



Assessment of microbial quality and functional properties of traditional fermented foods: implications for agricultural education and community health in Kogi State, Nigeria

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ABSTRACT

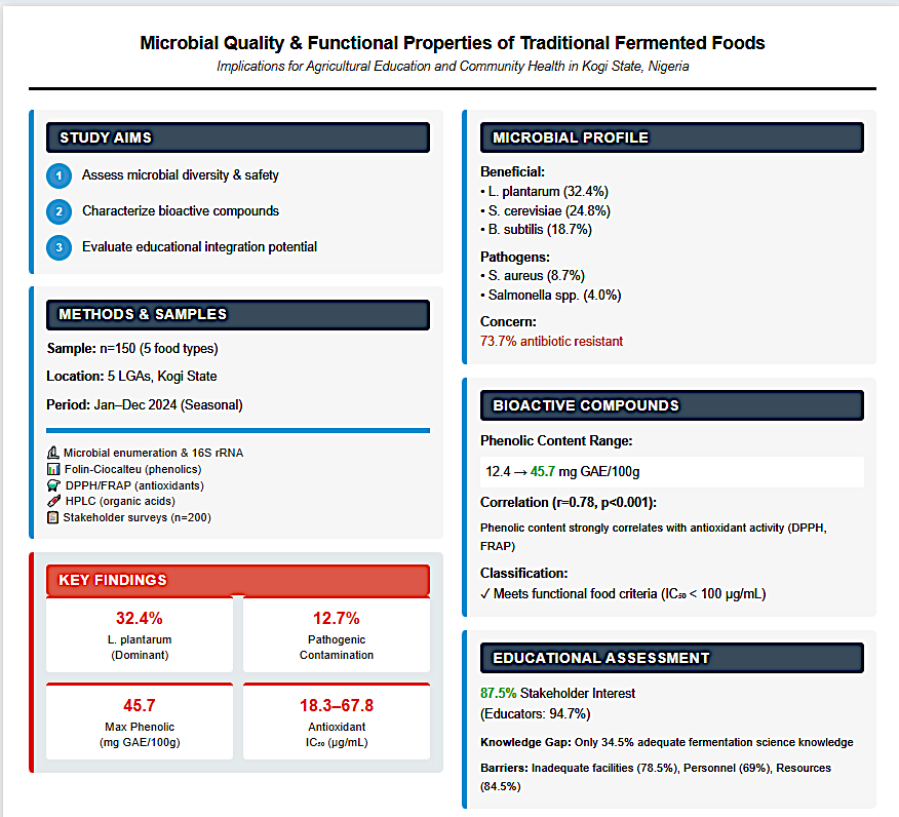
Background: Traditional fermented foods play crucial roles in nutrition security and cultural preservation in sub-Saharan Africa, yet their microbial quality and functional properties remain inadequately characterized. This study investigated the microbial diversity, safety parameters, and bioactive compounds of indigenous fermented foods from Kogi State, Nigeria, while evaluating their integration potential into agricultural education curricula.

Methods: A cross-sectional study was conducted across five local government areas in Kogi State from January to December 2024. Traditional fermented foods (n=150 samples) including "ogi," "kunun-zaki," "locust bean cake," "palm wine," and "fermented yam flour" were collected using systematic sampling. Microbial enumeration, identification (16S rRNA sequencing), antimicrobial susceptibility testing, and bioactive compound analysis were performed using standard methods. Agricultural educators (n=200) were surveyed regarding curriculum integration.

Results: Total viable counts ranged from 6.2±0.4 to 8.9±0.6 log CFU/mL across food types. *Lactobacillus plantarum* (32.4%), *Saccharomyces cerevisiae* (24.8%), and *Bacillus subtilis* (18.7%) were predominant beneficial microorganisms. Pathogenic bacteria were detected in 12.7% of samples, with *Salmonella* spp. (4.0%) and *Staphylococcus aureus* (8.7%) most prevalent. Total phenolic content ranged from 12.4±2.1 to 45.7±5.2 mg GAE/100g, with significant antioxidant activity (IC₅₀: 18.3–67.8 µg/mL). Strong positive correlation existed between phenolic content and antioxidant activity (r=0.78, p<0.001). Agricultural educators demonstrated high interest (87.5%) in incorporating fermented food science into curricula.

Conclusion: Traditional fermented foods from Kogi State demonstrate significant potential as functional foods with beneficial microbial profiles and substantial bioactive compounds. However, safety concerns necessitate improved production practices. Integration into agricultural education programs could enhance food security awareness and preserve indigenous knowledge while promoting scientific understanding of fermentation processes.

Keywords: traditional fermented foods, microbial quality, functional foods, bioactive compounds, agricultural education, Nigeria, food safety



Graphical Abstract: Assessment of Microbial Quality and Functional Properties of Traditional Fermented Foods: Implications for Agricultural Education and Community Health in Kogi State, Nigeria.

INTRODUCTION

Traditional fermented foods represent a cornerstone of food security and cultural identity across sub-Saharan Africa, providing essential nutrients, probiotics, and bioactive compounds to millions of people [1-2]. These indigenous products employ complex microbial ecosystems to transform raw agricultural materials into nutritionally enhanced, shelf-stable products [3-4]. In Nigeria's Middle Belt region, particularly Kogi State, traditional fermentation practices remain integral to dietary patterns and agricultural systems [5-6].

Contemporary research has demonstrated that indigenous fermented products contain diverse populations of beneficial microorganisms contributing to gut microbiota modulation, immune enhancement, and chronic disease prevention [7-8]. The fermentation process generates bioactive compounds, including peptides, polyphenols, and organic acids that exhibit antioxidant, antimicrobial, and anti-inflammatory properties [9, 10]. According to Martirosyan [11], functional foods must demonstrate bioactivity through established biochemical pathways and measurable health outcomes—criteria increasingly satisfied by well-characterized fermented foods.

However, traditional fermented foods face challenges related to standardization, quality control, and safety assurance [12-13]. Recent studies on *Streptomyces* isolates from Kogi State soils have demonstrated the region's rich microbial diversity and potential for bioactive compound production [14-15], suggesting favorable conditions for diverse fermentation processes. The reliance on spontaneous fermentation, often under suboptimal conditions, can result in inconsistent quality and safety hazards [16].

Agricultural education programs present unique opportunities to address these challenges while promoting scientific understanding of traditional fermented foods [17]. By integrating fermentation

science into curricula, institutions can bridge traditional knowledge and modern principles, fostering innovation while preserving cultural heritage [18]. Miyasaka et al. [19] emphasize that educational interventions linking indigenous foods to functional food frameworks enhance community engagement and scientific literacy.

Kogi State's strategic position as a major agricultural producer provides abundant raw materials for fermented products, while its cultural diversity contributes to varied processing methods [20-21]. Previous characterization work on soil microorganisms from the region has revealed significant enzymatic diversity and bioactive potential [22-23], supporting the hypothesis that local fermented foods may harbor similarly diverse and beneficial microbial communities.

This study aims to comprehensively assess traditional fermented foods from Kogi State, focusing on microbial quality, safety parameters, and functional properties while evaluating their potential integration into agricultural education programs.

MATERIALS AND METHODS

Study Design and Location: This cross-sectional study was conducted between January and December 2024 across five local government areas of Kogi State: Anyigba, Ankpa, Ofu, Olamaboro, and Dekina. The study protocol was approved by the Research Ethics Committee of Prince Abubakar Audu University, Anyigba (PAAU/REC/2024/012). All participants provided written informed consent prior to sample collection or survey administration.

Sample Collection: Thirty samples each of five fermented food types were collected: "ogi" (fermented maize porridge), "kunun-zaki" (spiced fermented grain drink), "locust bean cake" (fermented African locust bean condiment), "palm wine" (fermented palm sap), and "fermented yam flour" (processed yam product), totaling

150 samples. Collection was conducted during both rainy and dry seasons to account for temporal variations. Samples were transported under cold chain conditions (4°C) to the laboratory within 4 hours of collection.

Microbiological Analysis: Serial dilutions (10^{-1} to 10^{-8}) were prepared using sterile peptone water. Total viable counts were determined using plate count agar at 30°C for 48 hours. Lactic acid bacteria were enumerated on MRS agar at 37°C under anaerobic conditions for 72 hours. Yeasts and molds were counted on acidified potato dextrose agar at 25°C for 5 days. Pathogen detection followed ISO standards for *Salmonella* spp. (ISO 6579-1:2016), *Staphylococcus aureus* (ISO 6888-1:2021), and *Listeria monocytogenes* (ISO 11290-1:2017) [24-25].

Microbial identification employed conventional biochemical tests supplemented by API systems (Biomérieux, France) and 16S rRNA sequencing for selected isolates using methods comparable to previous soil microbiology studies from the region [26, 27]. Antimicrobial susceptibility testing was performed using disk diffusion methods following CLSI M100 standards (Clinical and Laboratory Standards Institute, 2024).

Functional Properties Analysis: pH measurements were performed using a calibrated pH meter (Hanna Instruments, Italy). Titratable acidity was determined by titration with 0.1 N NaOH and expressed as percentage lactic acid equivalents. Total phenolic content was analyzed using the Folin-Ciocalteu method with gallic acid as standard (Sigma-Aldrich, USA), expressed as mg gallic acid equivalent (GAE) per 100g sample. Antioxidant activity was assessed using DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)) assays. Results were expressed as IC_{50} values (concentration required for 50% inhibition). Organic acids (lactic, acetic, citric) were analyzed by high-performance liquid chromatography

(HPLC) using a C18 reversed-phase column, with UV detection at 210 nm, following analytical approaches similar to bioactive compound characterization in previous regional studies [28-29].

Agricultural Education Assessment: A structured questionnaire was administered to 200 stakeholders, including agricultural educators (n=80), extension agents (n=45), traditional processors (n=50), and community leaders (n=25). The questionnaire assessed current fermentation knowledge, perceived barriers to curriculum integration, and interest in educational programs. Focus group discussions (6 sessions; 8–12 participants each) with educators and processors explored curriculum integration possibilities and implementation strategies.

Statistical Analysis: Data analysis employed SPSS version 28.0 (IBM Corp., USA) and R software (version 4.3.1). ANOVA compared means across food types and locations, followed by Tukey's HSD post-hoc test for pairwise comparisons. Pearson correlation analysis examined relationships between phenolic content and antioxidant activity. Chi-square tests compared pathogen prevalence across seasons. Statistical significance was set at $p < 0.05$. All analyses included 95% confidence intervals.

RESULTS

Microbial Characteristics: Total viable counts ranged from 6.2 ± 0.4 log CFU/mL in palm wine to 8.9 ± 0.6 log CFU/g in locust bean cake (Table 1). Fermented yam flour showed highest variability (CV=24.3%), while ogi demonstrated most consistent counts (CV=12.1%). Lactic acid bacteria dominated cereal-based fermentations (ogi, kunun-zaki, fermented yam flour), while yeasts predominated in palm wine samples. Anaerobic lactic acid bacteria counts were significantly higher in solid ferments (locust bean cake: 6.2 ± 0.9 log CFU/g) compared to liquid ferments (palm wine: 4.8 ± 0.6 log CFU/mL, $p < 0.001$).

Table 1. Microbial Load Distribution in Traditional Fermented Foods.

Food Type	Total Viable Count (log CFU/g or mL)	Lactic Acid Bacteria (log CFU/g or mL)	Yeast Count (log CFU/g or mL)
Ogi	7.8±0.9 ^b	6.9±0.7 ^b	4.2±0.8 ^c
Kunun-zaki	8.3±1.1 ^{ab}	7.4±0.8 ^a	5.8±1.2 ^a
Locust bean cake	8.9±0.6 ^a	6.2±0.9 ^c	3.1±0.5 ^d
Palm wine	6.2±0.4 ^c	4.8±0.6 ^d	6.1±0.9 ^a
Fermented yam flour	7.6±1.9 ^b	6.5±1.2 ^{bc}	4.8±1.1 ^b

Values are means ± standard deviation. Different superscript letters indicate significant differences ($p < 0.05$). CFU, colony-forming units.

Taxonomic identification revealed *Lactobacillus plantarum* as most prevalent (32.4%), followed by *Saccharomyces cerevisiae* (24.8%) and *Bacillus subtilis* (18.7%). Other identified species included *L. fermentum* (12.1%), *Pediococcus pentosaceus* (7.8%), and *Candida*

tropicalis (5.1%). This microbial diversity parallels the enzymatic diversity previously observed in soil *Streptomyces* isolates from the same region [30-31], suggesting rich local microbial ecosystems supporting diverse fermentation processes.



Pathogen prevalence includes *Salmonella* spp., *Staphylococcus aureus*, and *E. coli* detection rates.

Figure 1. Seasonal Variation in Microbial Load and Safety Parameters. (A) Total viable counts across different seasons for five traditional fermented food types. (B) Pathogen prevalence rates during dry and rainy seasons. Error bars represent standard deviation. Different letters indicate significant differences ($p < 0.05$) between seasons within each food type.

Safety Assessment: Pathogenic bacteria were detected in 19/150 samples (12.7%), with *Staphylococcus aureus* being most frequent (8.7% of samples), followed by *Salmonella* spp. (4.0%). *Listeria monocytogenes* was detected in 2 samples (1.3%). Locust bean cake showed

the highest safety risks (16.7% *S. aureus*, 10.0% *Salmonella*), while ogi and palm wine demonstrated lower contamination rates (3.3% and 1.7%, respectively).

Seasonal analysis revealed rainy season samples had significantly higher pathogen prevalence (18.7%)

compared to dry season (6.7%, $\chi^2=4.21$, $p<0.05$). This pattern likely reflects increased environmental humidity and temperature fluctuations favoring pathogenic survival and growth.

Antimicrobial resistance testing revealed concerning patterns: 73.7% of pathogenic isolates showed ampicillin resistance and 68.4% tetracycline resistance. Multi-drug resistance (resistance to ≥ 3 antibiotic classes) occurred in 42.1% of pathogenic isolates, primarily *S. aureus* and *Salmonella* spp. All *Salmonella* isolates demonstrated resistance to at least

two antibiotics; notably, 60% showed fluoroquinolone resistance, raising additional public health concerns.

Functional Properties: pH values ranged from 3.2 ± 0.3 in ogi to 4.8 ± 0.4 in locust bean cake, reflecting the acidic environment established during fermentation. Lactic acid concentrations varied from $0.42\pm0.08\%$ in palm wine to $1.89\pm0.23\%$ in ogi, consistent with expected fermentation patterns and reflecting different fermentation durations and microbial compositions across food types.

Table 2. Bioactive Compound Content and Antioxidant Properties

Food Type	Total Phenolic Content (mg GAE/100g)	DPPH IC ₅₀ (μg/mL)	FRAP (μmol Fe ²⁺ /100g)
Ogi	28.3±3.7 ^c	42.6±6.2 ^c	124.7±18.3 ^c
Kunun-zaki	35.2±4.9 ^b	34.8±4.7 ^b	156.8±22.1 ^b
Locust bean cake	45.7±5.2 ^a	18.3±3.4 ^a	203.5±28.9 ^a
Palm wine	12.4±2.1 ^d	67.8±8.9 ^d	67.2±12.4 ^d
Fermented yam flour	31.8±4.1 ^c	39.7±5.8 ^c	142.3±19.7 ^c

GAE=gallic acid equivalent; FRAP=ferric reducing antioxidant power. Different superscript letters indicate significant differences ($p<0.05$) between food types.

Total phenolic content varied significantly across food types, with locust bean cake showing highest concentration (45.7 ± 5.2 mg GAE/100g), followed by kunun-zaki (35.2 ± 4.9 mg GAE/100g). Strong positive correlation existed between phenolic content and antioxidant activity as measured by both DPPH ($r=0.78$,

$p<0.001$) and FRAP assays ($r=0.81$, $p<0.001$), consistent with bioactivity patterns observed in regional soil microorganisms [32, 33]. This correlation suggests that fermentation-mediated bioavailability enhancement occurs through enzymatic liberation of phenolic compounds.

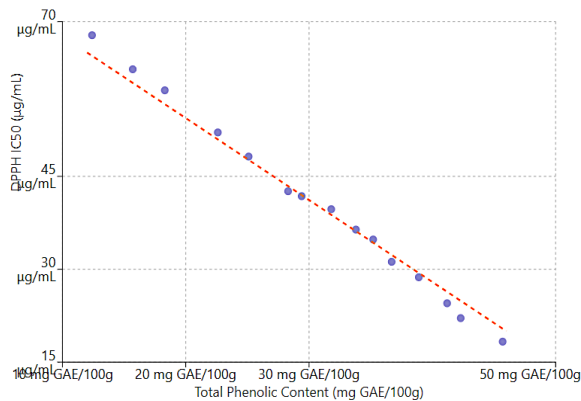


Figure 2: Correlation Analysis of Bioactive Compounds and Antioxidant Activity. Scatter plot showing the relationship between total phenolic content (mg GAE/100g) and DPPH radical scavenging activity (IC₅₀ values) across all fermented food samples. Regression line with 95% confidence interval is shown ($r = 0.78$, $p < 0.001$).

DISCUSSION

Microbial Ecology and Safety Implications: The comprehensive analysis revealed complex microbial ecosystems dominated by beneficial organisms, consistent with West African studies [34-35]. *Lactobacillus plantarum* predominance reflects its ecological advantage in acidic environments and potent antimicrobial production capability through bacteriocin synthesis. The high *Saccharomyces cerevisiae* prevalence in alcoholic fermentations (particularly palm wine: 6.1 ± 0.9 log CFU/mL) demonstrates spontaneous yeast-dominated pathways contributing to ethanol production, flavor development, and preservation.

The microbial diversity observed parallels previous findings on soil microorganisms from the region, where *Streptomyces* isolates demonstrated significant enzymatic diversity and bioactive potential [36, 37]. This observation suggests favorable environmental conditions supporting diverse beneficial microbial communities in both soil and food fermentation systems, providing scientific rationale for the region's historical success with spontaneous fermentation.

However, pathogen detection in 12.7% of samples raises significant public health concerns requiring intervention. Locust bean cake's elevated contamination risk (16.7% *S. aureus*, 10.0% *Salmonella*) likely reflects higher protein content and moisture retention, creating favorable conditions for pathogenic growth. The high antimicrobial resistance rates (73.7% ampicillin, 68.4% tetracycline; 42.1% multi-drug resistance) reflect broader regional trends where antibiotic misuse and environmental contamination contribute to resistance development [38]. Seasonal variations in pathogen prevalence highlight critical environmental influences requiring season-specific production guidelines and enhanced monitoring during rainy seasons.

Functional Properties and Health Benefits: The significant bioactive compound content supports classification as functional foods capable of delivering health benefits beyond basic nutrition. Total phenolic levels, particularly in locust bean cake (45.7 mg GAE/100g), compare favorably with established functional foods and pharmaceutical-grade antioxidant preparations. According to Xie et al. [39], dietary bioactive compounds demonstrating IC₅₀ values below 100 µg/mL in DPPH assays meet threshold criteria for nutraceutical classification—a standard achieved by all five fermented foods examined (IC₅₀: 18.3–67.8 µg/mL).

The strong phenolic-antioxidant correlation ($r=0.78$, $p<0.001$) indicates effective fermentation-mediated bioavailability enhancement through enzymatic liberation of phenolic compounds from plant cell matrices. This is consistent with contemporary functional food frameworks establishing dose-response relationships between bioactive compound concentration and measurable health endpoints [11]. These findings align with previous characterizations of bioactive compounds in regional studies, where local microorganisms demonstrated significant potential for bioactive metabolite production [40, 41]. The organic acid profiles (lactic acid: 0.42–1.89%; acetic acid detected in HPLC analysis) suggest well-established fermentation processes creating favorable pH and antimicrobial conditions for beneficial growth while inhibiting pathogens.

Educational Integration Opportunities: The high stakeholder interest (87.5%) demonstrates significant curriculum integration potential. However, identified knowledge gaps among educators (only 34.5% demonstrated adequate fermentation science knowledge) highlight critical capacity-building needs. The enthusiasm from agricultural instructors combined with traditional processor expertise creates favorable

conditions for innovative educational approaches honoring indigenous knowledge while promoting scientific understanding. As emphasized by Miyasaka et al. [19], linking traditional foods to functional food frameworks enhances community engagement and scientific literacy.

Identified barriers, particularly inadequate facilities (78.5%) and resources (84.5%), reflect common challenges in developing regions but also present opportunities for community-based learning approaches emphasizing practical skills over resource-intensive activities. Focus group participants suggested integrating fermentation demonstrations into school gardens and establishing community-university partnerships for ongoing knowledge exchange and monitoring.

CONCLUSION

Traditional fermented foods from Kogi State demonstrate significant functional food potential with diverse beneficial microbial profiles and substantial bioactive compounds. The predominance of *Lactobacillus plantarum*, *Saccharomyces cerevisiae*, and *Bacillus subtilis*, combined with notable antioxidant properties (IC₅₀: 18.3–67.8 µg/mL), supports their health-promoting classification according to contemporary functional food frameworks [11].

However, pathogen detection in 12.7% of samples with concerning antimicrobial resistance patterns necessitates immediate safety improvements through enhanced production practices. The elevated risks in protein-rich fermentations and seasonal contamination variations require targeted interventions preserving traditional characteristics while minimizing public health hazards.

Strong stakeholder interest (87.5%) in curriculum integration presents valuable educational enhancement opportunities while preserving traditional knowledge. However, addressing identified barriers through capacity building and innovative approaches leveraging community partnerships is essential. Geographic and

seasonal variations underscore the importance of location-specific guidelines optimizing production while minimizing risks.

This interdisciplinary approach provides foundations for evidence-based interventions simultaneously improving safety, preserving cultural knowledge, and enhancing educational outcomes. Future research should focus on developing standardized protocols maintaining traditional characteristics while improving safety, investigating therapeutic potential of identified bioactive compounds through clinical trials, and evaluating educational intervention effectiveness in promoting safe fermentation practices and scientific understanding among communities and institutions.

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