

Heavy Metals and Microbial Loads in Freshly Made Plantain Snacks ‘*Dodo-Ikire*’ from Production Sites in Nigeria

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Abstract

Plantain snack, locally called *Dodo-Ikire*, is produced from ripe plantain in Nigeria. The report on plantain snacks from the retailer's point-of-sale calls for attention to the production centers for establishing effective food safety interventions; hence, the need to assess them for microbial load and heavy metals at that stage. This study evaluated the microbiological quality and heavy metal profiles of *Dodo-Ikire* across five major production hotspots in Nigeria. Microbial analysis revealed that samples from Molalere and Isale-Abata exhibited the highest *Escherichia coli* counts (3.01×10^6 CFU/g and 2.35×10^5 CFU/g, respectively). phosphorus (P), aluminum (Al), chromium (Cr), cadmium (Cd), iron (Fe), copper (Cu), potassium (K), and sodium (Na) across all sites; however, concentrations did not exceed established maximum permissible limits, while lead (Pb) and mercury (Hg) remained undetected. Although the tested parameters currently fall within tolerable limits set by the International Commission on Microbiological Specifications for Foods (ICMSF), the presence of *E. coli*, yeasts, molds, chromium, and cadmium highlights marginal processing quality. This study bridges a critical gap by shifting the food safety focus from retail to the point of production, providing essential baseline data on heavy metal and microbial contamination. Consequently, there is an urgent need to implement targeted hygiene education regarding the health threats posed by these contaminants. Establishing rigorous surveillance for ready-to-eat plantain snacks will ultimately safeguard consumers while protecting the economic viability of traditional food markets.

Keywords: Plantain snack, *Dodo-Ikire*, heavy metals, microbiological analysis, production site

Introduction

The development of “*Dodo-Ikire*” emerged as a valorization strategy to utilize overripe plantains (Kaushal et al., 2022), thereby mitigating food loss and providing an alternative to waste disposal (Ladapo, 2011). Sellers, however, now use ripe plantains for preparing the delicacy (Olatoye & Lawal 2016). *Dodo-Ikire* is a spicy, fried, delicious plantain treat indigenous to Ikire in Osun State, Nigeria. Sales of *Dodo-Ikire* have now spread to nearby towns and have become an export commodity, made with overripe plantains/bananas fried in palm oil (Alao et al., 2020). This snack exemplifies the biochemical transformation of overripe (senescent) plantains into a shelf-stable, value-added product. By converting a highly perishable raw material into a uniquely flavored snack, this process monetizes potential waste resulting from post-harvest losses or physiological senescence (Evans-Amos, 2019). The upstream segment of the plantain value chain comprises producers, assemblers, wholesalers, processors, and exporters, whereas the downstream segment consists of retailers and consumers (Adewole, 2017; Ayanwale et al., 2018; Olajide & Olonibua, 2019).

Interestingly, the nutritional profile of *Dodo-Ikire* is nearly identical to that of standard fried plantains (Kara, 2019), suggesting that the fruit retains its nutritional integrity despite physiological senescence and subsequent processing. Plantain is a reliable source of carbohydrates (starch and sugar) and dietary fiber. Fried plantains are extremely high in

fat (saturated, polyunsaturated, and monounsaturated) "good" fats and may reduce the risk of heart disease (Kara, 2019). Fried plantains are rich in nutrients, providing essential vitamins and minerals. They are an excellent source of Vitamin A, which is crucial for healthy vision, immune function, red blood cell production, and gene regulation. Vitamin B-6 is vital for nervous system function, red blood cell synthesis, hormone regulation, and nucleic acid production. In addition, fried plantains are a valuable source of K and Mg. These minerals are essential for maintaining fluid balance and cardiovascular health, supporting key enzymatic functions. Energy metabolism, cell membrane structure, and chromosome integrity (Oyewole, 2012; Tunde, 2018). On average, *Dodo-Ikire* provides a substantial caloric density of 545 kcal/100g. Its proximate composition includes 2.1 g of protein, 34.2 g of fat, 63.2 g of carbohydrates, and 4.1 g of crude fiber (Ogundipe & Oladipupo, 2018). Furthermore, the snack is a source of sodium (250 mg) and is notably rich in vitamins C and B-complex, as well as essential minerals (Kayode et al., 2013). Production and marketing of *Dodo-Ikire* commonly occur in open environments with variable hygiene practices (exposure to dust, contaminated water, unwashed hands, and unrefrigerated storage). Previous assessments of overripe fried plantains and similar Nigerian snacks have revealed elevated Total Viable Counts (TVC) and coliform levels. The presence of these pathogens indicates significant post-processing recontamination, which effectively bypasses the safety margins established by the initial thermal kill-step. These microbial hazards may arise from handling, utensils, reuse of frying oil, or storage after frying (Xavier, 2002). Heavy metals and minerals may be introduced into street foods through various pathways, including unhygienic handling, degraded raw materials, and contaminated frying oils. Furthermore, the use of metallic cookware and exposure to environmental deposition—such as dust and vehicular emissions at roadside sites—contribute to the total elemental load.

Detecting contamination of food by metallic elements and microbes is a significant aspect of assuring food quality (Nkwunonwo et al., 2020). Since intake of heavy metal-contaminated vegetables may pose a risk to human health (Rai et al., 2019), for some years now, the international and national regulations on food quality have reduced the highest permissible levels of toxic metals in food products due to an increased awareness of the risk posed by these metals along the food chain (Radwan & Salama, 2006). Cadmium can cause both acute and chronic intoxications (Chakraborty et al., 2013). The similar oxidation states of cadmium and zinc allow cadmium to substitute for zinc in metallothionein, impairing its ability to neutralize free radicals and protect cells from oxidative damage. Exposure to high levels of cadmium can lead to cancer and kidney failure in humans (Puthiyavalappil et al., 2025). Recent findings suggest that cadmium exposure can cause health issues, such as kidney damage, bone problems, and fractures, at lower levels than previously thought (Jacobo-Estrada et al., 2018; Buha et al., 2019). Assessing the microbial quality of ready-to-eat foods is paramount for ensuring consumer safety. Kayode et al. (2013) observed significantly higher microbial loads in *Dodo-Ikire* samples sourced from local vendors compared to laboratory-prepared controls, highlighting the impact of commercial handling on food safety.

Street foods such as *Dodo-Ikire* serve as highly convenient sources of nutrition. In Nigeria, these products are widely consumed by travelers, contributing to a global phenomenon where an estimated 2.5 billion people in developing nations rely on street-vended foods daily (Mazi et al., 2023). The patronage and consumption of *Dodo-Ikire* is more common among all age groups from adults, young youths and children simply because it is delicious, nutritious and always available along the road in Ikire been a signature snack in the town which is located along a major road linking cities in

the Southwest Nigeria (Ogidi et al., 2016) Increase in patronage of *Dodo-Ikire* had been related to the obvious advantages such as been cheap, convenient, love for plantain and easy accessibility (Udoh & Oyetayo, 2024). A large proportion of the populace depends on *Dodo-Ikire* for survival until they reach their destination, while others buy as take home for family members and children. Consequently, evaluating the public health risks associated with *Dodo-Ikire* consumption is critical, given the large number of individuals who rely on these snacks for daily nutrition.

This study elucidates the safety risks and contamination pathways of *Dodo-Ikire*, offering a vital resource for local producers and public health officials. Beyond *Ikire*, this research contributes to the broader discourse on street food safety, providing a template for assessing contamination in similar artisanal snacks such as Kuli-kuli and Plantain Chips in diverse geographical contexts.

Materials and Methods

Source and Collection of Commercially Sold *Dodo-Ikire* Samples

Twelve packaged units of *Dodo-Ikire* were bought from five producers each in five different production sites in *Ikire*, Nigeria (Oja-Ale, Iyana-General, Sango, Molalere, and Isale -Abata) with coordinates from *Ikire-Iwo* road, Oke-Osun 232106, Osun State, Nigeria. To maintain the integrity of the samples, collection and storage followed the procedures outlined by George (2021). These steps were taken to achieve laboratory homogenization while precluding any contamination beyond that originating from the initial production sites. At the majority of production sites, processors utilized traditional iron cookware and utensils for frying and manual stirring. The process involved the use of crude palm oil as the frying medium, with traditional biomass (firewood) serving as the primary energy source for heating. The ground samples were packaged in a plastic container with air and watertight covers to minimise spoilage and other chemical reactions before analysis. All the samples were packaged aseptically in a polythene nylon exposed to ultraviolet rays and transported immediately at 40 °C to the laboratory for analysis.

Laboratory Analysis

Analyses carried out on the *Dodo-Ikire* samples include heavy metals, minerals, and microbial counts. All the experiments were carried out in triplicate, and the mean values were taken.

Elemental Analysis

Cd, Pb, Al, Cr, Fe, and Hg were quantified using ICP-OES, and the data were obtained in parts per million (mg/kg). A calibration curve was established using working standards for each element. To carry out the chemical digestion, 1g each of *Dodo-Ikire* dried sample was poured into separate digestion tubes and 6 ml of nitric acid solution (65% Merck, Germany) was added to the contents of the tubes at a ratio of 1:6. After this acidic digestion step, the contents in the storage tubes were placed in a fume hood with a heating system at 90 °C to dry, and a clear solution was obtained. The resulting clear solution was passed through a 45 mm Whatman filter paper and transferred to a volumetric flask with a volume of 15 ml. Finally, the samples were transferred to Falcon tubes with caps for injection.

Microbial Counts Analysis

Fungal Enumeration

Fungal counts were determined according to the method described by Jonathan and Olowolafe (2001) with slight modifications. One gram of each *Dodo Ikire* sample was aseptically weighed and homogenized in 10 mL of sterile distilled water to obtain an initial suspension. Serial decimal dilutions were prepared up to 10^{-4} . From the 10^{-4} dilution, 0.1 mL aliquots were aseptically inoculated onto sterile 100 mm petri dishes containing Potato Dextrose Agar (PDA) supplemented with 0.05 mg streptomycin to inhibit bacterial growth. The inoculum was evenly spread, and in parallel, an additional 0.1 mL of the same dilution was plated and overlaid with molten PDA to ensure uniform colony development. The plates were incubated at $29 \pm 2^{\circ}\text{C}$ for 72 hours. After incubation, visible fungal colonies were counted using a colony counter. Only plates with 30–300 colonies were considered for enumeration. Fungal counts were calculated and expressed as colony-forming units per gram (CFU/g).

Bacterial Analysis

For bacterial enumeration and detection of specific pathogens, 25 g of *Dodo Ikire* sample was aseptically homogenized in 225 mL of buffered peptone water (BPW) to obtain a 10^{-1} dilution. The homogenate was incubated at 37°C for 24 hours for pre-enrichment.

Detection of *Escherichia coli*

Following pre-enrichment, 1 mL of the homogenate was transferred into 10 mL of MacConkey broth and incubated at 37°C for 24 hours. A loopful of the culture was then streaked onto Eosin Methylene Blue agar plates and incubated at 37°C for 24 hours. Presumptive colonies with metallic green sheen were selected and subjected to molecular confirmation by polymerase chain reaction (PCR) (Hariri et al., 2022).

Detection of *Salmonella* spp.

For *Salmonella* spp. detection, 1 mL of the pre-enriched homogenate was transferred into 10 mL of Rappaport–Vassiliadis (RV) broth and incubated at 42°C for 24 hours. A loopful of the enriched culture was streaked onto Xylose Lysine Deoxycholate (XLD) agar plates and incubated at 37°C for 24 hours. Presumptive *Salmonella* colonies (red with black center colonies) were further confirmed using PCR techniques (Andrews et al., 2023).

Statistical Analysis

Data was subjected to Analysis of Variance (ANOVA) at 5% level, and the means were separated using Duncan Multiple Range Test procedure as described in the SAS release 8.3 software. (SAS, 2002).

Results and Discussion

The concentrations of Iron (Fe) and Aluminum (Al) in Dodo–Ikire samples across five major production sites in Ikire are presented in Table 1. The analytical results revealed that Fe levels ranged from 0.20 to 3.92 mg/kg, while Al concentrations varied between 1.01 and 5.11 mg/kg.

Table 1 The iron and aluminium content (mg/kg) of *Dodo-Ikire* produced from five production hotspots in Nigeria*

Production centre	Iron	Aluminium
Oja-Ale	0.36 ^b	2.07 ^c
Iyana -General	3.92 ^a	3.93 ^b
Sango	0.20 ^c	1.01 ^d
Molalere	0.22 ^c	2.20 ^c
Isale -Abata	0.59 ^b	5.11 ^a
Mean	1.05	2.86
Median	0.36	2.2
Max.	3.92	5.11
Min.	0.20	1.01
SEM	0.72	0.73

SEM: Standard error of means * Different letters indicate statistically significant differences

The highest Fe concentration was observed in samples from Iyana General (3.92 mg/kg), followed by Isale–Abata (0.59 mg/kg) and Oja Ale (0.36 mg/kg); however, these variations were not statistically significant ($p > 0.05$). The lowest Iron levels were recorded at Molalere (0.22 mg/kg) and Sango (0.20 mg/kg). Regarding Al, Isale– Abata yielded the highest concentration (5.11 mg/kg), followed by Iyana General (3.93 mg/kg). Values for Molalere and Oja–Ale showed no significant difference, while the minimum Aluminum content was recorded in Sango (1.01 mg/kg).

Toxic heavy metals, specifically Lead (Pb) and Mercury (Hg), were below the limit of detection in all *Dodo-Ikire* samples across the assessed locations (Table 2). However, Cadmium (Cd) and Chromium (Cr) were present, with concentrations ranging from 0.00–0.08 mg/kg and 0.00–0.62 mg/kg, respectively. Samples from Isale–Abata exhibited the highest Cadmium levels (0.08 mg/kg), while the element was completely absent in samples from Sango. Conversely, Chromium was not detected in Iyana–General or Isale–Abata, but peaked in samples from Molalere (0.62 mg/kg), followed by Oja Ale (0.35 mg/kg) and Sango (0.24 mg/kg)

Table 2 Selected heavy metal residues (mg/kg) in *Dodo-Ikire* produced from five production hotspots in Nigeria*

Production centre	Cadmium	Chromium	Lead	Mercury
Oja-Aale	0.003 ^d	0.350 ^b	0.000	0.000
Iyana-General	0.017 ^c	0.000 ^d	0.000	0.000
Sango	0.000 ^d	0.240 ^c	0.000	0.000
Molalere	0.030 ^b	0.620 ^a	0.000	0.000
Isale- Abata	0.080 ^a	0.000 ^d	0.000	0.000
Mean	0.026	0.24	0	0
Median	0.017	0.24	0	0
Max	0.08	0.62	0	0
SEM	0.01	0.12	0	0

*abcd = means on the same column with different subscript are significantly different ($p < 0.05$)

The mean microbial colony counts for *Dodo-Ikire* across five production hotspots are detailed in Table 3. The Total Viable Count (TVC) was highest in samples from Molalere (3.01×10^6 CFU/g), followed by Iyana–General (2.04×10^6 CFU/g). Regarding *E. coli* levels, Molalere again showed the highest concentration (7.0×10^4 CFU/g), which

was significantly different ($p < 0.05$) from Iyana-General (1.0×10^4 CFU/g) and Isale-Abata (2.0×10^4 CFU/g). However, the *E. coli* load in Molalere was statistically comparable to Sango (6.5×10^4 CFU/g) and Oja Ale (5.5×10^4 CFU/g). Conversely, the *Salmonella* count peaked at Iyana-General (1.3×10^5 CFU/g), followed by Isale-Abata, Sango, and Molalere, with no detection in samples from Oja-Ale.

Table 3 Total Viable Count (TVC), *E. coli*, and *Salmonella* of Coliform in *Dodo -Ikire* produced at Five Production hotspots in Nigeria (at Dilution factor 10^4)*

Production centre	TVC	<i>E. coli</i>	<i>Salmonella</i>
Oja-Ale	1.31×10^6 ^c	5.5×10^4 ^a	0×10^4 ^c
Iyana -General	2.04×10^6 ^b	1.0×10^4 ^b	1.30×10^5 ^b
Sango	1.92×10^6 ^b	6.5×10^4 ^a	3.00×10^4 ^b
Molalere	3.01×10^6 ^a	7.0×10^4 ^a	1.50×10^4 ^b
Isale -Abata	109×10^4 ^c	2.0×10^4 ^b	1.15×10^5 ^a

*abcd = means on the same column with different subscripts are significantly different ($p < 0.05$)

Qualitative analysis revealed that *Salmonella* spp. was present in 25g of *Dodo-Ikire* samples purchased from Iyana-General, Sango, Molalere, and Isale-Abata. Conversely, the pathogen was absent (not detected) in all samples sourced from Oja-Ale.

Fungal analysis (Table 4) revealed significant variations in microbial quality between locations. Iyana-General and Isale-Abata were identified as hotspots for mould contamination (1.30×10^5 CFU/g and 1.15×10^5 CFU/g, respectively). Yeast contamination peaked at Isale-Abata (2.35×10^5 CFU/g). Conversely, Oja-Ale demonstrated superior fungal stability, with no yeast or mould detected, likely reflecting better post-production handling or lower environmental moisture.

Table 4 The yeast and mould content (CFU/g) in *Dodo- Ikire* produced from Five hotspots in Nigeria (at Dilution factor 10^5)

Production centre	Mold	Yeast
Oja -Ale	–	–
Iyana -General	1.30×10^5	–
Sango	3.00×10^4	1.00×10^4
Molalere	1.50×10^4	–
Isale -Abata	1.15×10^5	2.35×10^5

Regulatory thresholds for heavy metals and microbial contaminants provide a benchmark for food safety (Tables 5 and 6) (Guo et al., 2026). While national limits vary by product type, the microbial quality of *Dodo-Ikire* from several hotspots in Ikire remains a concern. With counts reaching 10^6 CFU/g, the samples surpassed the ICMSF/FAO guidelines for 'acceptable' ready-to-eat snacks. This marginal microbial stability, combined with the presence of heavy metals, underscores a dual toxicological threat to consumers. The detection of *E. coli*, yeast, and mould at levels greater than 10^4 CFU/g confirms a pattern of post-production contamination consistent with reports by Amare et al. (2019) and Al-Nasir (2020).

Table 5 Permissible limit (mg/kg) of selected heavy metals in ready-to-eat snacks

Metals	WHO/FAO permissible limit	NAFDAC permissible limit
Cd	0.05 – 0.2	0.1 – 1.1
Cu	30	20
Pb	0.1 – 0.3	0.2–2.5
Zn	60	50
Fe	48	–
Ni	–	–

Table 6 Regulatory Threshold for microbes in ready-to-eat snacks

Property	ICMSF/FAO
Total Viable Count	0 – 10 ³ CFU/g (acceptable)
	10 ⁴ – 10 ⁵ CFU/g (tolerable)
	10 ⁷ CFU/g (unacceptable)

Numerous cases of foodborne illness, including dysentery and diarrhea, have been epidemiologically linked to the consumption of street-vended foods contaminated with pathogens such as *E. coli* (Jha et al., 2016; Jennison et al., 2004). As an opportunistic pathogen, *E. coli* serves as a critical indicator of fecal contamination, signaling significant health risks to the consumer (Manhique et al., 2020). The high TVC observed in this study aligns with previous reports attributing contamination to substandard handling techniques and poor personal hygiene during processing (Makinde et al., 2020; Oyedele et al., 2020). The observed disparities in contamination levels across the five locations likely stem from variations in traditional preparation methods and the types of utensils employed. Consequently, regulatory agencies must enforce strict adherence to safety limits to mitigate these public health risks.

In the present study, the concentrations of Fe and Al were highest in snacks sourced from Iyana-General (3.92 mg/kg) and Isale-Abata (5.11 mg/kg), respectively. These values are markedly higher than those reported by Kayode et al. (2013), who found relatively low Iron levels (0.002–0.004 mg/kg) in market-vended *Dodo-Ikire*. This elevation in metallic concentration may be attributed to the prolonged use of aged utensils. Specifically, the high Iron content likely results from the use of ferrous-based cookware during preparation; as noted by Ajayi et al. (2023), thermal processing in such vessels facilitates elemental leaching, which increases both total iron content and nutritional bioavailability. To mitigate these risks, interventions should focus on the adoption of Good Manufacturing Practices (GMP) and the transition to appropriate food-grade utensils. Furthermore, utilizing high-density polyethylene (HDPE) packaging, as recommended by Olatoye and Lawal (2016), provides superior protection against post-production contamination.

The maximum concentrations of Cadmium (0.080 mg/kg at Isale-Abata) and Chromium (0.620 mg/kg at Molalere) remained within the permissible limits established by NAFDAC and the WHO/FAO (1.00 µg/g). Observations at the Molalere site revealed the use of oxidized iron cookware, improvised stirring implements (shovels), and thermally degraded palm oil—practices prevalent across all surveyed locations. While heavy metal concentrations are currently low, continuous longitudinal monitoring is vital to prevent chronic exposure. Microbial contamination is likely multifactorial, stemming from traditional processing methods, non-food-grade containers, and environmental

exposure. Given that prolonged consumption may lead to bioaccumulation and associated health risks, this study underscores the urgent need for hygienic standardization and producer training to ensure consumer protection.

Conclusion and Suggestions

In conclusion, freshly prepared ready-to-eat plantain snacks from production hotspots in Ikire, Nigeria, exhibit a marginal safety profile. The identification of specific heavy metals and microbial loads highlights a significant public health concern. While fungal counts (yeasts and moulds) were within borderline ranges, the detected presence of *Salmonella* and *E. coli* underscores a critical need for hygiene intervention. These findings provide a foundational dataset for assessing the risk of similar artisanal snacks, such as Kuli-kuli, in other regional contexts where traditional processing dominates.

Contamination of traditional snacks by heavy metals and pathogens is frequently attributed to suboptimal handling during and after processing. In Nigeria, ready-to-eat snacks like *Dodo-Ikire* have gained significant popularity, driven by their affordability, convenience, and widespread accessibility in high-traffic areas such as schools, hospitals, and highways. The findings of this study suggest that while freshly prepared *Dodo-Ikire* is a nutritionally viable snack, its current safety status is only marginally acceptable. To effectively mitigate these chemical and microbial risks, modernizing traditional preparation methods, refining handling protocols, and adopting advanced food-grade packaging materials remain imperative. Consequently, there is an urgent need to implement targeted hygiene education regarding the structural vulnerabilities in artisanal processing. Empowering local producers through specialized capacity-building initiatives and workshops that emphasize the use of food-grade equipment will ultimately safeguard consumers while protecting the economic viability of traditional food markets.

Author Contributions

The contribution by each author to the manuscript is listed below;

Abiola Elizabeth Ojeleye: Conceptualization, development of methodology, contributions are development of methodology, Collection of data, Data analysis and interpretation, Manuscript writing, Manuscript review and editing.

Rosemary Oladoyin Oladeji: Providing materials and investigation of the research.

Conflict of Interests

All authors declare that they have no conflicts of interest.

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Declaration of Generative AI and AI-assisted Technologies

During the preparation of this manuscript, the authors used AI tools to improve readability and narrative flow. Following its use, the authors thoroughly reviewed and edited the content and accept full responsibility for the final version of the publication.

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