



International Journal of Advanced Research in Food Science and Agriculture Technology

Journal homepage:
<https://karyailham.com.my/index.php/fsat/index>
ISSN: 3030-556X



Biochemical and Nutritional Potentials of Indigenous Nigerian Fermented Foods: Implications for Gut Health, Micronutrient Bioavailability, and Chronic Disease Prevention

David Chinonso Anih^{1,*}, Kayode Adebisi Arowora¹, Verwiyeh Silas Tatah, Kenneth Chinekwa Ugwuoke¹, Richard-Harris Nsenreuti Boyi¹

¹ Department of Biochemistry, Faculty of Biosciences, Federal University Wukari, Taraba, Nigeria

ARTICLE INFO

Article history:

Received 17 August 2025

Received in revised form 18 September 2025

Accepted 5 February 2026

Available online 10 February 2026

ABSTRACT

Indigenous Nigerian fermented foods represent a vital component of the nation's dietary and cultural heritage, offering both nutritional sustenance and therapeutic potential. Produced largely through spontaneous fermentation, these foods—including ogi, kunu, iru, ugba, and nono—undergo profound biochemical transformations mediated by lactic acid bacteria, yeasts, and *Bacillus* species. This review synthesizes current evidence on their biochemical and nutritional potentials, with emphasis on gut health, micronutrient bioavailability, and chronic disease prevention. Fermentation significantly enhances the nutritional quality of cereals, legumes, and milk-based foods by increasing the synthesis of essential vitamins, amino acids, and bioactive compounds while reducing anti-nutritional factors such as phytates, tannins, and oxalates. These transformations improve mineral absorption, particularly of iron, zinc, and B vitamins, thereby addressing micronutrient deficiencies common in vulnerable populations. In addition, indigenous fermented foods are rich sources of probiotics and bioactive metabolites, including short-chain fatty acids, peptides, and polyphenols, which contribute to gut microbiota modulation, immune enhancement, and antioxidant defense. Evidence suggests that regular consumption of these foods may mitigate risks of chronic diseases such as type 2 diabetes, cardiovascular disorders, and inflammatory conditions, primarily through improved glycemic control, enhanced lipid metabolism, and anti-inflammatory signaling. Furthermore, fermentation-mediated reduction of mycotoxins and pathogen inhibition highlights their potential role in food safety. Despite these benefits, challenges remain regarding quality control and standardization, as traditional fermentation is often unregulated, leading to variability in safety and efficacy. Future perspectives emphasize the development of well-characterized starter cultures, application of omics-based tools for microbial and metabolite profiling, and clinical validation of health-promoting claims. In conclusion, indigenous Nigerian fermented foods exemplify sustainable,

* Corresponding author.

E-mail address: anih.david@fuwukari.edu.ng

Keywords:

Indigenous Nigerian fermented foods; nutrient bioavailability; probiotics; gut health; bioactive compounds; chronic disease prevention

culturally relevant functional foods with the potential to combat malnutrition and chronic diseases, underscoring the need for their broader integration into modern dietary strategies.

1. Introduction

Fermentation, an ancient biotechnological process, has been integral to food preservation and enhancement across diverse cultures for centuries [1,2]. In Nigeria, a country with a rich culinary heritage, indigenous fermented foods play a significant role in the diet, contributing not only to food security but also to the unique flavors and textures that characterize local cuisines [2,3]. These foods are typically produced through spontaneous fermentation, relying on the metabolic activities of naturally occurring microorganisms, primarily lactic acid bacteria (LAB), yeasts, and molds [3,6,9]. Examples include *ogi* (fermented cereal gruel), *kunu* (fermented cereal beverage), *iru* (fermented locust bean condiment), *ugba* (fermented African oil bean seed), and *nono* (fermented milk) [3,5,6].

Beyond their traditional appeal, a growing body of scientific evidence highlights the profound biochemical and nutritional transformations that occur during the fermentation of these indigenous Nigerian foods [2,4,7]. Fermentation can significantly improve the nutritional quality of raw materials by synthesizing vitamins, amino acids, and other beneficial compounds, while simultaneously reducing undesirable components such as anti-nutritional factors (ANFs) [4,7,8]. The breakdown of complex macromolecules into simpler, more digestible forms also contributes to enhanced nutrient bioavailability [7,8].

Moreover, the microbial communities, particularly LAB, associated with these fermented foods are increasingly recognized for their probiotic potential [6,9,10]. These beneficial microorganisms can survive the gastrointestinal tract and exert positive effects on gut health, including modulating the gut microbiota, enhancing immune function, and producing short-chain fatty acids (SCFAs) [10]. Such interactions between fermented foods, the gut microbiome, and host physiology have significant implications for overall well-being and the prevention of chronic diseases [2,10].

Despite their widespread consumption and recognized benefits, a comprehensive understanding of the biochemical and nutritional potentials of indigenous Nigerian fermented foods, particularly their implications for gut health, micronutrient bioavailability, and chronic disease prevention, remains crucial. This review aims to synthesize current knowledge in this area, providing a detailed overview of the transformative processes involved and their health-promoting outcomes.

2. Materials and Methods

To build a comprehensive understanding of the biochemical and nutritional potentials of indigenous Nigerian fermented foods, this review draws from a wide range of recent scientific literature. We conducted a systematic and thoughtful search across major academic databases—PubMed, Scopus, Web of Science, and Google Scholar—using carefully selected keywords and Boolean operators. Search terms included combinations like “Nigerian fermented foods,” “*ogi*,” “*kunu*,” “*iru*,” “*ugba*,” “*nono*,” “fermentation,” “nutritional quality,” “bioavailability,” “anti-nutritional factors,” “probiotics,” “gut health,” “chronic diseases,” “antioxidants,” and “bioactive peptides” [11,12].

We focused on peer-reviewed journal articles published between 2013 and 2025, prioritizing those with full-text access, a DOI, and relevance to Nigerian food culture. Studies were included if they provided empirical data or reviews on the biochemical composition, microbial diversity,

nutritional transformation, or health-promoting properties of fermented foods. Both spontaneous and starter culture-mediated fermentations were considered, as these approaches influence microbial dynamics and bioactivity [13,16].

From each selected study, we extracted key data points such as:

- **Raw materials used**, including cereals, legumes, and oil seeds [17]
- **Fermentation conditions and duration**, which affect microbial growth and metabolite production [18]
- **Microbial community structure**, assessed through culture-dependent and molecular techniques [13,18]
- **Proximate composition**, covering protein, fat, carbohydrate, fiber, moisture, and ash content [16,17]
- **Mineral and vitamin profiles**, especially micronutrients relevant to health [15,19]
- **Changes in anti-nutritional factors**, such as reductions in phytates, tannins, and oxalates [14,17]
- **Antioxidant activity**, measured using assays like DPPH, ABTS, and FRAP [14]
- **Presence of bioactive metabolites**, including short-chain fatty acids, peptides, and polyphenols [11,20]
- **Functional outcomes**, based on in vitro digestion models and in vivo studies using animal models [11,20]

We excluded studies that lacked methodological clarity or were based on non-Nigerian cultural contexts. Duplicate entries were removed, and each article was critically evaluated for scientific rigor and relevance. Thematic analysis was employed to synthesize findings into a cohesive narrative that links microbial activity to nutritional enhancement and health outcomes [13,20].

Table 1
 Summary of literature search strategy and inclusion criteria

Parameter	Description	Suggested Citation(s)
Databases searched	PubMed, Scopus, Web of Science, Google Scholar	[11], [13]
Search terms used	"Nigerian fermented foods," "ogi," "kunu," "iru," "ugba," "nono," "fermentation," "nutritional quality," "bioavailability," "anti-nutritional factors," "probiotics," "gut health," "chronic diseases," "antioxidants," "bioactive peptides" (with Boolean operators)	[11], [12]
Publication years	2013–2025	[13], [16]
Inclusion criteria	Peer-reviewed journal articles; empirical data or reviews on biochemical composition, nutritional transformation, microbial diversity, or health-promoting properties; full text with DOI; Nigerian context	[13], [16]
Exclusion criteria	Non-Nigerian cultural contexts; unclear methodology; lack of relevant biochemical or nutritional data	[13], [20]
Data extracted	Raw materials; fermentation conditions; microbial community structure; proximate composition; mineral and vitamin content; anti-nutritional factor changes; antioxidant activity; bioactive metabolite presence; functional outcomes	[14], [15], [16], [17], [18], [19], [20]

Table Legend (below the table): Table 1. Summary of literature search strategy and inclusion criteria for studies on the biochemical and nutritional potentials of indigenous Nigerian fermented foods.

Suggested citations correspond to references within this manuscript and illustrate representative sources for each parameter.

3. Overview of Indigenous Nigerian Fermented Foods and their Production

Nigeria is home to a vibrant tapestry of indigenous fermented foods, each crafted from locally available ingredients and steeped in cultural heritage. These foods are typically grouped into cereal-based, legume-based, and milk-based categories, with some unique condiments derived from oilseeds. What's especially interesting is that most of these fermentation processes happen naturally, without the need for added starter cultures, thanks to the microorganisms already present in the ingredients or the environment where they're prepared [26].

Let's start with the cereal-based varieties. Ogi, kunu, and burukutu are staples in many Nigerian households. Ogi, a smooth fermented porridge made from maize, sorghum, or millet, is prepared by soaking the grains, milling them wet, and allowing them to ferment for one to three days. After fermentation, the mixture is sieved and decanted to produce a tangy, easily digestible gruel. This transformation is largely driven by lactic acid bacteria (LAB), which not only give ogi its sour taste but also enhance its nutritional profile [24,26]. Kunu, another beloved drink, follows a similar process but often includes spices like ginger or cloves, adding both flavor and health benefits [24]. Burukutu, a traditional sorghum beer, is brewed through a longer fermentation process and is especially popular in northern Nigeria [27].

Moving on to legume-based fermented foods, these are known for their rich protein content and bold flavors. Iru, ugba, and ogiri are standout examples. Iru is made from African locust beans (*Parkia biglobosa*), which are boiled, dehulled, and fermented over several days. The result is a soft, pungent condiment that adds depth to soups and stews [22,28]. Ugba, on the other hand, is produced from African oil bean seeds (*Pentaclethra macrophylla*). After boiling and slicing, the seeds are fermented, often with *Bacillus* species that help break down proteins and fats, enhancing both flavor and digestibility [21,30]. Ogiri, made from melon or castor seeds and sometimes partially substituted with soybeans, is another strong-smelling condiment with a distinct taste, commonly used in southeastern Nigerian dishes [25,29].

Milk-based fermented foods also play a role in Nigerian cuisine, with nono being a prime example. Nono is a naturally fermented cow's milk product, similar to yogurt but with its own unique texture and flavor. It's made by allowing fresh milk to ferment spontaneously, resulting in a thick, sour beverage enriched by both lactic acid bacteria and yeasts [23]. This drink is especially popular in northern Nigeria and is often paired with cereal-based meals like fura.

To visualize these processes, Figure 1 maps out the fermentation pathways for three iconic Nigerian foods—ogi, iru, and nono—highlighting each step from raw material preparation to microbial transformation and final product formation. These traditional methods showcase the ingenuity of local food practices and the powerful role of natural fermentation in shaping taste, nutrition, and cultural identity [21-30].

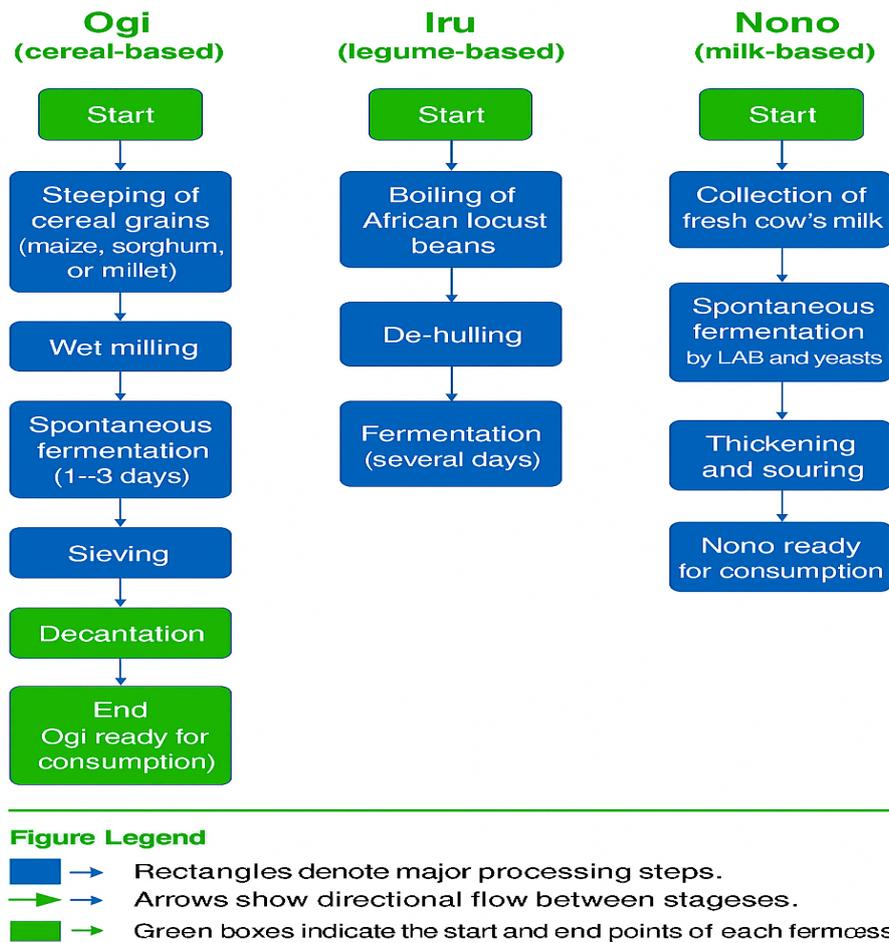


Fig. 1. Fermentation pathways for three iconic Nigerian foods

4. Microbial Diversity and Dynamics in Indigenous Nigerian Fermented Foods

The transformation of raw agricultural ingredients into flavorful, nutritious fermented foods is guided by a fascinating interplay of microorganisms. These tiny agents of change form complex communities that drive the fermentation process, shaping both the taste and health benefits of the final products [38].

In most Nigerian fermented foods, especially those made from cereals and milk, lactic acid bacteria (LAB) take center stage. They are responsible for producing acid, developing flavor, and keeping spoilage organisms at bay [31]. Common LAB genera found in these foods include *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Pediococcus*, and *Enterococcus* [35]. For example, in *ogi*, researchers have consistently identified *Lactobacillus plantarum*, *Lactobacillus fermentum*, and *Lactobacillus reuteri* as dominant species [33]. *Kunu* also hosts a vibrant LAB population, with frequent isolates of *Lactobacillus plantarum* and *Lactobacillus acidophilus* [40].

Yeasts play a supporting but essential role, especially in cereal-based fermentations. Species like *Saccharomyces cerevisiae*, *Candida tropicalis*, and *Pichia kudriavzevii* contribute to alcohol production, flavor complexity, and even nutrient enrichment [34,40]. In some cases, molds such as *Rhizopus* species are involved, particularly in the preparation of starter cultures for certain condiments [36].

When it comes to legume-based fermented foods like *iru* and *ugba*, *Bacillus* species are the microbial stars. *Bacillus subtilis* and *Bacillus licheniformis* are especially prominent, known for their

powerful enzymes that break down proteins and fats into simpler, more digestible compounds. This enzymatic activity is what gives these condiments their distinctive aroma and texture [37,39]. The succession and interaction of these microbial populations throughout fermentation ultimately determine the nutritional and sensory qualities of the food [32].

Understanding this microbial diversity isn't just academic it's key to improving fermentation techniques and developing reliable starter cultures for consistent, high-quality production [38]. Figure 2 offers a visual snapshot of the microbial landscape in three traditional Nigerian fermented foods: ogi, iru, and nono. A Venn diagram shows which microbial groups are shared and which are unique to each food, while a stacked bar chart breaks down the relative abundance of key genera. Notably, *Lactobacillus* appears as a dominant genus across all three, underscoring its central role in Nigerian fermentation traditions [31-40].

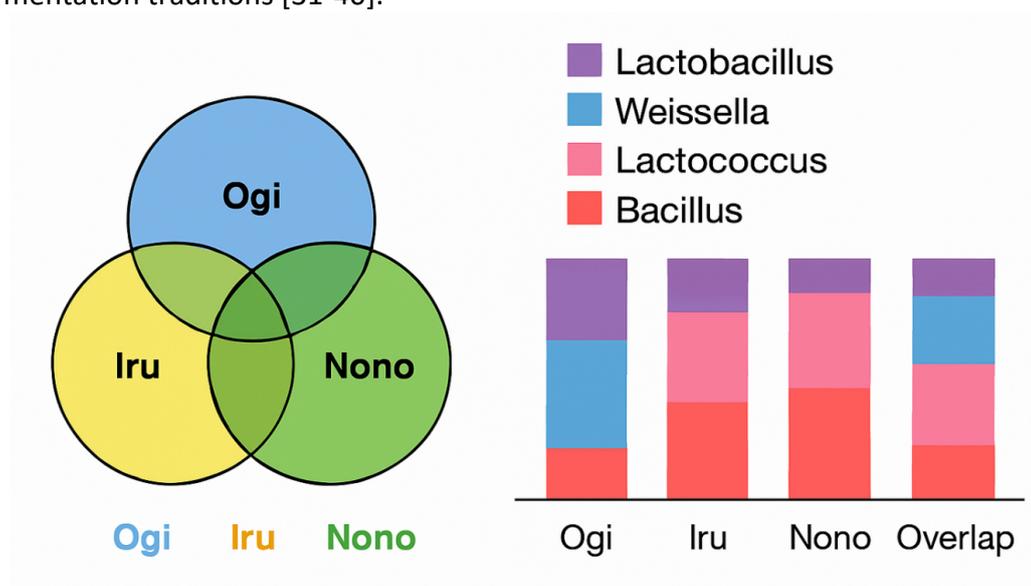


Fig. 2. Microbial community composition in Nigerian fermented foods

The Venn diagram shows microbial group overlaps among Ogi, Iru, and Nono. The stacked bar chart represents the relative abundance of four dominant microbial genera. Color codes correspond to microbial groups: *Lactobacillus* (purple), *Weissella* (blue), *Lactococcus* (pink), *Bacillus* (red).

5. Nutritional Enhancement and Anti-Nutritional Factor Reduction

Fermentation is more than just a preservation method it's a transformative process that enhances the nutritional value of indigenous Nigerian foods while reducing the impact of anti-nutritional factors (ANFs) [41]. Many staple ingredients like cereals and legumes naturally contain compounds such as phytates, oxalates, tannins, and cyanogenic glycosides. These ANFs can interfere with nutrient absorption by binding essential minerals or inhibiting digestive enzymes, ultimately lowering the bioavailability of key nutrients [42].

Fortunately, fermentation helps counteract these effects. Microorganisms, especially lactic acid bacteria (LAB) and yeasts, produce enzymes during fermentation that break down ANFs. For example, phytates, which bind minerals like iron and zinc, are hydrolyzed by phytase enzymes, making these micronutrients more accessible to the body [49]. Studies have shown significant reductions in phytate levels in fermented products like ogi and kunu [46,47]. Similarly, cassava-based foods such as fufu undergo fermentation that drastically lowers their cyanide content, making them safe to eat [43,44].

Beyond reducing harmful compounds, fermentation also boosts nutritional quality. It enhances the synthesis of B vitamins like folate, riboflavin, and thiamine, and improves protein digestibility by breaking down complex proteins into simpler peptides and amino acids [48]. For instance, fermented maize cowpea blends have shown increased protein digestibility [47], while fermented sorghum ogi has demonstrated enriched folate levels [48]. Additionally, fermentation can lead to the formation of beneficial bioactive compounds such as phenolic acids and short chain fatty acids, which contribute to the functional and health promoting properties of these foods [50].

Figure 3 captures this nutritional transformation. Chart (a) illustrates the percentage reduction in anti-nutritional compounds like phytate and cyanide, while chart (b) highlights the increase in essential nutrients—iron, zinc, and B vitamins—after fermentation [41-50].

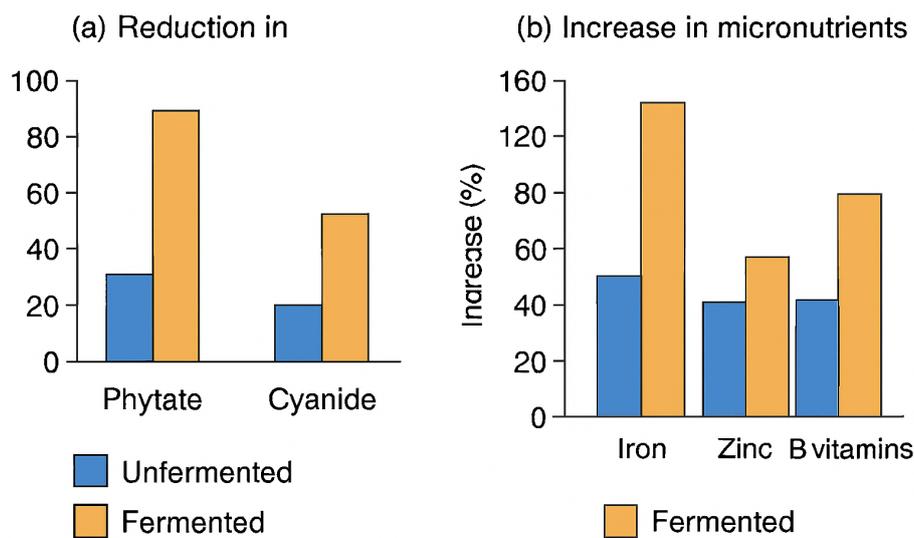


Fig. 3. Comparative analysis of anti-nutritional factor reduction and micronutrient enhancement in fermented vs. unfermented food samples

Blue bars represent unfermented food samples, while orange bars represent fermented samples. Chart (a) quantifies the reduction in anti-nutritional factors. Chart (b) displays the enhancement of key micronutrients due to fermentation.

6. Gut Health Modulation and Probiotic Potentials

Indigenous Nigerian fermented foods are gaining attention not just for their rich flavors, but also for their potential to support gut health. These traditional foods are packed with beneficial microorganisms, especially lactic acid bacteria (LAB), which play a key role in maintaining a healthy digestive system [51]. When consumed, these live microbes travel to the gastrointestinal tract, where they interact with the host's immune system and help shape the composition and function of the gut microbiota [54].

Several studies have isolated and characterized LAB strains from Nigerian fermented foods, revealing their probiotic potential. These strains often show impressive traits like surviving acidic and bile conditions, adhering to intestinal cells, and fighting off harmful pathogens [52,57]. For example, *Lactobacillus plantarum* and *Lactobacillus fermentum*, commonly found in ogi and kunu, have demonstrated strong probiotic properties [59,60]. Similarly, LAB strains from nono have shown excellent survival in simulated gut environments and notable antimicrobial activity [55,58].

The benefits of these probiotics go beyond digestion. They help strengthen the gut barrier, reduce inflammation, and produce short chain fatty acids (SCFAs) such as butyrate, propionate, and acetate. These SCFAs serve as energy sources for colon cells and offer broader health benefits, including improved metabolism and immune regulation [53,56]. A diverse microbial community, like those found in traditional fermented foods, contributes to a more balanced gut microbiome, which is linked to better digestive health and reduced risk of chronic diseases [57].

Figure 4 illustrates how probiotic bacteria from fermented foods journey through the digestive tract. It shows their interaction with the gut lining, their role in modulating immune responses, and their contribution to SCFA production—all of which support overall gut health [51-60].

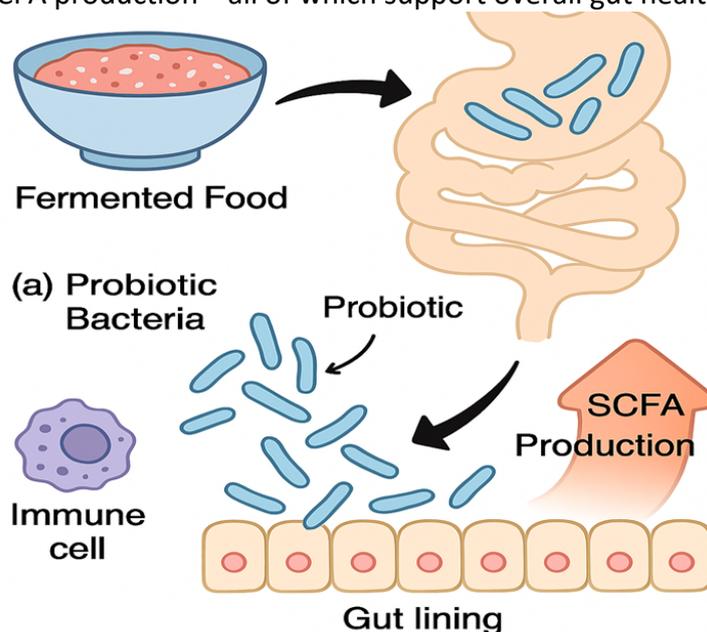


Fig. 4. Journey and functional impact of probiotic bacteria from fermented food to the gut

The figure depicts the sequential journey of probiotics and their physiological roles. Key components include fermented food sources, bacterial colonization, immune cell engagement, and SCFA synthesis. Arrows indicate directional flow and functional impact [61-70].

7. Bioactive Compounds and Antioxidant Properties

Fermentation does more than improve taste and shelf life, it unlocks a wealth of bioactive compounds that elevate indigenous Nigerian foods from basic nutrition to functional superfoods. These compounds, including phenolic acids, flavonoids, peptides, and exopolysaccharides, offer antioxidant, anti-inflammatory, and even therapeutic benefits [61].

Thanks to the enzymatic activity of fermenting microorganisms, many of these compounds become more bioavailable. For instance, fermentation helps release bound phenolic compounds from plant matrices, boosting their antioxidant potential [63,64]. This is evident in fermented products like ogi and kunu, which show increased levels of phenolic acids and enhanced antioxidant activity compared to their unfermented counterparts [62,66]. Legume-based foods such as ugba and iru also benefit from fermentation, producing bioactive peptides like ACE inhibitors that may help regulate blood pressure [67,69].

Exopolysaccharides (EPS), produced by certain LAB strains during fermentation, serve as natural prebiotics. These compounds not only support the growth of beneficial gut bacteria but also improve the texture and consistency of fermented foods [70]. The combined effect of these bioactive

components contributes to the health-promoting potential of traditional Nigerian fermented foods, making them valuable additions to diets aimed at preventing chronic diseases [65,68].

Figure 5 showcases the chemical structures of key phenolic compounds—gallic acid, vanillic acid, and catechin, alongside a representative bioactive peptide (Tyr-Cys-Ser-Val). The accompanying bar chart compares antioxidant activity between unfermented and fermented samples, clearly illustrating the nutritional boost that fermentation provides [61-70].

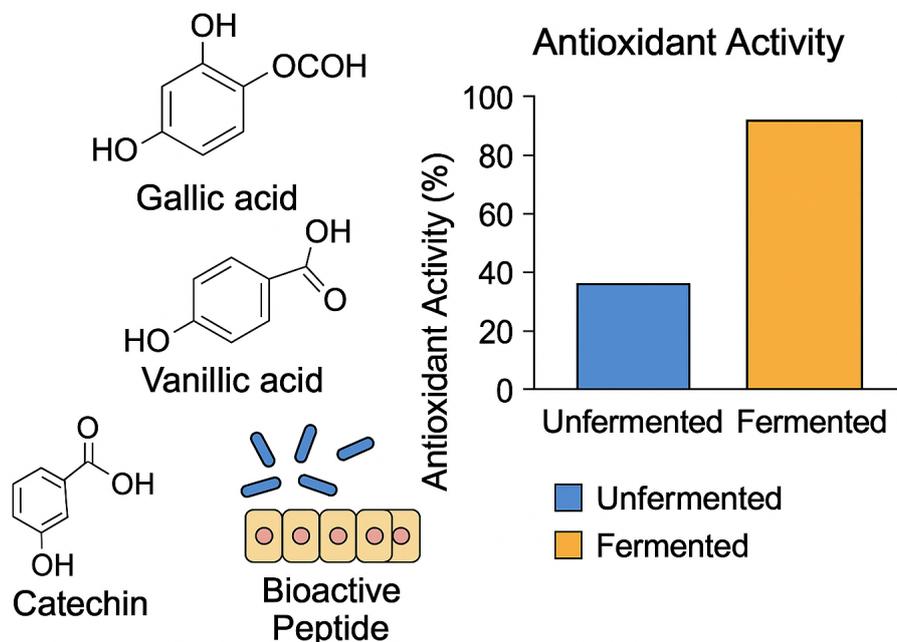


Fig. 5. Bioactive Molecules and Antioxidant Enhancement in Fermented Nigerian Foods
Left panel: molecular structures of phenolic compounds and a bioactive peptide.
Right panel: antioxidant activity (%) in fermented vs. unfermented samples.
Orange bars indicate fermented samples; blue bars indicate unfermented controls.

8. Implications for Chronic Disease Prevention

Indigenous Nigerian fermented foods are more than cultural staples they're emerging as powerful allies in the fight against chronic diseases. Thanks to their enhanced nutritional profiles, probiotic richness, and abundance of bioactive compounds, these foods offer promising benefits for managing and preventing conditions that are increasingly common in developing regions [71].

Type 2 Diabetes: Fermented cereals like ogi and kunu contain improved carbohydrate structures and dietary fiber that help slow glucose absorption, promoting better glycemic control [76]. Additionally, certain bioactive peptides formed during fermentation may inhibit enzymes involved in glucose metabolism, offering further support for blood sugar regulation [73].

Cardiovascular Diseases: Fermentation reduces anti-nutritional factors such as phytates, which improves the absorption of minerals like magnesium and potassium—essential for heart health. Some LAB strains found in fermented foods have also demonstrated cholesterol-lowering effects [75]. Moreover, antioxidant and ACE-inhibitory peptides produced during fermentation may help regulate blood pressure and reduce oxidative stress [74].

Malnutrition and Micronutrient Deficiencies: Fermented foods significantly boost the bioavailability of key micronutrients like iron, zinc, and B vitamins. These nutrients are often lacking in traditional diets, especially among vulnerable populations. Fermentation thus becomes a practical and culturally relevant strategy for addressing micronutrient deficiencies [79,80].

Inflammation and Immune Function: The anti-inflammatory properties of bioactive compounds and the immunomodulatory effects of probiotics found in fermented foods can help reduce systemic inflammation—a major contributor to chronic disease development [72,77]. Probiotics also support gut health, which in turn strengthens the immune system and enhances overall resilience [78].

Figure 6 illustrates how fermented foods influence three major biological pathways: the gut-brain axis, anti-inflammatory signaling, and antioxidant defense. It shows how probiotics and bioactive compounds interact with the gut and immune system to promote systemic health and reduce the risk of chronic diseases [71-80].

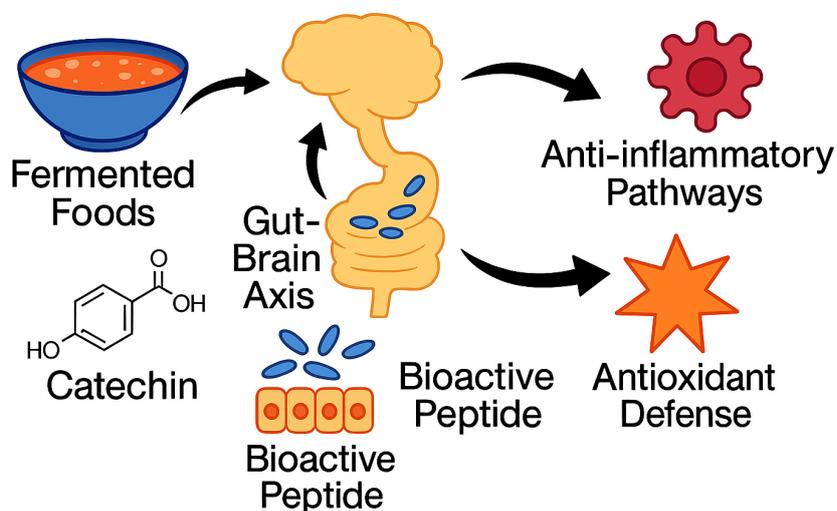


Fig. 6. Pathways through which fermented foods mitigate chronic disease risks

Arrows indicate directional flow from fermented food intake to physiological effects. Gut-brain axis shows neural and microbial communication. Anti-inflammatory and antioxidant pathways represent cellular-level disease mitigation.

9. Safety, Quality Control, and Future Perspectives

While indigenous Nigerian fermented foods offer a wealth of nutritional and health benefits, ensuring their safety and maintaining consistent quality remains a top priority. Traditional fermentation methods are often spontaneous and unregulated, which can lead to variations in taste, texture, and nutritional value—and in some cases, the presence of harmful microorganisms or mycotoxins [89].

Mycotoxin Reduction: Fermentation has been shown to reduce mycotoxin levels, such as aflatoxins in cereals, making these foods safer for consumption. However, this benefit depends heavily on proper handling and storage to prevent recontamination after fermentation [90].

Microbial Safety: The acidic environment created by lactic acid bacteria during fermentation naturally inhibits many pathogens [89]. Still, good hygiene practices during preparation and storage are essential to ensure microbial safety and prevent contamination [88].

Quality Control and Standardization: One of the challenges with traditional fermented foods is the lack of standardized starter cultures. This often results in inconsistent product quality and unpredictable health outcomes [85]. By developing and applying well-characterized starter cultures especially those with proven probiotic and functional properties, producers can achieve more reliable results and enhance both safety and nutritional value [84].

Future Research Directions: To fully unlock the potential of these foods, future research should focus on:

- Conducting metagenomic and metabolomic studies to better understand the microbial communities and biochemical changes during fermentation [87].
- Running clinical trials to validate the health benefits observed in lab and animal studies, especially those related to gut health, micronutrient absorption, and chronic disease prevention [86].
- Creating new fermented products with enhanced functional properties using designer starter cultures and fortification techniques [82,83].
- Scaling up traditional fermentation methods for industrial production while preserving their authenticity and health benefits [85].
- Exploring how different processing conditions affect flavor and aroma compounds, with the goal of optimizing sensory appeal [81].

Figure 7 outlines three key strategies for improving the safety and consistency of fermented foods: using starter cultures to guide microbial activity, applying HACCP principles to manage hazards, and enforcing strict hygiene during processing. Together, these interventions can help ensure that fermented foods remain both safe and beneficial [81-90].



Fig. 7. Strategies for enhancing safety and quality in fermented food production

Circular icons represent each strategy:

- Petri dish for starter culture application
- Checklist clipboard for HACCP principles
- Soap dispenser and hand for hygiene improvement

10. Conclusion

Indigenous Nigerian fermented foods are more than traditional staples; they represent a rich reservoir of nutrients, probiotics, and bioactive compounds with profound health-promoting potential. Their fermentation processes not only enhance nutrient quality and bioavailability but also reduce anti-nutritional factors, thereby addressing key micronutrient deficiencies. Beyond nutrition, these foods contribute to gut health, immune modulation, and protection against chronic diseases such as diabetes, cardiovascular disorders, and inflammatory conditions. Their safety benefits, including reduction of mycotoxins and inhibition of harmful pathogens, further strengthen their value in public health. However, challenges such as inconsistent quality, lack of standardized starter cultures, and limited clinical validation remain. To fully harness their promise, future research should emphasize omics-driven microbial profiling, development of safe starter cultures, and human trials to substantiate their therapeutic effects. Ultimately, indigenous Nigerian fermented foods stand as culturally relevant, sustainable functional foods with the capacity to contribute significantly to nutrition, health, and disease prevention in both local and global contexts.

Acknowledgement

We acknowledge Federal University Wukari for providing the institutional environment that facilitated this work. We also appreciate the academic support and constructive feedback from colleagues that enhanced the manuscript.

Abbreviations

LAB – Lactic Acid Bacteria
ANFs – Anti-Nutritional Factors
SCFAs – Short-Chain Fatty Acids
EPS – Exopolysaccharides
ACE – Angiotensin-Converting Enzyme
HACCP – Hazard Analysis and Critical Control Point
GC-MS – Gas Chromatography–Mass Spectrometry

Funding

No funding

Availability of Data And Materials

Most data generated or analyzed during this study are included in this published article. Any extra demanded details are available from the corresponding author on reasonable request.

Competing Interest

The authors declare that there is no conflict of interest.

References

- [1] Agyei, Dominic, James Owusu-Kwarteng, Fortune Akabanda, and Samuel Akomea-Frempong. "Indigenous African fermented dairy products: Processing technology, microbiology and health benefits." *Critical reviews in food science and nutrition* 60, no. 6 (2020): 991-1006. <https://doi.org/10.1080/10408398.2018.1555133>
- [2] Obafemi, Yemisi D., Adesola A. Ajayi, Humphrey A. Adebayo, Oluwafemi A. Oyewole, and Emmanuel O. Olumuyiwa. "The role of indigenous Nigerian fermented agrifoods in enhancing good health and well-being." *Discover Food* 4, no. 1 (2024): 133. <https://doi.org/10.1007/s44187-024-00206-4>
- [3] Ndudi, Winifred, Great Iruoghene Edo, Princess Oghenekeno Samuel, Agatha Ngukuran Jikah, Raphael Ajiri Opiti, Irene Ebosereme Ainyanbhor, Arthur Efeoghene Athan Essaghah, Helen Avuokerie Ekokotu, Ephraim Alex Evi

- Oghrora, and Joy Johnson Agbo. "Traditional fermented foods of Nigeria: microbiological safety and health benefits." *Journal of Food Measurement and Characterization* 18, no. 6 (2024): 4246-4271. <https://doi.org/10.1007/s11694-024-02490-1>
- [4] Kitessa, Daniel Asfaw. "Review on effect of fermentation on physicochemical properties, anti-nutritional factors and sensory properties of cereal-based fermented foods and beverages." *Annals of Microbiology* 74, no. 1 (2024): 32. <https://doi.org/10.1186/s13213-024-01763-w>
- [5] Noah, Abimbola A., and Mustapha A. Yusuf. "Nutritional and Sensory Qualities of Kunu-Zaki (A Non-alcoholic Local Beverage) Produced from Sorghum and Date Fruit." *American Journal of Food Science and Nutrition Research* 7, no. 1 (2020): 1-5. <https://www.openscienceonline.com/journal/fsnr>
- [6] Taale, Essodolom. "Involved microorganisms in the production of indigenous fermented food from West Africa: Technological characteristics and probiotic power." *IntechOpen eBooks* (2024): <https://doi.org/10.5772/intechopen.114893>
- [7] Adebo, Janet Adeyinka, Patrick Berka Njobeh, Sefater Gbashi, Ajibola Bamikole Oyedeji, Opeoluwa Mayowa Ogundele, Samson Adeoye Oyeyinka, and Oluwafemi Ayodeji Adebo. "Fermentation of cereals and legumes: Impact on nutritional constituents and nutrient bioavailability." *Fermentation* 8, no. 2 (2022): 63. <https://doi.org/10.3390/fermentation8020063>
- [8] Moyo, Siphosanele M., Oluymika Y. Famuyide, and Eugénie Kayitesi. "Urging bioactive peptide exploration in African fermented legumes: insights from microbial proteolysis to gastrointestinal stability." *Food Production, Processing and Nutrition* 6, no. 1 (2024): 90. <https://doi.org/10.1186/s43014-024-00265-1>
- [9] Ogunleke OB, Oladipo IC. Isolation and molecular characterization of lactic acid bacteria isolated from selected fermented food condiments. *World J Biol Pharm Health Sci.* 2025;23(1):64–70. <https://doi.org/10.30574/wjbpshs.2025.23.1.0634>
- [10] Park, Inmyoung, and Mohamed Manna. "Fermented Foods as Functional Systems: Microbial Communities and Metabolites Influencing Gut Health and Systemic Outcomes." *Foods* 14, no. 13 (2025): 2292. <https://doi.org/10.3390/foods14132292>
- [11] Obafemi, Yemisi D., Solomon U. Oranusi, Kolawole O. Ajanaku, Paul A. Akinduti, John Leech, and Paul D. Cotter. "African fermented foods: overview, emerging benefits, and novel approaches to microbiome profiling." *npj Science of Food* 6, no. 1 (2022): 15. <https://doi.org/10.1038/s41538-022-00130-w>
- [12] Wejinya, Adenike O., Patience C. Obinna-Echem, Lucretia I. Barber, and Sunday Y. Giami. "Probiotic Potentials of Lactic Acid Bacteria Isolated from Fermented Foods." (2022). <https://doi.org/10.9734/ejfnfs/2022/v14i630509>
- [13] Ndudi, Winifred, Great Iruoghene Edo, Princess Oghenekeno Samuel, Agatha Ngukuran Jikah, Raphael Ajiri Opiti, Irene Ebosereme Ainyanbhor, Arthur Efeoghene Athan Essaghah, Helen Avuokerie Ekokotu, Ephraim Alex Evi Oghrora, and Joy Johnson Agbo. "Traditional fermented foods of Nigeria: microbiological safety and health benefits." *Journal of Food Measurement and Characterization* 18, no. 6 (2024): 4246-4271. <https://doi.org/10.1007/s11694-024-02490-1>
- [14] Arueya, Gibson L., Maimuna Sani, and Akeem Olayemi Raji. "Comparative evaluation of anti-oxidative potentials of fermented locust bean condiment and its moringa fortified variant." *African Journal of Biotechnology* 16, no. 45 (2017): 2134-2141. <https://doi.org/10.5897/AJB2017.16123>
- [15] Ngene, Anayochukwu Chibuike, Chijioke E. Onwuakor, John C. Aguiyi, Virginia O. Ifeanyi, Chinedu Godspower Ohaegbu, Chukwuka Peter Okwuchukwu, Esther Garos Kim, and John O. Egbere. "Screening of some lactic acid bacteria isolated from selected Nigerian fermented foods for vitamin production." *Advances in Microbiology* 9, no. 11 (2019): 943-955. <https://doi.org/10.4236/aim.2019.911060>
- [16] Chen, Long, Zijian Zhao, Wei Yu, Lin Zheng, Lijia Li, Wei Gu, Haiyan Xu, Bingdong Wei, and Xiaogang Yan. "Nutritional quality improvement of soybean meal by *Bacillus velezensis* and *Lactobacillus plantarum* during two-stage solid-state fermentation." *Amb Express* 11, no. 1 (2021): 23. <https://doi.org/10.1186/s13568-021-01184-x>
- [17] Olayiwola, J. O., V. Inyang, and M. A. Bello. "Bacteriological and proximate evaluation of ginger-fortified fermented maize (ogi)." *American Journal of Food Technology* 12, no. 6 (2017): 374-378. <https://doi.org/10.3923/ajft.2017.374.378>
- [18] Ezekiel, Chibundu N., Kolawole I. Ayeni, Obinna T. Ezeokoli, Michael Sulyok, Deidre AB Van Wyk, Oluwawapelumi A. Oyedele, Oluwatosin M. Akinyemi et al. "High-throughput sequence analyses of bacterial communities and multi-mycotoxin profiling during processing of different formulations of Kunu, a traditional fermented beverage." *Frontiers in microbiology* 9 (2019): 3282. <https://doi.org/10.3389/fmicb.2018.03282>
- [19] Ngene, Anayochukwu Chibuike, Chijioke E. Onwuakor, John C. Aguiyi, Virginia O. Ifeanyi, Chinedu Godspower Ohaegbu, Chukwuka Peter Okwuchukwu, Esther Garos Kim, and John O. Egbere. "Screening of some lactic acid bacteria isolated from selected Nigerian fermented foods for vitamin production." *Advances in Microbiology* 9, no. 11 (2019): 943-955. <https://doi.org/10.4236/aim.2019.911060>

- [20] Obi CN, Oriaku CP, Ademe OF, Epundu IB, Okore CO. Microbiological, nutritional and organoleptic changes associated with fermented oil bean (ugba) stored at ambient temperature. *Niger J Microbiol.* 2021;35(3):6523–35. Available from: https://publications.nsmjournal.org.ng/full_paper.php?id=68
- [21] Nwanagba, N. L., P. C. Ojimelukwe, and C. F. Ezeama. "Evaluation of the effect of fermentation of African oil bean (*Pentaclethra macrophylla*) using *Bacillus subtilis* as starter and *Lactobacillus fermentum* as adjunct on the vitamin and mineral contents of the seeds." *International Journal of Food Science and Nutrition* 5, no. 2 (2020): 63-70. <https://www.foodsciencejournal.com/assets/archives/2020/vol5issue2/5-2-13-108.pdf>
- [22] Adeniyi, Paulina Oludoyin. "Fermented African Locust Bean (Iru), a Potential Dietary Prebiotic and Probiotic." *International Journal of Nutrition and Food Sciences* 13, no. 3 (2024): 114-125. <https://doi.org/10.11648/j.ijnfs.20241303.16>
- [23] Oyedokun, Nofisat Olaide, Gbadebo Barnabas Olukotun, Uchenna Iman Igwegbe, Binta Buba Adamu, Roseline Rumi Ideh, Olaitan Comfort Shekoni, and Amin Odera Igwegbe. "Detection, Biochemical and Molecular Characterization of *Clostridium sporogens* in Nono: A Nigerian Traditionally Fermented Yoghurt Drink." *Open Journal of Medical Microbiology* 13, no. 1 (2023): 91-100. <https://doi.org/10.4236/ojmm.2023.131008>
- [24] Agboola, S. A., O. O. Olaniyi, B. S. Adeleke, J. B. Akinyele, and O. Y. Amos-Agboola. "Nutritional and Antioxidant Properties of Fermented Kunu Using *Lactobacillus plantarum*, *Lb. fermentum*, *Bacillus subtilis* and *Saccharomyces cerevisiae* Isolates." <https://sustaine.org/nutritional-and-antioxidant-properties-of-fermented-kunu-using-lactobacillus-plantarum-lb-fermentum-bacillus-subtilis-and-saccharomyces-cerevisiae-isolates>
- [25] Okwunodulu, I. N., and E. F. Agha. "Nutritional properties of indigenous fermented condiment (ogiri) produced from partial substitution of castor oil bean (*Ricinus communis*) with soybean (*Glycine max*) seeds." *Nigerian Journal of Biotechnology* 37, no. 2 (2020): 32-46. <https://doi.org/10.4314/njb.v37i2.4>
- [26] Ndudi, Winifred, Great Iruoghene Edo, Princess Oghenekeno Samuel, Agatha Ngukuran Jikah, Raphael Ajiri Opiti, Irene Ebosereme Ainyanbhor, Arthur Efeoghene Athan Essaghah, Helen Avuokerie Ekokotu, Ephraim Alex Evi Oghrora, and Joy Johnson Agbo. "Traditional fermented foods of Nigeria: microbiological safety and health benefits." *Journal of Food Measurement and Characterization* 18, no. 6 (2024): 4246-4271. <https://doi.org/10.1007/s11694-024-02490-1>
- [27] Oladeji, Oluwatoyin Ajoke, Kehinde Adekunbi Taiwo, Clement Olusola Ogidi, and Adeyanmola Oluwaseyi Faturoti. "Production, nutritional benefits, limitations and strategies for enhancing the national value of fermented native condiments from selected legumes and wild seeds in Nigeria." *Discover Food* 5, no. 1 (2025): 142. <https://doi.org/10.1007/s44187-025-00409-3>
- [28] Ibeabuchi, J. C., I. A. Olawuni, M. C. Iheagwara, M. Ojukwu, and C. E. Ofoedu. "Microbiological evaluation of Iru and Ogiri–Isi used as food condiments." *Journal of Environmental Science, Toxicology and Food Technology* 8, no. 8 (2014): 45-50. <https://doi.org/10.9790/2402-08814550>
- [29] Agbo NJ. Comparative nutritional and mineral analysis of fermented *Pentaclethra macrophylla* (ukpaka), *Ricinus communis* (ogiri), and *Prosopis africana* (okpeye). *FUDMA J Sci.* 2023;7(2):112–22. <https://doi.org/10.33003/fjs-2024-0803-2351>
- [30] Ezegbe, Amarachi G., Uchechukwu D. Egumgbe, Obiageli I. Okoye, Chibundo A. Nwobi, and Bridget O. Mbah. "Effects of Processing Methods (Boiling, Soaking and Fermentation) on Nutrient and Anti-nutrient Composition of African Oil Bean (*Pentaclethra macrophylla*) Seeds." *Journal of Home Economics Research* 31, no. 2 (2024). <https://journals.heran.org/index.php/JHER/article/download/505/452/890>
- [31] Adesulu-Dahunsi, A. T., K. Jeyaram, and A. I. Sanni. "Probiotic and technological properties of exopolysaccharide producing lactic acid bacteria isolated from cereal-based nigerian fermented food products." *Food Control* 92 (2018): 225-231. <https://doi.org/10.1016/j.foodcont.2018.04.062>
- [32] Nath, Soumitra, Jibalok Sikidar, Monisha Roy, and Bibhas Deb. "In vitro screening of probiotic properties of *Lactobacillus plantarum* isolated from fermented milk product." *Food Quality and Safety* 4, no. 4 (2020): 213-223. <https://doi.org/10.1093/fqsafe/fyaa026>
- [33] Oziegbe, Olubukola, Azeta Iziegbe Joy, and Yemisi Dorcas Obafemi. "Probiotic Properties and Safety Profiling of *Lactobacillus* Species Obtained from Fermented Beverages in Ota, Nigeria." In *Harnessing Biotechnology Tools for Product Development: Selected Papers from the International Biotechnology Conference Exhibition and Workshop (IBCEW 2024)*, pp. 125-146. Cham: Springer Nature Switzerland, 2025. https://doi.org/10.1007/978-3-031-86002-7_9
- [34] Fagbemigun, Olakunle, Gyu-Sung Cho, Niels Rösch, Erik Brinks, Katrin Schrader, Wilhelm Bockelmann, Folarin A. Oguntoyinbo, and Charles MAP Franz. "Isolation and characterization of potential starter cultures from the nigerian fermented milk product nono." *Microorganisms* 9, no. 3 (2021): 640. <https://doi.org/10.3390/microorganisms9030640>
- [35] Zakari, David, Audu Amoka, Egbeja Idris, Aliyu Anoze, Adefila Moyosore, Momoh Boniface, Ali Bashir, Shuiab Danjuma, and Aliyu Omuya. "Characterization of lactic acid bacteria from fermented cereal-based foods in

- Anyigba, Nigeria, for potential probiotic and bio-preservation applications." *Agriculture and Food Bioactive Compounds-Online* ISSN: 3068-8051 2, no. 8 (2025): 171-182. <https://doi.org/10.31989/afbc.v2i8.1723>
- [36] Egwim, E. C., O. O. Ojo, F. U. Akpakpan, S. D. Oloninefa, and O. D. Akan. "Probiotics screening from selected Nigerian prebiotics: Alternative starter culture sources for yoghurt production." *Nigerian Journal of Biotechnology* 40, no. 2 (2023): 37-49. <https://doi.org/10.4314/njb.v40i2.5>
- [37] Oladipo IC, Ogunsona SB, Ogunleke OB, Elusakin OT. Therapeutic potentials of some Lactobacillus species isolated from fermented foods and condiments. *Int J Curr Microbiol Appl Sci.* 2025;14(5):59–71. <https://doi.org/10.20546/ijcmas.2025.1405.007>
- [38] Adesemoye, Elizabeth T., Abiodun I. Sanni, Giuseppe Spano, Vittorio Capozzi, and Mariagiovanna Fragasso. "Lactic acid bacteria diversity in fermented foods as potential bio-resources contributing to alleviate malnutrition in developing countries: Nigeria as a case study." *Fermentation* 11, no. 2 (2025): 103. <https://doi.org/10.3390/fermentation11020103>
- [39] Ajayi, A. O., and O. A. Ajenifuja. "Probiotic Potential of Lactic Acid Bacteria Isolated from Local Foods in Ado-Ekiti, South West Nigeria." *Nigerian Journal of Basic and Applied Sciences* 32, no. 1 (2024): 27-36. <https://doi.org/10.4314/njbas.v32i1.5>
- [40] Oluwajoba, Solakunmi Omotunde, Felix Akinsola Akinyosoye, and Victor Olusegun Oyetayo. "In vitro screening and selection of probiotic lactic acid bacteria isolated from spontaneously fermenting Kunu-Zaki." *Advances in Microbiology* 3, no. 04 (2013): 309. <https://doi.org/10.4236/aim.2013.34044>
- [41] Itaman, V. O., and E. Nwachukwu. "Microbial profile of fermented maize flour (Ogi) and African oil bean (*Pentaclethra macrophylla*) seeds." *Journal of Advances in Microbiology* 21, no. 8 (2021): 16-27. <https://doi.org/10.9734/jamb/2021/v21i830373>
- [42] Takale RY, Mishra N, Deshmukh AS, Purohit S. Effect of different fermentation methods on nutritional and anti-nutritional properties of finger millet products. *Int J Agric Food Sci.* 2025;7(4):282–6. <https://doi.org/10.33545/2664844X.2025.v7.i4d.365>
- [43] Akpeji, C. S., D. U. Ewetan, B. O. Bosah, C. C. Otali, and C. O. Ossai. "Microbiological and Nutritional Characteristics of Locally Fermented Fufu Commonly Sold in Amai, Delta State, Nigeria." *Journal of Applied Sciences and Environmental Management* 29, no. 2 (2025): 477-482. <https://doi.org/10.4314/jasem.v29i2.17>
- [44] Onyeka OV, Agu I, Ezerebo C. Effect of fermentation time on the nutrient and hydrogen cyanide content of cassava-based products (garri and fufu). *IOSR J Dent Med Sci.* 2024;23(2):64–72. <https://www.iosrjournals.org/iosr-jdms/papers/Vol23-issue2/Ser-1/N2302016472.pdf>
- [45] Fagbemigun, Olakunle, Gyu-Sung Cho, Niels Rösch, Erik Brinks, Katrin Schrader, Wilhelm Bockelmann, Folarin A. Oguntoyinbo, and Charles MAP Franz. "Isolation and characterization of potential starter cultures from the nigerian fermented milk product nono." *Microorganisms* 9, no. 3 (2021): 640. <https://doi.org/10.3390/microorganisms9030640>
- [46] Adesulu-Dahunsi, A. T., K. Jeyaram, and A. I. Sanni. "Probiotic and technological properties of exopolysaccharide producing lactic acid bacteria isolated from cereal-based nigerian fermented food products." *Food Control* 92 (2018): 225-231. <https://doi.org/10.1016/j.foodcont.2018.04.062>
- [47] Teniola, Olakunle David, Wilhelm H. Holzapfel, and Sunday Ayodele Odunfa. "Selection, use and the influence of starter cultures in the nutrition and processing improvement of ogi." *Journal of Food Science and Nutrition Research* 6, no. 3 (2023): 61-70.: <https://doi.org/10.26502/jfsnr.2642-110000131>
- [48] Dania, Margaret I., Bahram Faraji, and James Wachira. "Micronutrient Biosynthesis potential of spontaneous grain fermentation microbiomes." *International journal of environmental research and public health* 19, no. 24 (2022): 16621. <https://doi.org/10.3390/ijerph192416621>
- [49] Gupta, Raj Kishor, Shivraj Singh Gangoliya, and Nand Kumar Singh. "Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains." *Journal of food science and technology* 52, no. 2 (2015): 676-684. <https://doi.org/10.1007/s13197-013-0978-y>
- [50] Akpi, Uchenna K., Nurul Aqilah Mohd Zaini, Chukwudi Innocent Nnamchi, Jerry Obetta Ugwuanyi, Wan Abd Al Qadr Imad Wan, and Wan Syaidatul Aqma Wan Mohd Noor. "Biotechnology of Okpeye: a Nigerian traditional fermented food condiment." *Advances in Microbiology* 13, no. 8 (2023): 373-385. <https://doi.org/10.4236/aim.2023.138024>
- [51] Duche, Rachael T., Anamika Singh, Arundhati Ganesh Wandhare, Vikas Sangwan, Manvesh Kumar Sihag, Tochukwu NT Nwagu, Harsh Panwar, and Lewis I. Ezeogu. "Antibiotic resistance in potential probiotic lactic acid bacteria of fermented foods and human origin from Nigeria." *BMC microbiology* 23, no. 1 (2023): 142. <https://doi.org/10.1186/s12866-023-02883-0>
- [52] Huligere, Sujay S., V. B. Chandana Kumari, Taha Alqadi, Saurabh Kumar, Charley A. Cull, Raghavendra G. Amachawadi, and Ramith Ramu. "Isolation and characterization of lactic acid bacteria with potential probiotic activity and further investigation of their activity by α -amylase and α -glucosidase inhibitions of fermented batters." *Frontiers in Microbiology* 13 (2023): 1042263. <https://doi.org/10.3389/fmicb.2022.1042263>

- [53] Nami, Yousef, Bahman Panahi, Hossein Mohammadzadeh Jalaly, Mohaddeseh Rostampour, and Mohammad Amin Hejazi. "Probiotic characterization of LAB isolated from sourdough and different traditional dairy products using biochemical, molecular and computational approaches." *Probiotics and Antimicrobial Proteins* 17, no. 3 (2025): 1014-1037. <https://doi.org/10.1007/s12602-024-10234-2>
- [54] Onifade DA. Molecular identification and probiotic properties of lactic acid bacteria isolated from selected Nigerian fermented food products. *IOSR J Pharm Biol Sci.* 2023;18(4):1–6. <https://doi.org/10.9790/3008-1804010106>
- [55] Otunba, Ahmed Adebisi, Akinniyi Adediran Osuntoki, Daniel Kolawole Olukoya, and Benjamin Ayodipupo Babalola. "Genomic, biochemical and microbial evaluation of probiotic potentials of bacterial isolates from fermented sorghum products." *Heliyon* 7, no. 12 (2021). <https://doi.org/10.1016/j.heliyon.2021.e08536>
- [56] Ibezim, Chidozie NE, Catherine N. Stanley, Uchenna W. Isiofia, Amaka M. Awanye, Kingsley C. Anukam, Angus N. Oli, Anthony A. Attama, and Charles O. Esimone. "Lactic acid bacteria obtained from cereal-based fermented food products at different processing stages." *West African Journal of Pharmacy* 34, no. 2 (2023): 163-176. <https://doi.org/10.60787/wapcp-34-1-297>
- [57] Godspower, Ohaegbu Chinedu, Ngene Anayochukwu Chibuike, Asuquo Unyime Inyang, Coulthard Oluwatoyin Debby, and Nwachukwu Ejikeme. "Characterization and antimicrobial activities of lactic acid bacteria isolated from selected Nigerian traditional fermented foods." *African Journal of Biotechnology* 21, no. 5 (2022): 218-236. <https://doi.org/10.5897/AJB2021.17450>
- [58] Ogunleke OB, Oladipo IC. Isolation and molecular characterization of lactic acid bacteria isolated from selected fermented food condiments. *World J Biol Pharm Health Sci.* 2025;23(1):64–70. <https://doi.org/10.30574/wjpbphs.2025.23.1.0634>
- [59] Aderolake, A. D., O. E. Adeola, and A. O. Amos. "Probiotic properties of lactic acid bacteria isolated from spontaneously fermented Kunun-Zaki." (2023). <https://doi.org/10.9734/mrji/2023/v33i31371>
- [60] Uzoh, C. V., J. O. Orji, C. O. Okeh, C. O. Nworie, P. C. Igwe, and L. I. Uwanta. "Assessment of probiotic potentials of lactic acid bacteria isolated from some locally fermented foods." *Asian Journal of Food Research and Nutrition* 1, no. 1 (2022): 11-16. <https://journalajfrn.com/index.php/AJFRN/article/view/2>
- [61] Arouna, Nafiou, Morena Gabriele, Elena Tomassi, and Laura Pucci. "Traditional fermentation affects the nutraceutical properties of *Parkia biglobosa* seeds." *Plant Foods for Human Nutrition* 78, no. 2 (2023): 452-457. <https://doi.org/10.1007/s11130-023-01064-8>
- [62] Ajiboye TO, Iliasu GA, Adeleye AO, Abdussalam FA, Akinpelu SA, Jimoh SO, et al. Nutritional and antioxidant dispositions of sorghum/millet-based beverages indigenous to Nigeria. *Food Sci Nutr.* 2020;8(5):2345–56. <https://doi.org/10.1002/fsn3.140>
- [63] Bamidele, Oluwaseun Peter. "Effects of natural fermentation time on chemical composition, antioxidant activities, and phenolic profile of cassava root flour." *Applied Sciences* 15, no. 15 (2025): 8494. <https://doi.org/10.3390/app15158494>
- [64] Banwo, Kolawole, and Oluwatosin Timothy Taiwo. "Potential antioxidant activities and bioactive compounds in probiotic tiger nut date palm yogurt fermented with lactic acid bacteria." *Journal of Food Science and Technology* 62, no. 5 (2025): 919-929. <https://doi.org/10.1007/s13197-024-06081-2>
- [65] Anyogu, Amarachukwu, Ayomide Olukorede, Christian Anumudu, Helen Onyeaka, Esther Areo, Obadina Adewale, Joyce N. Odimba, and Ogueri Nwaiwu. "Microorganisms and food safety risks associated with indigenous fermented foods from Africa." *Food Control* 129 (2021): 108227. <https://doi.org/10.1016/j.foodcont.2021.108227>
- [66] Oladipo IC, Ogunsona SB, Ogunleke OB, Elusakin OT. Therapeutic potentials of *Lactobacillus* species isolated from Nigerian fermented foods. *Int J Curr Microbiol Appl Sci.* 2025;14(5):59–71. <https://doi.org/10.20546/ijcmas.2025.1405.007>
- [67] Maptouom CLF, Djouhou MC, Tchuenchieu AD, Mafogang B, Medoua G, et al. Nutritional, antioxidant and physicochemical properties of baobab (*Adansonia digitata*) fruit pulp from Cameroon. *J Food Nutr Sci.* 2025;13(3):139–49. Available from: <https://doi.org/10.11648/j.jfns.20251303.14>
- [68] Olaitan, Bamisaiye Yemisi, Janet Adeyinka Adebo, Dupe Temilade Otolowo, Oluwafemi Ayodeji Adebo, and Sunday Samuel Sobowale. "Effects of Bioprocessing and Ultrasonication on Nutritional, Functional and Antioxidant Properties of African Yam Bean Flour and Cookie Quality." *Legume Science* 7, no. 2 (2025): e70035. <https://doi.org/10.1002/leg3.70035>
- [69] Sobowale, Sunday Samuel, Oluwaseun Peter Bamidele, and Janet Adeyinka Adebo. "Physicochemical, functional, and antinutritional properties of fermented Bambara groundnut and sorghum flours at different times." *Food Chemistry Advances* 4 (2024): 100729. <https://doi.org/10.1016/j.focha.2024.100729>
- [70] Assamoi AA, Atobla K, Ouattara DH, Koné RT. Probiotic tiger nut–cashew nut milk fermented with lactic acid bacteria isolated from Ivorian staple foods. *Agric Sci.* 2023;14(4):584–600. <https://doi.org/10.4236/as.2023.144039>
- [71] Johnson EO, Okwuokei GC, Okafor JG, Akinboyewa I, Ononye OD, John C, et al.

- Antibacterial activity of lactic acid bacteria isolated from traditionally fermented food against food pathogens. *World J Adv Res Rev.* 2024;24(1):1962–73. Available from: <https://doi.org/10.30574/wjarr.2024.24.1.3157>
- [72] Onwughalu, Cynthia A., Chiamaka B. Ugwu, Ugochukwu M. Okezie, Chukwuebuka C. Onwuzuligbo, and Felix A. Onyegbule. "Antimicrobial and Antioxidant activities of Extract and fractions of the African yam bean (*Sphenostylis stenocarpa*) Seed." *Magna Scientia Advanced Biology and Pharmacy* 14, no. 01 (2025): 008-015. <https://doi.org/10.30574/msabp.2025.14.1.0012>
- [73] Adeoye, Babatunde Kazeem, Elizabeth Funmilayo Aransiola, Gbenga Alebiowu, Mary Adejumo Bisi-Johnson, Felix Oluwasola Olorunmola, and Oluwarinu Aduramigba Adepoju. "The characterization and microbiological evaluation of probiotic isolated from bambara groundnut." *International Journal of Applied Sciences and Biotechnology* 9, no. 1 (2021): 54-64. <https://doi.org/10.3126/ijasbt.v9i1.32959>
- [74] Sehim, Amira E., Basma H. Amin, Mohammed Yosri, Hanaa M. Salama, Dalal Hussien Alkhalifah, Maha Abdullah Alwaili, and Rasha Y. Abd Elghaffar. "GC-MS analysis, antibacterial, and anticancer activities of Hibiscus sabdariffa L. methanolic extract: In vitro and in silico studies." *Microorganisms* 11, no. 6 (2023): 1601. <https://doi.org/10.3390/microorganisms11061601>
- [75] Obioha, Promiselynda I., Amarachukwu Anyogu, Brigitte Awamaria, Hamid B. Ghoddusi, and Labia Irene I. Ouoba. "Antimicrobial resistance of lactic acid bacteria from Nono, a naturally fermented milk product." *Antibiotics* 12, no. 5 (2023): 843. <https://doi.org/10.3390/antibiotics12050843>
- [76] Balli, Diletta, Lorenzo Cecchi, Giuseppe Pieraccini, Manuel Venturi, Viola Galli, Marta Reggio, Diana Di Gioia et al. "Millet fermented by different combinations of yeasts and lactobacilli: effects on phenolic composition, starch, mineral content and prebiotic activity." *Foods* 12, no. 4 (2023): 748. <https://doi.org/10.3390/foods12040748>
- [77] Obisesan, Abiola O., and Funmilola A. Ayeni. "African Fermented Food as Antimicrobial Agents." In *Food Security and Safety: African Perspectives*, pp. 833-853. Cham: Springer International Publishing, 2021. https://doi.org/10.1007/978-3-030-50672-8_41
- [78] Adesulu-Dahunsi, A. T., K. Jeyaram, and A. I. Sanni. "Probiotic and technological properties of exopolysaccharide producing lactic acid bacteria isolated from cereal-based nigerian fermented food products." *Food Control* 92 (2018): 225-231. <https://doi.org/10.1016/j.foodcont.2018.04.062>
- [79] Flibert, Guira, Tankoano Abel, and Savadogo Aly. "African cassava traditional fermented food: the microorganism's contribution to their nutritional and safety values-a review." *International Journal of Current Microbiology and Applied Sciences* 5, no. 10 (2016): 664-687. <https://doi.org/10.20546/ijcmas.2016.510.074>
- [80] Etsuyankpa, M. B., C. E. Gimba, E. B. Agbaji, K. I. Omoniyi, M. M. Ndamitso, and J. T. Mathew. "Assessment of the effects of microbial fermentation on selected anti-nutrients in the products of four local cassava varieties from Niger state, Nigeria." *American Journal of Food Science and Technology* 3, no. 3 (2015): 89-96. <https://doi.org/10.12691/ajfst-3-3-6>
- [81] Samtiya, Mrinal, Rotimi E. Aluko, Anil Kumar Puniya, and Tejpal Dhewa. "Enhancing micronutrients bioavailability through fermentation of plant-based foods: A concise review." *Fermentation* 7, no. 2 (2021): 63. <https://doi.org/10.3390/fermentation7020063>
- [82] Banwo, Kolawole, and Oluwatosin Timothy Taiwo. "Potential antioxidant activities and bioactive compounds in probiotic tiger nut date palm yogurt fermented with lactic acid bacteria." *Journal of Food Science and Technology* 62, no. 5 (2025): 919-929. <https://doi.org/10.1007/s13197-024-06081-2>
- [83] Adeyanju, Adeyemi A., Johanita Kruger, John RN Taylor, and Kwaku G. Duodu. "Effects of different souring methods on the protein quality and iron and zinc bioaccessibilities of non-alcoholic beverages from sorghum and amaranth." *International journal of food science & technology* 54, no. 3 (2019): 798-809. <https://doi.org/10.1111/ijfs.13998>
- [84] Okolie, Pius Ifeanyi, Martins E. Itohan, Emilymary Chima Okolie, and Adewale Obadina. "Amino acid profile and protein quality of starter cultures fermented African yam bean (*Sphenostylis Sternocarp*) seed condiment." *Croatian journal of food science and technology* 15, no. 1 (2023): 28-36. <https://doi.org/10.17508/CJFST.2023.15.1.04>
- [85] Kumawat, Lokesh, Kamalesh Kumar Meena, Vishakha Singh, Hansa Choudhary, Sonali Das, Pooja Swami, and Monu Kanwar. "Fermented millets: Enhancing nutrition, gut health, and sustainable food systems." <https://doi.org/10.33545/26174693.2025.v9.i8f.5222>
- [86] Buta, M. B., and S. A. Emire. "Effects of fermentation on the nutritional quality of QPM and soybean blends for the production of weaning food." *J Food Process Technol* 6, no. 507 (2015): 507-517. <https://doi.org/10.4172/2157-7110.1000507>
- [87] Abdulwaliyu, Ibrahim, Shefiat O. Arekemase, Musa L. Batari, Joy O. Oshodin, Razaq A. Mustapha, Dahiru Ibrahim, Abeh T. Ekere, and Owolabi S. Olusina. "Nutritional and pharmacological attributes of baobab fruit pulp." *Food Production, Processing and Nutrition* 6, no. 1 (2024): 98. <https://doi.org/10.1186/s43014-024-00283-z>

- [88] Ibrahim, Salam A., Rabin Gyawali, Saddam S. Awaisheh, Raphael D. Ayivi, Roberta C. Silva, Kiran Subedi, Sulaiman O. Aljaloud, Shahida Anusha Siddiqui, and Albert Krastanov. "Fermented foods and probiotics: An approach to lactose intolerance." *Journal of Dairy Research* 88, no. 3 (2021): 357-365. <https://doi.org/10.1017/S0022029921000625>
- [89] Halake, Niguse Hotessa, and Bhaskarrao Chinthapalli. "Fermentation of traditional African Cassava based foods: microorganisms role in nutritional and safety value." *Journal of Experimental Agriculture International* 42, no. 9 (2020): 56-65. <https://doi.org/10.9734/JEAI/2020/v42i930587>
- [90] Adebo, Janet Adeyinka, Patrick Berka Njobeh, Sefater Gbashi, Ajibola Bamikole Oyedeji, Opeoluwa Mayowa Ogundele, Samson Adeoye Oyeyinka, and Oluwafemi Ayodeji Adebo. "Fermentation of cereals and legumes: Impact on nutritional constituents and nutrient bioavailability." *Fermentation* 8, no. 2 (2022): 63. <https://doi.org/10.3390/fermentation8020063>