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Integrating bioprocesses in the Nigerian food chain: Opportunities for public health impact and disease risk reduction

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Abstract

Nigeria faces significant challenges in food security, nutrition, and foodborne diseases that collectively impact public health outcomes across its diverse population. This review examines the potential for integrating modern and traditional bioprocesses throughout the food chain of Nigeria, aimed at addressing these challenges. Current literature on fermentation technologies was analyzed on biopreservation, biofortification, and their applications in the Nigerian context. The integration of bioprocesses presents substantial opportunities for enhancing nutritional value, reducing foodborne pathogens, and extending shelf-life of indigenous foods. Key bioprocessing interventions include controlled fermentation of traditional foods like garri and ogi, probiotic enhancement of dairy products, and biofortification of staple crops. However, implementation faces barriers including inadequate infrastructure, regulatory gaps, and limited technical capacity. Strategic recommendations include developing appropriate regulatory frameworks, investing in processing infrastructure, and building technical capacity among food processors. The successful integration of bioprocesses could significantly reduce malnutrition rates, decrease foodborne illness incidence, and improve overall population health outcomes while preserving cultural food traditions.

Keywords: Bioprocesses; Food Security; Fermentation; Nigeria; Public Health; Disease Prevention

1. Introduction

Nigeria, a populous nation with over 220 million inhabitants, confronts substantial challenges in achieving food security and ensuring optimal public health outcomes through its food systems (1). The complex food landscape of the country encompasses diverse agricultural systems, traditional processing methods, and emerging modern food industries, yet significant gaps remain in addressing malnutrition, foodborne diseases, and food safety concerns (2). Approximately 37% of Nigerian children under five years suffer from chronic malnutrition, while foodborne diseases affect millions annually, contributing to morbidity and mortality across all age groups (3).

Bioprocesses, defined as the application of biological systems including microorganisms, enzymes, and plant cells to transform raw materials into value-added products, offer promising solutions for enhancing food security and public health outcomes (4). These technologies encompass traditional fermentation practices that have been integral to Nigerian food culture for centuries, as well as modern biotechnological approaches that can be adapted to local contexts and needs (5). The integration of bioprocesses throughout the food chain of Nigeria presents opportunities to simultaneously address nutritional deficiencies, reduce foodborne disease risks, and improve food preservation while respecting cultural food preferences and economic constraints.

Traditional fermented foods such as garri (fermented cassava), ogi (fermented maize porridge), and dawadawa (fermented locust beans) already play crucial roles in Nigerian diets, contributing to food security and providing

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beneficial microorganisms that support digestive health (6). However, these traditional processes often lack standardization and quality control, potentially limiting their nutritional benefits and safety profiles (7). Modern bioprocessing technologies offer opportunities to optimize these traditional methods while introducing new applications such as biofortification, probiotic enhancement, and advanced preservation techniques.

This review aims to comprehensively examine the potential for integrating bioprocesses in the indigenous food chain, analyzing current challenges, identifying opportunities for public health impact, and proposing strategies for reducing disease risks. Focusing on evaluating the current state of bioprocessing in Nigeria, assessing the public health burden that could be addressed through bioprocess integration, and providing evidence-based recommendations for policymakers, researchers, and industry stakeholders.

2. Current State of Bioprocessing in Nigerian Food Systems

2.1. Traditional Bioprocessing Practices

The rich heritage of Nigeria on traditional food processing includes numerous fermentation practices that have evolved over generations to enhance food preservation, palatability, and nutritional value (8). Cassava processing into garri involves natural fermentation that reduces cyanogenic glycoside content while improving shelf-life and digestibility (9). Similarly, the production of ogi from maize, sorghum, or millet involves spontaneous lactic acid fermentation that enhances nutritional bioavailability and develops probiotic characteristics (10).

Fermented protein sources such as dawadawa from African locust beans and ogiri from castor seeds provide essential amino acids and serve as important protein supplements in vegetarian diets common across northern and eastern Nigeria (11). These traditional bioprocesses rely on indigenous microorganisms naturally present in the raw materials and processing environment, resulting in products with variable quality and safety profiles (12).

Recent studies have demonstrated that traditional Nigerian fermented foods contain diverse microbial communities including beneficial *Lactobacillus* species, *Bifidobacterium* strains, and various yeasts that contribute to both preservation and potential health benefits (13). However, these processes often occur under uncontrolled conditions, leading to inconsistent products and potential contamination with pathogenic microorganisms or mycotoxins (14).

2.2. Modern Food Processing Industry

The modern food processing sector has grown significantly over the past two decades in Nigeria, driven by urbanization, changing consumer preferences, and government policies promoting local content development (15). The sector includes multinational companies producing packaged foods, beverages, and dairy products, as well as numerous small and medium enterprises focusing on traditional food commercialization (16).

However, industry faces substantial challenges, including inadequate power supply, limited access to modern processing equipment, and insufficient cold chain infrastructure (17). These limitations particularly affect bioprocessing applications that require precise temperature and environmental control, such as controlled fermentation and probiotic production (18).

The regulatory environment for food processing in Nigeria is governed by the National Agency for Food and Drug Administration and Control (NAFDAC), which has established standards for various food products but has limited specific guidelines for many traditional fermented foods and emerging bioprocessed products (19).

3. Public Health Challenges in Nigerian Food Systems

3.1. Nutritional Deficiencies and Malnutrition

Nigeria experiences a significant burden of malnutrition, with micronutrient deficiencies affecting large portions of the population across all age groups (Table 1). Iron deficiency anemia affects approximately 58% of children under five years and 52% of women of reproductive age, while vitamin A deficiency impacts 29% of preschool children (20). Zinc deficiency, though less well documented, is estimated to affect substantial proportions of the population, particularly in rural areas with limited dietary diversity (21).

Protein-energy malnutrition remains prevalent, with 37% of children under five experiencing chronic malnutrition (stunting) and 18% suffering from acute malnutrition (wasting) (22). These conditions are particularly severe in

northern regions where conflict, climate change, and limited agricultural productivity compound food security challenges (23).

The burden of malnutrition extends beyond clinical deficiencies to include hidden hunger, where individuals consume sufficient calories but lack essential micronutrients due to diets dominated by processed cereals and tubers with limited nutritional diversity (24). This situation is exacerbated by post-harvest losses that can exceed 40% for perishable crops, reducing both food availability and nutritional quality (25).

Table 1 Prevalence of Nutritional Deficiencies in Nigeria

Nutritional Indicator	Children <5 years	Women 15-49 years	National Average
Iron deficiency anemia	58%	52%	48%
Vitamin A deficiency	29%	15%	22%
Zinc deficiency	45%*	35%*	40%*
Stunting (height-for-age)	37%	-	37%
Wasting (weight-for-height)	18%	-	18%
Underweight	29%	11%	20%

*Estimated based on dietary intake studies and regional data

3.2. Foodborne Diseases and Contamination

Foodborne diseases constitute a major public health challenge in Nigeria, with estimated annual incidence rates exceeding 200 cases per 1,000 population (26). Common pathogens include *Salmonella* species, *Escherichia coli*, *Campylobacter jejuni*, and various enteric viruses that cause diarrheal diseases, particularly affecting children and immunocompromised individuals (27).

Mycotoxin contamination, particularly aflatoxins in groundnuts, maize, and other cereals, poses significant health risks including acute poisoning, chronic liver damage, and increased cancer risk (28). Studies have detected aflatoxin levels exceeding international safety standards in up to 80% of locally produced and marketed cereals, with particularly high concentrations in products from northern regions with hot, humid storage conditions (29).

Chemical contamination from pesticide residues, heavy metals, and food adulterants further compounds food safety challenges, with limited monitoring and enforcement capacity constraining effective risk management (30).

4. Bioprocessing Opportunities for Public Health Impact

4.1. Nutritional Enhancement Through Bioprocesses

Bioprocessing technologies offer multiple pathways for addressing nutritional deficiencies prevalent in Nigerian populations (Table 2). Fermentation processes can significantly increase bioavailability of essential nutrients by breaking down antinutrients such as phytates and tannins that inhibit mineral absorption (31). Studies on fermented ogi have demonstrated 2-3 fold increases in iron and zinc bioavailability compared to unfermented alternatives (32).

Biofortification through microbial fermentation presents opportunities for enhancing traditional foods with vitamins and minerals. Research on vitamin B_{12} production through fermentation of cassava products has shown promising results for addressing B_{12} deficiency common in populations with limited animal protein consumption (33). Similarly, folate-producing lactobacilli can be incorporated into traditional fermented foods to address folate deficiency in women of reproductive age (34).

Protein quality improvement through fermentation processes can enhance the amino acid profiles of plant-based foods, particularly important in regions where animal protein access is limited (35). Controlled fermentation of legume-cereal combinations used in traditional Nigerian foods can optimize protein complementation and digestibility (36).

Table 2 Bioprocessing Applications for Nutritional Enhancement

Bioprocess Type	Target Nutrients	Traditional Foods	Expected Benefits
Lactic acid fermentation	Iron, Zinc, Folate	Ogi, Garri, Fufu	2-3x mineral bioavailability
Probiotic enhancement	Vitamin B12, Riboflavin	Nono (yogurt), Kunun-zaki	Vitamin synthesis in gut
Protein fermentation	Essential amino acids	Dawadawa, Ogiri	25-40% protein quality improvement
Enzyme treatment	Vitamin A precursors	Palm oil, Yellow maize	50-70% beta-carotene release
Biofortification	Multiple micronutrients	Cassava, Maize, Rice	Target-specific enhancement

4.2. Food Safety and Preservation Benefits

Bioprocessing technologies offer significant advantages for improving food safety and extending shelf-life of traditional Nigerian foods. Controlled fermentation processes can reduce pH levels and produce organic acids that inhibit pathogenic bacteria while promoting beneficial microorganisms (37). Research on controlled fermentation of garri has demonstrated substantial reductions in *enterobacteria* counts and elimination of potential pathogens compared to traditional spontaneous fermentation (38).

Biopreservation using natural antimicrobial compounds produced by beneficial microorganisms represents a sustainable alternative to chemical preservatives. Nigerian researchers have identified indigenous *Lactobacillus* strains that produce bacteriocins effective against common foodborne pathogens including *Listeria monocytogenes* and *Staphylococcus aureus* (39).

Mycotoxin reduction through bioprocessing presents particular opportunities given the high contamination rates in Nigerian cereals. Specific yeast and bacterial strains have demonstrated ability to bind or degrade aflatoxins during fermentation processes, potentially reducing exposure risks by 60-80% (40).

5. Disease risk reduction strategies

5.1. Pathogen Control Through Bioprocesses

Bioprocessing strategies can effectively reduce disease risks associated with foodborne pathogens through multiple mechanisms. Competitive exclusion by beneficial microorganisms prevents pathogen colonization during food production and storage, while acidification and antimicrobial compound production create hostile environments for harmful bacteria (41).

Implementation of Hazard Analysis and Critical Control Points (HACCP) principles in bioprocessing facilities can ensure consistent pathogen reduction while maintaining beneficial microbial activities (42). Studies on commercial ogi production facilities that implemented HACCP with controlled fermentation protocols achieved >99% reduction in pathogen indicators compared to traditional processing methods (43).

Probiotic enhancement of traditional foods offers additional protection by supporting consumer immune function and maintaining healthy gut microbiomes that resist pathogen colonization (44). Clinical studies in Nigerian populations consuming probiotic-enhanced fermented foods have demonstrated reduced incidence of diarrheal diseases, particularly in children (45).

5.2. Mycotoxin Mitigation Approaches

Biological approaches to mycotoxin control through bioprocessing show considerable promise for Nigerian applications. Competitive exclusion using non-toxigenic *Aspergillus* strains can prevent aflatoxin production in stored grains, with field trials demonstrating 70-90% reductions in aflatoxin contamination (46).

Fermentation-based detoxification processes can transform mycotoxins into less harmful compounds, with specific yeast strains showing ability to reduce aflatoxin levels in fermented cereal products by up to 85% (47). Integration of these approaches into traditional fermentation processes could significantly reduce population exposure to mycotoxins while maintaining cultural food practices.

6. Implementation Challenges and Barriers

6.1. Technical and Infrastructure Limitations

The bioprocessing sector of Nigeria faces substantial technical challenges that limit widespread implementation of advanced bioprocessing technologies. Inadequate electricity supply affects up to 30% of processing facilities, constraining temperature-sensitive fermentation processes and cold chain maintenance (48). Limited availability of specialized equipment and technical expertise further restricts adoption of controlled fermentation and quality assurance systems.

Water quality issues in many regions pose additional challenges for bioprocessing applications that require consistent water quality for optimal microbial performance (49). Infrastructure gaps in transportation and storage facilities result in post-harvest losses that could be mitigated through improved bioprocessing and preservation technologies.

6.2. Regulatory and Policy Framework Gaps

The regulatory framework for bioprocessed foods in Nigeria is challenged by insufficient comprehensive standards for traditional fermented products and emerging bioprocessing technologies. While NAFDAC and Standard Organization of Nigeria (SON) have established basic food safety standards, specific guidelines for probiotic foods, biofortified products, and traditional fermented foods remain limited (50).

Certification and quality assurance systems for bioprocessed products need strengthening to ensure consumer confidence and facilitate market access. The absence of standardized testing protocols for traditional fermented foods limits quality control and creates barriers for commercial scale-up of improved processing methods.

7. Strategic Recommendations and Policy Framework

7.1. Regulatory Development and Harmonization

Developing comprehensive regulatory frameworks for bioprocessed foods should prioritize establishing science-based standards that recognize both traditional practices and modern bioprocessing applications. This includes creating specific categories for traditional fermented foods with appropriate safety and quality standards that facilitate commercial production while preserving cultural authenticity.

Investment in regulatory capacity building is essential, including training personnel in bioprocessing technologies, establishing modern testing facilities, and developing risk assessment capabilities for novel bioprocessed products. Regional harmonization with other West African countries could facilitate trade and technology transfer while reducing regulatory barriers.

7.2. Capacity Building and Technology Transfer

Comprehensive capacity building programs should target multiple stakeholder groups including small-scale processors, extension agents, researchers, and regulatory personnel. Technical training programs focusing on good manufacturing practices, quality control, and modern bioprocessing techniques could significantly improve product safety and quality.

Research and development infrastructure investments should prioritize establishing regional centers of excellence for bioprocessing research, with emphasis on characterizing indigenous microorganisms and optimizing traditional fermentation processes for commercial applications.

8. Future Directions and Research Priorities

Future research priorities should focus on characterizing indigenous microbial biodiversity to identify beneficial strains with potential for bioprocessing applications. This includes isolating and characterizing probiotic bacteria from traditional fermented foods and developing starter cultures optimized for local conditions and raw materials (Table 3).

Table 3 Priority Research Areas for Bioprocessing in Nigeria

Research Area	Specific Focus	Expected Outcomes	Timeline
Indigenous microorganisms	Isolation and characterization	Commercial starter cultures	2-3 years
Process optimization	Traditional method improvement	Standardized protocols	1-2 years
Nutritional enhancement	Biofortification strategies	Enhanced food products	2-4 years
Safety assessment	Risk evaluation studies	Regulatory guidance	3-5 years
Consumer studies	Acceptance and preferences	Market development strategies	1-2 years
Economic analysis	Cost-benefit assessments	Investment frameworks	2-3 years

Climate-resilient bioprocessing technologies should be developed to address challenges posed by climate change, including developing fermentation processes that remain stable under varying temperature and humidity conditions common in different Nigerian regions.

9. Conclusion

The integration of bioprocesses throughout the Nigerian food chain presents substantial opportunities for improving public health outcomes and reducing disease risks while preserving cultural food traditions and supporting economic development. Traditional fermented foods already provide a foundation for bioprocessing applications, with significant potential for enhancement through modern biotechnological approaches.

Key opportunities include nutritional enhancement through biofortification and improved nutrient bioavailability, pathogen reduction through controlled fermentation and biopreservation, and mycotoxin mitigation through biological control methods. However, successful implementation requires addressing substantial challenges including infrastructure limitations, regulatory gaps, and capacity constraints.

Strategic priorities for realizing these opportunities include developing appropriate regulatory frameworks, investing in processing infrastructure and technical capacity, and conducting targeted research on indigenous microorganisms and process optimization. Success will require coordinated efforts among government agencies, research institutions, private sector stakeholders, and international development partners.

The transformation of Nigerian food systems through bioprocessing integration could significantly contribute to achieving Sustainable Development Goals related to food security, nutrition, and health while supporting economic growth and environmental sustainability. With appropriate investment and policy support, bioprocessing technologies could help address persistent challenges of malnutrition and foodborne diseases while creating economic opportunities for millions of food system participants in Nigeria.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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