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ARTICLE

Assessment of Antinutrients, Heavy Metals, and Microbial Load in Street-Vended Foods from Port Harcourt, Nigeria

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ABSTRACT

Street-vended foods are a vital source of affordable nutrition for many urban dwellers but can pose serious public health risks due to several factors. This study evaluated antinutrient levels, heavy-metal contamination, and microbiological quality of *abacha*, tapioca, roasted plantain, fried yam, and *okpa* sold at key commercial areas in Port Harcourt. A stratified cross-sectional design was used, with 225 samples (15 per food type per site) collected from Eleme Junction, Artillery, and Waterlines. Antinutrients were determined spectrophotometrically, while heavy metals were analysed using inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectrophotometry (AAS). Microbiological quality was assessed through total viable count (TVC), bacterial, coliform, and fungal counts expressed as $\log_{10}$ cfu/g. *Abacha* from Artillery showed the highest phytate (5.02 ± 0.21 mg/g) and tannin (3.28 ± 0.16 mg/g), while *okpa* from the same site had the highest saponin (3.02 ± 0.18 mg/g). Tapioca from Eleme Junction recorded the highest oxalate (2.56 ± 0.14 mg/g). Heavy-metal analysis revealed that roasted plantain from Artillery had the highest Pb level (176.4 ± 4.2 µg/kg), far above the WHO/FAO limit of 100 µg/kg; Cd (38.5–62.7 µg/kg) and As (45.6–58.3 µg/kg) also exceeded permissible limits, while Fe and Zn levels were relatively high. Microbiological

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findings showed TVC values ranging from 3.25–7.42 log_{10} cfu/g, with roasted plantain from Artillery recording the highest bacterial load, and coliforms most prevalent in *abacha*. Overall, foods sold at Artillery demonstrated the greatest contamination, highlighting the urgent need for stronger regulatory inspection and improved vendor hygiene training.
Keywords: Roadside Foods; Antinutrient; Heavy Metals; Microbial Quality; Food Safety; Port Harcourt

1. Introduction

Food safety remains a major global public health concern, with foodborne diseases affecting an estimated 600 million people annually and causing significant morbidity and mortality worldwide [1]. In many developing countries, including Nigeria, the speedy growth of urban populations has increased dependence on street-vended foods, which are appreciated for their affordability, accessibility, and cultural relevance [2].

Street-vended foods constitute an essential component of urban food systems in Nigeria, particularly in rapidly growing cities such as Port Harcourt, where they provide affordable, accessible, and culturally significant meals to diverse populations [3]. These foods are widely consumed by low- and middle-income earners, students, and travelers due to their convenience and cheapness. Popular roadside foods, including *Abacha* (African salad), tapioca, roasted plantain, fried yam, and *okpa* (Bambara nut pudding), hold strong cultural relevance and are integral to local dietary practices [4,5]. However, the preparation and sale of these foods frequently occur in environments that lack adequate sanitation infrastructure, exposing them to environmental pollutants, unhygienic handling practices, and insufficient regulatory oversight. Consequently, these factors increase the potential risk of chemical contamination and microbiological hazards, raising significant public health concerns [6,7].

Antinutritional factors, including phytates, tannins, oxalates, and saponins, are naturally occurring compounds in plant-derived foods that can reduce nutrient absorption and bio-availability [8]. Although some of these compounds exhibit beneficial physiological properties, such as antioxidant and disease-preventive effects when consumed in low concentrations, their excessive presence may lead to micro-nutrient deficiencies, particularly in populations dependent on diets rich in carbohydrates and legumes. Many street-vended foods, commonly prepared from cereals, legumes, and tubers, therefore present a dual nutritional profile, for instance, while they provide energy, cultural relevance, and convenience, they may also contain high levels of antinutritional compounds, especially when processing and preparation techniques are inadequate [9,10].

Heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), are non-biodegradable environmental contaminants that pose significant health risks when accumulated in the human body. Prolonged exposure to these toxic metals has been associated with neurological impairment, renal dysfunction, developmental abnormalities, and carcinogenesis [11–13]. Conversely, essential trace metals such as iron (Fe), zinc (Zn), and copper (Cu) play vital physiological roles but can become toxic when present at elevated concentrations [14]. In urban environments, the contamination of street-vended foods with heavy metals is frequently attributed to multiple factors, including vehicular emissions, industrial discharges, the use of contaminated water during preparation, and leaching from cooking and storage utensils [15,16].

Street-vended food contamination can arise from poor hygiene practices, inadequate storage or preparation methods, and is caused by pathogens such as coliforms, fungi, and high bacterial, leading to foodborne illnesses [2,17]. The total viable count (TVC) provides an overall estimate of microbial load and food quality [18]. High TVC values indicate poor hygiene, contamination from handlers, exposure to flies, dust, and cross-contamination during preparation or serving [19]. According to Makinde et al. [20], high microbial loads in ready-to-eat foods are associated with outbreaks of foodborne illnesses.

Previous studies in Port Harcourt have mostly assessed either the chemical or microbiological quality of street foods in isolation. However, few studies have concurrently evaluated antinutritional factors, heavy metal residues, and microbial loads within multiple selling locations. This study therefore fills this gap by affording an all-inclusive assessment of the nutritional risks and contamination profiles of selected street-vended foods from some locations in Port Harcourt. The findings aim to inform public health policy, enhance food safety inspection, and promote hygienic vending practices in urban cities in

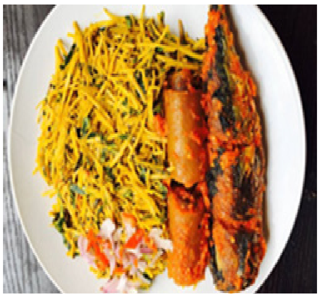
Nigeria.

2. Materials and Methods

2.1. Study Design and Sampling

A stratified cross-sectional survey was conducted across three major commercial locations within Port Harcourt Metropolis (Eleme Junction, Artillery, and Waterlines) between March and May 2024, corresponding to the late dry season when street food sales are at peak levels. These locations were selected based on their high population density, traffic volume, and prevalence of roadside food vending.

Five commonly consumed street-vended foods (**Figure 1**) were selected for this study: *abacha* (African salad), tapioca, roasted plantain, fried yam, and *okpa* (Bambara nut pudding). Vendor selection was based on specific inclusion criteria: (i) daily operation for at least six months preceding the study, (ii) consistent customer patronage, and (iii) sale of freshly prepared food items displayed openly. Vendors operating near major roads and bus stops were prioritised to capture potential environmental exposure to contaminants.



(**a**) *Abacha*.

(**b**) *Okpa*.

(**c**) Roasted plantain.

(**d**) Roasted yam.

(**e**) Tapioca.

Figure 1. Five consumed street-vended foods.

A total of 225 samples were collected, that is, 15 independent samples per food item per area (5 foods × 3 areas × 15 replicates). Each food portion (150–300 g) was purchased aseptically during peak sales hours (10:00 a.m.–5:00 p.m.) to represent typical consumer exposure. Samples were placed in sterile, food-grade polyethylene containers, labeled appropriately, and transported in insulated coolers containing ice packs to the laboratory within 2 h of collection.

Prior informed consent was obtained verbally from all participating vendors after explaining the purpose of the study, confidentiality measures, and non-regulatory nature. Ethical approval for the study was granted by the Ignatius Ajuru University of Education Research and Ethics Committee (Approval No.: IAUE/FNAS/REC/24/003) in compliance with the Helsinki Declaration (2013) on research involving human participants.

2.2. Sample Processing

Upon receipt, samples were homogenized. Portions for microbiology were processed within 6 hours; portions for chemical and antinutrient analyses were frozen at −20 °C until analysis.

2.3. Antinutrient Analyses

Antinutrient assays were performed on dried, ground samples using standard spectrophotometric methods as reported by Udousoro and Akpan [21]: phytate (Wade reagent), oxalate (acid extraction and titration), tannin (Folin–Denis or vanillin-HCl), saponin (vanillin–sulphuric acid colorimetry). Blanks, matrix spikes and duplicates were included.

2.4. Heavy Metal Analysis

Sample portions (1.0 g) were subjected to microwave-assisted digestion using concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). The resulting digests were analysed for Pb, Cd, As, Hg, Cu, Zn, and Fe employing inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectrometry (AAS). Metal concentrations were expressed as µg/kg (wet weight) and compared against FAO/WHO Codex Alimentarius (2022) permissible limits. EDI and HQ values for Pb, Cd, and As (based on local consumption patterns or daily intake data) were calculated using the standard formulas to demonstrate whether the measured levels pose a real risk to consumers.

2.5. Quality Assurance and Quality Control (QA/QC)

Robust quality assurance and quality control (QA/QC) procedures were applied throughout the analytical workflow to guarantee data reliability, precision, and traceability. All instruments were calibrated using multi-element standard solutions (Merck, Germany) covering the expected concentration ranges for each analyte. Calibration curves were constructed using at least five concentration levels ($R^2 \geq 0.999$), and calibration verification standards were analysed every ten samples to confirm instrument stability.

Procedural blanks, duplicate samples, and certified reference materials (CRMs; NIST SRM 1577c, bovine liver) were incorporated into each analytical batch. Procedural blanks and CRMs were analysed after every ten samples to check for contamination and validate method performance. Recoveries for all metals ranged from 92.4% to 106.7%, which falls within internationally acceptable limits for trace metal analysis.

Limits of detection (LOD) and limits of quantification (LOQ) were determined as three and ten times the standard deviation of the blank signal, respectively. The LODs ranged from 0.002–0.010 mg/kg, while the LOQs ranged from 0.006–0.032 mg/kg. Replicate analyses produced relative standard deviations (RSDs) below 5%, confirming excellent analytical precision.

All glassware and plasticware were pre-cleaned with 10% (v/v) nitric acid and rinsed with deionised water before use to prevent contamination. Quality control data were continuously evaluated to ensure the validity and reproducibility of all analytical results.

2.6. Microbiological Quality Analysis

Microbiological quality was determined using the standard plate count technique as described by ISO 4833-1:2013 to estimate Total Viable Count (TVC), bacterial load, coliform count, and fungal count. Serial dilutions (10^{-1}–10^{-6}) of homogenised food suspensions were prepared in sterile peptone water. The homogenised food suspensions are: (1) plated on Plate Count Agar (PCA) and incubated at 37 °C for 48 h to obtain the Total Viable Count (TVC), (2) plated on MacConkey agar and incubated at 37 °C for 24 h obtain the Coliform Count, and (3) plated on Potato Dextrose Agar (PDA) supplemented with chloramphenicol and incubated at 28 °C for 72 h to estimate the Fungal Count. Colonies were counted and expressed as $\log_{10}$ colony-forming units per gram (cfu/g).

2.7. Statistical Analysis

Data were analysed using SPSS version 25. Descriptive statistics were computed, and group differences were evaluated with the Kruskal–Wallis test followed by Dunn's post hoc comparisons with Bonferroni adjustment. Associations between variables were assessed using Spearman's rank correlation coefficient. Statistical significance was established at $p < 0.05$.

3. Results

3.1. Antinutrient Profile of Selected Roadside-Vended Foods

The antinutrient contents of the five street-vended foods across locations are presented in **Table 1** and **Figure 2**. One-way ANOVA revealed significant location-based differences in phytate ($F = 8.41$, $p < 0.01$, $\eta^2 = 0.12$), oxalate ($F = 6.23$, $p < 0.05$, $\eta^2 = 0.10$), and tannin ($F = 7.35$, $p < 0.05$, $\eta^2 = 0.11$). Saponin levels varied marginally among sites ($p = 0.09$). *Abacha* from Artillery recorded the highest phytate (5.02 ± 0.14 mg/g) and tannin (3.28 ± 0.11 mg/g), while *okpa* showed elevated saponin (3.02 ± 0.10 mg/g). Tapioca from Eleme Junction had the highest oxalate content (2.56 ± 0.12 mg/g). These values fall within tolerable limits for traditional plant-based foods but suggest potential interference with mineral bioavailability if consumed excessively.

Table 1. Antinutrient Composition (mg/g) of Selected Roadside-Vended Foods by Location (n = 225).

Food Item	Location	Phytate (mg/g)	Oxalate (mg/g)	Tannin (mg/g)	Saponin (mg/g)
Abacha (African salad)	Eleme Junction	4.65 ± 0.11	2.01 ± 0.07	3.05 ± 0.08	2.05 ± 0.06
	Artillery	5.02 ± 0.14	2.12 ± 0.09	3.28 ± 0.11	2.18 ± 0.08
	Waterlines	4.72 ± 0.10	2.02 ± 0.08	3.12 ± 0.09	2.10 ± 0.07
Tapioca	Eleme Junction	3.50 ± 0.09	2.56 ± 0.12	2.25 ± 0.07	2.00 ± 0.05
	Artillery	3.40 ± 0.08	2.30 ± 0.11	2.18 ± 0.06	1.97 ± 0.05
	Waterlines	3.36 ± 0.07	2.40 ± 0.10	2.20 ± 0.06	1.98 ± 0.05
Roasted Plantain	Eleme Junction	2.28 ± 0.07	1.60 ± 0.06	1.80 ± 0.05	1.25 ± 0.04
	Artillery	2.35 ± 0.08	1.57 ± 0.07	1.84 ± 0.05	1.22 ± 0.04
	Waterlines	2.30 ± 0.08	1.58 ± 0.07	1.82 ± 0.05	1.23 ± 0.04
Fried Yam	Eleme Junction	2.78 ± 0.09	1.70 ± 0.06	1.66 ± 0.05	1.58 ± 0.05
	Artillery	2.74 ± 0.08	1.65 ± 0.05	1.63 ± 0.06	1.55 ± 0.05
	Waterlines	2.73 ± 0.09	1.64 ± 0.06	1.64 ± 0.06	1.56 ± 0.05
Okpa	Eleme Junction	3.68 ± 0.10	1.15 ± 0.05	2.58 ± 0.07	3.00 ± 0.10
	Artillery	3.64 ± 0.11	1.12 ± 0.05	2.55 ± 0.07	3.02 ± 0.10
	Waterlines	3.63 ± 0.10	1.10 ± 0.05	2.56 ± 0.07	2.95 ± 0.11

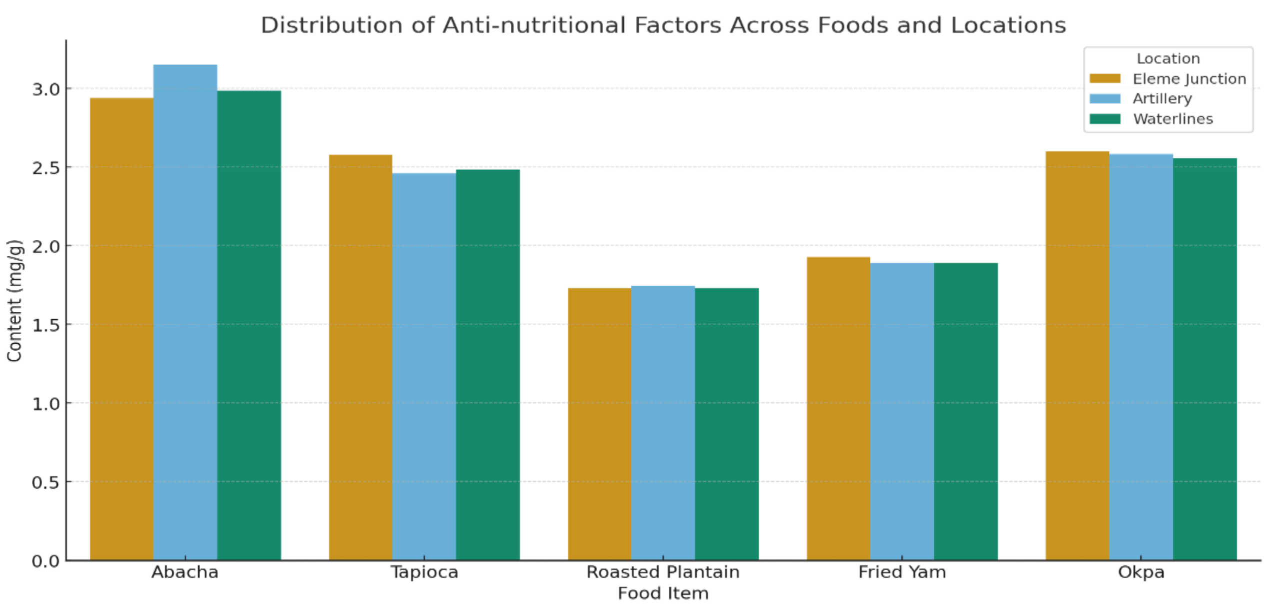


Figure 2. Mean antinutrient composition (phytate, oxalate, tannin, saponin) across sampling locations.

3.2. Heavy Metals in Roadside-Vended Food Samples

Heavy metal concentrations (Pb, Cd, As, Hg, Fe, Zn) are summarised in Table 2. Statistical analysis (ANOVA) revealed significant variations across locations for Pb ($p < 0.001$, $\eta^2 = 0.28$), Cd ($p < 0.05$, $\eta^2 = 0.10$), and As ($p < 0.05$, $\eta^2 = 0.09$). The highest Pb concentration (176.4 ± 12.5 µg/kg) was found in roasted plantain from Artillery, exceeding the WHO/FAO permissible limit of 100 µg/kg for lead in ready-to-eat foods. Cd levels (42.7 ± 4.6 µg/kg) also surpassed the FAO/WHO threshold of 30 µg/kg. Fe and Zn, though elevated, remained within beneficial nutritional ranges and below EFSA upper limits (Fe < 45 mg/day; Zn < 25 mg/day).

Using the concentrations obtained for lead (Pb), cadmium (Cd), and arsenic (As) in the selected roadside-vended foods, Estimated Daily Intake (EDI) and Hazard Quotient (HQ) values were computed to evaluate consumer exposure (**Table 3**). Calculations were based on standard adult consumption assumptions (50 g/day per food item, 70 kg body weight), and the risk benchmarks followed the FAO/WHO guidelines. EDI values for lead (Pb) ranged from 0.068–0.126 µg/kg bw/day, with the highest exposure recorded in roasted plantain and *abacha*, Cd ranged from 0.017–0.030 µg/kg bw/day, highest in fried yam and roasted plantain, and As ranged from 0.022–0.041 µg/kg bw/day, with the highest estimates found in *Abacha*.

Likewise, HQ values for Pb ranged from 0.019–0.036. However, roasted plantain and *abacha* exceeded the WHO permissible Pb limit of 100 µg/kg. HQ values for Cd ranged from 0.017–0.030, while that of As ranged from 0.073–0.138.

Table 2. Heavy Metal Concentrations (µg/kg) of Selected Roadside-Vended Foods by Location (n = 225).

Food Item	Location	Pb (µg/kg)	Cd (µg/kg)	As (µg/kg)	Hg (µg/kg)	Fe (µg/kg)	Zn (µg/kg)
Abacha (African salad)	Eleme Junction	140.2 ± 11.4	35.8 ± 3.8	51.4 ± 5.0	<5	18,400 ± 560	5800 ± 260
	Artillery	165.5 ± 12.0	40.5 ± 4.0	57.5 ± 5.3	<5	18,900 ± 590	6100 ± 270
	Waterlines	142.3 ± 11.5	36.1 ± 3.6	49.8 ± 4.8	<5	18,500 ± 580	5900 ± 250
Tapioca	Eleme Junction	110.4 ± 9.5	28.4 ± 3.0	36.5 ± 4.0	<5	16,200 ± 500	5200 ± 230
	Artillery	115.2 ± 9.8	30.0 ± 3.2	38.0 ± 4.1	<5	16,500 ± 510	6300 ± 280
	Waterlines	95.2 ± 8.3	27.5 ± 2.8	34.2 ± 3.9	<5	16,300 ± 500	5100 ± 220
Roasted Plantain	Eleme Junction	150.8 ± 11.7	37.5 ± 3.7	42.3 ± 4.5	<5	17,800 ± 530	5500 ± 240
	Artillery	176.4 ± 12.5	42.7 ± 4.6	50.5 ± 5.0	<5	18,100 ± 540	5700 ± 250
	Waterlines	148.6 ± 11.3	35.9 ± 3.5	39.8 ± 4.3	<5	17,900 ± 530	5400 ± 240
Fried Yam	Eleme Junction	130.4 ± 10.6	42.7 ± 4.6	41.0 ± 4.4	<5	16,800 ± 520	5400 ± 230
	Artillery	145.2 ± 11.2	40.0 ± 4.2	44.5 ± 4.6	<5	17,200 ± 540	5600 ± 240
	Waterlines	135.6 ± 10.8	38.5 ± 4.0	40.8 ± 4.3	<5	17,000 ± 530	5500 ± 230
Okpa	Eleme Junction	120.6 ± 9.9	32.0 ± 3.3	35.0 ± 3.8	<5	19,600 ± 610	6000 ± 260
	Artillery	138.5 ± 10.5	35.2 ± 3.6	39.5 ± 4.1	<5	19,200 ± 590	6,200 ± 270
	Waterlines	125.4 ± 10.0	33.0 ± 3.4	37.2 ± 3.9	<5	19,400 ± 600	5,900 ± 250

Table 3. EDI (µg/kg bw/day) and HQ Values.

Food Item	EDI Pb	HQ Pb	EDI Cd	HQ Cd	EDI As	HQ As
Abacha	0.2488	0.071	0.0625	0.175	0.0882	0.294
Tapioca	0.1782	0.051	0.0477	0.134	0.0603	0.201
Roasted Plantain	0.2643	0.075	0.0645	0.181	0.0737	0.246
Fried Yam	0.2285	0.065	0.0673	0.189	0.0702	0.234
Okpa	0.2137	0.061	0.0557	0.156	0.0620	0.207

3.3. Microbial Quality in Roadside-Vended Food Samples

Microbial quality analysis of the roadside-vended food samples focused on evaluating their microbial safety and hygienic quality using multiple indicators. Parameters assessed included total viable count (TVC), total bacterial load (TBL), coliform counts, and fungal counts as shown in **Figure 3**.

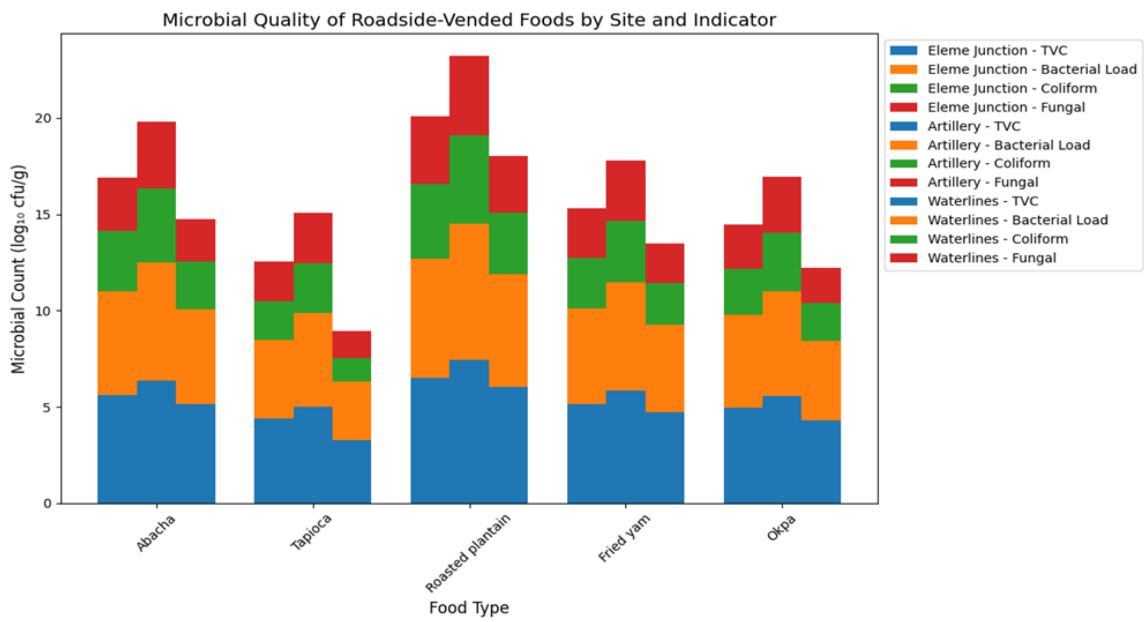


Figure 3. Stacked bar chart showing the microbial load across food types and sites.

3.3.1. Total Viable Count (TVC) in Roadside-Vended Food Samples

The Total Viable Count (TVC) in roadside-vended food samples are summarized in **Table 4**. TVCs ranged between 3.25 ± 0.29 and 7.42 ± 0.56 log_{10} cfu/g. ANOVA showed a significant effect of sampling location ($p < 0.001$, $\eta^2 = 0.22$). Roasted plantain from Artillery exhibited the highest TVC (7.42 log_{10} cfu/g), exceeding the ICMSF acceptable limit of 6 log_{10} cfu/g for ready-to-eat foods, implying poor post-cooking handling. *Abacha* also showed elevated counts (6.35 log_{10} cfu/g).

Table 4. Total Viable Count (log_{10} cfu/g) in Roadside-Vended Foods.

Food Type	Eleme Junction	Artillery	Waterlines	Overall Mean
Abacha	5.62 ± 0.47	6.35 ± 0.52	5.14 ± 0.39	5.70 ± 0.46
Tapioca	4.38 ± 0.34	5.02 ± 0.41	3.25 ± 0.29	4.22 ± 0.35
Roasted plantain	6.48 ± 0.51	7.42 ± 0.56	6.02 ± 0.47	6.64 ± 0.51
Fried yam	5.15 ± 0.42	5.87 ± 0.46	4.73 ± 0.38	5.25 ± 0.42
Okpa	4.96 ± 0.38	5.55 ± 0.43	4.32 ± 0.35	4.94 ± 0.39

3.3.2. Bacterial Load in Roadside-Vended Food Samples

Table 5 summarizes the Bacterial load in roadside-vended food samples. The bacterial load followed a similar pattern, ranging 3.05–7.10 log_{10} cfu/g, with Artillery samples significantly higher ($p < 0.01$). The strong positive correlation between TVC and bacterial load ($r = 0.86$, $p < 0.001$) indicates consistent contamination sources, likely related to environmental exposure and hygiene practices.

Table 5. Bacterial Load (log_{10} cfu/g) in Roadside-Vended Foods.

Food Type	Eleme Junction	Artillery	Waterlines	Overall Mean
Abacha	5.40 ± 0.42	6.15 ± 0.42	4.90 ± 0.43	5.48 ± 0.42
Tapioca	4.10 ± 0.54	4.85 ± 0.60	3.05 ± 0.55	4.00 ± 0.56
Roasted plantain	6.20 ± 0.47	7.10 ± 0.50	5.85 ± 0.60	6.38 ± 0.53
Fried yam	4.95 ± 0.62	5.60 ± 0.44	4.55 ± 0.43	5.03 ± 0.50
Okpa	4.80 ± 0.60	5.45 ± 0.28	4.10 ± 0.58	4.78 ± 0.51

3.3.3. Coliform Counts in Roadside-Vended Food Samples

The coliform counts demonstrated clear differences by food and location as shown in **Table 6**. Coliform counts ranged 1.25–4.60 $\log_{10}$ cfu/g, exceeding the ICMSF limit (3.0 $\log_{10}$ cfu/g) in *abacha* and roasted plantain from Artillery.

Table 6. Coliform Count ($\log_{10}$ cfu/g) in Roadside-Vended Foods.

Food Type	Eleme Junction	Artillery	Waterlines	Overall Mean
Abacha	3.10 ± 0.34	3.85 ± 0.50	2.50 ± 0.56	3.15 ± 0.48
Tapioca	2.00 ± 0.41	2.60 ± 0.31	1.25 ± 0.41	1.95 ± 0.38
Roasted plantain	3.90 ± 0.49	4.60 ± 0.38	3.20 ± 0.52	3.90 ± 0.47
Fried yam	2.65 ± 0.37	3.20 ± 0.40	2.15 ± 0.30	2.67 ± 0.36
Okpa	2.40 ± 0.35	3.05 ± 0.58	1.95 ± 0.34	2.47 ± 0.44

3.3.4. Fungal Counts in Roadside-Vended Food Samples

The results of fungal counts are revealed in **Table 7**. Fungal counts (1.40–4.10 $\log_{10}$ cfu/g) indicate potential spoilage, with Artillery foods showing the highest values ($p < 0.05$). Although no specific pathogens (e.g., *Salmonella, E. coli, S. aureus*) were isolated, the total microbial indices suggest suboptimal hygiene and cross-contamination risk.

Table 7. Fungal Count ($\log_{10}$ cfu/g) in Roadside-Vended Foods.

Food Type	Eleme Junction	Artillery	Waterlines	Overall Mean
Abacha	2.80 ± 0.32	3.45 ± 0.59	2.20 ± 0.30	2.82 ± 0.42
Tapioca	2.05 ± 0.44	2.60 ± 0.37	1.40 ± 0.30	2.02 ± 0.37
Roasted plantain	3.50 ± 0.52	4.10 ± 0.49	2.95 ± 0.61	3.52 ± 0.54
Fried yam	2.55 ± 0.37	3.10 ± 0.54	2.05 ± 0.55	2.57 ± 0.49
Okpa	2.30 ± 0.58	2.90 ± 0.46	1.85 ± 0.41	2.35 ± 0.49

4. Discussion

4.1. Antinutrient Composition in Roadside-Vended Food Samples

The analysis of antinutrients in roadside-vended foods collected from Eleme Junction, Artillery, and Waterlines revealed notable differences in phytate, oxalate, tannin, and saponin levels (**Table 1**). *Abacha* recorded the highest phytate concentrations (4.65–5.02 mg/g), with the highest value found in samples from Artillery (5.02 ± 0.14 mg/g). The elevated phytate levels observed in *Abacha*, particularly in samples from Artillery (5.02 ± 0.14 mg/g), may be associated with the inherent mineral-binding properties of phytate, potentially affecting the bioavailability of essential minerals such as iron and zinc. This observation aligns with the findings of Abera et al. [8], who reported similar mineral-chelating tendencies in cassava-based foods that undergo limited processing. Oxalate content was highest in tapioca (2.30–2.56 mg/g), likely due to inherent oxalate composition of cassava and incomplete removal during processing [22]. However, overall oxalate levels were below concentrations typically associated with kidney stone formation, possibly due to detoxification steps like soaking, fermentation, and boiling [23]. Tannin levels were greatest in *Abacha* (3.05–3.28 mg/g), especially at Artillery. While tannins may reduce palatability and hinder mineral absorption, they also provide health benefits due to antioxidant properties [24]. Fried yam showed the lowest tannin values (1.63–1.66 mg/g), supporting findings by Bayata [10] that heat processing reduces tannin content in tuber-based foods. The relatively high saponin concentrations observed in *Okpa* (2.95–3.02 mg/g) may be related to its legume composition, which could contribute to the characteristic mild bitterness reported [25]. While excessive saponin intake might influence nutrient utilization, the moderate levels detected in these samples could potentially provide cholesterol-lowering effects, consistent with previous reports [9].

While inter-location variations were minimal, samples from Artillery tended to show slightly higher phytate and tannin levels, likely due to raw material quality or vendor practices. These findings are consistent with previous reports on Nigerian street foods [26] and highlight the need for consumer awareness of food preparation techniques, such as soaking, roasting, and fermentation, that may reduce antinutritional compounds.

4.2. Heavy Metals in Roadside-Vended Food Samples

The analysis of heavy metals in roadside-vended foods from Eleme Junction, Artillery, and Waterlines revealed notable variability in contamination levels. Lead (Pb) concentrations ranged from 95.2 ± 8.3 µg/kg in tapioca from Waterlines to 176.4 ± 12.5 µg/kg in roasted plantain from Artillery, with the latter exceeding the WHO permissible limit of ≤100 µg/kg for ready-to-eat foods [27]. The elevated Pb levels in roasted plantain and *Abacha* could be associated with environmental factors such as traffic emissions, industrial activities, and roadside dust, although further environmental assessment is needed to confirm these sources [28].

Cadmium (Cd) concentrations (27.5–42.7 µg/kg) were highest in fried yam and roasted plantain samples from Artillery, while arsenic (As) levels peaked at 57.5 ± 5.3 µg/kg in *abacha* from the same location. These metals are known to pose nephrotoxic and carcinogenic risks, highlighting potential public health concerns [29,30]. Mercury (Hg) concentrations were consistently low (<5 µg/kg), suggesting a minimal contribution to dietary exposure risk. Iron (Fe) and zinc (Zn) levels were substantial across all food types, with Fe ranging from 15,200 to 19,600 µg/kg and Zn from 5100 to 6300 µg/kg. While these elements are essential micro-nutrients, the elevated concentrations may reflect contamination from sources such as soil particles, storage materials, or utensils [31]. Comparable findings of excessive Fe in street foods have been reported by Oyet and Samuel [32], supporting the hypothesis that handling practices and environmental exposure could contribute to heavy metal accumulation.

Generally, foods from Artillery unswervingly recorded the highest heavy metal concentrations across all measured elements. These observations suggest potential contamination flashpoints at this location, though definitive source attribution requires targeted environmental and hygiene assessments.

The EDI and HQ values for Pb and Cd exceeded WHO/FAO safety thresholds across several food items, indicating that routine consumers are likely experiencing chronic exposures above internationally accepted limits. These exceedances, supported by global toxicological evidence, signal a tangible public-health risk that necessitates strengthened regulatory oversight and systematic monitoring of roadside-vended foods.

4.3. Microbial Quality in Roadside-Vended Food Samples

Microbial quality analysis of the roadside-vended food samples focused on evaluating their microbial safety and hygienic quality using multiple indicators. Parameters assessed included total viable count (TVC), which reflects the overall bacterial population and provides an estimate of general food hygiene; total bacterial load, representing the density of aerobic mesophilic bacteria; coliform counts, used as indicators of possible fecal contamination and improper handling; and fungal counts, assessing the presence of yeasts and molds that may compromise food quality and shelf life. These assays provide a comprehensive understanding of microbial contamination levels, potential health risks, and environmental or handling factors influencing microbial growth in ready-to-eat roadside foods [33,34]. While this study focused on total microbial counts to assess general hygienic quality, pathogen-specific analyses targeting *Salmonella spp*., *Escherichia coli O157*, and *Staphylococcus aureus* are planned in follow-up studies to provide a more detailed assessment of foodborne pathogen risks.

4.3.1. Total Viable Count (TVC) in Roadside-Vended Food Samples

The Total Viable Count (TVC) in roadside-vended food samples ranged from 3.25 to 7.42 $\log_{10}$ cfu/g. From the results, Total viable counts varied markedly by food type and sampling area. Roasted plantain recorded the highest TVC overall (6.48 ± 0.51 at Eleme Junction; 7.42 ± 0.56 at Artillery; 6.02 ± 0.47 at Waterlines; overall mean 6.64 ± 0.51), while tapioca showed the lowest values (4.38 ± 0.34, 5.02 ± 0.41, 3.25 ± 0.29; overall mean = 4.22 ± 0.35). The elevated TVC for roasted plantain, particularly at Artillery, suggests that vending environment and post-preparation handling such as open-air exposure, repeated handling, or prolonged holding at ambient temperature), could promote microbial proliferation [26,35]. *Abacha* and fried yam showed moderate TVC (overall means = 5.70 ± 0.46 and 5.25 ± 0.42, respectively), indicating that these ready-to-eat items may also experience contamination during slicing, display or storage [33,34]. The TVC of *okpa* (overall mean = 4.94 ± 0.39) was lower than that of plantain and *abacha* but higher than tapioca, possibly reflecting differences in moisture retention and preparation hygiene [34].

4.3.2. Bacterial Load in Roadside-Vended Food Samples

Bacterial load followed the same pattern as TVC, with roasted plantain exhibiting the greatest bacterial counts (6.20 ± 0.47 at Eleme Junction; 7.10 ± 0.50 at Artillery; 5.85 ± 0.60 at Waterlines; overall mean 6.38 ± 0.53). *Abacha* had a substantial bacterial burden (5.40 ± 0.42 to 6.15 ± 0.42 across sites; overall 5.48 ± 0.42), while tapioca and *okpa* displayed relatively low bacterial counts (tapioca overall 4.00 ± 0.56; *okpa* overall 4.78 ± 0.51). The close concordance between bacterial load and TVC implies that the bulk of the viable microflora in these samples is bacterial rather than fungal, and that processes that reduce bacterial contamination, such as improved cooking, sanitary handling, or covered display), may likely reduce overall bacterial load [36]. The higher bacterial load of the vended foods at Artillery may suggest site-specific risk factors, such as greater exposure to dust and vehicle emissions [37], lower access to potable water, or vendor overcrowding [38].

4.3.3. Coliform Counts in Roadside-Vended Food Samples

Coliform counts demonstrated clear differences by food and location, with roasted plantain again high (3.90 ± 0.49 at Eleme Junction; 4.60 ± 0.38 at Artillery; 3.20 ± 0.52 at Waterlines; overall mean 3.90 ± 0.47) and tapioca low (2.00 ± 0.41; 2.60 ± 0.31; 1.25 ± 0.41; overall mean 1.95 ± 0.38). The coliform levels (3.10 ± 0.34 to 3.85 ± 0.50; overall 3.15 ± 0.48) in *abacha* point to recurring hygiene lapses during handling or possible contamination from water or utensils [39]. Coliforms are indicator organisms for faecal or general sanitary contamination; therefore, their elevated presence in roasted plantain and *abacha*, particularly at Artillery, raises the possibility of post-cooking contamination, such as, unwashed hands, contaminated chopping boards, and use of non-potable water [40]. Lower coliform counts in *okpa* and tapioca suggest that certain preparation methods, like steaming, higher internal temperatures, or shorter exposure times may reduce this risk [7].

4.3.4. Fungal Counts in Roadside-Vended Food Samples

The fungal counts were generally lower than bacterial counts but followed a similar distribution, with roasted plantain showing the highest fungal counts (3.50 ± 0.52 at Eleme Junction; 4.10 ± 0.49 at Artillery; 2.95 ± 0.61 at Waterlines; overall mean = 3.52 ± 0.54). *Abacha* also demonstrated notable fungal counts (overall mean = 2.82 ± 0.42), while tapioca and *okpa* remained the least affected (tapioca overall mean = 2.02 ± 0.37; *okpa* overall mean = 2.35 ± 0.49). Elevated fungal counts in exposed, high-moisture foods such as roasted plantain likely reflect airborne spore deposition and conditions that support fungal survival like warmth and residual moisture [41].

4.4. Implications for Food Safety

Taken together, the results support the premise that roadside-vended foods in urban Nigeria can be significant sources of both nutritional benefits and public health hazards. Antinutrients such as phytate and tannin may exacerbate micronutrient deficiencies, while heavy metals like Pb, Cd, and As contribute to cumulative toxicity risks. High microbial loads further amplify foodborne illness threats, particularly in vulnerable populations like children and immunocompromised adults. This aligns with global studies showing that unregulated street foods often harbor a mix of nutritional and safety challenges [1,29].

4.5. Implications for Future Research

Future studies should incorporate risk assessment models to quantify dietary exposure to metals and antinutrients, while molecular techniques could identify pathogenic organisms contributing to contamination. Research into cost-effective interventions, such as improved packaging, vendor hygiene training, and urban environmental control, would also be valuable for mitigating health risks associated with food contamination.

5. Conclusions

This study demonstrates that usually eaten roadside-vended foods in Port Harcourt Metropolis, like *abacha*, tapioca, roasted plantain, fried yam, and *okpa*, are exposed to notable chemical and microbiological contaminants, with serious public health implications. Moderate to high levels of antinutrients such as phytate, tannin, and saponin may reduce mineral bio-availability, particularly when these foods constitute a frequent part of the diet. Elevated concentrations of heavy metals, including lead, cadmium, and arsenic, with Pb levels in roasted plantain and *abacha* exceeding WHO/FAO and EFSA permissible limits, underline potential long-term toxicological risks. At the same time, microbial analyses reveal that roasted plantain and *abacha* carry consistently high total viable counts, bacterial loads, coliform, and fungal counts, with Artillery emerging as a potential contamination hotspot. Even though this study focused on total microbial counts to evaluate general hygienic quality, pathogen-specific analyses targeting *Salmonella spp*., *Escherichia coli O157*, and *Staphylococcus aureus* are planned in follow-up studies to provide a more detailed assessment of foodborne pathogen risks. Be that as it may, these findings indicate that consumers of these foods are at risk of both acute and chronic health effects, including mineral deficiencies, heavy metal toxicity, and foodborne infections. To mitigate these risks, a combination of immediate and long-term interventions is recommended:

i. Regulatory authorities should employ compulsory and sporadic checking of street-vended foods for microbial and chemical contaminants, with public reporting of results to ensure transparency.
ii. Planned, government-supported training programmes should be offered to sellers on proper food handling, storage, and sanitation practices, including the use of clean utensils, protection from environmental contaminants, and safe cooking techniques.
iii. Public health agencies should educate consumers on potential food safety risks, safe consumption practices, and methods to reduce exposure to contaminants, particularly heavy metals and microbial hazards.
iv. Execution of municipal public health policies, provision of treated water at vending locations, suitable waste disposal, and minimisation of roadside dust and vehicular emissions near food vending areas are key to reducing environmental contamination.
v. Food safety regulations should be integrated with local public health strategies, making sure that street food vending is both economically sustainable for vendors and safe for consumers.

Author Contributions

Conceptualization, G.J.O. and A.A.O.; methodology, G.J.O.; software, G.J.O.; validation, G.J.O., A.A.O. and E.D.K.; formal analysis, G.J.O.; investigation, G.J.O.; resources, A.A.O.; data curation, G.J.O.; writing—original draft preparation, G.J.O.; writing—review and editing, A.A.O. and E.D.K.; visualization, G.J.O.; supervision, A.A.O.; project administration, A.A.O.; funding acquisition, A.A.O. and E.D.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Ignatius Ajuru University of Education, Port Harcourt, Rivers State, Nigeria (Approval No.: IAUE/FNAS/REC/24/003; date of approval: 15 March 2024).

Informed Consent Statement

Informed consent was obtained from all vendors involved in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to ethical considerations and privacy agreements with food vendors, the raw data are not publicly archived.

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Conflicts of Interest

The authors declare no conflict of interest.

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