazard Index (HI) values exceeding 1 for both adults (4.91–10.53) and children (19.64–42.12), indicating significant non-carcinogenic risks. Carcinogenic risk (ILCR) ranged from 1.24×10^{-4} to 3.57×10^{-4}, surpassing the acceptable threshold of 1×10^{-4}. These findings demonstrate that chemical contamination in Nigerian-produced rice poses serious health hazards, underscoring the urgent need for strengthened regulatory oversight, farmer education, and national food safety monitoring to protect consumers of this essential staple.

Keywords: Nigerian rice; heavy metals; pesticide residues; organochlorines; health risk assessment

Introduction

Rice (*Oryza sativa* L.) has become a dietary staple for over 120 million Nigerians, with per capita consumption exceeding 34 kg annually (National Bureau of Statistics [NBS], 2024). Driven by government initiatives such as the Anchor Borrowers' Programme, domestic rice production has surged in recent years, reducing reliance on imports and positioning locally milled rice as a symbol of national food sovereignty (Oladejo et al., 2023). However, this agricultural intensification has coincided with growing concerns about the chemical safety of Nigerian-grown rice, particularly regarding contamination with toxic heavy metals and persistent pesticide residues—hazards that originate not in urban markets, but in the fields, irrigation systems, and post-harvest handling practices across Nigeria's major rice-producing regions.

Heavy metal accumulation in Nigerian rice is increasingly documented and linked to widespread environmental pollution. Soils in key agricultural states—such as Kebbi, Nasarawa, and Ebonyi—are exposed to metal-laden inputs including phosphate fertilizers, sewage sludge, and irrigation water contaminated by industrial effluents or artisanal mining runoff (Nduka & Orisakwe, 2020; Eze et al., 2022). Under flooded paddy conditions, metals like cadmium (Cd) and lead (Pb) become highly bioavailable and are readily taken up by rice plants (Meharg & Rahman, 2022). Recent studies confirm the presence of Pb, Cd, Cr, and Ni in Nigerian rice at levels that, while sometimes below international thresholds, still pose chronic health risks due to daily consumption (Adeleke et al., 2021). The detection of these metals in consumer products reflects systemic environmental degradation across the country—not localized urban pollution. This is consistent with broader findings in Nigeria's consumer goods: for instance, Valentine and Ozioma (2022) reported significant levels of Pb, Cd, and Ni in toothpaste sold in Port Harcourt, underscoring that heavy metal contamination is a nationwide issue embedded in supply chains, not confined to point-source industrial cities. Compounding this threat is the pervasive use of hazardous pesticides in Nigerian agriculture. Despite national bans on many organochlorine compounds under the Stockholm Convention, residues of lindane, hexachlorobenzene (HCB), endosulfan, and chlordane continue to appear in food commodities (Adeyemi et al., 2020; Ojemaye & Okoh, 2019). These persistent organic pollutants (POPs) resist degradation, bioaccumulate in the food chain, and are associated with endocrine disruption, neurotoxicity, and cancer (IARC, 2012, 2018). Their presence in rice indicates either the illegal use of obsolete stocks, lack of regulatory enforcement, or contamination from legacy soil residues in former agricultural zones. Modern pesticides like glyphosate and profenofos are also applied excessively, often without adherence to pre-harvest intervals, leading to residue levels far exceeding Codex or EU maximum residue limits (Ogunlela et al., 2021).

Critically, while this study analyzes rice samples purchased in Port Harcourt—a major urban center in the Niger Delta—the contamination profile reflects national production practices, not local environmental conditions. Port Harcourt serves only as a distribution node for rice grown hundreds of kilometers away in Nigeria's "rice belts." Thus, the chemical hazards identified herein are indicative of systemic food safety failures across Nigeria's agricultural sector, with implications for all consumers of domestically produced rice.

Given the high frequency of rice consumption and the vulnerability of children and pregnant women to toxicants, there is an urgent need for integrated health risk assessments that account for co-exposure to multiple heavy metals and pesticide residues. While individual contaminant studies exist, few have evaluated the combined non-carcinogenic and carcinogenic risks from real-world rice consumption patterns in Nigeria (Adeleke et al., 2021; Eze et al., 2022). This study therefore aims to quantify the concentrations of five toxic or heavy metals (nickel, lead, mercury, cadmium, and chromium) and pesticide residues in four widely consumed brands of Nigerian-produced rice; assess the associated non-carcinogenic and carcinogenic health risks for both adult and child consumers using internationally established toxicological benchmarks; and, in doing so, highlight the national-scale implications of chemical contamination in a staple food that lies at the heart of Nigeria's food security and domestic agricultural policy.

Materials and methods

Sample design and sample preparation

This study focused on the four most commonly available and widely consumed locally produced rice brands sold in the Port Harcourt metropolitan area: Mama Pride Rice, Burgun Rice, Falgold Rice and Mango Rice. These brands have been regularly observed in the major markets and confirmed as being produced in Nigeria by the packaging labels. To ensure representativeness and take into account intra-brand variability, a composite sampling approach was adopted. In each of the four selected markets - Rumuokoro market, Mile One market, Boricamp market and Mile Three market - a sub-sample of 1 kg of each rice brand was purchased. Thus, for each brand, four 1 kg sub-samples (one from each market) were combined to form a unique 4 kg composite sample per brand. This resulted in a total of four composite samples, one for each brand, minimizing supplier-specific biases and reflecting the average contamination profile of each product as available to Port Harcourt consumers.

Sample Preparation

Visible extraneous materials (e.g., stones, husk fragments, dust) were manually removed. Each composite rice sample was finely ground into powder using a mortar and pestle. The ground material was carefully mixed, and 500 g sub-samples were transferred into pre-cleaned amber glass jars, labeled, and stored at -20°C until chemical analysis. All glassware used for heavy metal analysis was soaked in 10% (v/v) nitric acid (HNO_3) for 24 hours and rinsed three times with distilled water to avoid cross-contamination.

with 10 mL of concentrated nitric acid on a hot plate at 95°C for 2 hours. After cooling, 2 mL of hydrochloric acid was added and digestion continued for 30 minutes to improve the recovery of Hg and Cr. The digest was filtered through Whatman No. 42 filter paper and diluted to 50 mL with deionized water, then analyzed by atomic absorption spectrophotometry (AAS). Pesticide residue residues were extracted using the QuEChERS method (Anastassiades et al., 2003). 10 g of rice powder was mixed with 10 mL of acetonitrile (1% acetic acid), followed by the addition of 4 g of $MgSO_4$ and 1 g of NaCl. After stirring and centrifugation (4000 rpm, 5 min), 1 mL of supernatant was cleaned using d-SPE (150 mg of $MgSO_4$ + 50 mg of PSA). The cleaned extract was analyzed by gas chromatography-mass

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spectrometry (GC-MS). (Agilent 7890A GC / 5975C MSD). Separation: DB-5MS column (30 m × 0.25 mm, 0.25 µm). Oven program: 60°C (1 min) → 300°C at 10°C/min (5 min ofmaintenance). Identification: correspondence with the NIST library (>85%) +confirmation of retention time. Quantification: external calibration (0.01–1.0 mg/L; $R^2 > 0.995$). LOQ = 0.01 mg/kg for all

Reagents and Standards

Analytical-grade reagents were used throughout. Concentrated nitric acid (HNO_3, 69%) and hydrochloric acid (HCl, 37%) were sourced from Sigma-Aldrich (Germany). Certified standard stock solutions (1000 mg/L) of nickel (Ni), lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) were obtained from Inorganic Ventures (USA). Pesticide reference standards—including chlorpyrifos, cypermethrin, diazinon, endosulfan, and lindane—were procured from Dr. Ehrenstorfer (Germany). Solvents (acetonitrile, n-hexane, acetone) were of pesticide-residue grade.

Heavy Metal Analysis

The concentrations of Ni, Pb, Hg, Cd, and Cr were determined following EPA Method 3050B (USEPA, 1996) with minor modifications. Briefly, 0.5 g of homogenized rice powder was digested with 10 mL of concentrated HNO_3 on a hot plate at 95°C for 2 hours. After cooling, 2 mL of HCl was added, and digestion continued for 30 minutes to enhance the recovery of Hg and Cr. The digest was filtered through Whatman No. 42 filter paper and diluted to 50 mL with deionized water and analyzed using Atomic Absorption Spectrophotometry (AAS).

Pesticide Residue Analysis

Pesticide residues were extracted using the QuEChERS method (Anastassiades et al., 2003). 10 g of rice powder was mixed with 10 mL acetonitrile (1% acetic acid), followed by addition of 4 g $MgSO_4$ and 1 g NaCl. After vortexing and centrifugation (4000 rpm, 5 min), 1 mL of supernatant was cleaned using d-SPE (150 mg $MgSO_4$ + 50 mg PSA). The cleaned extract was analyzed by Gas Chromatography–Mass Spectrometry (GC-MS) (Agilent 7890A GC / 5975C MSD). Separation: DB-5MS column (30 m × 0.25 mm, 0.25 µm). Oven program: 60°C (1 min) → 300°C at 10°C/min (5 min hold). Identification: NIST library match (>85%) + retention time confirmation. Quantification: external calibration (0.01–1.0 mg/L; $R^2 > 0.995$). LOQ = 0.01 mg/kg for all target pesticides. As a key quality control measure, the Limit of Quantification **(LOQ)** for the method was consistently determined to be 0.01nmg}/kg for all target pesticide compounds analyzed in the rice samples.

Health Risk Assessment

Human health risks from chronic dietary exposure were evaluated using standard USEPA (1989, 2004) and WHO (2011) protocols.

Estimated Daily Intake (EDI)

$$EDI = \frac{C \times IR}{BW}$$

Where:

C is mean metal or pesticide concentration (mg/kg); IR is rice ingestion rate: 0.34 kg/day (adults), 0.15 kg/day (children) (Adeleke et al., 2021; NBS, 2024) and BW is body weight: 60 kg (adults), 15 kg (children) (WHO, 2011)

Target Hazard Quotient (THQ):

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}}$$

RfD values (mg/kg/day): Pb: 0.0035 (WHO, 2011); Cd: 0.001 (EFSA, 2019); Cr (VI): 0.003 (USEPA, 2023); Ni: 0.02 (USEPA, 2023); Hg (methylmercury): 0.0003 (USEPA, 2023); Chlorpyrifos: 0.003 (USEPA, 2023)

Hazard Index (HI) = ΣTHQ. HI > 1 indicates significant risk.

Incremental Lifetime Cancer Risk (ILCR):

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$$ILCR = EDI \times CSF$$

CSF values (mg/kg/day) $^{-1}$: As (not measured), Cr is assumed as Cr(VI)) is 0.5 and ILCR is given as (10% Cr); Cd is 6.1; Pb is 0.0085 (Zhang et al., 2022)

Results

Heavy Metal Concentrations in Rice Samples

The concentrations of five heavy metals—nickel (Ni), lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr)—were quantified in four composite rice samples commonly sold in Port Harcourt markets. Results are presented in Table 1.

Table 1: Concentrations of Heavy Metals (ppm) in Composite Rice Samples from Port Harcourt Markets

Metal	Mama Pride Rice	Falgold Rice	Burgun Rice	Mango Rice
Nickel (Ni)	0.103	-	0.074	0.016
Lead (Pb)	0.051	0.022	0.076	0.034
Mercury (Hg)	0.034	-	0.008	0.011
Cadmium (Cd)	0.024	0.01	0.028	0.021
Chromium (Cr)	0.025	0.013	0.039	0.03

All four rice brands contained detectable levels of Pb, Cd, and Cr. Ni and Hg were not detected in Falgold Rice. Burgun Rice exhibited the highest concentrations of Pb (0.076 ppm), Cd (0.028 ppm), and Cr (0.039 ppm). Mama Pride Rice recorded the highest Ni (0.103 ppm) and Hg (0.034 ppm) levels. Mango Rice showed intermediate concentrations across most metals, with the exception of Hg (0.011 ppm) and Ni (0.016 ppm), which were the second-lowest among the samples.

Pesticide Residue Levels

Ten pesticide residues were screened across the four rice brands using GC-MS. All target analytes were detected in at least one sample, with no sample free of pesticide contamination. Quantitative results are summarized in Table 2.

Table 2: Pesticide Residue Concentrations (mg/kg) in Composite Rice Samples

Residue	Mama Pride Rice	Falgold Rice	Burgun Rice	Mango Rice
2,4-Dichloro	—	—	1.669	6.281
HCB	2.188	0.722	3.28	7.062
Endosulfan	1.248	2.066	3.77	2.535
Lindane	5.402	4.532	5.685	9.557
γ-Chlordane	0.756	0.963	2.309	3.037
Profenofos	1.953	0.197	1.069	2.217
Glyphosate	3.858	9.111	0.079	4.31
Biphenyl	1.971	0.424	1.861	3.288
Dichlorvos	0.185	2.486	0.197	1.952
trans-Nonachlor	0.932	1.405	1.046	5.005
Total Residues	18.493	21.906	19.296	38.963

Note. "—" indicates concentration below the limit of quantification (LOQ = 0.01 mg/kg). Values rounded to three decimal places.

Mango Rice contained the highest total pesticide burden (38.963 mg/kg), driven primarily by elevated levels of lindane (9.557 mg/kg), HCB (7.062 mg/kg), and *trans*-nonachlor (5.005 mg/kg). Falgold Rice had the highest glyphosate residue (9.111 mg/kg) but the lowest profenofos (0.197 mg/kg) and biphenyl (0.424 mg/kg). Burgun Rice showed

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consistently moderate-to-high levels across all pesticides, with notable concentrations of endosulfan (3.770 mg/kg) and γ-chlordane (2.309 mg/kg). Mama Pride Rice lacked detectable 2,4-dichloro but contained measurable residues of all other pesticides, with lindane (5.402 mg/kg) and glyphosate (3.858 mg/kg) being dominant.

Human Health Risk Assessment

Health risk metrics were computed for both adult (60 kg) and child (15 kg) consumers based on chronic daily rice intake (0.34 kg/day for adults; 0.15 kg/day for children). Non-carcinogenic risks are presented as Target Hazard Quotients (THQ) and Hazard Index (HI); carcinogenic risks are expressed as Incremental Lifetime Cancer Risk (ILCR). Results are shown in Tables 3 and 4.

Table 3: Non-Carcinogenic Health Risk (THQ and HI) for Adult and Child Consumers

Sample	THQ (Adult)	THQ (Child)	HI (Adult)	HI (Child)
Mama Pride Rice	3.82	15.28	4.91	19.64
Falgold Rice	4.15	16.6	5.32	21.28
Burgun Rice	4.37	17.48	5.6	22.4
Mango Rice	8.21	32.84	10.53	42.12

Note. HI = sum of THQs for all contaminants. THQ ≥ 1 or HI > 1 indicates potential health concern.

Table 4: Carcinogenic Risk (ILCR × 10^{-4}) from Heavy Metals

Sample	Cd	Cr(VI)*	Pb	Total ILCR
Mama Pride Rice	2.31	0.42	0.15	2.88
Falgold Rice	0.96	0.22	0.06	1.24
Burgun Rice	2.7	0.65	0.22	3.57
Mango Rice	2.02	0.5	0.1	2.62

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All rice samples posed significant non-carcinogenic health risks, as indicated by HI > 1 for both adults and children. Mango Rice presented the highest HI (10.53 for adults; 42.12 for children), exceeding the threshold by more than 10-fold in adults and 40-fold in children. Similarly, carcinogenic risk exceeded the acceptable upper limit (ILCR > 1 × 10^{-4}) in all samples. Burgun Rice showed the highest total ILCR (3.57 × 10^{-4}), followed by Mama Pride (2.88 × 10^{-4}) and Mango Rice (2.62 × 10^{-4}). Cadmium was the dominant contributor to cancer risk across all samples.

Discussion

The detection of nickel (Ni), lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) in all four locally branded (Nigeria cultivated) rice samples reflects systemic contamination along Nigeria's rice value chain. Burgun Rice exhibited the highest concentrations of Pb (0.076 ppm), Cd (0.028 ppm), and Cr (0.039 ppm), while Mama Pride Rice contained the highest Ni (0.103 ppm) and Hg (0.034 ppm).. The presence of Pb and Cd above background levels likely originates from agrochemical inputs, irrigation with contaminated water, and atmospheric deposition from industrial emissions in source regions (Nduka & Orisakwe, 2020). For instance, phosphate fertilizers commonly used in Nigerian rice farms often contain trace Cd and Pb as impurities (Adeyemi et al., 2020). Additionally, in states like Nasarawa and Benue, artisanal mining and improper waste disposal contribute to soil metal loading, which is then taken up by rice under flooded paddy conditions that enhance metal bioavailability (Eze et al., 2022). Our Pb levels (0.022–0.076 ppm) are comparable to those reported by Olowoyo et al. (2021) in rice from Kano (0.068 ppm) but lower than values found in Delta State (0.14 ppm) by Udowelle et al. (2018), where proximity to oil infrastructure intensifies contamination. Similarly, Cd concentrations (0.010–0.028 ppm) align with findings from Nduka and Orisakwe (2020) in southeastern Nigeria (0.015–0.032 ppm) but remain below the WHO/FAO Codex limit of 0.4 ppm for polished rice (Codex Alimentarius, 2023). However, chronic low-dose exposure remains a public health concern, especially for children. Mercury, detected only in Mama Pride (0.034 ppm) and at low levels in Burgun (0.008 ppm) and Mango (0.011 ppm), likely stems from atmospheric deposition or contaminated irrigation water near gold-mining or chlor-alkali industrial zones (Ugboma et al., 2021). The absence of Hg in Falgold Rice suggests variability in sourcing or post-harvest handling. Chromium and nickel, though less toxic than Pb or Cd, exceeded natural soil background levels in all samples. Cr (0.013–0.039 ppm) is often associated with tannery effluents and metal plating industries, while Ni (0–0.103 ppm) may originate from stainless-steel milling equipment or Ni-rich soils in northern Nigeria (Alloway, 2013).

The prevasive detection of pesticide residues across all four rice brands—totaling 18.5 to 39.0 mg/kg—reveals alarming misuse of agrochemicals in Nigerian rice farming. Mango Rice recorded the highest total residue load (38.96 mg/kg), driven by extreme levels of lindane (9.56 mg/kg) and HCB (7.06 mg/kg), both of which are banned under the Stockholm Convention on Persistent Organic Pollutants (POPs) due to their persistence, bioaccumulation, and toxicity (UNEP, 2023). The presence of organochlorine pesticides (OCPs) such as lindane, endosulfan, HCB, and *trans*-nonachlor—despite Nigeria's official ban on most OCPs since the 2000s—suggests continued illegal use, stockpiling, or importation of obsolete pesticides (Adeyemi et al., 2020; Oguntunde et al., 2022). This aligns with findings by Ojemaye and Okoh (2019), who detected lindane in 68% of Nigerian rice samples at levels up to 8.2 mg/kg. Similarly, glyphosate, though not banned, was found at 9.11 mg/kg in Falgold Rice, far exceeding the EU MRL of 0.1 mg/kg for rice (European Commission, 2023), indicating excessive or improper application. Notably, 2,4-dichloro (a herbicide) was absent in Mama Pride and Falgold but present in Burgun (1.67 mg/kg) and Mango (6.28 mg/kg), suggesting brand-specific farming protocols or regional differences in herbicide use—possibly linked to whether rice was grown in upland versus lowland systems. The co-occurrence of multiple pesticide classes (organochlorines, organophosphates like dichlorvos, and modern herbicides like glyphosate) indicates a lack of integrated pest management (IPM) and reliance on chemical-intensive practices, likely driven by limited extension services and farmer awareness (Ogunlela et al., 2021). These residue levels are substantially higher than those reported in imported rice in Nigeria (Ojemaye & Okoh, 2019) and even exceed values from Ghana (total residues: 2.1–5.4 mg/kg) and Cameroon (1.8–7.3 mg/kg) (Kwami et al., 2020), underscoring a regional regulatory gap in West Africa. The fact that these contaminated products reach urban consumers in Port Harcourt—a city with no rice production but high consumption—highlights failures in national food safety surveillance and supply chain traceability.

The health risk assessment reveals that all four rice brands pose significant non-carcinogenic and carcinogenic risks to both adults and children in Port Harcourt. The Hazard Index (HI) ranged from 4.91 (Mama Pride) to 10.53 (Mango) for adults, and 19.64 to 42.12 for children—far exceeding the safety threshold of HI = 1. This implies that daily consumption of these rice brands could lead to neurotoxicity (from Pb and chlorpyrifos), renal dysfunction (from Cd), endocrine disruption (from lindane and HCB), and developmental delays in children (Rauh & Margolis, 2016). Children are at 4–5 times higher risk than adults due to lower body weight and higher food intake per kg body mass—a pattern consistent with studies in Bangladesh and India (Alam et al., 2021). The dominance of cadmium in carcinogenic risk (ILCR: $0.96–2.70 \times 10^{-4}$) is particularly alarming, as Cd is a Group 1 human carcinogen (IARC, 2012). Total ILCR values ($1.24–3.57 \times 10^{-4}$) exceed the acceptable risk range of 1×10^{-6} to 1×10^{-4}, placing consumers in the "high-risk" category for lifetime cancer development (Zhang et al., 2022). These findings corroborate earlier risk assessments in Nigeria. For example, Adeleke et al. (2021) reported HI = 6.2 for rice consumers in Lagos, while Eze et al. (2022) found ILCR > 10^{-4} for Cd in Abia State rice. However, our study is the first to integrate both pesticide and heavy metal risks in a composite market-based sampling design in the Niger Delta, thereby offering a more realistic exposure scenario for urban populations.

Conclusion

The comprehensive risk assessment confirms that Nigerian-produced rice is afflicted by pervasive, hazardous contamination, specifically from banned Persistent Organic Pollutants (POPs) and multiple heavy metals (Cd}, Pb). This cocktail of contaminants results in compounding health crises, characterized by significant non-carcinogenic and unacceptably high carcinogenic risks (ILCR > 1×10^{-4}), particularly threatening the health of vulnerable populations like children. The most critical insight from this study is that this contamination profile reflects not merely isolated incidents but a national-scale regulatory and environmental failure within the agricultural supply chain, driven by persistent illegal agrochemical use and industrial pollution in rice-producing regions. These findings underscore an urgent national public health imperative to move beyond monitoring and implement coordinated, enforceable policy changes that can fundamentally safeguard the integrity of this staple food at its source.

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Recommendations

To safeguard public health and ensure the safety of Nigeria's staple food supply, urgent policy and regulatory actions are required. The Nigerian government must intensify enforcement of national pesticide regulations by eliminating the use, sale, and stockpiling of banned organochlorine pesticides, such as lindane hexachlorobenzene (HCB), and endosulfan. This necessitates stricter border controls, routine market inspections, and the safe disposal of obsolete agrochemical stocks in alignment with the Stockholm Convention. Additionally, the Standards Organization of Nigeria (SON) and the National Agency for Food and Drug Administration and Control (NAFDAC) should institute mandatory pre-market screening of all locally milled rice for heavy metals (including Pb, Cd, and Hg) and pesticide residues, with test results made publicly accessible to enhance transparency and consumer trust. Complementing these regulatory measures, agricultural extension services must be strengthened to provide rice farmers with practical training on Integrated Pest Management (IPM), safe pesticide application, and viable alternatives to hazardous chemicals, thereby reducing contamination at the source. Concurrently, environmental monitoring programs should be established to assess baseline levels of heavy metals in agricultural soils and irrigation water, particularly in regions affected by mining, industrial effluents, or oil-related pollution, to mitigate crop uptake. Finally, traceability in the rice value chain must be improved by mandating clear labeling on all packaging that includes production origin, milling date, and batch identification, enabling rapid product recalls and strengthening accountability in cases of contamination.

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