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Assessment of lead levels and microbial quality in selected spices sold in Onitsha Markets, Anambra State, Nigeria

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Abstract

Background: Spices and seasonings are widely consumed food additives valued for their flavoring, preservative, and health-promoting properties. However, contamination by heavy metals and microorganisms remains a significant food safety concern, particularly in open-market environments where handling and storage conditions may be inadequate.

Objectives: This study assessed the level of adulteration in selected spices and seasonings sold in major markets in Onitsha, Anambra State, Nigeria, with emphasis on lead (Pb) contamination and microbiological quality.

Materials and Methods: A laboratory-based experimental and analytical study was conducted on thirty (30) samples comprising ginger, turmeric, garlic, curry, and ground pepper obtained from vendors in Main Market, Ochanja Market, and Relief Market. Lead concentration was determined using Atomic Absorption Spectrophotometry (AAS) following acid digestion. Microbiological analyses included total bacterial count (TBC), total coliform count, and fecal coliform determination using standard microbiological techniques. Results were compared with established international food safety standards.

Results: Lead was detected in most samples at low concentrations ranging from non-detectable levels to 0.056 mg/kg. Turmeric recorded the highest Pb concentration (0.056 mg/kg), followed by ginger (0.042 mg/kg) and ground pepper (0.010 mg/kg), while garlic and curry showed negligible levels. All detected concentrations were substantially below Codex Alimentarius permissible limits, indicating compliance with international safety standards. Microbiological analysis revealed total bacterial counts in all samples, with ginger recording the highest counts (1.5×10^6–1.8×10^6 CFU/g) and garlic the lowest (1.0×10^3–1.3×10^3 CFU/g). Total and fecal coliforms were absent in ginger, turmeric, garlic, and ground pepper samples but were detected in all curry samples, with fecal coliforms occurring in 50% of the curry samples.

Conclusion: The analyzed spices and seasonings were safe with respect to lead contamination. However, the occurrence of coliform contamination in curry samples indicates deficiencies in hygiene and sanitary practices. Strengthening food safety measures and routine monitoring is essential to ensure the microbiological safety of spices and seasonings sold in local markets.

Keywords: Spices; Seasonings; Lead Contamination; Microbiological Quality; Food Safety.

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1. Introduction

Spices and seasonings play a vital role in human diets worldwide by enhancing the flavor, aroma, texture, and appearance of foods. In addition to their culinary uses, many spices possess nutritional, antioxidant, antimicrobial, and preservative properties that support human health and food preservation. For example, ginger, garlic, turmeric, and pepper contain bioactive compounds that may reduce oxidative stress and inhibit microbial growth [1]. In Nigeria, commonly consumed spices and seasonings—including curry powder, thyme, ginger, garlic, bouillon cubes, and monosodium glutamate (MSG)—are widely used in households, restaurants, and food-processing industries [2; 3].

Despite their nutritional and economic importance, spices and seasonings are highly susceptible to contamination and adulteration during processing, storage, transportation, and marketing. Food adulteration involves the deliberate addition of inferior, undeclared, or harmful substances, or the substitution of valuable ingredients with cheaper alternatives for economic gain—often to increase bulk, improve appearance, or reduce production costs [4]. Spices are particularly vulnerable because they are often sold in powdered or granular forms, making visual detection of contaminants difficult [5]. Common adulterants include brick dust, sawdust, starch, artificial colorants, and industrial dyes such as Sudan I–IV, which are used to enhance appearance or increase profit margins [6]. In addition, heavy metals such as lead, cadmium, chromium, and arsenic have been detected in spices, either as a result of environmental pollution, poor handling practices, or deliberate adulteration with substances like lead chromate to intensify color [7].

Contamination of spices and seasonings is a significant food safety and public health concern because these products are consumed regularly over extended periods. Heavy metals are non-biodegradable and can accumulate in body tissues with chronic exposure, leading to health issues such as neurological disorders, kidney damage, reproductive toxicity, immune suppression, and cancer [7; 8; 9]. Similarly, Sudan dyes—illegally used in some spices—are recognized as genotoxic and carcinogenic, increasing the risk of cancer in humans [10; 11].

In addition to chemical contamination, microbial contamination of spices and seasonings remains a major global food safety challenge. Spices may become contaminated during harvesting, drying, grinding, packaging, and open-market display under unhygienic conditions. Pathogenic microorganisms such as *Salmonella* species, coliform bacteria, *Staphylococcus aureus*, and fungal organisms have been reported in contaminated spices [1]. Consumption of contaminated spices may lead to foodborne infections and intoxications. Fungal contamination may also result in the production of aflatoxins, which are associated with liver cancer, immune suppression, and growth impairment in children [12].

Although regulatory agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC), Standards Organisation of Nigeria (SON), WHO, FAO, and the Codex Alimentarius Commission have established food safety standards, enforcement in many Nigerian local markets is often inadequate. In these markets, most unpackaged spices are displayed openly under dusty and humid conditions, which increases their susceptibility to contamination during storage and marketing [13].

Onitsha is one of the largest commercial cities in southeastern Nigeria and serves as a major distribution center for food commodities [14]. Markets such as Main Market, Ochanja Market, and Relief Market attract traders and consumers from across the country. The widespread sale of unpackaged food products in these markets increases the risk of adulteration and microbial contamination of spices and seasonings. Despite this, there is limited scientific information on the microbiological quality and heavy metal contamination of these products in Onitsha markets. This study was therefore conducted to assess the level of adulteration in selected spices and seasonings sold in Onitsha local markets, focusing on lead contamination and microbiological quality. The results are intended to inform food safety regulation, environmental health monitoring, public health protection, and consumer awareness regarding the safety of spices and seasonings in the study area.

2. Materials and methods

Study Design: This study adopted an experimental and analytical laboratory-based design to assess the level of adulteration in selected spices and seasonings sold in Onitsha local markets, Anambra State, Nigeria. Laboratory investigations focused on evaluating heavy metal contamination and microbiological quality of selected spice and seasoning samples. Analytical results obtained were compared with permissible limits established by national and international food safety regulatory agencies.

Study Area: The study was conducted in Onitsha, Anambra State, Southeastern Nigeria. Onitsha is a densely populated commercial city located on the eastern bank of the River Niger and is widely recognized for its large open-air markets, including Main Market, Ochanja Market, and Relief Market. These markets serve as major distribution centers for food products, spices, and seasonings sourced both locally and internationally. The extensive commercial activities and widespread sale of unpackaged food products make the area suitable for investigating food adulteration and contamination practices.

Sample Size and Sampling Procedure: A total of thirty (30) representative samples comprising selected spices and seasonings were analyzed. Five sample groups were investigated, with six samples obtained from each group. Samples were purchased from different vendors across Main Market, Ochanja Market, and Relief Market to ensure representativeness and comparability. Purposive sampling technique was employed in selecting the spices and seasonings based on their high consumer demand and apparent susceptibility to adulteration. Within each market, samples were randomly obtained from different vendors to minimize sampling bias. All samples were aseptically collected into sterile labeled polyethylene bags and transported under controlled laboratory conditions for analysis.

Materials and Equipment: The following materials and laboratory equipment were used during the study:

- Sterile labeled polyethylene bags for sample collection
- Varian AA240 Atomic Absorption Spectrophotometer for heavy metal analysis
- UV–Visible Spectrophotometer for dye detection
- Incubators and microbiological culture media for microbial analyses
- Compound microscope for morphological examination
- Analytical weighing balance
- Pipettes, conical flasks, digestion apparatus, and other standard laboratory glassware

All instruments were calibrated prior to use to ensure accuracy and reliability of analytical results.

2.1. Sample Collection and Laboratory Analysis

Representative spice and seasoning samples were randomly purchased from selected markets. Samples were aseptically collected, labeled, transported to the laboratory, and homogenized prior to analysis. Microbiological analyses , including total viable bacterial count and coliform count, were conducted following standard procedures described in the FDA Bacteriological Analytical Manual (BAM). Heavy metal concentrations were determined using validated analytical methods such as Atomic Absorption Spectrophotometry (AAS) in accordance with FDA Elemental Analysis Manual (EAM) and AOAC Official Methods

Sterilization of Materials: Glassware including test tubes, conical flasks, pipettes, Petri dishes, and culture media were sterilized by autoclaving at 121°C and 15 psi for 15 minutes. Dry heat sterilization was performed using a hot air oven at 150°C for one hour where necessary. Laboratory benches and working surfaces were disinfected with isopropyl alcohol prior to analysis.

Preparation of Culture Media: The following microbiological media were prepared according to manufacturers' instructions:

- Nutrient Agar (NA)
- MacConkey Agar

Lactose Broth

- Brilliant Green Lactose Bile Broth (BGLB)
- Eosin Methylene Blue Agar (EMB)
- Salmonella-Shigella Agar (SSA)
- Mannitol Salt Agar (MSA)

All media were prepared using sterile distilled water and sterilized appropriately before use.

2.2. Determination of Total Bacterial Count

Total bacterial count was determined using the spread plate method as described by the FDA Bacteriological Analytical Manual (BAM) and APHA standard methods. Serial dilutions were prepared in sterile normal saline, and 0.1 mL aliquots from appropriate dilutions were spread in duplicate onto Nutrient Agar plates. The plates were incubated at 37°C for 24–48 h, after which colonies were counted and results expressed as colony-forming units per gram (cfu/g) [15].

The total bacterial count was calculated using the expression:

$$\text{TBC (CFU/mL)} = \frac{\text{Number of colonies} \times \text{Dilution factor}}{\text{Volume Plated (mL)}}$$

Where:

- Number of colonies = colonies counted on the agar plate (preferably 30–300 colonies)
- Dilution factor = reciprocal of the dilution used
- Volume plated = amount of diluted sample inoculated onto the plate (usually 0.1 mL or 1.0 mL)
- CFU = Colony Forming Units

Determination of Total Coliform Count: Ten-fold serial dilutions of samples were prepared and aliquots inoculated onto MacConkey Agar plates. The plates were incubated at 37°C for 24 hours, after which characteristic coliform colonies were enumerated and recorded as cfu/g.

Determination of Fecal Coliforms: Fecal coliform analysis was carried out using the Most Probable Number (MPN) technique with Lactose Broth, Brilliant Green Lactose Bile Broth (BGLB), and Eosin Methylene Blue Agar (EMB). Presumptive, confirmatory, and completed tests were conducted according to standard microbiological procedures.

Sample Digestion Procedure: Two grams of each sample were digested using a mixture of concentrated nitric acid (HNO_3), hydrochloric acid ($HClO_4$), and sulfuric acid (H_2SO_4). The digested samples were subsequently diluted to 100 mL with distilled water prior to instrumental analysis.

Heavy Metal Analysis: Lead (Pb) concentration was determined using Varian AA240 Atomic Absorption Spectrophotometer following acid digestion of samples according to the procedures described by the American Public Health Association [15].

Principle of Atomic Absorption Spectrophotometry: Atomic Absorption Spectrophotometry (AAS) operates on the principle that free metallic atoms in the gaseous state absorb light at specific characteristic wavelengths. The amount of light absorbed is directly proportional to the concentration of the metal present in the sample.

Data Analysis: Data obtained from laboratory analyses were expressed as mean ± standard deviation (SD). Statistical analysis was performed using Analysis of Variance (ANOVA) to compare contaminant concentrations among sample groups. Results obtained were compared with permissible safety limits established by NAFDAC, Standards Organisation of Nigeria (SON), WHO/FAO, and Codex Alimentarius guidelines. Findings were presented using tables and charts.

Ethical Considerations: Ethical approval for the study was obtained from the Faculty of Health Sciences and Technology Research Ethics Committee. Market vendors were informed about the purpose of sample collection, and verbal consent was obtained prior to sample acquisition. All information obtained during the study was treated confidentially and used strictly for academic and research purposes.

3. Results

Table 1 Lead (Pb) concentration in selected spice and seasoning samples (ppm**)**

Sample Code	Sample Name/Source	Pb (ppm)
GI1	Ginger from 1st vendor in main market	0.022
GI2	Ginger from 2nd vendor in main market	0.019
GI3	Ginger from 1st vendor in Ochanja	0.02
GI4	Ginger from 2nd vendor in Ochanja	0.034
GI5	Ginger from 1st vendor in Relief market	0.042
GI6	Ginger from 2nd vendor in Relief market	0.018
TU1	Turmeric from 1st vendor in main market	0.056
TU2	Turmeric from 2nd vendor in main market	0.05
TU3	Turmeric from 1st vendor in Ochanja	0.045
TU4	Turmeric from 2nd vendor in Ochanja	0.052
TU5	Turmeric from 1st vendor in Relief market	0.053
TU6	Turmeric from 2nd vendor in Relief market	0.049
CU1	Curry from 1st vendor in main market	Nil
CU2	Curry from 2nd vendor in main market	Nil
CU3	Curry from 1st vendor in Ochanja	Nil
CU4	Curry from 2nd vendor in Ochanja	0.0001
CU5	Curry from 1st vendor in Relief market	Nil
CU6	Curry from 2nd vendor in Relief market	Nil
GP1	Grounded pepper from 1st vendor in main market	0.008
GP2	Grounded pepper from 2nd vendor in main market	0.007
GP3	Grounded pepper from 1st vendor in Ochanja	0.01
GP4	Grounded pepper from 2nd vendor in Ochanja	0.008
GP5	Grounded pepper from 1st vendor in Relief market	0.009
GP6	Grounded pepper from 2nd vendor in Relief market	0.01
GA1	Garlic from 1st vendor in main market	Nil
GA2	Garlic from 2nd vendor in main market	Nil
GA3	Garlic from 1st vendor in Ochanja	Nil
GA4	Garlic from 2nd vendor in Ochanja	0.0001
GA5	Garlic from 1st vendor in Relief market	Nil
GA6	Garlic from 2nd vendor in Relief market	Nil

Table 1 shows the lead (Pb) concentrations in the analyzed spice and seasoning samples. Turmeric recorded the highest Pb levels (0.045–0.056 ppm), followed by ginger (0.018–0.042 ppm) and ground pepper (0.007–0.010 ppm), while garlic and curry samples showed negligible or undetectable levels.

Table 2 Comparison of maximum detected lead (Pb) levels per spices/seasoning with international permissible limits

Sample	Maximum Detected level	International reference limit	Source/Standard	Safety status
Tumeric	0.056 mg/kg (ppm)	2.5 mg/kg (dried bark spices)	Codex Alimentarius (CAC48, 2025 adoption)	Safe
Ginger	0.042 mg/kg (ppm)	2.0 mg/kg (dried culinary herbs)	Codex Alimentarius (CAC48, 2025 adoption)	Safe
Garlic	0.0001mg/kg (ppm)	2.5mg/kg (dried bark spices)	Codex Alimentarius (CAC48, 2025 adoption)	Safe
Grounded pepper	0.01 mg/kg (ppm)	2.0 mg/kg (dried culinary herbs)	Codex Alimentarius (CAC48, 2025 adoption)	Safe
Curry	0.0001 mg/kg (ppm)	2.5mg/kg (dried bark spices)	Codex Alimentarius (CAC48, 2025 adoption)	Safe

Table 2 compares the detected lead (Pb) levels in the analyzed spices and seasonings with Codex Alimentarius permissible limits. All samples recorded Pb concentrations far below the applicable international limits, indicating that they are safe with respect to lead contamination.

Table 3 Microbiological quality of 30 selected samples

Parameter	TBC (cfu/g)	Total coliform (cfu/g)	Fecal coliform
GP1	9×10^5	0	0
GP2	8×10^5	0	0
GP3	8.2×10^5	0	0
GP4	7.8×10^5	0	0
GP5	8.5×10^5	0	0
GP6	8.9×10^5	0	0
GI1	1.6×10^6	0	0
GI2	1.8×10^6	0	0
GI3	1.7×10^6	0	0
GI4	1.5×10^6	0	0
GI5	1.6×10^6	0	0
GI6	1.6×10^6	0	0
GA1	1.0×10^3	0	0
GA2	1.1×10^3	0	0
GA3	1.2×10^3	0	0
GA4	1.0×10^3	0	0
GA5	1.2×10^3	0	0
GA6	1.3×10^3	0	0
CU1	1.0×10^5	2.0×10^5	1.0×10^5
CU2	1.1×10^5	1.8×10^5	1.2×10^5
CU3	1.3×10^5	2.0×10^5	0

CU4	$1.0×10^5$	$1.7×10^5$	0
CU5	$1.2×10^5$	$2.1×10^5$	$1.0×10^5$
CU6	$1.0×10^5$	$2.1×10^5$	0
TU1	$1.0×10^5$	0	0
TU2	$1.2×10^5$	0	0
TU3	$1.1×10^5$	0	0
TU4	$1.5×10^5$	0	0
TU5	$1.0×10^5$	0	0
TU6	$1.0×10^5$	0	0

Table 3 presents the microbiological quality of the analyzed spice and seasoning samples. Ginger samples recorded the highest total bacterial counts, while garlic samples had the lowest. Total and fecal coliforms were absent in ground pepper, ginger, garlic, and turmeric samples but were detected in all curry samples, indicating poorer hygienic quality.

4. Discussion

4.1. Lead (Pb) Concentration in Selected Spices and Seasonings

The present study revealed that lead (Pb) was detected in most of the analyzed spice and seasoning samples; however, the concentrations were generally low and remained within internationally accepted safety limits. The highest Pb concentrations were observed in the Turmeric (TU) samples (0.045–0.056 mg/kg), followed by the Ginger (GA) samples (0.018–0.042 mg/kg), whereas Grounded Pepper (GP) samples contained comparatively lower concentrations (0.007–0.010 mg/kg). Lead was largely undetectable in the Garlic (GA) and Curry (CU) samples, with only trace concentrations (0.0001 mg/kg) recorded in isolated samples. The observed variability among product groups suggests that contamination was not uniform and may be influenced by differences in raw material sourcing, cultivation environment, atmospheric deposition, irrigation water quality, drying surfaces, processing equipment, packaging materials, transportation conditions, and market handling practices [16; 17].

The heterogeneous distribution of Lead (Pb) contamination observed in this study agrees with previous reports indicating that heavy metal contamination of spices is strongly influenced by both environmental and anthropogenic factors. Heavy metals may enter spices through uptake from contaminated soils, irrigation with polluted water, application of agrochemicals, industrial emissions, roadside dust deposition, and contamination during post-harvest processing and storage [16; 18]. Consequently, substantial variations in metal concentrations can occur even among samples of the same spice obtained from different geographical locations and supply chains.

The Lead (Pb) concentrations recorded in the present study were considerably lower than those reported in several previous investigations conducted in Nigeria. In Awka, Anambra State, [19] reported Pb concentrations ranging from 2.61 to 8.97 mg/kg in selected spices, with several samples exceeding recommended safety limits. Compared with the highest value obtained in the present study (0.056 mg/kg), the concentrations reported by [17], were approximately 47–160 times higher, suggesting a substantially lower burden of lead contamination in the spice samples analyzed in the present investigation. Similarly, [17] reported Pb concentrations of up to 4.72 mg/kg in selected spices sold in Northern Nigerian markets, values that greatly exceed those recorded in this study. Likewise, [20], reported Pb levels ranging from 1.34 to 3.81 mg/kg in spices marketed in Port Harcourt, Rivers State, further demonstrating the geographical variability of contamination patterns within Nigeria.

Comparable studies conducted outside Nigeria have also reported higher Pb concentrations than those observed in the present investigation. For example, [18] reported Pb concentrations ranging from 0.20 to 7.80 mg/kg in spices marketed in Pakistan, while [21] documented elevated levels of Pb and other toxic metals in certain spice products sold in European markets. The substantially lower Pb concentrations recorded in this study therefore suggest comparatively better chemical quality of the analyzed spice and seasoning samples.

The findings of the present study nevertheless support broader evidence indicating that heavy metal contamination of spices remains an important food safety concern worldwide [21; 17]. Although the Pb concentrations detected were low, the toxicological significance of lead exposure should not be underestimated. According to the World Health

Organization [9], lead is a cumulative toxicant that affects multiple body systems and there is no known exposure level that is considered completely safe. Children are particularly vulnerable because lead interferes with neurological development, resulting in reduced intelligence quotient (IQ), impaired learning capacity, behavioral disorders, and decreased cognitive performance [9]. In adults, chronic exposure has been associated with hypertension, cardiovascular disease, kidney dysfunction, reproductive impairment, and neurological disorders 9; 22].

Although all Lead (Pb) concentrations recorded in this study were substantially below international regulatory limits, including the Codex Alimentarius maximum levels for spices [23], continuous monitoring remains necessary. This recommendation is justified because spices and seasonings are consumed regularly and repeatedly throughout life, and chronic exposure to low concentrations of lead from multiple dietary sources may contribute to cumulative body burden over time ([9; 24]. The low Pb concentrations observed in this study are therefore encouraging and suggest minimal immediate health risk; however, routine surveillance of spices and seasonings remains essential to ensure continued consumer protection and to detect any future increase in contamination arising from environmental pollution or poor handling practices.

4.2. Microbiological Quality of the Spice and Seasoning Samples

The microbiological assessment revealed substantial differences in microbial quality among the analyzed spice and seasoning groups. Total bacterial counts (TBC) were detected in all sample groups, indicating varying degrees of microbial contamination. The highest bacterial loads were recorded in the Ginger (GI) samples (1.5×10^6–1.8×10^6 CFU/g), followed by the Grounded pepper (GP) samples (7.8×10^5–9.0×10^5 CFU/g). Moderate bacterial counts were observed in Turmeric (TU) and Curry (CU) samples (approximately 10^5 CFU/g), whereas the Garlic (GA) samples exhibited the lowest bacterial load (10^3 CFU/g range), suggesting comparatively superior microbiological quality. The presence of viable bacteria in all analyzed samples is not unexpected, as spices and seasonings are agricultural products that are frequently exposed to soil, dust, water, insects, harvesting equipment, processing surfaces, storage facilities, and market environments before consumption [25; 26].

A particularly important finding was the distribution of coliform bacteria among the analyzed samples. Total coliforms and fecal coliforms were absent in all GP, GI, GA, and TU samples. In contrast, total coliform contamination was detected in all CU samples, with counts ranging from 1.7×10^5 to 2.1×10^5 CFU/g, while fecal coliforms were detected in three of the six CU samples analyzed. The presence of fecal coliforms is of considerable public health significance because these organisms are widely recognized as indicators of fecal contamination and poor sanitary conditions during food production, processing, storage, transportation, or retail handling [27; 28]. Potential sources of contamination include the use of contaminated water during processing, poor personal hygiene among handlers, unsanitary equipment, exposure to contaminated surfaces, and inadequate storage conditions [29; 30].

The findings of the present study are consistent with previous investigations conducted in Nigeria and other developing countries. In Kano State, Nigeria, [31], reported high aerobic bacterial counts, coliform contamination, and the presence of potentially pathogenic microorganisms in *yaji* spice mixtures sold in local markets. The authors concluded that inadequate hygiene during processing, packaging, transportation, and retail display contributed significantly to microbial contamination. Similarly [32], reported substantial microbial contamination in spices marketed in southeastern Nigeria and linked contamination to poor environmental sanitation and unhygienic handling practices. The occurrence of coliform bacteria in the CU samples examined in the present study therefore supports existing evidence that locally marketed spices may serve as vehicles for microbial contaminants when appropriate hygiene controls are lacking.

Comparable observations have also been reported elsewhere in West Africa. [33], in a study conducted in Tamale, Ghana, detected coliform bacteria in nearly all spice samples analyzed and identified fecal coliforms and *Escherichia coli* as indicators of contamination originating from fecal sources. The authors attributed contamination primarily to poor handling practices, contaminated storage facilities, exposure to dust, and inadequate environmental sanitation. Similar contamination pathways may explain the microbiological profile observed in the CU samples analyzed in the present study. Furthermore, [33] emphasized that contamination of spices often occurs during processing, transportation, and storage rather than through microbial growth within the dried products themselves.

The microbial counts observed in the present study are also comparable to reports from other parts of the world. Accordingly, [25] reported aerobic mesophilic bacterial counts ranging from 10^3 to 10^7 CFU/g in commercial spice samples analyzed in India and observed widespread contamination with bacteria, yeasts, and molds. Likewise, [34] documented high microbial loads in spices and herbs marketed in Spain and identified environmental contamination during production and handling as important contributors to microbial burden. These studies collectively demonstrate that microbial contamination of spices is a global food safety issue and is not restricted to developing countries.

Interestingly, although the GI and GP groups exhibited the highest total bacterial counts, neither group showed evidence of total coliform or fecal coliform contamination. This observation highlights the fact that elevated bacterial counts do not necessarily indicate fecal contamination. The microbial populations present in these samples may have originated from environmental sources such as soil microorganisms, dust particles, plant-associated microflora, drying surfaces, harvesting equipment, and storage environments [25; 27]. Similar observations have been reported by [35], who noted that spices frequently contain large populations of environmental microorganisms that may not necessarily be of fecal origin or pose direct health risks. Consequently, total bacterial count should be interpreted as an indicator of overall hygienic quality rather than direct evidence of fecal contamination.

The observed microbiological profile aligns with the Codex Alimentarius Code of Hygienic Practice for Low-Moisture Foods, which recognizes spices and dried herbs as commodities capable of harboring microorganisms introduced from environmental and processing sources. Codex emphasizes that contamination may persist throughout storage because many microorganisms, including pathogenic species, can survive in low-moisture environments for prolonged periods despite limited opportunities for growth [27]. For this reason, effective control measures should focus on good agricultural practices (GAP), good manufacturing practices (GMP), hazard analysis and critical control point (HACCP) systems, environmental monitoring, and hygienic handling throughout the supply chain.

From a public health perspective, the microbiological findings are of greater concern than the lead concentrations observed in this study. The World Health Organization estimates that contaminated food causes approximately 600 million cases of foodborne illness and 420,000 deaths annually worldwide, with bacterial pathogens accounting for a substantial proportion of this burden [30]. Vulnerable populations, including children, older adults, pregnant women, and immunocompromised individuals, are particularly susceptible to adverse outcomes arising from foodborne infections [30]. The detection of fecal coliforms in 50% of the CU samples analyzed therefore indicates significant lapses in hygiene and raises concerns regarding the possible presence of enteric pathogens that were not specifically investigated in the present study.

Similarly, the United States Food and Drug Administration [29] recognizes spices as potential vehicles for foodborne pathogens and has identified *Salmonella* spp. as one of the most important microbiological hazards associated with spice products. Several international outbreaks of salmonellosis have been linked to contaminated spices and spice blends, highlighting the importance of microbiological surveillance and preventive controls throughout the spice production chain [29; 36]. Consequently, the microbiological quality of spices and seasonings should remain a critical component of food safety monitoring programmes.

Overall, the findings indicate that while the analyzed spices and seasonings showed relatively low levels of chemical contamination, microbiological contamination remains a significant concern. The presence of coliforms and fecal coliforms in the CU samples is indicative of inadequate hygiene and sanitary conditions during processing, storage, or distribution. In contrast, the comparatively lower bacterial counts recorded in the GI and GP groups may be associated with the intrinsic antimicrobial properties of ginger and pepper, whose bioactive constituents have been shown to inhibit the growth of several pathogenic and spoilage microorganisms [37; 38]. Strengthening hygiene measures throughout the production and distribution chain is therefore essential to ensure the microbiological safety of spices and seasonings marketed in Onitsha and similar urban markets.

4.3. Safety Assessment Relative to National and International Standards

Comparison of the analytical results with established national and international food safety standards demonstrated that all analyzed spice and seasoning samples complied with permissible limits for lead (Pb) contamination. The highest Pb concentration detected in the present study (0.056 mg/kg) was substantially lower than the maximum levels established by the Codex Alimentarius Commission. According to the latest amendments to the General Standard for Contaminants and Toxins in Food and Feed [37], maximum Pb limits of 2.5 mg/kg and 2.0 mg/kg have been established for dried bark spices and dried culinary herbs, respectively [24, 39]. The maximum Pb concentration recorded in the present study therefore represents less than 3% of the applicable Codex limits, indicating compliance with internationally accepted food safety standards in the analyzed samples.

The findings are also consistent with contemporary international regulatory frameworks governing contaminants in foods. The European Union establishes category-specific maximum levels for lead in herbs, spices, and related food products under Commission Regulation (EU) 2023/915 on contaminants in food. These regulatory limits are substantially higher than the Pb concentrations detected in the analyzed samples [40]. Consequently, the results suggest that the investigated spices and seasonings do not presently constitute a significant source of dietary lead exposure. Similar conclusions have been reported in studies conducted in India, Egypt, and Türkiye, where Pb concentrations below international regulatory thresholds were considered indicative of acceptable chemical safety and low consumer health risk [18].

Although the observed Pb concentrations were well below established regulatory limits, the public health significance of lead exposure should not be overlooked. Lead is recognized as a cumulative toxicant capable of affecting multiple organ systems, and the World Health Organization has stated that no level of lead exposure is completely free from adverse health effects [9]. Chronic exposure has been associated with neurodevelopmental impairment in children, reduced cognitive performance, hypertension, cardiovascular disease, renal dysfunction, and reproductive toxicity [9; 22]. Nevertheless, considering the very low Pb concentrations detected in the present study, the likelihood of significant health risks arising specifically from these spice and seasoning products appears minimal.

With respect to microbiological safety, the findings reveal a more complex situation. The Codex Alimentarius Code of Hygienic Practice for Low-Moisture Foods identifies spices and dried herbs as commodities capable of harboring pathogenic microorganisms despite their low water activity. Among these pathogens, *Salmonella* spp. is recognized as the principal microbiological hazard associated with spices because of its ability to survive for prolonged periods in dry food matrices and its documented involvement in numerous foodborne outbreaks worldwide [29; 36]. Consequently, Codex recommends the implementation of preventive food safety systems including Good Agricultural Practices (GAP), Good Manufacturing Practices (GMP), Hazard Analysis and Critical Control Point (HACCP) programmes, environmental monitoring, and process validation measures to minimize microbial contamination risks [27].

Although *Salmonella* was not investigated in the present study, the microbiological indicators assessed provide valuable information regarding hygienic quality. The absence of total coliforms and fecal coliforms in the GP, GI, GA, and TU samples suggests satisfactory sanitary conditions during processing, handling, and storage. Coliform bacteria are widely used as indicators of hygienic quality because their presence may reflect contamination arising from inadequate sanitation, contaminated water, unsanitary equipment, or poor personal hygiene among food handlers [27; 29]. Therefore, the absence of these indicator organisms in most sample groups represents a positive food safety outcome.

Conversely, the detection of total coliforms in all CU samples and fecal coliforms in 50% of the CU samples indicates significant deficiencies in sanitary practices within that product category. Fecal coliforms are recognized indicators of possible fecal contamination and may signal conditions conducive to the introduction of enteric pathogens into food products [29; 30]. Similar findings have been reported in studies conducted in Nigeria and Ghana, where coliform contamination of spices was attributed to poor handling practices, exposure to contaminated processing environments, inadequate storage conditions, and the use of contaminated water during processing [33]. The occurrence of fecal coliforms in the CU samples therefore raises concerns regarding the microbiological safety of these products and highlights the need for improved hygiene interventions throughout the production and distribution chain.

The elevated total bacterial counts observed in the GI and GP samples, despite the absence of fecal contamination indicators, warrant further consideration. High total bacterial counts do not necessarily imply the presence of pathogenic microorganisms or fecal contamination. Rather, they may reflect contamination from environmental sources such as soil particles, dust, plant-associated microorganisms, drying surfaces, harvesting equipment, storage facilities, and retail display environments [25; 35]. Similar observations have been reported in studies from India, Spain, and Nigeria, where spices exhibited high aerobic bacterial counts but low prevalence of fecal indicator organisms [25; 41; 32]. Nevertheless, elevated bacterial loads generally indicate suboptimal hygienic quality and suggest deficiencies in post-harvest handling, drying, storage, packaging, or retail practices.

At the national level, the existence of microbiological quality guidelines for spices and herbs within Nigeria further emphasizes the importance of routine microbiological surveillance. The Standards Organisation of Nigeria (SON), through the adoption of Codex-based standards and microbiological guidelines, recognizes the need to monitor microbial contamination in spices and related food products as part of broader food safety assurance programmes [42]. Effective regulatory oversight, coupled with industry compliance with established hygiene standards, is essential for safeguarding public health.

Overall, the safety assessment indicates that lead contamination does not currently constitute a major public health concern in the analyzed spice and seasoning samples because all measured concentrations were substantially below national and international regulatory limits. In contrast, microbiological contamination represents a more immediate food safety challenge. The occurrence of total and fecal coliforms in CU samples, together with elevated bacterial loads observed in certain product groups, highlights the need for strengthened hygienic practices, improved processing controls, routine microbiological monitoring, and enhanced regulatory enforcement. Addressing these issues will contribute significantly to improving the safety and quality of spices and seasonings available to consumers.

5. Conclusion

This study assessed the safety of selected spices and seasonings sold in major markets in Onitsha, Anambra State, Nigeria, through the determination of lead (Pb) concentrations and evaluation of microbiological quality. The findings demonstrated that Pb contamination was generally low across all analyzed samples, with concentrations ranging from non-detectable levels to a maximum of 0.056 mg/kg. All detected values were substantially below the maximum limits established by the Codex Alimentarius Commission and other international regulatory frameworks, suggesting that the analyzed products are unlikely to pose a significant risk of lead toxicity to consumers. The most important food safety concern identified in this study was the occurrence of total coliforms in all CU samples and fecal coliforms in 50% of the samples examined. The presence of these indicator organisms suggests inadequate sanitary conditions during processing, storage, transportation, or marketing. Although specific pathogens such as *Escherichia coli* O157:H7 and *Salmonella* spp. were not investigated, the findings indicate hygiene failures that may compromise consumer safety.

Overall, the study demonstrates that microbiological contamination was more frequently detected than lead contamination in the analyzed spices and seasonings. While chemical safety with respect to lead was satisfactory, deficiencies in hygienic handling and post-processing practices remain important concerns requiring intervention. Ensuring the microbiological safety of spices and seasonings is particularly important because these products are widely consumed and are often added to foods without further heat treatment sufficient to eliminate microbial contaminants.

To improve the safety and quality of spices and seasonings sold in Onitsha and similar markets, greater emphasis should be placed on maintaining hygienic practices throughout the supply chain, including processing, drying, packaging, storage, transportation, and retail display. Food safety training on Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), and Hazard Analysis and Critical Control Point (HACCP) principles should be provided to processors, vendors, and other handlers to reduce the risk of microbial contamination. Improved packaging and storage systems are also necessary to minimize exposure to dust, moisture, insects, and other environmental contaminants. Regulatory agencies, particularly the Standards Organisation of Nigeria (SON), the National Agency for Food and Drug Administration and Control (NAFDAC), and relevant public health authorities, should strengthen surveillance and routine monitoring of spices and seasonings to ensure compliance with established food safety standards. Regular assessment of both heavy metal contamination and microbiological quality is recommended to detect emerging risks and protect consumer health. Implementation of these measures will contribute significantly to improving the safety, quality, and public health value of spices and seasonings marketed in Onitsha and other urban markets across Nigeria.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest in the course of this research whatsoever.

Compliance with ethical standards:

Ethical approval for the study was obtained from the Faculty of Health Sciences and Technology Research Ethics Committee. Market vendors were informed about the purpose of sample collection, and verbal consent was obtained prior to sample acquisition. All information obtained during the study was treated confidentially and used strictly for academic and research purposes

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