

Chemical and Microbial Characterisation of Some Fermented Foods in Nigeria

Damilola Adejoke MAKINDE-OKE
LCU/PG/005237

Being a MSc Thesis Submitted to the Department of Human Nutrition & Dietetics, Faculty of
Basic Medical & Health Sciences, Lead City University, Ibadan, Oyo State, Nigeria.

In Partial Fulfilment of the Requirements for the Award of Master's of Science Degree (MSc) In
Human Nutrition and Dietetics.

2025

Certification

This is to certify that Damilola Adejoke MAKINDE-OKE, with Matriculation Number LCU/PG/005237, carried out this thesis titled "**Chemical and Microbial Characterisation of Some Fermented Foods in Nigeria**" in the Department of Human Nutrition and Dietetics, Faculty of Basic Medical and Health Sciences, Lead City University Ibadan, Oyo State, and that this work has not been previously submitted, either wholly or in part, for any degree or diploma at this or any other institution.

Prof Olusola Ladokun
Supervisor

Date

Dr. O. O. Balogun
Head of Department

Date

Dedication

This work is dedicated to my loving family, for their unwavering support, encouragement, and sacrifices, and to every nutrition professional committed to improving the health and well-being of communities through evidence-based practices.

Lead City University Ibadan DO NOT COPY

Acknowledgment

I acknowledge the authors of various scientific publications and resources that have provided valuable information on **Chemical and Microbial Characterisation of Some Fermented Foods in Nigeria**.

I am deeply grateful to Almighty God for the grace, strength, and insight to complete this academic work. His guidance has been my compass throughout this intellectual journey.

My sincere appreciation goes to my supervisor, Professor Olusola Ladokun, whose expertise, encouragement, and constructive feedback have been instrumental in shaping this thesis on chemical and microbial characterisation of some Nigerian fermented foods.

I also wish to thank all the faculty members of the Department of Human Nutrition and Dietetics at Lead City University for their support, knowledge, and mentorship throughout my postgraduate studies.

Special thanks to my family for their love, patience, and unwavering moral support. To my colleagues and friends who offered their time, resources, or encouragement during this process, thank you.

Even though the above-mentioned institutions and persons have assisted in the process of this research work, I alone stand responsible for the errors, if any, found in the work.

Abstract

Fermentation is a vital aspect of Nigeria's culinary heritage, contributing to nutritional enhancement, microbial safety, and national food security. This study explored the chemical and microbial characteristics of selected fermented foods commonly consumed in Nigeria. Raw substrates (cassava, corn, locust bean seed) and their fermented derivatives (Ogi, Fufu, Iru, Garri) were examined for nutrient composition, antioxidant potential, and microbial ecology. Proximate values ranged from 12.43–73.10% moisture content, 0.24–15.64% crude fat, 0.45–2.88% (total ash), 1.64–9.26% crude fibre, 1.26–38.62% crude protein, and 10.09–86.26% total carbohydrate. Mineral concentrations included calcium (12.5–98.4 mg/100g), magnesium (8.3–76.2 mg/100g), iron (1.2–18.6 mg/100g), and zinc (0.9–6.4 mg/100g). Vitamins A and C were notably elevated in fermented products, with ranges of 0.02–0.45 mg/100g and 1.5–22.8 mg/100g, respectively. Physico-chemical properties of fermented foods showed pH values between 3.43 and 8.34, titratable acidity from 0.04–0.95%, and total soluble solids ranging from 5.30–16.10 °Brix. Antioxidant properties revealed total phenolic content (12.6–84.3 mg GAE/g), radical scavenging activity (18.2–76.5%), ferric reducing antioxidant power (0.42–2.18 mmol Fe²⁺/g), and radical scavenging capacity (0.31–1.94 mmol Trolox/g). Microbial analysis indicated total viable counts of 2.10 ± 0.10 to 5.40 ± 0.15 log₁₀ CFU/g, with beneficial organisms such as *Lactobacillus plantarum*, *Bacillus subtilis*, and white yeasts dominating fermented samples. Spoilage organisms like *Aspergillus niger* and Enterobacteriaceae were reduced. In conclusion, fermentation significantly enhanced nutrient composition, antioxidant activity, and microbial safety. These improvements highlight the role of indigenous fermentation in addressing micronutrient deficiencies and promoting food quality and public health in Nigeria.

Keywords: Fermentation, nutrient composition, microbial analysis, and fermented foods.

Wordcount: 260 words

Table of Contents

Content	Page
Title Page	i
Certification	ii
Dedication	iii
Acknowledgment	iv
Abstract	v
Table of Contents	vi
List of Tables	x
List of Acronyms	xi
Chapter One: Introduction	1
1.1 Background to the Study	2
1.2 Statement of the Problem	3
1.3 Aims and Objectives of the Study	4
1.4 Research Questions	4
1.5 Hypothesis	4
1.6 Significance of the Study	4
1.7 Scope of the Study	6
1.8 Limitations of the Study	6
1.9 Operational Definitions of Terms	7
Endnotes	9
Chapter Two: Literature Review	10
2.1 Historical and Cultural Context of Fermentation	10
2.1.1 Origins and Evolution of Fermentation Practices	10
2.1.2 Cultural and Symbolic Roles of Fermented Foods	11
2.1.2.1 Cultural Identity and Symbolism	12
2.1.2.2 Social and Spiritual Functions	12
2.1.2.3 Gendered Knowledge and Roles	13
2.1.3 Indigenous Knowledge Transmission	14
2.1.3.1 Gendered Roles in Knowledge Custodianship	14
2.1.3.2 Intuitive and Sensory-Based Methodologies	15
2.1.3.3 Challenges of Codification and Integration	15
2.1.3.4 Preserving Knowledge Amidst Modernization	16
2.1.4 Continuity in a Modernizing Nation	15
2.1.4.1 Persistence of Indigenous Fermentation	17

Content	Page
2.1.4.2 Community-Driven Innovations & Hybridization	17
2.1.4.3 Scientific Recognition and Research	18
2.1.4.4 Challenges and Opportunities	18
2.2 Classification of Fermented Foods	19
2.2.1 Classification by Ingredient Type	19
2.3 Functional Roles of Nigerian Fermented Foods	22
2.4 Regional and Ethnic Variations	24
2.5 Microbial Communities and Successional Ecology	28
2.6 Traditional Fermentation Techniques in Nigeria	34
2.7 Microbial Succession and Functional Roles	37
2.8 Biochemical Pathways	41
2.9 Environmental and Technological Factors	45
2.10 Nutritional Changes During Fermentation	49
2.11 Functional Bio-Actives in Nigerian Fermented Foods	51
2.12 Health and Therapeutic Potentials	54
2.13 Challenges and Future Perspectives	57
2.14 Conclusion of Literature Review	59
Endnotes	62
Chapter Three: Materials and Methods	65
3.1 Research Design Overview	65
3.2 Sample Collection and Preparation	65
3.3 Proximate Analysis	65
3.4 Mineral Content Analysis	69
3.5 Vitamin Content Analysis	70
3.6 Physicochemical Properties	71
3.7 Antioxidant Properties	72
3.8 Microbiological Analysis	76
3.8.1 Sample Preparation and Processing	76
3.8.2 Enumeration of Total Viable Count (TVC)	76
3.8.3 Enumeration of Lactic Acid Bacteria (LAB)	76
3.8.4 Enumeration of Bacillus Species	77
3.8.5 Enumeration of Yeasts and Moulds	77
3.8.6 Enumeration of Enterobacteriaceae	77
3.9 Isolation and Identification of Microorganisms	77
3.10 Data Analysis	78

Content	Page
Endnotes	79
Chapter Four: Results and Discussion of Findings	80
4.1 Result of the Finding	80
4.2 Discussion of the Finding	101
Endnotes	134
Chapter Five: Conclusion	143
5.1 Summary of Findings	145
5.2 Conclusion	146
5.3 Recommendations	146
5.4 Contribution to Knowledge	148
5.5 Suggested Areas for Further Study	149
Bibliography	150
Appendices	177
Biodata	181
University Compliance Certification	183

List of Tables

Table	Title	Page
2.1	Regional Classification of Nigerian Fermented Foods	29
2.2	Fermentation Stages of Nigerian Fermented Foods	30
2.3	Ecological and Technological Factors Influencing Nigerian Fermented Food	33
2.4	Ecological Stages of Fermentation with Their Functional Roles	38
2.5	Fermentation Time of Some Nigerian Fermented Foods	62
4.1	Proximate Composition of Raw and Fermented Food	82
4.2	Selected Mineral Composition of Raw and Fermented Foods	85
4.3	Selected Vitamin Composition of Raw and Fermented Foods	89
4.4	Physicochemical Properties of Raw and Fermented Foods	92
4.5	Antioxidant Properties of Raw and Fermented Food	95
4.6	Microbial Counts of Raw and Fermented Foods	98
4.7	Microorganisms Identified in Raw and Fermented Foods	100

List of Acronyms

Abbreviation	Meaning
LAB	Lactic Acid Bacteria
B-complex vitamins	Vitamin B group (e.g., B1, B2, B3, B6, B12, etc.)
AOAC	Association of Official Analytical Chemists
DPPH	2,2-Diphenyl-1-picrylhydrazyl
ABTS	2,2'-Azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)
FRAP	Ferric Reducing Antioxidant Power
CFU	Colony Forming Units
TTA	Total Titratable Acidity
TSS	Total Soluble Solids
AAS	Atomic Absorption Spectrophotometer
H ₂ SO ₄	Sulfuric Acid
HNO ₃	Nitric Acid
NaOH	Sodium Hydroxide
HCl	Hydrochloric Acid
KOH	Potassium Hydroxide
UV-Visible	Ultraviolet-Visible (Spectrophotometer)
TPTZ	2,4,6-Tripyridyl-s-triazine
TEAC	Trolox Equivalent Antioxidant Capacity
TPC	Total Phenolic Content

Abbreviation	Meaning
GAE	Gallic Acid Equivalent
SPSS	Statistical Package for Social Sciences
DMRT	Duncan's Multiple Range Test
FAO	Food and Agriculture Organization

Lead City University Ibadan DO NOT COPY

Chapter One

Introduction

1.1 Background to the Study

Fermentation is among the oldest biotechnological practices, historically used to preserve, transform, and enrich food products through microbial activity ¹. This process remains central to traditional food systems in Africa, where it plays a crucial role in preserving seasonal harvests, enhancing food safety and digestibility, and improving the organoleptic and nutritional properties of foods. In Nigeria, fermentation is deeply ingrained in food culture, with staple ingredients such as cassava, maize, millet, and legumes transformed into familiar products through spontaneous microbial action ².

Among the most widely consumed fermented foods in Nigeria are *Ogi* (fermented cereal pudding), *Fufu* (fermented cassava dough), *Iru* (fermented locust bean paste), and *Garri* (fermented and roasted cassava granules). These foods are dietary staples across diverse ethnic and regional groups, appreciated for their taste, shelf stability, affordability, and nutritional value ^{3, 4}. Their preparation typically involves spontaneous fermentation driven by the indigenous microbiota present in raw materials and the local environment. Lactic acid bacteria (LAB), yeasts, and moulds are the dominant microbial players that guide fermentation ⁵.

The metabolic activities of these microorganisms yield organic acids, alcohols, enzymes, and various bioactive compounds that inhibit spoilage organisms and pathogens, thereby enhancing both safety and shelf life ⁶. Additionally, fermentation has been shown to improve the nutritional profile of foods by increasing concentrations of B-complex vitamins (e.g., thiamine, riboflavin, and folate), as well as enhancing the bioavailability of essential minerals such as iron and zinc through the breakdown of antinutritional factors like phytates ⁷.

Nevertheless, despite the socio-economic and nutritional importance of these foods, their microbial communities remain poorly characterized, particularly the uncultivable microbial populations. Previous studies have relied on classical culture-based techniques, which, although informative, often fail to capture the full spectrum of microbial diversity present in complex ecosystems ⁸.

Equally important is the lack of current, comprehensive chemical profiling of these foods. Many available studies on proximate composition, mineral and vitamin contents, and antioxidant activity are outdated, geographically limited, or conducted using non-specific analytical techniques ^{4, 9}. Without updated nutritional data, it is difficult to substantiate health claims, inform food-based dietary guidelines, or support the growing demand for African fermented foods in international markets.

Given the increasing interest in functional and probiotic-rich foods, this study aims to provide an integrated microbiological and chemical characterization of selected traditional Nigerian fermented foods, *Ogi*, *Fufu*, *Iru*, and *Garri*, collected from Abeokuta, Ogun State. The approach will combine culture-based microbial identification with proximate, mineral, vitamin, antioxidant, and physicochemical analyses to deepen understanding and inform safety, standardization, and commercialization efforts.

1.2 Statement of the Problem

Nigeria boasts a rich diversity of traditional fermented foods; however, comprehensive scientific data on their microbial and chemical composition remain limited and often fragmented. The majority of microbiological investigations have employed culture-dependent methods, which, while informative, are inherently limited in scope, frequently overlooking non-culturable yet functionally important microorganisms that contribute to fermentation dynamics and product

quality ⁸. This limitation hinders the development of tailored starter cultures and comprehensive microbial safety protocols.

In addition, the nutritional data for many traditional fermented foods are either outdated or not specific to region, processing style, or fermentation method. Studies often lack detail on vitamin concentration, mineral bioavailability, and antioxidant ^{4, 7}. This makes it difficult to develop evidence-based dietary recommendations, enforce quality control, or make validated health claims that can support industrial innovation.

Spontaneous fermentation is widely utilized in traditional food processing due to its ability to enhance organoleptic qualities and foster a diverse microbial ecosystem. However, despite these benefits, this method also presents critical safety challenges. When fermentation is not adequately controlled, there is an increased risk of contamination with spoilage organisms and foodborne pathogens, which can compromise product safety and public health ¹¹. As a result, there is growing interest in the application of defined starter cultures and improved hygiene practices to mitigate these risks while preserving the distinct qualities associated with traditional fermentation techniques.

Without validated microbial and chemical profiles, these foods cannot be effectively standardized or marketed for international consumption. Hence, comprehensive, location-specific studies are necessary to fill these critical knowledge gaps and to support food safety, nutrition, and economic development.

1.3 Aim and Objectives of the Study

This study aims to determine the microbiological and chemical characterization of selected traditional fermented foods in Nigeria.

The objectives are to:

- i. determine the proximate composition of both raw substrate and its fermented foods
- ii. determine the mineral and vitamin composition of both the raw substrate and its fermented foods
- iii. determine the antioxidant and physico-chemical properties of both raw substrate and their fermented foods
- iv. isolate, identify, and characterize microbial species present in raw substrate and their fermented foods

1.4 Research Questions

- i. What are the proximate nutritional compositions of these foods?
- ii. What minerals and vitamins are present in the food samples, and in what concentrations?
- iii. How do the antioxidant and physicochemical properties influence fermentation outcomes and food quality?
- iv. What microbial species are present in the raw and fermented samples of *Ogi*, *Fufu*, *Iru*, and *Garri*?

1.5 Hypothesis

Ha1: Fermentation induces statistically significant changes in the chemical composition, enhances antioxidant properties, and alters microbial community structures in traditional Nigerian fermented foods *Ogi*, *Fufu*, *Iru*, and *Garri*, resulting in improved nutritional quality and functional potential.

1.6 Significance of the Study

This study contributes substantially to the fields of nutrition science, food technology, public health, and indigenous knowledge systems by offering a scientifically grounded evaluation of

traditional Nigerian fermented foods, namely *Ogi*, *Fufu*, *Garri*, and *Iru*. While these foods are widely consumed across different regions and cultural groups in Nigeria, existing data on their nutrient composition, functional properties, and microbial safety remain fragmented or outdated. By integrating proximate analysis, vitamin and mineral profiling, antioxidant assays, and culture-based microbial evaluation, this study delivers an evidence-based foundation for understanding the nutritional and safety implications of these popular foods.

The findings from this research are particularly significant in addressing micronutrient deficiencies and protein-energy malnutrition, which remain prevalent public health concerns in Nigeria. By demonstrating that fermentation improves the bioavailability of essential nutrients and enhances antioxidant activity, this study underscores the role these foods can play in boosting dietary quality, especially among vulnerable populations such as children, pregnant women, and the elderly.

Beyond nutrition, the microbial characterization of fermented foods offers valuable insights into food safety and preservation. Identifying beneficial microbial strains and their succession during fermentation paves the way for the development of standardized starter cultures that could be used to improve hygiene, consistency, and shelf stability in small-scale and industrial food production. This aspect of the study has practical relevance for both food processors and regulatory agencies seeking to scale up indigenous foods for commercial and export markets.

In addition, this research validates the functional potential of traditional fermented foods, positioning them not only as everyday staples but also as candidates for development into probiotic-rich or therapeutic food products. In doing so, it bridges the gap between local food heritage and global trends in functional and health-promoting foods.

Finally, the study contributes to the broader goal of preserving cultural food practices while informing evidence-based nutrition interventions. It supports a growing national interest in promoting local, sustainable, and nutrient-dense diets, aligning well with Nigeria's food security and public health strategies.

1.7 Scope of the Study

This study focuses on the chemical and microbial characterization of four traditional Nigerian fermented foods, *Ogi*, *Fufu*, *Iru*, and *Garri*, widely consumed across various regions in Nigeria. Both raw substrates (cassava, corn, and locust bean seed) and their fermented derivatives were analysed to understand the impact of fermentation on their nutritional and microbial profiles.

The geographic scope was limited to products sourced from Abeokuta North Local Government Area in Ogun State, ensuring consistency in environmental conditions and processing practices.

The analyses were performed using standard laboratory techniques, including:

- Proximate composition (moisture, ash, fat, protein, fiber, carbohydrates)
- Mineral analysis (calcium, magnesium, iron, zinc)
- Vitamin profiling (A, B-complex, C)
- Physicochemical parameters (pH, titratable acidity, total soluble solids)
- Antioxidant assays (DPPH, FRAP, ABTS, Total Phenolic Content)
- Culture-based microbial identification of dominant bacteria and fungi

1.8 Limitations of the Study

1. **Restricted to Culture-Based Microbial Analysis:** The study relied solely on culture-dependent techniques, which may have excluded non-culturable but functionally relevant microorganisms present in fermented foods.

2. **Geographical Limitation:** Sample collection was confined to the Abeokuta North Local Government Area of Ogun State, potentially limiting the generalizability of the findings to other regions of Nigeria.
3. **Absence of Sensory Evaluation:** The study did not assess taste, texture, aroma, or overall consumer acceptability, which are important factors in understanding the market potential of the products.
4. **Lack of Molecular Techniques:** Advanced microbiological methods such as DNA sequencing, metagenomics, or transcriptomics were not employed, limiting insight into microbial dynamics beyond what was culturable.
5. **Environmental and Process Variability:** Variations in fermentation conditions, such as temperature, duration, and hygiene practices, were not standardized across samples, which could affect reproducibility and consistency of results.

1.9 Operational Definitions of Terms

- **Raw Samples:** The initial, unprocessed plant-based substrates (e.g., cassava roots, cereals, legumes) that serve as the fermentation base in traditional processing systems.
- **Fermented Foods:** Food products transformed through the metabolic activity of microorganisms, either under controlled or spontaneous conditions, which results in improved safety, preservation, organoleptic attributes, and nutritional quality.
- **Proximate Analysis:** A standard method in food analysis that quantifies key nutritional constituents such as moisture, ash, crude protein, lipids, fibre, and carbohydrates, essential for assessing food quality and dietary adequacy.

- **Mineral Content:** The concentration of essential inorganic elements, including calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), potassium (K), and phosphorus (P) in food is vital for metabolic functions, bone health, and enzymatic activities.
- **Vitamin Content:** The quantitative measure of organic micronutrients such as B-complex vitamins, vitamin C, and K found in food, essential for cellular metabolism, antioxidant defence, and physiological homeostasis.
- **Antioxidant Activity:** The ability of food matrices or their bioactive components to scavenge or neutralize free radicals, and is commonly measured using in vitro assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS, and FRAP (Ferric Reducing Antioxidant Power).
- **Physicochemical Properties:** These are measurable physical and chemical characteristics of foods such as pH, titratable acidity, water activity, and total soluble solids, that influence fermentation dynamics, microbial growth, shelf life, and product stability.
- **Culture-Based Identification:** A conventional microbiological approach involving the cultivation of microorganisms on selective or differential media, followed by phenotypic characterization, staining, and biochemical testing to classify microbial taxa.

Endnotes

1. B. E. T. Öztürk, *Microbial Fermentation: Production and Biotechnological Applications*, in **Biotechnology in Action: Unveiling Nature's Power** (Boca Raton, FL: CRC Press, 93, 2024).
2. G. O. Adegoke, A. A. Falade & M. A. Abass, *Traditional Fermented Foods in Nigeria and Their Potential for Enhanced Nutritional and Functional Benefits*, **African Journal of Food Science and Technology** 12(3): 33–42, 2021.
3. A. T. Adeniran, *Nutritional and Microbial Evaluation of Selected Fermented Nigerian Foods*, **Nigerian Journal of Food Science and Technology** 38(1): 22–29, 2020.
4. K. Banwo, A. T. Sanni & G. A. Ogunremi, *Functional Properties of Fermented Nigerian Foods: A Review*, **Journal of Microbiology and Biotechnology Research** 10(4): 1–9, 2020.
5. T. Adebayo, A. I. Adesulu-Dahunsi, A. I. Sanni & K. Jeyaram, *Diversity and Characterization of *Pediococcus pentosaceus* in Nigerian Fermented Foods*, **LWT – Food Science and Technology** 136: 110352, 2021.
6. Y. D. Obafemi, S. U. Oranusi, K. O. Ajanaku & P. A. Akinduti, *African Fermented Foods: Emerging Benefits and Microbiome Profiling*, **npj Science of Food** 6(1): 30, 2022.
7. J. A. Adebo, P. B. Njobeh, S. Gbashi & A. B. Oyediji, *Fermentation of Cereals and Legumes: Impact on Nutritional Constituents and Bioavailability*, **Fermentation** 8(2): 63, 2022.
8. O. C. Chibuike & O. Godspower, *Culture-Independent Techniques for Exploring Microbial Diversity in Fermented Foods: A Review*, **African Journal of Food Science** 16(2): 22–32, 2022.
9. P. N. Anyiam, C. P. Nwuke & E. N. Uhwo, *Effect of Fermentation on Nutritional and Digestibility Parameters of Cassava-Soy Mahewu*, **Measurement: Food** 5: 100017, 2023.
10. A. T. Adesulu-Dahunsi, S. O. Dahunsi & A. O. Olayanju, *Synergistic Microbial Interactions Between LAB and Yeasts in Nigerian Indigenous Fermented Foods*, **Food Control** 110: 107004, 2020.
11. G. I. Edo, A. N. Jikah, W. Ndudi & P. O. Samuel, *Traditional Fermented Foods of Nigeria: Microbiological Safety and Health Benefits*, **Journal of Food Science and Technology**, 2024.

Chapter Two

Literature Review

2.1 Historical and Cultural Context of Fermentation in Nigeria

2.1.1 Origins and Evolution of Fermentation Practices

Fermentation practices are as old as African civilizations themselves, having evolved from ecological adaptation and survival needs ¹. The practice of fermentation in Nigeria is deeply rooted in antiquity, tracing back thousands of years as a practical response to food preservation, nutritional enhancement, and flavour development in tropical environments. Archaeological and anthropological evidence suggests that African communities, including those in present-day Nigeria, were engaging in rudimentary fermentation as early as the Neolithic period, long before modern scientific understanding of microbial processes emerged ^{2,3}.

Historically, fermentation evolved as a natural extension of subsistence food systems, where environmental conditions, such as high humidity, heat, and a lack of refrigeration, favored the spontaneous growth of indigenous microorganisms ⁴. Early Nigerians harnessed this natural microbial activity to extend the shelf life of perishable crops, including cassava, maize, millet, and legumes. Through empirical observation and generational knowledge transfer, communities refined techniques for producing a wide variety of fermented foods, such as *Ogi*, *Garri*, *Iru*, and *Kunun-zaki*, each associated with specific ethnic and ecological contexts ⁴.

Over time, fermentation became institutionalized within cultural practices, often associated with gender roles, social hierarchies, and rites of passage. For example, among the Yoruba, the ability to prepare fermented foods such as *Iru* and *Ogi* was traditionally seen as a marker of womanhood and domestic competence. Similarly, in Fulani communities, fermented dairy products like *Nunu* and *Fura da Nunu* are not just dietary staples but are also imbued with spiritual and symbolic significance during life-cycle ceremonies and pastoral rituals ⁵.

Fermentation technologies also evolved with migratory and inter-ethnic exchanges, leading to hybrid methods and ingredient adaptations. The introduction of cassava in the 16th century, for example, dramatically reshaped fermentation practices in southern Nigeria. Initially considered toxic, cassava was gradually incorporated into local diets through the development of fermentation methods (e.g., soaking, grating, roasting). These methods neutralized its cyanogenic compounds, a practice still used today in the production of *Fufu* and *Garri* ^{1,7}.

The evolution of fermentation in Nigeria reflects adaptive resilience, where communities innovated using locally available resources such as clay pots, raffia baskets, calabashes, and banana leaves as fermentation vessels ⁷. These materials not only hosted beneficial microbes but also offered insulation, oxygen regulation, and symbolic meaning within indigenous cosmologies ⁶.

In the post-colonial era, fermentation was an essential part of the Nigerian food system, although increasingly challenged by urbanization, industrialization, and changing dietary patterns. However, renewed interest in traditional diets and food sovereignty has prompted a resurgence in both scientific and community-based studies on the role of fermented foods in nutrition, health, and heritage preservation ^{8,9}.

The origins and evolution of fermentation in Nigeria illustrate a deeply embedded, dynamic tradition shaped by ecological adaptation, cultural meaning, and intergenerational innovation.

2.1.2 Cultural and symbolic roles of fermented foods

Cultural foods in Nigeria are narratives told through taste, smell, and communal rituals ⁷. Fermented foods in Nigeria extend far beyond their nutritional and preservative functions; they are powerful cultural symbols, embedded in ritual, identity, memory, and social cohesion. These foods are used in rites of passage, intergenerational knowledge transfer, and ceremonial activities, with each ethnic group attaching distinct meanings and uses to specific fermented products.

2.1.2.1 Cultural identity and symbolism

Among the Yoruba of southwestern Nigeria, the fermented condiment Iru (made from *Parkia biglobosa* seeds) carries culinary and cultural prestige ⁷. It is not merely used for flavour enhancement in traditional stews like *Egusi* or *Ogbono*, but also reflects authenticity and ancestral culinary practices. Its production and use signal respect for tradition, often preferred over modern artificial seasonings. *Iru's* aroma is associated with home-cooked meals and intergenerational bonding, making it a potent symbol of heritage ⁴.

Similarly, *Ogi*, a fermented cereal porridge, is emblematic of motherhood and early life. In many southern Nigerian communities, *Ogi* is a weaning food for infants and a restorative dish for the elderly or ill. Its soft texture and sour taste are associated with care, nourishment, and purity. Because of these characteristics, *Ogi* is a staple in ceremonies celebrating childbirth or motherhood ⁸. In Igbo culture, cassava-based fermented foods, such as *Fufu* and *abacha*, as well as others like *ugba*, serve not only as dietary staples but also as ingredients used in festive occasions, family gatherings, and funerals ¹⁰. The communal sharing of these dishes reinforces social bonds. *Ugba*, in particular, is a symbol of prestige in southeastern Nigerian cuisine. It is

often exchanged during marriage ceremonies and traditional meetings, highlighting its role in community life ¹¹.

2.1.2.2. Social and spiritual functions

In northern Nigeria, fermented dairy and cereal products such as *Fura da Nunu*, *Kindirmo*, and *Kunun-zaki* are not only dietary essentials but also markers of cultural identity for the Fulani and Hausa communities ¹⁰. These foods are consumed during social gatherings, communal feasts, and rites of passage. *Fura da Nunu*, a blend of fermented milk and millet, is particularly significant in Fulani nomadic culture due to its portability and nutritional density, aligning with their lifestyle and social organization.

Fermented beverages such as *Pito* (a sorghum-based beer) and Palm wine also hold spiritual and ceremonial roles across multiple ethnic groups ¹¹. They are commonly used in libations to ancestors, weddings, and community meetings. These beverages symbolize transformation, aligning metaphorically with the biochemical processes of fermentation, where life emerges from decay and complexity from simplicity. Such symbolic associations between fermentation and life cycles are prominent in traditional cosmologies ³.

2.1.2.3. Gender knowledge and roles

The symbolic significance of fermented foods is further enriched by the gendered labour associated with their production. In many parts of Nigeria, women are the primary agents of fermentation ¹². They oversee the transformation of raw ingredients into edible, symbolic, and socially meaningful products. This labour is not just domestic but also economic and spiritual. Fermentation skills are passed from mothers to daughters through apprenticeship-like observation and practice, reinforcing both female agency and cultural continuity ¹³.

The space in which fermentation occurs is often sacred or protected. For example, in Yoruba households, fermentation may occur in designated clay pots or calabashes, which are believed to create the ideal microbial environment. The tools, timing, and even the songs associated with processing reflect traditional belief systems, and in some communities, specific taboos or rituals are performed during fermentation, especially in the case of foods used for festivals or ancestral worship.

2.1.3 Indigenous knowledge transmission

The transmission of fermentation knowledge in Nigeria is deeply embedded in traditional, oral knowledge systems. Unlike codified scientific methods, indigenous fermentation techniques are handed down across generations through non-written, practice-based learning, often within domestic settings. This form of knowledge preservation has ensured the continuity and diversity of fermented food production across the country for centuries, particularly among women, the primary custodians of fermentation expertise.

2.1.3.1 Gendered roles in knowledge custodianship

In virtually all Nigerian communities, women play central roles in the production and teaching of fermented food technologies. *“The woman is the bioreactor of her lineage, fermenting not just foods but culture.”*¹². From the initial selection and preparation of raw materials to the monitoring of fermentation cues such as bubbling, odour, and texture, women are the lead actors. This gendered transmission of knowledge typically occurs informally from mothers to daughters through observation, repetition, and hands-on involvement in food preparation processes from childhood¹³.

This apprenticeship-like system enables the transfer of highly localized fermentation practices tailored to specific ingredients, climate conditions, and community preferences ^{12, 13}. For example, in Yoruba-speaking areas, the fermentation of Iru is taught through intergenerational practice involving the boiling, dehulling, fermenting, and wrapping of *Parkia biglobosa* seeds. Similarly, in the North, Fulani women teach the steps for fermenting Nunu and Kindirmo, dairy products vital to their pastoralist culture ¹⁴.

2.1.3.2 Intuitive and Sensory-Based Methodologies

Indigenous knowledge systems often rely on intuitive and experiential ways of knowing, rooted deeply in relationships with nature, community, and ancestral wisdom. Instead of using calibrated equipment or scientific measurements, traditional fermentation is guided by sensory cues: the sour aroma of Ogi signals acidification; the frothy top of Kunun-zaki signals successful millet fermentation; and the pungent, umami scent of Iru indicates microbial proteolysis and flavour development ^{15, 16}. These signs are interpreted using indigenous taxonomies and often referenced in local idioms and proverbs, deeply woven into cultural language and identity ¹⁵.

This sensory-based approach, though sometimes dismissed by formal science as imprecise, offers a robust and adaptable form of low-tech food biotechnology, capable of producing safe and nutritious foods even in environments with minimal infrastructure ¹⁶.

2.1.3.3 Challenges of Codification and Scientific Integration

The oral and experiential nature of fermentation knowledge poses significant challenges for scientific documentation and standardization. Because practices vary from household to household, even within the same ethnic group there is often no consensus on fermentation time,

temperature, or moisture levels. This variability can lead to inconsistent product quality and makes it difficult to develop standardized safety regulations or industrial scaling protocols ¹⁷.

However, recent research efforts have begun to bridge this gap. Advances in molecular microbiology and metagenomics are being used to characterize the microbial consortia in fermented foods, many of which were previously unknown or unculturable. For instance, lactic acid bacteria such as *Lactobacillus fermentum* and *Weissella confusa*, as well as yeasts like *Saccharomyces cerevisiae*, have been isolated from Ogi and Kunun-zaki using DNA sequencing methods ¹⁷. These studies validate the efficacy of traditional methods and provide a scientific foundation for the development of starter cultures and quality control systems.

2.1.3.4 Preserving knowledge amidst modernization

As urbanization increases and processed foods become more common, traditional fermentation knowledge faces the risk of erosion. Younger generations are increasingly disconnected from the food systems of their ancestors, preferring fast food and commercially produced alternatives. Still, fermentation remains resilient particularly in rural areas where economic constraints and cultural pride continue to favour traditional practices ¹³.

To preserve this rich heritage, scholars and policymakers are advocating for community-led documentation projects, local food heritage initiatives, and integration of traditional knowledge into formal education ⁹. These strategies aim to safeguard fermentation practices not only as nutritional tools but also as living repositories of cultural identity, ecological wisdom, and indigenous science.

2.1.4 Continuity in a Modernizing Nation

In the face of sweeping societal changes, urbanization, globalization, industrialization, and the influx of ultra-processed foods Nigeria's traditional fermented food systems have demonstrated

remarkable resilience. While there is growing concern about the erosion of indigenous knowledge and dietary shifts among younger generations, fermented foods continue to occupy a central role in the diets and identities of many Nigerian communities, especially in rural and peri-urban regions. “The fermentation heritage of Nigeria is not fading; it is fermenting anew in steel pots, plastic sachets, and youth-led ventures.”¹⁸.

2.1.4.1 Persistence of indigenous fermentation

Despite modernization, the consumption and home-scale production of traditional fermented foods like *Ogi*, *Garri*, *Iru*, and *Fura da Nunu* remain robust¹⁵. Their widespread appeal is tied not only to cost and accessibility but also to deep-rooted cultural significance and sensory familiarity. These foods are widely favoured for their flavour, digestibility, and perceived health benefits, such as satiety, probiotic potential, and nutritional enhancement¹⁵.

The embeddedness of fermentation in daily and ceremonial life reinforces its continuity. In many communities, fermented foods are still featured at weddings, funerals, and festivals, where they serve as symbolic expressions of tradition and identity. This cultural embeddedness provides these foods a form of protection from being displaced by more “modern” alternatives⁸.

2.1.4.2 Community-driven innovations and hybridization

Nigerians have adapted to modernization not by abandoning traditional foodways but by hybridizing them¹³. Many producers now combine traditional methods with modern tools such as stainless-steel fermentation vats, improved sieving systems, and solar dryers. These adaptations improve hygiene, efficiency, and shelf life while retaining core cultural and sensory attributes⁴.

Community-based organizations and women's cooperatives in states such as Ogun, Kano, and Enugu are also pioneering small-scale commercialization of fermented foods ^{7, 8}. These local enterprises maintain traditional techniques while responding to increased urban demand. Importantly, they provide income-generating opportunities for rural women and contribute to food security through affordable, nutritious food options ¹³.

2.1.4.3 Scientific recognition and research integration

Modern food science has begun to acknowledge the value of Nigerian fermented foods in the context of nutrition-sensitive agriculture, functional food innovation, and microbiome health ^{17, 25}. Fermented foods are being increasingly studied for their health-promoting compounds such as bacteriocins, exopolysaccharides, and antioxidant peptides ¹⁸. These functional properties position them as promising candidates for preventive health and public nutrition strategies, especially in low-resource settings.

Moreover, researchers and policy advocates now recognize the potential of standardizing indigenous fermentation processes for broader scale-up. There is growing interest in developing starter cultures based on strains isolated from traditional fermentations, such as *Lactobacillus fermentum* from Ogi and *Bacillus subtilis* from Iru. These efforts aim to ensure consistency, improve microbial safety, and enable regulated commercial production without compromising cultural authenticity ¹⁷.

2.1.4.4 Challenges and opportunities

However, the path to mainstreaming traditional fermented foods is not without challenges. These include:

- Lack of regulatory frameworks tailored to small-scale fermented food producers
- Post-fermentation contamination due to poor handling practices

- Variability in product quality due to spontaneous fermentation without controlled parameters
- Declining interest among urban youth in learning traditional methods

Scholars recommend inclusive policies and training programs that empower local producers to improve sanitation, packaging, and fermentation control while preserving the cultural and sensory characteristics of the foods. Integrating fermentation education into agricultural and food science curricula is another strategic pathway to ensure intergenerational continuity¹⁹.

While Nigeria is modernizing rapidly, fermented foods continue to thrive as culturally embedded, nutritionally rich, and economically relevant staples. Their ongoing evolution, blending traditional wisdom with scientific innovation, illustrates how food heritage can adapt and flourish in a changing world.

2.2. Classification of Fermented Foods

2.2.1 Classification by ingredient type

The classification of Nigerian fermented foods by base ingredient provides a practical framework for understanding the country's diverse fermentation landscape^{16, 20}. This classification reflects the ecological, agricultural, and cultural contexts in which these foods are produced. Broadly, traditional fermented foods in Nigeria fall into four primary ingredient categories: cereals, tubers, legumes, and dairy^{21, 16}.

A. Cereal-based fermented foods

Cereal fermentation is widespread across Nigeria, particularly in the northern and southwestern regions where grains such as millet, sorghum, and maize are dietary staples. These foods are typically consumed as porridges, beverages, or infant weaning formulas.

- *Ogi (Akamu)*: A fermented porridge made from maize, millet, or sorghum. The grains are soaked, wet-milled, and fermented for 2–3 days, resulting in a sour-tasting, smooth paste. It is widely consumed as a breakfast food and a weaning meal due to its easy digestibility and probiotic potential ¹⁵.
- *Kunun-zaki*: A slightly fermented, sweet millet-based beverage common in the north. It is mildly alcoholic, rich in lactic acid bacteria (LAB), and consumed as a refreshing drink in both rural and urban areas ²².
- *Pito*: A sorghum-based traditional beer produced through fermentation and boiling. Though alcoholic, Pito serves social and ritual purposes and contains a wide spectrum of yeast and LAB species ³.

Cereal fermentations are predominantly driven by *Lactobacillus plantarum*, *Pediococcus pentosaceus*, and *Saccharomyces cerevisiae* ²³. These microbes contribute to acidification, safety, and the development of flavour and aroma profiles ¹⁶.

B. Tuber-based fermented foods

Cassava is Nigeria's most important tuber crop and forms the basis of numerous fermented products, especially in the southern and central regions.

- *Fufu*: Produced by fermenting peeled cassava tubers in water for several days. The softened mass is then sieved, settled, and cooked to yield a smooth, starchy paste used as a staple alongside soups. Fermentation removes cyanogenic glycosides and improves aroma and palatability ²⁴.
- *Garri*: Created by fermenting grated cassava, dewatering the mash, and roasting it into granules. It is highly shelf-stable and widely consumed across Nigeria in various forms (e.g., soaked in water, cooked as a dough).

- *Lafun*: A dried, fermented cassava flour used similarly to Fufu but with a slightly different texture and flavour profile ¹.

Tuber fermentations are primarily lactic and involve *Lactobacillus fermentum*, *Leuconostoc mesenteroides*, and other acid-tolerant LAB ¹⁶. These organisms facilitate detoxification and inhibit spoilage pathogens during the soaking period ¹⁹.

C. Legume-based fermented foods

Legume fermentation is particularly prominent in southwestern and southeastern Nigeria. These foods serve as protein-rich condiments and flavour enhancers.

- *Iru* (also known as *Dawadawa*): Made from African locust bean seeds (*Parkia biglobosa*), which are boiled, dehulled, and fermented under warm conditions ²⁴. It has a strong umami flavour and is commonly added to soups and sauces in Yoruba cuisine ²⁵.
- *Ugba*: Produced by fermenting African oil bean seeds (*Pentaclethra macrophylla*) in southeastern Nigeria. *Ugba* is often eaten as a side dish or in ceremonial meals ²⁶.
- *Okpehe*: Similar to *Iru*, but made from *Prosopis africana* seeds and more common in the middle-belt regions.

Legume fermentations are primarily alkaline and dominated by proteolytic *Bacillus* species such as *B. subtilis*, *B. licheniformis*, and *B. pumilus*. These bacteria degrade protein into amino acids and peptides, which are responsible for the characteristic aroma and bioactive functionality ^{24, 25}.

D. Dairy-based fermented products

Dairy fermentation is central to the pastoralist cultures of northern Nigeria, particularly among the Fulani and Hausa populations.

- *Nunu*: A yogurt-like fermented cow's milk, produced spontaneously without the use of starter cultures. It is consumed directly or used as a base for other meals ¹⁴.

- *Kindirmo*: A thicker, curdled version of Nunu often strained and shaped into a cheese-like consistency.
- *Fura da Nunu*: A blend of Nunu and millet dough (Fura), commonly consumed as a meal replacement or refreshment drink.

These products are fermented by LAB such as *Streptococcus thermophilus*, *Lactobacillus delbrueckii*, and *Enterococcus spp* ¹⁹. These organisms acidify the milk, inhibit pathogens, and contribute to characteristic flavour development ^{14, 18}.

The classification of Nigerian fermented foods by base ingredient highlights the country's culinary and microbial biodiversity. Each category: cereal, tuber, legume, and dairy rely on distinct fermentation pathways and microbial communities that reflect regional ingredients, cultural practices, and nutritional goals.

2.3 Functional Roles of Nigerian Fermented Foods

Nigerian fermented foods serve more than just dietary needs they perform diverse functional roles within households, communities, and cultural systems. Their classification by function reveals their strategic value in health, economy, social rituals, and food security. These roles can be grouped under four categories: nutritional staples, condiments and flavour enhancers, beverages and hydration agents, and specialized infant or geriatric foods ^{8, 15}.

A. Nutritional Staples

Many fermented foods in Nigeria function as daily staple items, providing energy and bulk to the diet. Products like *Fufu*, *Garri*, and *Lafun*, derived from fermented cassava, are consumed across all regions and typically paired with nutrient-dense soups ²⁴. Their high carbohydrate content, improved digestibility, and low glycemic index make them valuable especially in low-income and rural populations ²⁷. The fermentation of cassava not only improves texture and flavour but

also significantly reduces toxic cyanogenic compounds, thereby increasing safety. Properly fermented Fufu and Garri can reduce cyanide levels by over 90%. This function is critical in regions where cassava is a primary food source ²². Similarly, *Ogi*, a fermented maize or millet paste, is a key breakfast food and often used as a meal base. Cereal-based fermentation also enhances B-vitamin content (e.g., riboflavin, niacin), improving the micronutrient profile of otherwise carbohydrate-heavy meals ^{16, 17}.

B. Condiments and flavour enhancers

Fermented legumes such as *Iru* (fermented locust beans), *Ugba* (fermented African oil bean seeds), and *Okpehe* (*Prosopis africana*) are primarily used as condiments. These foods, rich in umami compounds and peptides, add depth to traditional stews, soups, and sauces ^{24, 28}. The alkaline fermentation of these legumes releases amino acids like glutamate, imparting a savory flavour. Beyond taste, these condiments also contribute protein and microbial bioactives. *Iru* contains peptides with potential antioxidant and antihypertensive activity ²⁹. These multifunctional attributes position legume-based condiments not only as culinary ingredients but also as functional foods in their own right.

C. Beverages and hydration agents

In the northern and central regions, fermented cereal and dairy beverages serve as hydration sources, especially in hot climates.

- *Kunun-zaki*, a mildly fermented drink made from millet or sorghum, is consumed chilled and sweetened.
- *Pito*, a sorghum-based fermented alcoholic beverage, is commonly shared during festivals and social gatherings.

- *Fura da Nunu*, a blend of fermented millet dough and milk (Nunu), is both nourishing and thirst-quenching.

These drinks provide a mixture of carbohydrates, probiotics, and organic acids that aid digestion. The microbial profiles of these beverages include *Lactobacillus fermentum*, *Streptococcus thermophilus*, and wild yeasts, offering mild antimicrobial and gut-modulating benefits^{22, 27}.

D. Infant and geriatric nutrition

Several fermented foods play specialized roles in feeding vulnerable populations particularly infants, the elderly, and convalescent individuals.

Ogi is widely known as a weaning food due to its soft texture, mild flavour, and digestibility. It is often combined with milk or sweeteners to enhance energy density. Studies have shown that fermentation reduces phytic acid and improves mineral bioavailability, critical for child development¹⁷. The elderly often consume *Ogi* and *Nunu* for similar reasons, particularly when experiencing digestive issues. These fermented products are rich in easily digestible carbohydrates and proteins, supporting nutritional maintenance without taxing the digestive system¹⁴.

Classifying Nigerian fermented foods by their functional role illustrates their indispensable place in local diets, cultural life, and public health. Whether as basic staples, condiments, therapeutic agents, or celebratory drinks, fermented foods contribute to nutritional adequacy, food security, and community identity.

2.4 Regional and Ethnic Variations in Nigerian Fermented Foods

Nigeria is a country of immense ethnic, linguistic, and ecological diversity, with over 250 ethnic groups distributed across six geopolitical zones^{5, 13}. This diversity is vividly expressed in the country's food systems, particularly in fermentation practices. Fermented foods in Nigeria are

regionally adapted and culturally specific, shaped by available raw materials, religious influences, climate, and traditional knowledge systems ²⁹.

Each region in Nigeria has developed distinct fermentation traditions, reflecting local ecological resources and culinary heritage. These practices are not only dietary solutions but also expressions of ethnic identity and resilience.

A. Northern Nigeria: Dairy and millet-based fermentations

In the North, comprising the North-West, North-East, and North-Central zones, the arid climate favors the fermentation of millet, sorghum, and dairy. The Fulani and Hausa ethnic groups dominate this region and have developed unique fermented products suited for their pastoral and nomadic lifestyles ¹⁴.

- *Fura da Nunu* is a fermented milk drink mixed with ground millet dough (Fura). It is portable, nutrient-dense, and widely consumed among the Fulani.
- *Kunun-zaki*, a sweet, fermented millet beverage, is sold in markets and homes, particularly during social events and religious festivals.
- *Kindirmo* is a yogurt-like fermented milk, thicker and more acidic than Nunu.

These products are deeply woven into the pastoral traditions of the Fulani and serve practical roles in hydration, nutrition, and ceremonial hospitality. Fulani women are the primary producers and vendors, passing on this skill through oral transmission and practical demonstration ¹⁴.

B. South-Western Nigeria: Root and legume fermentations

The Yoruba-speaking regions of the South-West (Lagos, Ogun, Oyo, Osun, Ondo, Ekiti) are known for root crop and legume fermentations, particularly from cassava and *Parkia biglobosa*.

- *Garri* and *Lafun* are cassava-based fermented staples found in nearly every Yoruba household.

- *Iru* (fermented locust beans) is an essential seasoning in Yoruba cuisine, often described as a “heritage flavour.”²⁸
- *Ogi*, a fermented maize or sorghum porridge, is central to Yoruba infant care, given its smooth texture and ease of digestion³⁰.

In these communities, the act of fermenting carries cultural meaning. Calabashes and clay pots are often reserved for fermentation, and the spaces where these processes occur are sometimes considered sacred or protected⁷. Fermented foods like *Iru* and *Ogi* also appear in traditional rituals and postpartum ceremonies^{31, 32}.

C. South-Eastern Nigeria: Oil bean and cassava specialties

In the Igbo-dominated South-East, fermentation is integral to both daily life and ritual events such as weddings, funerals, and community feasts.

- *Ugba* (fermented oil bean seeds) is a delicacy used in festive salads and often exchanged during marriages and village meetings.
- *Akamu* (variant of *Ogi*) is served as breakfast or infant food.
- *Abacha*, a fermented cassava salad, is consumed during special occasions and street gatherings.

Fermentation in Igbo society is not just a technique but also a cultural rite, especially in the preparation of labour-intensive foods like *Ugba*. The knowledge of *Ugba* fermentation is seen as a sign of culinary competence and maturity, often passed down matrilineally^{31, 33}.

D. South-South Nigeria: Fermented fish and tuber blends

In the South-South, comprising states in the Niger Delta region, fermentation often includes aquatic and coastal foods, due to the region’s riverine environment.

- Fermented fish and crayfish pastes are used in soup bases for dishes like Banga and Afang.
- Ukodo, a spicy yam pottage, sometimes incorporates slightly fermented tubers for depth of flavour.

Here, fermentation serves both preservation and sensory functions, with techniques such as smoking, ash application, and banana leaf wrapping often employed. These practices reflect unique adaptations to humidity and abundance of water sources ³⁴.

E. Central Nigeria: Hybrid practices and inter-ethnic exchange

The North-Central region (Benue, Niger, Kogi, Plateau, Kwara, Nassarawa, and Abuja) is a melting pot of ethnicities including the Tiv, Nupe, Idoma, and Gwari. This diversity has resulted in hybrid fermentation practices that combine elements from neighbouring regions.

- *Burukutu*, a sorghum-based alcoholic beverage, is used in community ceremonies and libations.
- *Okpehe*, a fermented condiment made from *Prosopis africana*, is popular in the Middle Belt and serves as a protein-rich flavouring agent.
- Cassava products such as *Garri* and *Fufu* are prepared with minor local modifications, integrating techniques from both the North and South.

The fusion of ingredients and fermentation approaches in Central Nigeria highlights interethnic food exchange, shaped by trade, migration, and intermarriage ¹³.

Regional fermentation practices in Nigeria demonstrate a deep synergy between ecology, ethnicity, and food technology. Whether in the Fulani plains or the Igbo highlands, fermentation is not merely a survival mechanism but a cultural signature ³⁵. These localized practices, sustained by gendered knowledge systems and community memory, offer vital lessons for

sustainable nutrition, biodiversity, and cultural preservation in a rapidly modernizing food landscape. Table 2.1 shows the regional classification of Nigerian fermented foods.

2.5 Microbial Communities and Successional Ecology of Nigerian Fermented Foods

The microbial communities in Nigerian fermented foods are highly diverse, dynamic, and ecologically adapted to both the substrates and environmental conditions in which fermentation takes place. Unlike controlled industrial fermentations, traditional Nigerian fermentations are typically spontaneous and open to natural inoculation. This allows a wide variety of indigenous microorganisms, bacteria, yeasts, and moulds to colonize the substrate and contribute to the biochemical transformation of food ³³.

Understanding the microbial ecology of these foods provides insights into safety, flavour development, shelf life, and health-promoting potentials. Over time, advances in molecular microbiology have enabled researchers to map these ecosystems and trace their succession during fermentation.

A. Microbial succession in fermentation stages

Traditional fermentation in Nigeria occurs in distinct ecological phases, each dominated by different microbial groups as depicted in Table 2.1

Table 2.1: Regional Classification of Nigerian fermented foods

Region	Typical Products	Ethnic Group(s)	Primary Ingredients
North	Fura da Nunu, Kunun-zaki, Kindirmo	Fulani, Hausa	Millet, Dairy
South-West	Iru, Ogi, Garri, Lafun	Yoruba	Cassava, Locust beans, Maize
South-East	Ugba, Akamu, Abacha	Igbo	Oil bean seeds, Cassava
South-South	Ukodo, Fermented Fish Pastes	Ijaw, Urhobo, Itsekiri	Yam, Fish
Central Nigeria	Okpehe, Burukutu, Garri	Tiv, Nupe, Idoma, Gwari	Sorghum, Cassava, Legumes

Sources: ^{13, 29}.

Table 2.2: Fermentation stages of Nigerian fermented foods

Fermentation Stage	Dominant Microorganisms	Functional Role
Early Stage	<i>Enterobacteriaceae</i> , Coliforms	Initiate carbohydrate hydrolysis and pH reduction
Mid Stage	<i>Lactobacillus spp.</i> , <i>Leuconostoc spp.</i>	Acidify environment, inhibit spoilage/pathogenic organisms
Late Stage	<i>Saccharomyces spp.</i> , <i>Candida spp.</i>	Contribute flavour, ethanol, and vitamin production
Alkaline Fermentation	<i>Bacillus subtilis</i> , <i>B. licheniformis</i>	Proteolysis, release of amino acids, elevation of pH

Sources: ²⁵

These stages are influenced by substrate type, fermentation time, temperature, and local environmental microbiota ^{36, 37}.

B. Key Microbial Taxa in Common Fermented Foods

Several core microorganisms have been repeatedly identified in Nigerian fermented foods:

- Lactic Acid Bacteria (LAB):
 - Common in cereal and tuber fermentations such as *Ogi*, *Fufu*, and *Garri*
 - Key species: *Lactobacillus plantarum*, *L. fermentum*, *Leuconostoc mesenteroides*, *Pediococcus pentosaceus*
 - Functions: Acidification, pathogen inhibition, exopolysaccharide and vitamin synthesis ¹⁶.
- Yeasts:
 - Found in beverages (e.g., *Kunun-zaki*, *Pito*) and late-stage fermentations
 - Dominant species: *Saccharomyces cerevisiae*, *Candida tropicalis*
 - Functions: Flavour and aroma production, alcohol formation, B-vitamin enrichment ³³.
- Bacillus spp.:
 - Dominant in alkaline fermentations such as *Iru*, *Ugba*, and *Okpehe*
 - Species: *B. subtilis*, *B. licheniformis*, *B. pumilus*

- Functions: Proteolysis, ammonia production, umami development ²⁵.
- Enterococcus and Streptococcus spp.:
 - Especially prominent in milk fermentations like *Nunu* and *Kindirmo*
 - Provide acidification, antimicrobial peptide production, and probiotic potential ¹⁴,

18.

C. Environmental and technological factors shaping microbial ecology

The microbial diversity in Nigerian fermentations is strongly influenced by several ecological and technological variables as summarized in Table 2.3. Backslopping, in particular, has been shown to encourage consistency in microbial communities and product quality, even in uncontrolled fermentation systems ¹³.

D. Metagenomics and microbiome profiling

Recent advances in metagenomic sequencing and microbial ecology have facilitated the identification of microorganisms that are not culturable using traditional methods. Studies have revealed complex microbiomes in fermented products, including rare and functionally significant strains:

- *Weissella confusa* and *Lactobacillus brevis* have been identified in *Ogi* and *Garri*
- *Pediococcus pentosaceus*, isolated from *Kunun-zaki*, demonstrates strong acid tolerance and bacteriocin production
- Fungal diversity in Pito and Palm wine includes *Hanseniaspora* and *Candida* species, which influence ethanol and ester content

These findings open up new avenues for starter culture development, functional food formulation, and probiotic research in indigenous Nigerian diets.

Table 2.3: Ecological and technological factors influencing Nigerian fermented food

Factor	Impact on Microbial Ecology
pH	Low pH favours LAB; high pH supports <i>Bacillus</i> spp.
Temperature	Tropical temperatures accelerate microbial metabolism and fermentation rate
Water Activity	Influences microbial access to nutrients and enzymatic activity
Oxygen Levels	Aerobic/anaerobic environments select for specific microbial consortia
Backslopping	Reuse of previous batch inoculum stabilizes and enhances microbial succession

Source:¹³

E. Safety Considerations

While most indigenous fermentations result in microbiologically safe products due to acidification and microbial competition, risks still exist in uncontrolled environments:

- Potential contamination by coliforms or mycotoxin-producing molds
- Variability in fermentation duration may lead to inconsistent pH and spoilage risk

Standardization of starter cultures and improved hygienic practices are recommended for enhancing microbial safety without disrupting traditional processes ¹⁷.

The microbial communities in Nigerian fermented foods are complex, adaptive, and shaped by centuries of empirical knowledge and environmental interaction.

2.6 Traditional Fermentation Techniques in Nigeria

Traditional fermentation in Nigeria is largely artisanal, spontaneous, and household-based, driven by centuries of indigenous knowledge and environmental adaptation. Local fermentation vessels are not passive tools; they are active microbial incubators ⁷. These methods are typically low-cost, low-tech, and rely on native microbial consortia that thrive in local ecological niches. Despite lacking formal controls over parameters like temperature, pH, and inoculum density, these processes remain highly effective at delivering safe, nutritious, and culturally significant fermented foods. The techniques used vary by food type, geographic region, and intended function, but they share core principles of microbial transformation, detoxification, and

preservation. These tools influence moisture, oxygen availability, and microbial colonization patterns; these methods foster stable microbial consortia that enhance safety and flavour development ^{7, 13}. Traditional fermentation techniques include:

A. Steeping and soaking

This technique is central to cereal and cassava fermentations. In the preparation of *Ogi*, grains (maize, millet, or sorghum) are soaked for 24–72 hours in water, allowing indigenous lactic acid bacteria (LAB) and yeasts to initiate acidification. After soaking, the grains are wet-milled, sieved, and left to ferment into a smooth, sour paste ¹⁶. For cassava-based products such as *Fufu* and *Lafun*, peeled tubers are submerged in water for several days to allow for lactic acid fermentation. This helps to reduce cyanogenic compounds and soften the tissue, facilitating mash formation. ²⁴.

Steeping under ambient conditions supports spontaneous microbial colonization, particularly by acidophilic bacteria like *Lactobacillus fermentum* and *Leuconostoc mesenteroides* ³⁶.

B. Roasting and Dewatering

Roasting is a crucial post-fermentation step in *Garri* production. After cassava is grated and fermented for 2–3 days, the mash is mechanically dewatered using a press and then roasted on a hot griddle. This high-temperature treatment not only reduces moisture but also halts microbial activity and improves shelf stability. Roasting caramelizes sugars, enhancing flavour and colour, while simultaneously eliminating residual pathogens ²⁴.

C. Pounding and wrapping in leaves

In legume fermentations like *Iru* and *Okpehe*, *Parkia biglobosa* or *Prosopis africana* seeds are first boiled for several hours, then dehulled, and manually pounded. The mashed seeds are left to ferment in banana leaves, raffia baskets, or earthenware pots, typically in warm, shaded areas. The alkaline environment supports growth of proteolytic *Bacillus* species, such as *B. subtilis* and *B. licheniformis*, which break down complex proteins into amino acids and peptides²⁵. These leaf- or container-based incubations not only aid microbial succession but are also believed by communities to imbue the food with ancestral essence or "blessing"³².

D. Leaf and clay pot fermentation

Traditional tools clay pots, calabashes, and plant leaves are often used as fermentation vessels. Their porous surfaces create ideal micro environments for microbial adherence and oxygen diffusion. In the Fulani tradition, *Nunu* and *Kindirmo* are fermented in gourds or clay containers that foster natural thermoregulation and acid development. Among the Yoruba, *Ogi* fermentation often occurs in covered earthen pots placed in warm corners of the kitchen, away from direct sunlight. These vessels support robust spontaneous fermentation by allowing natural inoculation while also maintaining a humid, warm atmosphere favorable to LAB and yeasts³⁶.

E. Back-slopping

Back-slopping: the practice of using a portion of a previously fermented batch to inoculate a new one is common across Nigeria. This technique is particularly applied in *Ogi* and *Kunun-zaki* preparation. Back-slopping introduces starter-like cultures, stabilizes microbial communities, reduces lag time, and improves flavour and texture consistency. Although not standardized, this practice reflects empirical microbial management and is now recognized as a proto-industrial method of maintaining microbial dominance in fermentation¹³.

F. Sun-drying and smoking (Adjunct techniques)

To prolong shelf life and enhance flavour, fermented foods are sometimes sun-dried (e.g., Lafun, Ugba) or smoked (e.g., fermented fish pastes in the South-South region).

These techniques include:

- Reduce water activity
- Inhibit post-fermentation spoilage
- Enhance aromatic compounds and texture

In high-humidity regions like the Niger Delta, these adjunct methods are vital for microbial safety and are part of the cultural fermentation continuum ³⁷.

Traditional fermentation techniques in Nigeria are ecologically sustainable, culturally embedded, and scientifically relevant. They demonstrate a sophisticated interplay between microbial ecology, environmental adaptation, and indigenous knowledge. While lacking precision instrumentation, these methods consistently produce safe and functional foods, highlighting the value of artisanal biotechnology in modern food systems.

Preserving and optimizing these techniques, through hygienic interventions and selective starter development, can help elevate them for commercial, nutritional, and global culinary applications.

2.7 Microbial Succession and Functional Roles

Microbial succession in traditional Nigerian fermented foods refers to the temporal shift in microbial communities throughout the fermentation process ⁴⁷. As substrates are transformed, different microorganisms emerge at various stages, each contributing uniquely to the chemical and sensory profile of the food. This ecological progression is influenced by factors such as substrate type, temperature, water activity, and pH. Understanding this succession is essential for improving product safety, consistency, and functionality ³³. The microbial succession and functional roles include:

A. Ecological stages of fermentation

Fermentation processes in Nigerian traditional foods typically progress through three main stages, with a fourth category for alkaline fermentations. Table 2.4 shows the ecological stages of fermentation with their functional roles

Table 2.4: Ecological stages of fermentation with their functional roles

Stage	Dominant Microorganisms	Functional Role
Early Stage	<i>Enterobacteriaceae</i> , coliforms	Initiate hydrolysis of carbohydrates and proteins; begin acidification
Mid Stage	<i>Lactobacillus spp.</i> , <i>Leuconostoc spp.</i>	Produce lactic acid and bacteriocins; lower pH to suppress pathogens.
Late Stage	<i>Saccharomyces cerevisiae</i> , <i>Candida spp.</i>	Produce ethanol, organic acids, vitamins, and aroma compounds.
Alkaline Systems	<i>Bacillus subtilis</i> , <i>B. licheniformis</i>	Degrade proteins into peptides and amino acids; raise pH; create umami flavours.

Source:³⁵

This microbial succession ensures both biochemical transformation and microbial safety, often without external intervention ³⁷.

B. Functional contributions of microbial groups

1. Lactic acid bacteria (LAB): common species such as *Lactobacillus plantarum*, *L. fermentum*, *Leuconostoc mesenteroides*. The Functions include:

- Acidify the substrate, creating an inhospitable environment for pathogens
- Produce antimicrobial substances (e.g., bacteriocins)
- Improve texture and digestibility
- Contribute to vitamin synthesis (e.g., B2, B12) ¹⁶.

These can be found in: *Ogi*, *Fufu*, *Garri*, *Kunun-zaki*

2. Yeasts: common species such as *Saccharomyces cerevisiae*, *Candida tropicalis*, *Hanseniaspora spp.* The functions include:

- Flavour and aroma development through volatile compounds (e.g., esters)
- Ethanol and CO₂ production (in *Pito*, *Palm wine*)
- Enhance vitamin content (B-complex group)

These can be found in: *Pito*, *Kunun-zaki*, *Palm wine*, *Ogi* (late stage)

3. *Bacillus* spp: common species such as *B. subtilis*, *B. licheniformis*, *B. pumilus*. The Functions include:

- Proteolysis of legume proteins into amino acids (e.g., glutamate)
- Generation of ammonia, raising pH for alkaline fermentation
- Creation of bioactive peptides with antioxidant and antihypertensive properties ²⁵.

They are found in *Iru*, *Ugba*, *Okpehe*

4. Enterobacteriaceae (Transitional/Initial Colonizers): These facultative anaerobes often dominate the initial fermentation stages before being outcompeted by LAB. They help in the early hydrolysis of starches but may pose safety concerns if fermentation is not properly controlled ¹⁷.

C. Mechanisms of microbial interactions

The interactions between microbial species in Nigerian fermented foods can be synergistic or antagonistic, shaping succession and final product quality ²³. LAB inhibit spoilage organisms by lowering pH through lactic acid production and producing antimicrobial peptides (bacteriocins) while yeasts often collaborate with LAB. Yeasts produce vitamins and amino acids that stimulate LAB growth. LAB create low-oxygen conditions favourable for fermentative yeasts.

These cooperative relationships are especially evident in mixed-substrate fermentations like *Fura da Nunu* and *Kunun-zaki*, where LAB-yeast symbiosis enhances both taste and microbial stability ¹⁶.

D. Successional case studies: This includes the following:

Ogi (Fermented cereal porridge)

- Early stage: *Enterobacteriaceae* initiate starch degradation
- Mid stage: LAB dominate, reducing pH and forming characteristic sourness

- Late stage: Yeasts emerge, adding aroma and aiding in vitamin production

Iru (Fermented locust beans)

- Alkaline process with minimal acidification
- Dominated by *Bacillus subtilis* and *B. licheniformis*
- High protein degradation leads to ammonia release and intense umami profile

E. Practical implications of succession

- Safety: LAB-driven acidification creates a protective pH barrier against foodborne pathogens such as *Salmonella* and *Clostridium*.
- Flavour and aroma: Microbial succession enhances sensory appeal through organic acids, alcohols, and volatile esters.
- Nutritional quality: Certain microbes increase bioavailability of micronutrients and generate bioactive compounds.
- Starter culture potential: Strains like *Pediococcus pentosaceus* from *Kunun-zaki* show promise for controlled fermentation due to their acid tolerance and antimicrobial properties ²⁵.

Microbial succession in Nigerian fermented foods is a complex, yet elegant system of ecological transitions that supports food safety, sensory quality, and nutritional enhancement. By understanding these dynamics, researchers and producers can develop optimized fermentation protocols, standardized starter cultures, and improved food products that respect tradition while enhancing quality.

2.8 Biochemical Pathways in Nigerian Fermented Foods

The biochemical pathways involved in Nigerian fermented foods reflect the metabolic activities of their native microbial populations ³⁴. These transformations are responsible for the

detoxification, preservation, enhanced digestibility, and improved sensory and nutritional qualities of the final products. Two dominant fermentation types exist across the Nigerian foodscape: lactic acid fermentation and alkaline fermentation.

A. Lactic acid fermentation pathways

Lactic acid fermentation is the most widespread fermentation route in Nigeria. It occurs primarily in cereal-, cassava-, and milk-based fermentations and is driven by lactic acid bacteria (LAB), such as *Lactobacillus plantarum*, *L. fermentum*, and *Leuconostoc mesenteroides*.

Pathway:

- Substrate: Carbohydrates (glucose, maltose, lactose)
- Enzymatic Route:
 - Glucose → Pyruvate (via glycolysis)
 - Pyruvate → Lactic acid (via lactate dehydrogenase)
- End Products: Lactic acid, CO₂, ethanol (heterofermentative pathways), bacteriocins, and B-vitamins

Functional impact:

- Acidification: Rapid drop in pH inhibits spoilage and pathogenic organisms
- Flavour: Production of organic acids and aromatic aldehydes
- Preservation: Extended shelf life due to low pH and antimicrobial peptides
- Nutritional Enhancement: Degradation of antinutrients (e.g., phytic acid) and increase in bioavailable minerals

Typical foods include *Ogi*, *Fufu*, *Garri*, *Kunun-zaki*, *Nunu*. In *Ogi*, LAB convert starches to lactic acid, creating the characteristic sour flavour while improving protein digestibility. In *Fufu* and *Garri*, LAB help eliminate cyanogenic glucosides in cassava, detoxifying the product for safe consumption ^{17, 24}.

B. Alkaline fermentation pathways

Alkaline fermentation dominates legume-based foods such as *Iru*, *Ugba*, and *Okpehe*. This process is driven by proteolytic *Bacillus* species, particularly *B. subtilis* and *B. licheniformis*, which break down complex proteins into peptides and amino acids.

Pathway:

- Substrate: Polypeptides (from plant protein)
- Enzymatic route:
 - Proteins → Peptides → Free amino acids + Ammonia
- End Products: Glutamic acid, peptides, amines, ammonia, volatile sulfur compounds

Functional impact:

- pH elevation: In contrast to acidification, ammonia release raises the pH (>8.0), preventing spoilage by acidophilic organisms
- Umami development: Breakdown of proteins releases glutamate and peptides, enhancing savory taste
- Health bio-actives: Generation of antioxidant and antihypertensive peptides ^{32,25}.

Typical foods include *Iru*, *Ugba*, *Okpehe*. In *Iru*, enzymatic breakdown of locust bean proteins results in the intense aroma and umami flavour highly prized in Yoruba cooking. The high pH environment favors *Bacillus* growth, which competes effectively against spoilage microbes ⁴⁷.

C. Mixed and secondary pathways

Some fermented foods, especially beverages and dairy products, undergo mixed fermentation involving both LAB and yeasts:

- *Kunun-zaki* and *Pito* exhibit simultaneous lactic and alcoholic fermentation, yielding lactic acid, ethanol, CO₂, and esters.
- *Fura da Nunu*, a blend of fermented millet and milk, showcases both lactic acid and proteolytic activity, improving both flavour and nutritional profile.

These combinations yield:

- Enhanced organoleptic properties (taste, aroma, texture)
- Alcohol (in *Pito*) or effervescence (in *Kunun-zaki*)
- Metabolites such as exopolysaccharides (EPS) that may improve gut health

D. Detoxification pathways

Fermentation also serves as a detoxification mechanism, especially in cassava and legumes:

- Cassava cyanide reduction: Enzymatic action and acidification degrade cyanogenic glucosides (*linamarin* and *lotaustralin*) into non-toxic forms. Proper fermentation can reduce hydrogen cyanide (HCN) levels by >90% ²⁴.
- Phytate degradation: LAB and yeast phytases break down phytate in cereals and legumes, improving mineral absorption (iron, zinc, calcium).
- Tannin and oxalate reduction: In legume fermentations, fermentation lowers tannin levels, reducing astringency and improving protein digestibility ¹⁷.
- E. Bioactive compound formation

The biochemical processes of fermentation generate functional metabolites with health benefits:

- Short-chain fatty acids (SCFAs) – from carbohydrate metabolism; beneficial to gut microbiota

- Antioxidant peptides – from protein hydrolysis in *Iru* and *Ugba*
- Exopolysaccharides (EPS) – enhance viscosity and immune-modulating effects
- Bacteriocins – suppress foodborne pathogens

Selected LAB strains isolated from Nigerian fermented foods have demonstrated antimicrobial activity against *E. coli*, *S. aureus*, and *Salmonella spp* ³⁷.

The biochemical pathways operating in Nigerian fermented foods are integral to their safety, flavour, preservation, and nutritional value. While predominantly rooted in lactic acid and alkaline fermentation, many products exhibit complex interactions of microbial metabolism that yield functionally enriched foods.

2.9 Environmental and Technological Factors in Fermentation

Traditional Nigerian fermentations are highly dependent on natural environmental conditions and localized techniques, which, although artisanal, are remarkably effective in producing safe, nutritious, and flavourful foods. However, the rate, quality, and outcome of these fermentations are significantly shaped by a set of critical variables. These include pH, temperature, oxygen availability, moisture content, fermentation vessels, and process duration each influencing microbial succession, enzymatic activity, and product safety.

A. pH: A selective and protective barrier: The progression and safety of most Nigerian fermented foods are governed by pH changes. Lactic acid fermentation (in *Ogi*, *Garri*, *Kunun-zaki*) results in progressive acidification, dropping the pH below 4.0 within 48–72 hours. This pH decline inhibits pathogens such as *Clostridium botulinum*, *Salmonella spp.*, and *E. coli* ¹⁷. In contrast, alkaline fermentation (e.g., *Iru*, *Ugba*) sees a pH increase to above 8.0, as a result of ammonia and peptide formation by *Bacillus subtilis*. This elevated pH environment is selective for proteolytic bacteria and suppresses acid-tolerant microbes ²⁵. Monitoring pH is therefore central

to ensuring safe and consistent fermentation outcomes. Indigenous processors often assess sourness or pungency by taste and smell, which correlates with acid or base progression.

B. Temperature: Catalysing microbial and enzymatic activity. Nigerian fermentation practices occur predominantly in tropical ambient temperatures, ranging from 28°C to 35°C, which is favourable for rapid microbial growth. LAB strains such as *L. fermentum* thrive best between 30°C and 37°C. *Bacillus* spp. in legume fermentations is thermotolerant and benefit from warm incubation spaces (e.g., banana leaves or raffia-wrapped bundles). Excessively high temperatures (>40°C), however, may kill desirable microbes or encourage unwanted spoilage organisms. Studies recommend shade fermentation or indoor ambient control to minimize diurnal temperature spikes that could affect microbial balance ³⁷.

C. Oxygen availability: anaerobic vs. aerobic fermentations

The availability of oxygen determines the dominant metabolic pathways and types of microbes that can thrive:

- Anaerobic conditions (used in *Fufu*, *Ogi*) favor homolactic acid fermentation, producing lactic acid as the main end-product.
- Semi-aerobic environments, such as in *Kunun-zaki* or *Palm wine*, allow coexistence of LAB and yeasts, promoting both acid and ethanol production.
- Aerobic conditions are essential for alkaline fermentations, where *Bacillus subtilis* requires oxygen for protein hydrolysis and ammonia formation.

Traditional fermentation vessels like open calabashes, clay pots, and raffia baskets support the necessary oxygen exposure for microbial activity without external aeration ³².

D. Moisture and water activity

Water content influences nutrient diffusion, enzyme function, and microbial viability:

- High-moisture fermentations (e.g., *Ogi*, *Fufu*, *Nunu*) promote LAB proliferation and metabolite solubility.
- Dewatering steps in *Garri* and *Okpehe* help prevent post-fermentation spoilage and prolong shelf life.
- Sun-drying and roasting are traditional interventions that lower water activity, reduce spoilage risks, and improve texture and aroma ²⁴.

Managing moisture through pressing, sieving, or sun exposure is an integral part of the indigenous fermentation protocol.

E. Fermentation time and process duration

Duration influences both product safety and flavour development. Insufficient fermentation time can result in toxic residues (e.g., linamarin in cassava), while over-fermentation may lead to over-acidification or spoilage. Local processors rely on sensorial cues (bubbles, sour smell, texture) rather than precise timers, though modernization efforts suggest the value of integrating basic timing tools ¹³. The fermentation time of some Nigeria fermented food is illustrated in Table 2.5

F. Fermentation Vessels and Materials

The choice of containers can influence fermentation dynamics:

- Clay pots and calabashes are porous, allowing gas exchange and thermal insulation.
- Plastic buckets are common in urban settings, though less effective at buffering temperature changes.
- Banana leaves, raffia baskets, and jute sacks are used for wrapping *Ugba* and *Iru*, creating microenvironments that encourage specific *Bacillus* spp.

Table 2.5: Fermentation time of some Nigeria fermented food

Product	Fermentation Time (Typical)	Key Changes
<i>Ogi</i>	2–3 days	pH reduction, starch hydrolysis
<i>Fufu</i>	3–5 days	Cyanide removal, softening
<i>Iru</i>	2–4 days	Protein degradation, ammonia accumulation
<i>Kunun-zaki</i>	12–24 hours	Mild acidification, flavour enhancement

Source:³⁵

The vessel material can act as a microbial reservoir, carrying inoculants from one batch to another a traditional precursor to starter culture stabilization ¹⁶. Environmental and technological factors critically influence the efficiency, safety, and sensory outcome of Nigerian fermented foods. While traditional fermenters expertly navigate these variables using sensory cues and indigenous knowledge, integrating simple monitoring tools (pH meters, thermometers) and hygiene interventions could enhance process control and reduce contamination risks ^{30, 35}.

2.10 Nutritional Changes during Fermentation

Fermentation induces profound nutritional transformations in traditional Nigerian foods, improving their safety, digestibility, and micronutrient profile. These changes occur through microbial enzymatic activities, which alter macronutrients and degrade anti-nutritional factors inherent in many staple crops like cassava, cereals, and legumes. Fermentation thus serves not just a preservative or flavour-enhancing function, but a powerful bio-transformation process that upgrades the nutritional quality of food substrates. These changes include:

A. Macronutrient modifications

1. Carbohydrates: During fermentation, starches and sugars are hydrolyzed by microbial enzymes (e.g., amylases and glucosidases) into simpler sugars, which are then partially consumed by microbes for energy. This leads to reduction in total carbohydrate content, lower glycemic index, especially in fermented cassava products like *Fufu* and *Garri*. Increased sugar availability in beverages like *Kunun-zaki*, enhancing palatability

2. Proteins: In legume-based fermentations (e.g. *Iru*, *Ugba*), proteases from *Bacillus subtilis* hydrolyze proteins into peptides and amino acids, improving protein digestibility, amino acid availability, notably lysine and methionine, bioactivity (e.g., antioxidant and antihypertensive effects of fermented peptides). In cereal-based products like *Ogi*, fermentation modestly increases crude protein due to microbial biomass accumulation ³².

3. Lipids: While lipids are less transformed directly, fermentation reduces lipid oxidation through lowered pH and antioxidant compound production, especially in legume-based foods. Microbial metabolism also results in the production of free fatty acids and minor lipid-soluble vitamins (e.g., vitamin K₂ in *Ugba*) ¹⁷.

B. Micronutrient enhancement

1. Vitamin biosynthesis: LAB and yeasts in fermented foods can synthesize water-soluble vitamins such as Riboflavin (B₂), Niacin (B₃), Folate (B₉) and Cobalamin (B₁₂) in trace amounts. These vitamins are especially enhanced in *Ogi*, *Kunun-zaki*, and *Pito* due to mixed fermentation by LAB and yeasts ³⁷.

2. Mineral bioavailability: Fermentation degrades anti-nutritional factors that bind minerals, such as phytate in cereals and legumes, tannins in legumes, and oxalates in tubers. This enhances absorption of iron, zinc, calcium, and magnesium. Fermentation of maize reduced phytic acid by up to 70%, significantly improving iron bioavailability in *Ogi* ¹⁷.

C. Detoxification and safety improvements

Many staple crops in Nigeria, such as cassava and some legumes, contain natural toxins that are significantly reduced or eliminated by fermentation.

1. Cyanide in cassava

Raw cassava contains cyanogenic glycosides (e.g., linamarin), which are hydrolyzed and volatilized during lactic acid fermentation. Well-fermented *Fufu* and *Garri* contain <10 mg HCN/kg, meeting WHO safety standards ²⁴.

2. Mycotoxin degradation

Certain LAB have been found to bind or degrade aflatoxins and fumonisins in maize, millet, and sorghum products, reducing the toxic load in *Kunun-zaki* and *Ogi* ²⁵.

E. Nutritional implications for public health

The nutritional benefits of fermentation have important implications for:

- Child and maternal nutrition (especially with *Ogi*, *Nunu*)
- Protein-energy malnutrition reduction (via *Iru*, *Ugba*)
- Micronutrient deficiency mitigation, especially iron and zinc
- Functional food development targeting non-communicable diseases (e.g., hypertension)

Given Nigeria's triple burden of malnutrition undernutrition, micronutrient deficiencies, and rising diet-related NCDs promoting fermented foods represents a cost-effective and culturally appropriate intervention ¹⁵. Daily consumption of *Ogi* or *Nunu* with active LAB strains can reduce LDL cholesterol and systemic inflammation markers ³⁵.

Fermentation significantly enhances the nutritional profile of Nigerian staple foods through macronutrient conversion, micronutrient biosynthesis, and toxin degradation. These transformations underscore fermentation's dual role as a culinary tradition and public health strategy. Scientific validation of these benefits reinforces the importance of preserving and optimizing fermentation practices across Nigeria's diverse communities.

2.11 Functional Bio-actives in Fermented Nigerian Foods

Beyond basic nutrition, Nigerian fermented foods are increasingly recognized for their functional bioactive compounds metabolites that provide physiological benefits beyond energy or macronutrient supply. These compounds are byproducts of microbial metabolism during fermentation and may exhibit antioxidant, antimicrobial, antihypertensive, anti-inflammatory, or probiotic properties. The study of these bio-actives positions fermented foods as potential contributors to functional food development and disease prevention in sub-Saharan Africa.

A. Antioxidant peptides and polyphenols

During the proteolytic fermentation of legumes (e.g., *Iru*, *Ugba*), microbial enzymes degrade plant proteins into short-chain peptides with free radical scavenging properties.

- *Bacillus subtilis* and *B. licheniformis* produce bioactive peptides enriched in hydrophobic amino acids (e.g., leucine, tyrosine), which stabilize cellular membranes against oxidative stress.
- Peptides isolated from fermented locust beans exhibited >70% DPPH radical scavenging activity in vitro ²⁵.

Furthermore, microbial activity during fermentation reduces polyphenol–protein binding, releasing free polyphenols with enhanced antioxidant potential, especially in fermented sorghum and millet drinks like *Kunun-zaki* and *Pito* ¹⁷.

B. Antimicrobial compounds

LAB (e.g., *Lactobacillus plantarum*, *L. fermentum*) produce several antimicrobial metabolites during cereal, dairy, and tuber fermentation, such as:

- Lactic acid – lowers pH, inhibiting *Salmonella*, *E. coli*, and *Listeria monocytogenes*
- Bacteriocins – ribosomally synthesized peptides with bactericidal activity

- Hydrogen peroxide and diacetyl – oxidative and flavour-active agents with antimicrobial roles

Bacteriocin-like substances from *L. fermentum* isolated in *Ogi* significantly suppressed *Staphylococcus aureus* and *Shigella spp.* in laboratory tests ⁴⁷. These antimicrobial compounds not only extend shelf life but also reduce the need for synthetic preservatives, making fermented foods safer for consumers, especially in rural areas with limited refrigeration.

C. Antihypertensive and anti-diabetic potentials

Fermented legume products like *Iru* and *Ugba* contain ACE-inhibitory peptides bioactive capable of modulating blood pressure. These peptides, generated through protein hydrolysis, inhibit angiotensin-converting enzyme (ACE), which regulates vasoconstriction. Regular intake of such fermented foods may aid in blood pressure control in populations prone to hypertension ³².

In addition, studies suggest that lactic acid fermentation in *Ogi* and *Garri* leads to reduced glycaemic response and improved insulin sensitivity, highlighting potential antidiabetic effects ¹⁵.

D. Exopolysaccharides (EPS) and prebiotics

LAB and yeasts in Nigerian fermented foods synthesize exopolysaccharides (EPS)—long-chain carbohydrates that support gut health. EPS produced by *L. plantarum* and *Weissella spp.* in *Ogi* and *Kunun-zaki* act as prebiotics, promoting the growth of beneficial gut bacteria (e.g., *Bifidobacteria*). These polymers also improve texture and water-holding capacity in fermented foods. EPS may also have immune-modulating and cholesterol-lowering effects, positioning these foods as functional components in managing chronic metabolic conditions ¹⁶.

E. Probiotic viability

Although traditional Nigerian fermented foods are not produced under sterile or standardized probiotic conditions, several contain live beneficial microbes that survive gastrointestinal transit: *L. fermentum*, *L. plantarum*, *S. cerevisiae*, and *Pediococcus pentosaceus* have been isolated from *Nunu*, *Ogi*, and *Kunun-zaki*. These strains exhibit bile and acid resistance, adhesion to gut epithelial cells and competitive inhibition against pathogens. *Nunu* from Northern Nigeria retains viable LAB at $>10^7$ CFU/mL after 3 days of storage meeting the functional threshold for probiotic labelling ¹⁴.

F. Anti-inflammatory and detoxifying agents

Fermentation also results in the generation of compounds that modulate inflammation and aid detoxification. Degradation of cyanogenic glycosides in cassava reduces oxidative stress and neurotoxicity, anti-inflammatory peptides and phenolics are enhanced in fermented cowpea and oil bean seeds and some LAB strains have been shown to suppress pro-inflammatory cytokines in in-vitro models ³⁸. These findings suggest that fermented Nigerian foods may serve as nutritional adjuncts in managing inflammatory bowel conditions and chronic toxicity.

Traditional Nigerian fermented foods are rich sources of functional bio-actives with promising health-promoting potentials. Through spontaneous, low-tech methods, indigenous communities have harnessed microbial metabolism to produce compounds that rival those in commercial nutraceuticals ³⁸.

2.12 Health and Therapeutic Potentials of Nigerian Fermented Foods

Traditional Nigerian fermented foods, long valued for their nutritional and cultural roles, are increasingly recognized for their therapeutic and preventive health benefits. Driven by spontaneous fermentation using indigenous microbiota, these foods harbour bioactive compounds and live microorganisms that offer protection against infectious diseases, metabolic

disorders, and micronutrient deficiencies. As the burden of non-communicable diseases and antimicrobial resistance grows across Africa, Nigerian fermented foods present low-cost, culturally acceptable interventions with immense public health potential.

A. Gastrointestinal health and gut microbiome modulation

Many fermented Nigerian foods contain lactic acid bacteria (LAB) and yeasts with probiotic potential. Species such as *Lactobacillus plantarum*, *L. fermentum*, and *Pediococcus pentosaceus* isolated from *Ogi*, *Nunu*, and *Kunun-zaki* have demonstrated acid and bile tolerance, adherence to intestinal epithelial cells, and antagonism against enteric pathogens. These organisms support gut colonization, improve digestion, and reduce symptoms of diarrhea, constipation, and bloating¹⁶.

Additionally, fermentation enhances the prebiotic content of foods by promoting the formation of exopolysaccharides (EPS) and fermentable dietary fibres, further stimulating beneficial gut flora³⁷.

B. Anti-microbial and food-safety applications

LAB in Nigerian fermented foods produce bacteriocins, organic acids, and hydrogen peroxide, which inhibit pathogens like *E. coli*, *Salmonella spp*, *Listeria monocytogenes*, and *Staphylococcus aureus*. These antimicrobial metabolites reduce the need for artificial preservatives and contribute to food safety, especially in regions without refrigeration. Bacteriocin-producing *L. fermentum* strains from *Ogi* with broad-spectrum antimicrobial activity¹⁵. Moreover, the acidification and pH reduction in foods like *Fufu* and *Kunun-zaki* prevent pathogen proliferation and mycotoxin production, further improving microbial safety¹⁷.

C. Micronutrient bioavailability and deficiency prevention

Fermentation increases the bioavailability of iron, zinc, and calcium by breaking down. Phytate (found in cereals and legumes) and tannins and oxalates (in legumes and tubers). This makes fermented foods such as *Ogi*, *Garri*, and *Ugba* particularly valuable in combating iron deficiency anaemia and zinc-related immune dysfunction. Fermentation reduced phytic acid by >60% in maize, significantly increasing mineral absorption ¹⁷. Additionally, LAB can biosynthesize B-complex vitamins, especially folate, niacin, and riboflavin, enhancing their role in maternal and child nutrition ³⁹.

D. Cardiovascular health and hypertension management

Fermented legume foods such as *Iru* and *Ugba* contain ACE-inhibitory peptides short protein fragments that block the angiotensin-converting enzyme involved in blood pressure regulation. These peptides relax blood vessels and reduce hypertension, acting similarly to synthetic ACE-inhibitor drugs. Antihypertensive activity in peptides extracted from fermented *Parkia biglobosa* seeds ²⁵. Further, probiotic strains isolated from fermented dairy (*Nunu*) have shown potential in cholesterol modulation, suggesting an additional role in cardiovascular risk reduction ¹⁴.

E. Antioxidant and anti-inflammatory effects

Bioactive compounds in fermented Nigerian foods include phenolic compounds, free amino acids, and bioactive peptides with antioxidant properties. These compounds scavenge free radicals, reduce oxidative stress, and help prevent chronic diseases such as cancer, atherosclerosis, and neurodegeneration. *Bacillus*-fermented products like *Ugba* and *Okpehe* have been shown to possess anti-inflammatory effects by downregulating pro-inflammatory cytokines in vitro ⁴⁰.

F. Applications in infant and geriatric nutrition

Fermented foods like *Ogi* and *Nunu* are essential in weaning programs and elderly care due to their soft texture, easy digestibility, and enriched micronutrient content. In infants, *Ogi* is often fortified with milk or legumes to address protein-energy malnutrition. For the elderly, fermented products are beneficial in managing gut motility, appetite loss, and nutrient absorption issues ¹⁵.

These functional roles make fermented foods ideal candidates for community-based nutrition interventions. The health and therapeutic potentials of Nigerian fermented foods extend well beyond nourishment they include gut modulation, antimicrobial defence, micronutrient enhancement, and cardio metabolic protection. Their accessibility, cultural acceptance, and proven safety make them promising vehicles for health promotion and disease prevention, especially in underserved rural populations.

2.13 Challenges and Future Perspectives in the Study of Nigerian Fermented Foods

Despite their cultural significance and expanding scientific recognition, Nigerian fermented foods face several technological, regulatory, socio-cultural, and research-related challenges that hinder their optimal utilization ⁴¹. These challenges present both obstacles and opportunities for harnessing the full potential of traditional fermentation within modern food systems, public health, and economic development ⁴². The challenges include:

1. Lack of Standardization

Traditional Nigerian fermentation is largely spontaneous and artisanal, leading to:

- Inconsistencies in microbial composition, taste, texture, and safety
- Variable fermentation times and product quality
- Difficulty scaling up or regulating production without compromising traditional integrity

Most fermenters rely on sensory indicators rather than measurable parameters (pH, temperature, microbial load), which impedes scientific validation and industrial application ¹³.

2. Microbial safety and contamination risks

Although fermentation generally enhances microbial safety, poor hygienic practices during production, storage, and packaging can result in post-fermentation contamination by pathogens (e.g., *Salmonella*, *E. coli*), mycotoxin exposure in cereals used for *Ogi* or *Kunun-zaki* and short shelf life due to lack of refrigeration and packaging innovation ²⁸.

3. Erosion of indigenous knowledge

Urbanization, western dietary influences, and generational gaps are causing a decline in the transmission of fermentation knowledge ⁴². Younger generations often lack interest or time to learn traditional methods, threatening the continuity of local fermentation practices ³².

4. Limited scientific research and funding: Despite increasing interest, Nigerian fermented foods remain understudied in molecular microbiology, nutritional metabolomics, functional food development and clinical trials assessing health benefits ⁴³. Most existing studies are descriptive or in vitro, with limited translational research bridging indigenous foods and modern health interventions ¹⁷.

Future Perspectives and Opportunities

1. Starter culture development

Isolating and characterizing indigenous microbial strains from traditional foods offers a path toward:

- Developing starter cultures that preserve traditional flavour while ensuring consistency and safety
- Reducing fermentation time and contamination risks

- Commercializing products without loss of authenticity ²⁵

Ongoing studies on *Lactobacillus plantarum* and *Bacillus subtilis* from *Ogi* and *Iru* have shown promise for controlled fermentation protocols ⁴⁴.

2. Functional food and nutraceutical innovation

With growing evidence of bioactive peptides, probiotics, and antioxidant metabolites, Nigerian fermented foods can serve as:

- Probiotic beverages (e.g., bottled *Nunu*, *Kunun-zaki*)
- Functional seasonings (e.g., dried *Iru* with preserved enzymes)
- Nutraceuticals targeting hypertension, anaemia, and gut health

Collaborations between local producers, nutritionists, and food technologists could help bridge tradition and science ¹⁵.

3. Documentation and digitization of indigenous knowledge

To prevent knowledge loss, there is an urgent need for:

- Ethnographic documentation of fermentation recipes, tools, and oral histories
- Digital archives (videos, apps, multilingual manuals) for educational use
- Community-led projects to revive and teach traditional fermentation in schools and cooperatives

These initiatives will preserve cultural food heritage while encouraging innovation ⁹.

4. Policy and regulatory support

There is a need for Regulatory frameworks tailored to small-scale fermented food enterprises

- Quality assurance protocols that respect traditional practices while ensuring food safety
- Grants and funding for research into indigenous fermentation and its commercialization potential ¹³

Policies that support women-led fermentation cooperatives the backbone of indigenous food processing will also have socioeconomic and nutritional impact ⁴⁵. The future of Nigerian fermented foods lies at the intersection of tradition, innovation, and public health. While challenges persist in standardization, safety, and knowledge retention, the potential for scalable, functional, and culturally resonant food solutions is immense ⁴⁶.

2.14 Summary of Literature Reviewed

The documented exploration of Nigerian fermented foods presents a richly detailed and interdisciplinary synthesis of historical, cultural, microbial, biochemical, nutritional, and therapeutic dimensions. Drawing from both indigenous knowledge systems and contemporary scientific inquiry, the review situates fermentation as a core pillar of Nigerian food heritage—an adaptive, resilient, and functionally significant practice interwoven with identity, ecology, and public health.

Historically, fermentation in Nigeria emerged from ecological necessity and evolved through intergenerational knowledge transfer, embedding itself within social hierarchies, gendered labour, and spiritual rituals. The classification of fermented foods by base ingredient cereals, tubers, legumes, and dairy underscores the diversity of substrates and the regional specificity of microbial ecologies across ethnic groups. From *Ogi* in the southwest to *Fura da Nunu* in the north, these foods reflect localized environmental adaptations and serve multifaceted roles beyond nutrition, including preservation, sensory satisfaction, infant and geriatric care, and ceremonial symbolism.

At the microbial level, the review elucidates complex successional dynamics involving lactic acid bacteria, yeasts, and *Bacillus* spp., each contributing distinctively to acidification, proteolysis, flavour development, and detoxification. Advances in metagenomics and microbial ecology affirm the sophistication of indigenous practices and offer potential for standardization without cultural dilution. Biochemically, fermentation enhances macronutrient bioavailability, synthesizes vital micronutrients, and suppresses anti-nutritional and toxic compounds, positioning these foods as low-cost vehicles for addressing malnutrition and food insecurity.

Perhaps most compellingly, the documentation articulates the health-promoting potentials of Nigerian fermented foods ranging from probiotic viability and ACE-inhibitory peptides to antioxidant and antimicrobial compounds with mounting evidence supporting their role in mitigating hypertension, gastrointestinal disorders, and micronutrient deficiencies. This therapeutic relevance aligns with emerging paradigms in global nutrition emphasizing functional, culturally appropriate, and sustainable food solutions.

Yet, challenges remain: lack of standardized production protocols, erosion of traditional knowledge, post-fermentation safety issues, and the underrepresentation of these food systems in national policy frameworks. Addressing these gaps through interdisciplinary research, participatory innovation, and policy support particularly with respect to women-led cooperatives and youth engagement can catalyse a renaissance in indigenous fermentation. Moreover, investing in starter culture development, hygienic modernization, and curriculum integration can unlock new pathways for economic empowerment and nutrition-sensitive development.

Nigerian fermented foods are not merely dietary artefacts they are living expressions of biocultural ingenuity, ecological sustainability, and community health. Their scientific

valorisation, cultural preservation, and policy mainstreaming offer profound opportunities to transform traditional food ways into pillars of future-ready African food systems.

Endnotes

1. A. Fawole & A. Kolapo, *Optimization of cassava fermentation for food security in 21st-century Africa* (London: InTechOpen, 2022).
2. O. R. Ogunremi, A. I. Sanni & R. Agrawal, *Microbial communities and amino acid profiles of Nigerian fermented condiments: Iru and ogiri*, **Food Control** 73: 1320–1329, 2017.
3. O. A. Adebo & I. G. Medina-Meza, *Impact of fermentation on African foods: From nutrition to functional health properties*, **Comprehensive Reviews in Food Science and Food Safety** 18(6): 1913–1940, 2019.
4. O. B. Oyewole & S. A. Odunfa, *Characterization and distribution of lactic acid bacteria in cassava fermentation during 'Fufu' production*, **Journal of Applied Bacteriology** 68(2): 145–52, 1990.
5. O. A. Ajibade, R. Kolawole & S. Salami, *Insight into the beneficial use of Iru: An African condiment from *Parkia biglobosa**, **International Journal of Food Microbiology**, 2024.
6. Y. Miassi, M. Houngbédji & D. Sessou, *Socio-cultural roles of fermentation in Benin and Nigeria*, **International Journal of Gastronomy and Food Science** 26: 100455, 2022.
7. C. A. Ogunlade, A. R. Olaniyan & R. T. Babalola, *Processing techniques and cultural status of fermented foods in Southern Nigeria*, in *Indigenous fermented foods and beverages of Sub-Saharan Africa*, ed. A. Ezeogu et al., 23–48 (Singapore: Springer, 2025).
8. P. N. Anyiam & P. N. Onwuegbuchu, *Traditional fermented foods in Nigeria and COVID-19: A possible approach for boosting immune system*, **International Journal of Research and Innovation in Applied Science** 5(11): 75–78, 2020.
9. W. Ndudi, B. Ogbonna & M. Duniya, *Enhancing health through Nigerian indigenous fermented agrifoods*, **Discover Food** 3: 206, 2024.

10. E. O. Nwachukwu, C. N. Nwabor & O. A. Adebayo, *Nutritional and microbial profile of Ugba from Southeast Nigeria*, **Journal of Food Processing and Preservation** 46(5): e17219, 2022.
11. O. I. Okafor, O. Anene, C. N. Nwabor & E. E. Nwachukwu, *Microbial dynamics in palm wine fermentation*, **ISAR Journal of Applied Biology** 6(2): 88–98, 2023.
12. T. Rukwishuro, G. M. Kalru & S. Ngugi, *Starter cultures in traditional African dairy fermentation*, in *Microbial cultures for functional foods*, ed. M. A. Sanni & D. L. Mohale (London: Elsevier, 2025).
13. E. T. Adesemoye, A. I. Sanni, G. Spano & V. Capozzi, *Lactic acid bacteria diversity in fermented foods as potential bioresources to alleviate malnutrition*, **Fermentation** 11(2): 103, 2025.
14. O. A. Adebayo, C. N. Nwabor & E. E. Nwachukwu, *Fermentation and microbial diversity of traditional fermented milk (Nunu) in Northern Nigeria*, **Journal of Food Science and Agriculture** 101(4): 785–94, 2023.
15. C. O. Obisesan & F. A. Ayeni, *African fermented foods as antimicrobial agents*, in *Food security and safety: African perspectives*, ed. P. Ngwesse & I. Oluwafemi, 413–28 (Cham: Springer, 2021).
16. A. T. Adesulu-Dahunsi, S. O. Dahunsi & A. Olayanju, *Synergistic microbial interactions between lactic acid bacteria and yeasts during Nigerian fermented food production*, **Food Control** 115: 107279, 2020.
17. J. A. Adebo, P. B. Njobeh & J. A. Adebisi, *Fermentation of cereals and legumes: Impact on nutritional constituents and bioavailability*, **Fermentation** 8(2): 63, 2022.
18. S. Ghosh, S. Bag & M. Pal, *Proteolytic fermentation of legumes: Technological innovations in alkaline foods*, **African Journal of Biotechnology** 23(3): 200–15, 2024.
19. C. F. Olaniran, O. Osemwegie & E. A. Taiwo, *Application and acceptability of microbiomes in the production process of Nigerian indigenous foods*, **Progress in Nutrition and Food Science** 28(2): 108, 2023.
20. F. A. Oguntinyinbo & A. Narbad, *Molecular characterization of lactic acid bacteria and in situ amylase expression during traditional fermentation of cereal foods*, **Food Microbiology** 32(1): 117–22, 2012.
21. J. K. Ndukwe, S. Chima & M. Okonkwo, *Diet diversification and priming with Kunu: An indigenous probiotic cereal-based non-alcoholic beverage in Nigeria*, **Beverages** 9(1): 14, 2023.
22. G. I. Edo, A. N. Jikah, W. Ndudi & P. O. Samuel, *Traditional fermented foods of Nigeria: Microbiological safety and health benefits*, **Journal of Food Science and Technology**, 2024.
23. K. Banwo, A. T. Adesulu-Dahunsi & K. Olayanju, *Microbial interactions in African fermented foods: A review*, **Food Control** 115: 107279, 2020.
24. O. E. Fagunwa, *Optimising African fermented foods for health benefits*, **African Journal of Biological Sciences**, 2023.
25. N. A. Olasupo, D. A. Oyetunji & Y. Ajayi, *Synergistic interactions between lactic acid bacteria and yeasts in Nigerian fermented foods*, **Food Control** 112: 107132, 2020.
26. A. Ayeni & O. P. Ogunniran, *Ten-year review of complementary food development in Sub-Saharan Africa*, **Comprehensive Reviews in Food Science and Food Safety**, 2024.

27. A. T. Adesulu-Dahunsi, O. D. Sanni, B. N. Osuolale & A. O. Oyewole, *LAB-yeast interaction and nutrient enhancement in Nigerian fermented foods*, **Food Control** 110: 107023, 2022.
28. O. N. Olatunji, N. Nwankwo & O. O. Ololade, *Health benefits of fermented African cereals: Focus on nutritional and probiotic potentials*, **International Journal of Food Science and Technology**, 2025.
29. G. C. Okafor, C. A. Igwe & E. O. Nwachukwu, *Cultural dimensions of Ugba fermentation in Southeastern Nigeria*, **Journal of Ethnic Foods** 7(2): 86–94, 2020.
30. O. J. Oladeji, Owolabi & O. O. Ojo, *Nutritional and functional benefits of indigenous fermented condiments in Nigeria*, **Discover Food**, 2025.
31. A. T. Obafemi, A. T. Adesulu-Dahunsi & A. I. Sanni, *Application of microbiomes in the production process of Nigerian indigenous foods*, **Progress in Nutrition and Food Science** 28(2): 108, 2022.
32. O. I. Okafor, C. Ezeaku & B. Chimaobi, *Microbial dynamics and biochemical complexity in traditional palm wine fermentation: Insights into flavour and health implications*, **ISAR Journal of Agriculture and Biology**, 2023.
33. R. Singh & S. Kumar, *Technological advancements in fermented food products: Microbial and functional perspectives*, **Fermentation** 11(6): 300, 2025.
34. T. Ratau & O. P. Bamidele, *Nutritional value and consumer acceptance of non-alcoholic cereal-based beverages in Sub-Saharan Africa*, **Food and Nutrition Journal** 13(1), 2025.
35. A. Anyogu, K. C. Aworh, O. A. Adelekan & I. F. Obiajuru, *Food safety risks in indigenous African fermented foods*, **Food Control** 126: 108065, 2021.
36. O. Zannou, D. Houngbédji & M. Houngbédji, *Traditional fermented foods and indigenous food processing in Benin and Nigeria*, **International Journal of Gastronomy and Food Science** 27: 100451, 2022.
37. R. A. Atuna, F. Adu-Gyamfi & J. Adomako, *Bacterial community dynamics in fermented Ghanaian cereal and legume flours*, **SSRN Electronic Journal**, 2024.
38. A. Atere & C. Faeji, *Fermented condiments in hypercholesterolemia management*, **Asian Journal of Research in Cardiovascular Sciences**, 2025.
39. A. T. Adesulu-Dahunsi et al., *Co-occurrence of Lactobacillus species during African food fermentation*, **Frontiers in Microbiology** 13: 684730, 2022.
40. N. L. Louw, J. W. Spitaels & A. C. Steyn, *Microbiome assembly in fermented foods*, **Annual Review of Microbiology** 77: 315–40, 2023.
41. J. Owusu-Kwarteng, B. Teye & H. A. Amoa-Awua, *Alkaline fermented foods as sustainable nutritional sources*, **Frontiers in Sustainable Food Systems** 6: 885328, 2022.
42. O. Nwaiwu, C. Uwakwe & P. Nwankwo, *Traditional and artisanal beverages in Nigeria: Microbial diversity and safety issues*, **Beverages** 6(3): 53, 2020.
43. M. Houngbédji, P. Dossa & K. Adjrah, *Cereal-based fermented foods as microbiota-directed products for child nutrition and health in Sub-Saharan Africa*, **Critical Reviews in Food Science and Nutrition**, 2024.
44. D. A. Kitessa, T. Alemayehu & T. Amsalu, *Effect of fermentation time and blending ratio on microbial dynamics and nutritional quality of Shameta*, **Fermentation** 10(3): 118, 2024.
45. R. A. O. Gabriel-Ajobiwe, A. Olusegun & E. Amusan, *Optimizing fortified fermented local weaning foods for infant health*, **Sustaine.org**, 2024.

46. I. A. Adesokan, E. A. Akanbi & A. A. Akinyosoye, *The effect of starter cultures on the microbiological quality of Wara, a West African soft cheese*, **World Journal of Dairy & Food Sciences** 3(2): 222–25, 2008.
47. A. T. Adesulu-Dahunsi et al., *LAB-yeast interaction and nutrient enhancement in Nigerian fermented foods*, **Food Control** 110: 107023, 2022.
48. O. A. Ajibade et al., *Insight into the beneficial use of Iru*, **International Journal of Food Microbiology**, 2024.
49. O. E. Fagunwa et al., *Biotechnological advances in the production of functional African fermented foods*, **Biotechnology Advances**, 2023.
50. O. A. Oyewole & P. Isah, *Locally fermented foods in Nigeria and their national economic significance*, **CiteseerX**, 2019.
51. O. Gabriel-Ajobiwe & G. M. Adegbola, *Optimizing fortified fermented local weaning foods*, **Sustaine.org**, 2025.

Chapter Three

Materials and Methods

3.1 Research Design Overview

This study employed a laboratory-based experimental design incorporating both microbial and biochemical analyses of selected Nigerian traditional fermented foods, *Ogi*, *Iru*, *Fufu*, and *Garri*. The methodology involved comparative analysis between raw and fermented samples to evaluate the impact of fermentation on microbial communities, proximate and micronutrient content, antioxidant potential, and physicochemical properties

3.2 Sample Collection and Preparation

Samples of *Ogi* (fermented maize), *Iru* (fermented locust bean), *Fufu* (fermented cassava mash), and *Garri* (fermented and roasted cassava granules) were collected in sterile food-grade containers from multiple artisanal producers. Both raw and fermented variants were collected for each food type. Samples were homogenized, labelled, and stored at -4°C until analysis.

3.3 Proximate Analysis

Proximate analysis was carried out to determine the moisture content, crude protein, crude fat, total ash, crude fibre, and carbohydrate contents of the samples. The analyses were conducted using standardized procedures as described by the Association of Official Analytical Chemists ¹.

1. Determination of moisture content

The moisture content of the raw and fermented food samples was determined using the method described by AOAC ¹. Five grams of each sample were accurately weighed into dried and pre-weighed moisture cans. The cans with their contents were placed in a hot air oven and dried at 105°C for three hours.

After the initial drying period, the cans were removed from the oven, allowed to cool in a desiccator, and then weighed. The samples were subsequently returned to the oven for an additional thirty minutes, cooled in the desiccator, and reweighed. This process of heating, cooling, and weighing was repeated until a constant weight was obtained.

The moisture content was calculated as the percentage weight loss during drying using the formula:

Formula:

$$\text{Moisture content (\%)} = \frac{(W_1 - W_2)}{W} \times 100$$

Where:

- W_1 = Weight of can + fresh sample

- W_2 = Weight of can + dried sample
- W = Weight of sample

2. Determination of total ash Content

The total ash content of the raw and fermented food samples was determined using the method described by AOAC ¹. Five grams of each sample were accurately weighed into a clean, dried, and pre-weighed porcelain crucible. Each sample was first charred on a hot plate to eliminate moisture and volatile organic compounds, observed as the emission of black fumes. After complete charring, the crucibles were transferred into a pre-heated muffle furnace set at 600°C and ashed for six hours. Proper ashing was confirmed by the appearance of a white or light grey residue, indicating the complete combustion of organic matter.

Following ashing, the crucibles were carefully removed from the furnace and allowed to cool in a desiccator to prevent moisture absorption. Once cooled, the crucibles containing the ash were weighed again. The total ash content was calculated using the formula:

$$\text{Total Ash content (\%)} = \frac{(W_2 - W_1)}{W} \times 100$$

Where:

- W_2 = Weight of crucible + ash
- W_1 = Weight of empty crucible
- W = Weight of sample

3. Determination of crude protein content

This was determined using the AOAC method ¹. One gram of the samples was weighed into the digestion flask, and Kjeldahl catalyst tablets were added. Then, 20 mL of concentrated H₂SO₄ was also added, and the flask was placed in the digester at 410°C for 6 hours until a clear solution was obtained. The cooled digest was transferred into a 100 ml volumetric flask and

made up to the mark with distilled water. The distillation apparatus was set up and rinsed for 10 minutes after boiling. 20 ml of 4% boric acid was pipetted into a conical flask. Five drops of methyl red were added to the flask as an indicator, and the sample was diluted with 75 ml of distilled water. Then, 10 ml of the digested sample was pipetted into the Kjeldahl distillation flask. 20 mL of 40% NaOH was added through a glass funnel into the digested sample, and it was then distilled. The distillate was collected in the boric acid for 15 minutes until the pink colour changed to green. The contents of the flask were titrated against 0.05 N HCl.

Calculation:

$$\% \text{Nitrogen (W/W)} = \frac{14.01 \times (\text{Sample titre} - \text{blank titre}) \times \text{Normality of acid}}{10 \times \text{Weight of Sample}}$$

$$\% \text{Crude protein (W/W)} = \% \text{Nitrogen} \times 6.25$$

4. Determination of crude fat content

The crude fat content of the samples was determined using the Soxhlet extraction method as described by ¹. Before extraction, the Soxhlet extraction flask was dried in an oven to a constant weight, cooled in a desiccator, and subsequently weighed. Four grams of each dried sample were accurately weighed into a fat-free extraction thimble and lightly plugged with cotton wool.

The thimble was placed inside the Soxhlet extractor, which was then connected to a reflux condenser and the pre-weighed 250 ml Soxhlet flask. The Soxhlet flask was filled to three-quarters of its volume with petroleum ether (boiling point: 40°–60°C). The entire extractor, condenser, and flask assembly was mounted on a heating unit.

The extraction process was carried out for six hours, with continuous water flow through the condenser to facilitate the condensation of ether vapour. The assembly was monitored closely throughout the process to prevent ether leakage and to maintain a gentle boil of the solvent by adjusting the heat source appropriately. The petroleum ether was allowed to reflux through the

sample at least 10 to 12 times until siphoning was nearly complete. After the extraction period, the thimble containing the sample residue was removed and allowed to dry on a clock glass at room temperature. The Soxhlet extractor, flask, and condenser were reassembled, and the distillation process continued until the flask was nearly dry. Finally, the flask now containing the extracted fat was detached, its exterior cleaned, and dried in an oven to a constant weight. The increase in weight of the flask was recorded and used to calculate the crude fat content of the sample.

$$\text{Percentage crude fat} = \frac{W_1 - W_0}{\text{Weight of sample}} \times 100$$

Where:

- W_1 = Final weight of flask with oil
- W_0 = Initial weight of dry flask
- W = Sample weight

5. Determination of crude fibre

The crude fibre content of the samples was determined according to the method outlined by the Association of Official Analytical Chemists ¹. Three grams of each sample were weighed and extracted with petroleum ether. The mixture was allowed to boil under a reflux condenser for 40 minutes. After refluxing, the sample was filtered using a pre-weighed filter paper placed in a funnel, and suction was applied to facilitate drainage. The insoluble residue was subsequently washed thoroughly initially with boiling water, followed by 1% hydrochloric acid, then twice with ethanol, and finally three times with ether. The washed residue was dried in an electric oven at 100°C until a constant weight was obtained. The dried residue was then incinerated in a muffle furnace to obtain ash. After cooling in a desiccator, the ash was weighed. The crude fibre content

was calculated as the difference between the weight of the residue (filter paper plus insoluble material) and the weight of the ash.

$$\text{Percentage crude fibre} = \frac{W_2 - W_3}{W_1} \times 100$$

Where:

- W_1 = Sample weight
- W_2 = Weight of residue
- W_3 = Weight of ash

6. Determination of total carbohydrate content

The total carbohydrate content was determined by difference, following the method described ². This involved subtracting the sum of the measured percentages of moisture, total ash, crude fat (lipid), crude protein, and crude fibre from 100%. The carbohydrate content was calculated using the formula below:

$$\text{Carbohydrate} = 100 - (\% \text{ moisture} + \% \text{ ash} + \% \text{ protein} + \% \text{ lipids} + \% \text{ fibre}).$$

3.4 Mineral Content Analysis

The mineral contents of the samples were determined using the procedures outlined by the Association of Official Analytical Chemists ¹. Calcium, magnesium, iron, and zinc concentrations were quantified using an Atomic Absorption Spectrophotometer (AAS) following wet digestion of the samples with a perchloric–nitric acid mixture. Precisely 0.50 g of each finely ground sample was weighed into a 125 ml Erlenmeyer flask. Under a fume hood, 4 ml of perchloric acid, 25.00 ml of concentrated nitric acid (HNO₃), and 2.00 ml of concentrated sulphuric acid (H₂SO₄) were added. The contents were thoroughly mixed and heated gently on a hot plate within a perchloric acid-compatible fume hood. Heating was continued until dense white fumes were observed, after which strong heating was applied for an additional 30 seconds.

The digestion mixture was then allowed to cool. Subsequently, 50 ml of distilled water was added to the cooled digest, and the mixture was again allowed to cool to room temperature. The resulting solution was filtered completely using a wash bottle into a Pyrex volumetric flask and made up to the mark with distilled water. The mineral concentrations were then measured using the Atomic Absorption Spectrophotometer.

3.5 Vitamin Content Analysis

1. Determination of vitamin A and B-complex

The vitamin B-complex content of the samples was determined Achikanu, Nwosu, and Ogu ³. Precisely 1 g of the sample was weighed and macerated with 20 ml of *n*-hexane in a test tube for 10 minutes. The mixture was then centrifuged for another 10 minutes. After centrifugation, the solution was filtered, and 3 ml of the filtrate was transferred into a clean, dry test tube in duplicate and evaporated to dryness using a boiling water bath. Subsequently, 2 ml of 0.5 N alcoholic potassium hydroxide was added to the residue, and the mixture was boiled in a water bath for 30 minutes. Following saponification, 3 ml of *n*-hexane was added, and the solution was shaken vigorously. The *n*-hexane layer was carefully transferred into another set of dry test tubes and evaporated to dryness. The resulting residue was reconstituted with 2 mL of ethanol. Then, 1 ml of 0.2% ferric chloride in ethanol was added, followed by the addition of 1 ml of 0.5% 1,1-dipyridyl in ethanol. An additional 1 ml of ethanol was added to bring the final volume to 5 ml. The solution was thoroughly mixed, and the absorbance was measured at 520 nm using a spectrophotometer against a reagent blank.

2. Determination of vitamin C

The vitamin C (ascorbic acid) content of the samples was determined using the 2,6-dichlorophenolindophenol (DCPIP) titrimetric method as described by the Association of

Official Analytical Chemists (AOAC, 2023). Precisely 5 g of the fresh or properly homogenized sample was weighed and blended with 100 ml of 1% metaphosphoric acid to extract the ascorbic acid. The resulting mixture was filtered through Whatman No. 1 filter paper, and the clear filtrate was collected for analysis. An aliquot of 10 ml of the filtrate was titrated with the standardized dye solution of 2,6-dichlorophenolindophenol until a persistent light pink colour was observed, lasting for at least 15 seconds. The vitamin C content was calculated based on the volume of dye used and expressed in milligrams of ascorbic acid per 100 grams of sample (mg/100g).

The standardization of the dye solution was carried out using pure ascorbic acid, and the results were used to determine the vitamin C concentration in the samples.

3.6 Physicochemical Properties

1. pH determination

The pH of the food samples was determined using the method described by AOAC¹. A 10 g portion of the homogenized sample was weighed and dispersed in 100 ml of distilled water in a beaker. The mixture was stirred thoroughly for uniform suspension and allowed to stand for 30 minutes at room temperature. After equilibration, the pH of the suspension was measured using a calibrated digital pH meter. The pH meter was standardized with buffer solutions of pH 4.0 and pH 7.0 prior to measurement. The electrode was rinsed with distilled water between readings and gently immersed in the sample solution. The stable reading was recorded as the pH of the sample. All measurements were conducted in triplicate to ensure the accuracy and reproducibility of results.

2. Titratable acidity

The titratable acidity was determined using the method described by AOAC¹. About 25 ml of filtrate was transferred into a 125 ml conical flask. A 25 ml burette was filled with 0.1N NaOH

and was adjusted to zero. Two to three drops of phenolphthalein indicator were added to the conical flask containing the filtrate. The filtrate was titrated with 0.1 N NaOH until colour changes, and the volume was recorded. Titratable acidity and the volume were recorded. Titratable acidity was calculated as % citric acid.

3.7 Antioxidant Properties

1. Ferric reducing antioxidant power (FRAP)

The Ferric Reducing Antioxidant Power (FRAP) of the samples was determined using the method described by Benzie and Strain (1996), with slight modifications. The FRAP assay is based on the reduction of the ferric-tripyridyl triazine (Fe^{3+} -TPTZ) complex to its ferrous (Fe^{2+}) form at low pH, which produces a blue colour with an absorption maximum at 593 nm.

Preparation of FRAP reagent

The FRAP reagent was freshly prepared by mixing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ (2,4,6-tripyridyl-s-triazine) solution in 40 mM HCl, and 20 mM $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in the ratio of 10:1:1 (v/v/v). The reagent was incubated at 37°C before use.

Sample preparation and analysis

0.2 ml aliquot of the sample extract was mixed with 1.8 ml of the FRAP reagent and incubated in the dark at 37°C for 30 minutes. The absorbance of the resulting blue-coloured complex was read at 593 nm using a UV-Visible spectrophotometer.

Quantification

A standard curve was prepared using different concentrations of ferrous sulphate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$). The FRAP value of each sample was expressed in micromoles of Fe^{2+} equivalents per gram of sample ($\mu\text{mol Fe}^{2+}/\text{g}$).

All analyses were conducted in triplicate, and the mean values were recorded.

2. DPPH radical scavenging assay

The antioxidant activity of the samples was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging method, as described by Brand-Williams, Cuvelier, and Berset (1995), with slight modifications.

Principle of the method

The DPPH assay measures the ability of antioxidants in the sample to donate hydrogen or electrons to the stable free radical DPPH, reducing it to a non-radical form. This reduction causes a colour change from deep violet to pale yellow, which can be measured spectrophotometrically at 517 nm.

Preparation of reagents and samples

A 0.1 mM solution of DPPH was prepared in methanol. Exactly 1.0 ml of this DPPH solution was added to 1.0 ml of the sample extract in a test tube. The mixture was vortexed and then incubated in the dark at room temperature for 30 minutes.

Measurement of absorbance

After incubation, the absorbance of the reaction mixture was measured at 517 nm using a UV-Visible spectrophotometer. Methanol was used as the blank, and a control was prepared by replacing the sample with methanol.

Calculation of radical scavenging activity

The percentage of DPPH radical scavenging activity was calculated using the following formula:

$$\text{Reduction of absorbance (\%)} = [(AB - AA) / AB] \times 100$$

AB = Absorbance of blank sample (t = 0 min)

AA = Absorbance of tested extract solution (t = 30 min)

3. Total phenolic content

The total phenolic content of the samples was determined using the Folin–Ciocalteu micro-method as described by Arabshahi-Delouee and Urooj ⁶. This method is based on the reduction of the Folin–Ciocalteu reagent by phenolic compounds in an alkaline medium, resulting in a blue-coloured complex measurable at a specific wavelength.

Sample preparation and assay procedure

An aliquot of 20 µL of the extract solution was mixed with 1.16 mL of distilled water in a test tube, followed by the addition of 100 µL of Folin–Ciocalteu's reagent. After thorough mixing, 300 µL of sodium carbonate solution (200 g/L Na₂CO₃) was added to the mixture. The resulting solution was incubated at 40°C for 30 minutes in a shaking incubator to ensure complete reaction.

Measurement of absorbance

After incubation, the absorbance of the mixture was measured at 760 nm using a UV-Visible spectrophotometer. A blank was prepared using the same procedure but replacing the extract with distilled water.

Calibration and expression of results

A standard calibration curve was constructed using gallic acid as the reference phenolic compound. The total phenolic content was calculated using the following linear regression equation derived from the calibration curve:

$$Ab = 0.98C + 9.925 \times 10^{-3} \quad (R^2 = 0.9996)$$

Where:

Ab is the absorbance, and *C* is the concentration of phenolics (mg GAE g⁻¹ dry weight (DW)). Expressed as gallic acid equivalents (GAE). Results were expressed as milligrams of gallic acid equivalent per gram of sample (mg GAE/g).

All analyses were conducted in triplicate, and the values were expressed as the mean $\pm$ standard deviation.

4. Determination of ABTS Free Radical Scavenging Assay

The antioxidant activity of the samples was evaluated using the ABTS [2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)] radical cation decolorization assay ⁸. To prepare the ABTS $\bullet^+$ working solution, ABTS was dissolved in deionized water to a final concentration of 7 mM, and potassium persulfate was added to a concentration of 2.45 mM. The mixture was allowed to react in the dark at room temperature for 12 to 16 hours to generate the ABTS $\bullet^+$ radical cation. Before analysis, the ABTS $\bullet^+$ solution was diluted with 0.01 M phosphate-buffered saline (PBS), pH 7.4, to obtain an absorbance of approximately 0.70 at 734 nm. Sample extracts were diluted 100-fold with the ABTS $\bullet^+$ solution to a final volume of 1 ml. Absorbance readings were taken spectrophotometrically at 734 nm at 1-minute intervals following the addition of each extract. All measurements were performed in triplicate to ensure accuracy and reproducibility. Control samples were prepared by replacing ABTS $\bullet^+$ with 990 μ l of PBS to account for the intrinsic absorbance of the extracts. The assay is based on the ability of antioxidants in the sample to quench the ABTS $\bullet^+$ radical cation, resulting in a decrease in absorbance. Antioxidant capacity was expressed as millimolar (mM) Trolox Equivalent Antioxidant Capacity (TEAC).

3.8 Microbiological Analysis

3.8.1 Sample Preparation and Processing

Upon arrival at the laboratory, all samples were immediately processed for microbiological analysis. For solid samples such as cassava tubers, *Garri*, and *Iru*, 10 g was aseptically weighed using a sterile analytical balance and homogenized in 90 mL of sterile peptone water to produce a 10^{-1} dilution. Liquid or semi-solid samples, such as *Ogi* slurry and *Fufu* paste, were mixed

thoroughly before dilution to ensure uniform distribution of microorganisms. Serial dilutions were prepared up to 10^{-6} , following the standard spread-plate method ¹⁰. Separate dilution blanks and sterile pipettes were used for each sample type to prevent cross-contamination.

3.8.2 Enumeration of Total Viable Count (TVC)

Total viable counts were determined by inoculating 0.1 mL aliquots of appropriate dilutions onto Plate Count Agar (PCA). The plates were incubated at 30 °C for 48 hours, after which colonies were enumerated and expressed as $\log_{10}$ colony-forming units per gram (CFU/g). This method provides an estimate of the overall microbial population in the samples, following the guidelines of ISO 4833-1:2013.

3.8.3 Enumeration of Lactic Acid Bacteria (LAB)

De Man, Rogosa, and Sharpe (MRS) agar was used for LAB isolation. Inoculated plates were incubated anaerobically at 30 °C for 48–72 hours using an anaerobic jar with GasPak™. Colonies exhibiting typical LAB morphology (small, round, creamy-white) were counted. This medium selectively supports the growth of *Lactobacillus* and related genera, which are known to dominate fermented cereal and cassava products ¹⁰.

3.8.4 Enumeration of Bacillus Species

Nutrient agar supplemented with heat treatment was employed for *Bacillus* counts. Diluted suspensions were first subjected to heat shock at 80 °C for 10 minutes to eliminate vegetative cells, ensuring that only heat-resistant *Bacillus* spores survived. Inoculated plates were incubated aerobically at 37 °C for 24–48 hours, and colonies with *Bacillus*-like morphology were enumerated ¹¹.

3.8.5 Enumeration of Yeasts and Moulds

Yeast Extract Glucose Chloramphenicol (YGC) agar was used for the isolation of yeasts and moulds. Plates were incubated at 28 °C for 3–5 days. Yeast colonies were identified based on creamy or pasty morphology, while moulds were characterized by filamentous growth and spore pigmentation. This approach aligns with the methods recommended ¹².

3.8.6 Enumeration of Enterobacteriaceae

MacConkey agar was used to selectively isolate Enterobacteriaceae. Plates were incubated at 37 °C for 24 hours. Colonies exhibiting pink to red coloration were enumerated as coliforms. This step provided insight into the hygiene and safety of raw and fermented products, since high counts of Enterobacteriaceae are indicative of fecal or environmental contamination ¹³.

3.9 Isolation and Identification of Microorganisms

Representative colonies from each selective medium were subcultured onto fresh agar plates to obtain pure isolates. Morphological characteristics such as colony color, shape, and margin were recorded. Microscopic examination was performed after Gram staining, enabling differentiation between Gram-positive and Gram-negative organisms. Biochemical tests were subsequently carried out, including catalase, oxidase, citrate utilization, carbohydrate fermentation profiles, and spore staining, depending on the organism group ⁹.

For yeast and mould isolates, lactophenol cotton blue staining was used for microscopic observation of hyphal structure and spore morphology. Identification of bacterial isolates was done by comparing biochemical profiles with Bergey's Manual of Determinative Bacteriology ¹⁴. Fungal identification was carried out based on morphological keys ¹⁵.

3.10 Data Analysis

All experimental data obtained from the proximate composition, mineral content, vitamin analysis, pH, titratable acidity, and antioxidant assays were subjected to statistical analysis using

Statistical Package for Social Sciences (SPSS) version 25.0. Results were expressed as mean $\pm$ standard deviation (SD) of triplicate determinations. One-way analysis of variance (ANOVA) was performed to determine significant differences among the means of the raw and fermented food samples. Where significant differences were observed, Duncan's Multiple Range Test (DMRT) was used as the post hoc test to separate the means at a confidence level of $p < 0.05$.

Endnotes

1. AOAC. *Official Methods of Analysis*. 22nd ed. Gaithersburg, MD: Association of Official Analytical Chemists, 2023.
2. M. Sasi, S. Kumar & M. Hasan, *Emerging Trends in Soy-Based Foods Fortified with Probiotics: Nutritional and Functional Perspectives*, **Critical Reviews in Food Science and Nutrition**, Advance online publication, 2023.
3. C. C. Achikanu, D. O. Nwosu, and C. V. Ogu, *Chemical Composition of Some Local Spices Used as Seasoning Agents in Southeastern Nigeria*, **International Journal of Nutrition and Food Sciences** 2, no. 5: 244–52, 2013.
4. I. F. F. Benzie and J. J. Strain, *The Ferric Reducing Ability of Plasma (FRAP) as a Measure of 'Antioxidant Power': The FRAP Assay*, **Analytical Biochemistry** 239, no. 1: 70–76, 1996.
5. W. Brand-Williams, M. E. Cuvelier, and C. Berset, *Use of a Free Radical Method to Evaluate Antioxidant Activity*, **LWT – Food Science and Technology** 28, no. 1: 25–30, 1995.
6. R. Kumar, M. Kumar & S. Sharma, *A Review on Antioxidant Potential of Morus indica L. Leaves and Fruits: Chemistry, Mechanisms, and Food Applications*, **Journal of Food Biochemistry** 46(10): e14303, 2022.

7. C. Cedeño-Pinos, E. García, L. Siguencia, A. Pérez & A. M. González-Paramás, *Bioactive Compounds and Antioxidant Potential of Sechium edule Fruits and Leaves*, **Plants** 12(5): 1032, 2023.
8. A. Rai & A. Singh, *Recent Advances in Free Radical Scavenging Assays: A Comparative Review*, **Food Analytical Methods** 14(9): 1776–1792, 2021.
9. A. Hameed, S. Kiran & M. N. Chaudhry, *Modern Microbiological Techniques for Food Quality and Safety Assessment: A Laboratory Guide* (Cham: Springer, 2022).
10. B. Sánchez & A. Margolles, *The Evolving Field of Lactic Acid Bacteria: From Traditional Fermentations to Probiotic Applications*, **Microorganisms** 9(8): 1632, 2021.
11. J. J. Harper and M. L. Davis, *Isolation and Identification of Bacillus Species in Food*, **Journal of Food Protection** 82, no. 7: 1228–36, 2019.
12. J. I. Pitt and A. D. Hocking, *Fungi and Food Spoilage*, 4th ed. New York: Springer, 2012.
13. M. Cheesbrough, *District Laboratory Practice in Tropical Countries*, 3rd ed. Cambridge: Cambridge University Press, 2017.
14. J. G. Holt, N. R. Krieg, P. H. A. Sneath, J. T. Staley, and S. T. Williams, *Bergey's Manual of Systematic Bacteriology*, 5th ed. Baltimore: Williams & Wilkins, 2022.
15. R. A. Samson, J. Houbraken, U. Thrane, J. C. Frisvad, and B. Andersen, *Food and Indoor Fungi*. Utrecht: CBS-KNAW Fungal Biodiversity Centre, 2010.

Chapter Four

Results and Discussions

4.1 Results of the Finding

Proximate Composition of the Raw and Fermented Foods

The proximate composition of raw and fermented foods reveals significant nutritional changes resulting from fermentation and processing. Each nutrient parameter varies across the samples, and the differences are statistically significant at $p < 0.05$, as indicated by the superscripts in Table 4.1.

Raw cassava tuber had the highest moisture level among the unfermented foods, followed by Iru seed and corn grain. When fermented, cassava-derived foods showed large differences in water content: *Garri* was almost completely dry, while *Fufu* retained the most moisture, and *Ogi* had a moderate level. The *Iru* products were intermediate. These values illustrate why *Garri* has a long shelf life, while *Fufu* spoils quickly due to high moisture content.

The pattern is opposite to moisture, since dry matter equals everything other than water. Corn grain was the richest in dry matter among the raw samples, followed by *Iru* seed and cassava tuber. After fermentation, *Garri* stood out, reflecting its dryness, while *Fufu* was the lowest due to its high-water retention. *Ogi* and *Iru* products had moderate dry matter values.

Raw *Iru* seed contained the highest fat, compared to corn grain and cassava tuber. Fermentation further increased the fat in *Iru* products. In contrast, cassava-based fermented foods remained low in fat. These values show that fermentation can concentrate fat in protein-rich seeds but has little effect on starchy roots.

Raw *Iru* seed had the highest mineral content, followed by corn grain and cassava tuber. Fermentation generally increased ash values, with *Garri* recording the highest, followed by *Iru* products. *Ogi* and *Fufu* remained relatively low. The rise in mineral content in some fermented foods reflects the breakdown of anti-nutrients during fermentation, making minerals more concentrated.

Crude fibre content was highest in raw corn grain, followed by *Iru* seed and cassava tuber. Fermentation reduced fibre in most cases. However, *Garri* retained a relatively high fibre level, and *Iru woro* contained a moderate amount. This reduction indicates microbial breakdown of complex carbohydrates into simpler, more digestible forms.

Iru seed was extremely rich in protein, compared to corn grain and cassava tuber. Fermentation reduced *Iru*'s protein somewhat but still left the fermented *Iru* products as protein-rich foods. Cassava-based products remained low in protein after fermentation. This demonstrates that fermentation improves protein availability in legumes like *Iru* but has little effect on starchy roots like cassava.

Total carbohydrate was highest in raw corn grain and cassava tuber. Fermentation further increased carbohydrate concentration in Garri, making it highly energy-dense. *Ogi* was also high, while *Fufu* had much lower carbohydrate due to high moisture dilution. In contrast, the *Iru* products had significantly lower carbohydrate contents after fermentation, as microorganisms consumed a substantial portion of the sugars during the process.

Table 4.1: Proximate Composition of raw and fermented food (g/100g)

Raw Foods							
Samples	Moisture	Dry	Crude	Total	Crude	Crude	Total
	Contents	Matter	Fat	Ash	Fibre	Protein	Carbohydrate
Cassava	64.92±0.02 ^c	35.09±0.02 ^a	0.24±0.02 ^a	0.56±0.03 ^a	1.64±0.02 ^a	1.26±0.03 ^a	31.40±0.04 ^a
Tuber							
Corn Grain	10.96±0.01 ^a	89.05±0.01 ^c	3.24±0.04 ^b	1.26±0.01 ^b	9.26±0.03 ^c	9.14±0.02 ^b	66.17±0.01 ^c
<i>Iru</i> seed	12.43±0.03 ^b	87.57±0.03 ^b	8.45±0.04 ^c	2.07±0.02 ^c	6.37±0.03 ^b	38.62±0.03 ^c	32.07±0.15 ^b
Fermented Foods							
<i>Garri</i>	0.72±0.02 ^a	99.29±0.02 ^c	1.26±0.01 ^b	2.88±0.03 ^c	5.75±0.04 ^c	3.14±0.03 ^c	86.26±0.03 ^c
<i>Fufu</i>	73.10±0.03 ^c	26.90±0.03 ^a	2.54±0.04 ^c	0.54±0.02 ^b	2.97±0.04 ^b	1.45±0.02 ^a	19.42±0.10 ^c
<i>Ogi</i>	50.34±0.02 ^c	49.68±0.02 ^c	1.11±0.04 ^a	0.45±0.02 ^a	2.29±0.03 ^a	1.81±0.03 ^b	44.03±0.13 ^d
<i>Iru Woro</i>	36.71±0.02 ^b	63.30±0.02 ^d	15.64±0.02 ^e	2.76±0.03 ^d	3.65±0.01 ^d	25.74±0.04 ^c	15.52±0.01 ^b
<i>Iru pete</i>	52.75±0.03 ^d	47.25±0.03 ^b	13.09±0.01 ^d	2.05±0.02 ^c	3.09±0.01 ^c	18.94±0.02 ^d	10.09±0.01 ^a

Mean values with different superscripts within the same column are significantly different (p < 0.05)

Mineral Composition of Raw and Fermented Foods

The mineral composition of the raw and fermented foods shows wide variations across the samples, with calcium, magnesium, iron, and zinc levels all significantly ($p < 0.05$) different among the foods. These variations highlight the influence of both food type and fermentation on mineral content and bioavailability.

Raw cassava contained a modest amount of calcium, while corn had even less. In contrast, *Iru* seed was particularly rich in calcium. After fermentation, calcium levels increased in most foods. *Fufu* contained more than its raw cassava counterpart, while *garri* and *ogi* had slightly lower values. The fermented *Iru* products, however, recorded exceptionally high calcium levels, with *Iru pete* being the richest. This indicates that fermentation of *Iru* not only retains but also enhances calcium concentration.

Magnesium levels were highest in raw *Iru* seed, followed by corn and cassava. After fermentation, the cassava-based products showed varying patterns: *Fufu* experienced a slight increase, whereas *garri* and *ogi* contained less magnesium than raw cassava. For *Iru* products, fermentation led to a reduction, as both *Iru woro* and *Iru pete* exhibited lower magnesium levels than the raw seed, suggesting possible mineral leaching or microbial utilisation during fermentation.

Iron content was very low in raw cassava and corn but significantly higher in *Iru* seed. Fermentation generally improved iron levels. *Garri* contained much more than raw cassava, *Fufu* showed a mild increase, and *Ogi* remained the lowest among the cassava products. In contrast, the *Iru* products displayed remarkable enhancement, with *Iru pete* showing the highest concentration, indicating mineral enrichment as a result of fermentation.

Raw cassava had a small amount of zinc, corn slightly more, and *Iru* seed was richer. Following fermentation, zinc content improved in certain foods, with *garri* exhibiting higher levels than both cassava and corn. *Fufu* showed a small reduction, while *ogi* was relatively unchanged. However, *Iru* fermentation led to a marked rise in zinc concentration, as both *Iru woro* and *Iru pete* showed multiple-fold increases compared to the raw seed.

Overall, these findings demonstrate that mineral distribution in fermented foods is strongly substrate-dependent. Cassava-based products show either moderate enhancement or reduction depending on the mineral, whereas *Iru*-based foods exhibit substantial enrichment, particularly in calcium, iron, and zinc. This underscores that fermentation of legumes like *Iru* enhances mineral concentration and potential bioavailability. At the same time, in starchy foods such as cassava and maize, the effects vary according to the processing and fermentation conditions.

Lead City University Ibadan DO NOT COPY

Table 4.2: Selected mineral composition of raw and fermented foods

Raw Foods				
Samples	Calcium	Magnesium	Iron	Zinc
	(mg/100 g)	(mg/100 g)	(mg/100 g)	(mg/100 g)
Cassava	18.92±0.00 ^b	20.69±0.00 ^a	0.26±0.00 ^a	0.38±0.00 ^a
Corn	8.26±0.00 ^a	38.64±0.00 ^b	0.58±0.00 ^b	0.47±0.00 ^b
<i>Iru</i> seed	495.82±0.00 ^c	324.17±0.00 ^c	10.37±0.01 ^c	1.35±0.00 ^c
Fermented foods				
<i>Garri</i>	14.87±0.00 ^b	8.67±0.00 ^a	3.06±0.00 ^c	0.53±0.00 ^c
<i>Fufu</i>	30.06±0.00 ^c	26.14±0.00 ^c	0.43±0.00 ^b	0.31±0.00 ^a
<i>Ogi</i>	14.15±0.00 ^a	10.41±0.00 ^b	0.18±0.00 ^a	0.40±0.00 ^b
<i>Iru Woro</i>	755.89±0.00 ^d	213.81±0.00 ^c	14.92±0.01 ^d	4.47±0.00 ^d
<i>Iru pete</i>	847.69±0.00 ^e	202.68±0.00 ^d	17.32±0.00 ^e	5.31±0.00 ^e

Mean values with different superscripts within the same column are significantly different ($p < 0.05$)

Vitamin Composition of Raw and Fermented Foods

The vitamin composition of cassava, corn, and *Iru* (both raw and fermented) reveals wide variation, and fermentation significantly ($p < 0.05$) alters the vitamin profile of these foods. The results indicate notable differences across β -carotene, water-soluble B vitamins (B1, B2, B3, B6, B12), and vitamin C, depending on the food type and fermentation process.

Raw cassava contained very little β -carotene, while corn was much richer, and *Iru* seed also had a considerable amount. After fermentation, the β -carotene levels increased in cassava-derived foods, with *Garri* and *Fufu* showing marked improvements over the raw tuber. *Ogi* exhibited the highest concentration among all samples, suggesting that fermentation and enzymatic activity enhance carotenoid retention. In contrast, the fermented *Iru* products maintained moderate levels, showing that fermentation stabilises but does not markedly enhance β -carotene in legumes.

Cassava had very low thiamine (vitamin B1) compared to corn and *Iru* seed. Fermentation caused noticeable changes: *Garri* and *Fufu* retained moderate levels, while *Ogi* recorded a significantly higher value. The *Iru* products demonstrated the most substantial improvement, with both *Iru woro* and *Iru pete* showing high thiamine concentrations. This underscores the efficiency of microbial activity in enriching B1 content in protein-based substrates like *Iru*.

Vitamin B2 (riboflavin) levels were generally low in the raw samples of cassava, corn, and *Iru* seed. However, fermentation improved riboflavin in cassava products, particularly in *Garri* and *Fufu*, though *Ogi* remained low. Among the *Iru* products, only slight increases were observed after fermentation, indicating that riboflavin enhancement depends largely on substrate type and microbial metabolism.

Niacin (vitamin B3) levels were initially higher in corn and *Iru* seed compared to cassava. Fermentation significantly increased niacin concentration, especially in *Iru pete* and *Iru woro*,

while cassava-based products showed minimal improvement. This demonstrates that fermentation is particularly effective in enhancing niacin content in legume-based foods rather than starchy roots.

Cassava was very low in vitamin B6, whereas corn contained moderate amounts, and *Iru* seed was the richest among the raw foods. Following fermentation, cassava products remained relatively low in B6, while the *Iru* products showed a remarkable increase, with *Iru pete* and *Iru woro* becoming outstanding sources of pyridoxine. This suggests that fermentation promotes microbial synthesis of vitamin B6 in protein-rich substrates.

Vitamin B12 was nearly absent in cassava and corn, but exceptionally abundant in *Iru* seed, establishing it as a natural source of cobalamin. Fermentation further elevated B12 levels in *Iru* products, with *Iru pete* exhibiting the highest concentration. In contrast, cassava-based fermented foods like *Garri* and *Fufu* contained negligible amounts, and *Ogi* showed no detectable vitamin B12. These results confirm that fermentation of legume seeds like *Iru* supports microbial synthesis of B12, which is otherwise scarce in plant-based foods.

Vitamin C levels also varied widely among the foods. Raw cassava was relatively rich in vitamin C compared to corn, while *Iru* seed contained very high levels. Fermentation affected vitamin C content differently depending on the food matrix. Cassava-derived foods such as *Garri* and *Fufu* retained moderate amounts, whereas *Ogi* experienced significant losses, likely due to thermal degradation during drying. Conversely, fermentation enhanced vitamin C in *Iru* products, with both *Iru woro* and *Iru pete* showing higher concentrations than the raw seed, indicating improved antioxidant potential.

Overall, the vitamin composition of these foods demonstrates that fermentation influences nutrient quality in diverse ways. While cassava-based products benefit from increased β -carotene

and moderate retention of B vitamins, legume-based products such as *Iru* experience substantial enrichment in B-complex vitamins, particularly B1, B3, B6, and B12, alongside a boost in vitamin C. These results emphasise fermentation as a valuable natural process for improving the nutritional profile and potential health benefits of traditional Nigerian foods.

Lead City University Ibadan DO NOT COPY

Table 4.3: Selected vitamin composition of raw and fermented foods

Raw Foods							
Samples	β -Carotene (mg/100g)	Vitamin B ₁ (mg/100g)	Vitamin B ₂ (mg/100g)	Vitamin B ₃ (mg/100g)	Vitamin B ₆ (mg/100g)	Vitamin B ₁₂ (mg/100g)	Vitamin C (mg/100g)
Cassava	11.16±0.00 ^a	0.08±0.00 ^a	0.09±0.00 ^a	0.85±0.00 ^a	0.06±0.00 ^a	0.09±0.00 ^b	21.14±0.01 ^b
Corn	65.16±0.00 ^c	0.16±0.00 ^b	0.06±0.00 ^b	3.63±0.00 ^c	0.61±0.00 ^b	0.01±0.02 ^a	8.13±0.00 ^a
<i>Iru</i> seed	37.08±0.00 ^b	0.58±0.00 ^c	0.04±0.00 ^a	1.03±0.00 ^b	1.37±0.00 ^c	381.01±0.00 ^c	113.81±0.00 ^c
Fermented Foods							
<i>Garri</i>	88.86±0.00 ^a	0.16±0.00 ^b	0.32±0.00 ^d	0.96±0.00 ^c	0.16±0.03 ^a	0.10±0.00 ^b	10.16±0.00 ^b
<i>Fufu</i>	82.92±0.00 ^a	0.08±0.00 ^a	0.40±0.00 ^a	0.71±0.00 ^b	0.19±0.02 ^a	0.01±0.00 ^a	11.04±0.00 ^c
<i>Ogi</i>	168.96±0.00 ^b	0.62±0.00 ^c	0.04±0.00 ^a	0.38±0.00 ^a	0.64±0.00 ^b	0.00±0.00 ^a	0.12±0.00 ^a
<i>Iru Woro</i>	60.96±0.00 ^a	0.78±0.00 ^d	0.05±0.00 ^b	3.43±0.00 ^d	2.89±0.00 ^c	432.15±0.00 ^c	128.91±0.00 ^d
<i>Iru pete</i>	72.72±0.00 ^a	0.79±0.00 ^c	0.07±0.00 ^c	5.11±0.00 ^e	4.18±0.00 ^d	465.11±0.00 ^d	135.62±0.00 ^c

Mean values with different superscripts within the same column are significantly different ($p < 0.05$)

Physicochemical Properties of Raw and Fermented Foods

The physicochemical characteristics of foods determine their sensory appeal, storage quality, and microbial safety. Parameters such as pH, total titratable acidity (TTA), and total soluble solids (TSS) provide valuable information about the biochemical transformations that take place during fermentation and are key indicators of product quality.

The raw samples, cassava, corn, and *Iru* showed pH levels characteristic of fresh, unfermented materials, with cassava being slightly acidic, corn more acidic, and *Iru* moderately neutral. After fermentation, significant pH alterations occurred. Cassava-based *Garri* retained mild acidity, whereas *Fufu* became more acidic due to the generation of organic acids by fermenting microorganisms. *Ogi* showed the lowest pH among all samples, signifying intense acid production, which contributes to its sour taste and enhanced keeping quality. In contrast, the fermented *Iru* varieties exhibited alkaline reactions, with *Iru pete* being slightly more alkaline than *Iru woro*. This alkalinity results from proteolytic microbial activity that liberates ammonia and other nitrogenous bases, producing *Iru*'s characteristic pungent odour.

Total titratable acidity followed a complementary pattern to pH. Initially, cassava had the least acidity, corn was moderate, and *Iru* seed had relatively higher acidity. After fermentation, cassava products displayed varying acid responses: *Garri* recorded a mild increase, *Fufu* slightly declined, and *Ogi* experienced a marked rise, confirming lactic acid fermentation as its dominant biochemical process. Fermented *Iru* samples retained relatively high acidity despite their alkaline pH values, indicating simultaneous production of both acidic and basic compounds. This dual metabolic activity contributes to *Iru*'s unique flavour profile and aids in protein hydrolysis during fermentation.

The total soluble solids also varied significantly between raw and fermented samples. Raw cassava and *Iru* had moderate levels of soluble substances, whereas corn contained less. Following fermentation, *Garri* showed a small increase in TSS, *Fufu* exhibited a slight decrease, likely from solute loss during soaking, and *Ogi* recorded the highest value. The elevated TSS in *Ogi* suggests starch degradation and accumulation of sugars and organic acids. Similarly, *Iru woro* and *Iru pete* displayed increased soluble solids compared to raw *Iru* seed, reflecting extensive enzymatic breakdown of complex macromolecules into soluble peptides, amino acids, and sugars that define the rich taste and aroma of fermented *Iru*.

Fermentation induced pronounced physicochemical transformations in the foods. Cassava and corn fermentations were characterised by acidification and lactic acid production, improving preservation and taste, while *Iru* fermentation was defined by alkaline reactions and solute accumulation due to proteolytic microbial activity. These changes collectively enhance the flavour, nutritional composition, and shelf stability of the fermented products.

Table 4.4: Physicochemical properties of raw and fermented foods

Raw Foods			
Samples	pH	TTA (%)	TSS (%)
Cassava	6.63±0.01 ^c	0.05±0.00 ^a	6.53±0.04 ^c
Corn	6.13±0.02 ^a	0.52±0.00 ^b	2.83±0.02 ^a
<i>Iru</i> seed	6.34±0.02 ^b	0.98±0.00 ^c	6.14±0.02 ^b
Fermented foods			
<i>Garri</i>	6.43±0.03 ^c	0.17±0.00 ^b	7.64±0.03 ^b
<i>Fufu</i>	5.87±0.04 ^b	0.04±0.00 ^a	5.30±0.02 ^a
<i>Ogi</i>	3.43±0.03 ^a	0.71±0.00 ^c	16.10±0.02 ^a
<i>Iru Woro</i>	8.12±0.01 ^d	0.95±0.00 ^c	8.63±0.03 ^c
<i>Iru pete</i>	8.34±0.03 ^c	0.76±0.00 ^d	9.84±0.03 ^d

Mean values with different superscripts within the same column are significantly different ($p < 0.05$). TTA = total titratable acidity, TSS = total soluble solid

Antioxidant Properties of Raw and Fermented Foods

Four antioxidant indices were evaluated: total phenolic content (TPC), DPPH radical scavenging activity, ferric reducing antioxidant power (FRAP), and ABTS radical scavenging capacity. These parameters provide insight into the ability of foods to neutralise free radicals and protect against oxidative stress.

Distinct trends were observed between the raw and fermented foods. The total phenolic content, which represents the concentration of phenolic compounds responsible for antioxidant activity, was generally higher in the raw samples than in their fermented forms. Raw cassava exhibited the highest phenolic level, but this declined notably after fermentation in *garri* and *Fufu*, suggesting that processing and microbial activity may have caused the degradation or leaching of phenolic compounds. Only *ogi* retained a relatively higher amount compared to other cassava-based fermented products. In contrast, fermentation of *Iru* slightly enhanced its phenolic composition, as observed in *Iru woro* and *Iru pete*, indicating that microbial enzymes may have broken down complex bound phenolics into simpler, more extractable forms.

The DPPH radical scavenging activity, which measures the capacity to neutralise free radicals, improved in most fermented samples compared to their raw equivalents. Raw cassava exhibited the weakest antioxidant response, whereas its fermented derivatives—particularly *ogi*—showed marked improvement. Similarly, the fermentation of *Iru* led to greater DPPH activity, with *Iru pete* showing the highest enhancement, suggesting that fermentation promotes the release of bioactive antioxidant compounds in *Iru* products.

In terms of ferric reducing antioxidant power (FRAP), the raw foods displayed stronger reducing capacity than their fermented counterparts, except for *Iru*, where fermentation significantly boosted reducing power. Cassava-based fermented foods showed a decline in FRAP, implying

the loss of reducing agents during fermentation. However, both *Iru woro* and *Iru pete* recorded higher FRAP values than raw *Iru* seed, highlighting the ability of fermentation to enhance electron-donating potential and overall antioxidant strength in *Iru*-based foods.

The ABTS radical scavenging activity exhibited a similar pattern. Fermentation reduced ABTS activity in cassava-derived products but enhanced it considerably in *Iru*-based foods. While raw cassava, corn, and *Iru* seed displayed moderate to high ABTS activity, fermentation led to a decrease in *garri* and *Fufu*, whereas *ogi* maintained an intermediate level. In contrast, *Iru woro* and *Iru pete* showed substantial increases, indicating superior antioxidant performance following fermentation.

Fermentation tended to reduce the antioxidant potential of cassava-based foods but improved that of *Iru*. The process contributed to the loss of phenolic and reducing substances in cassava, while encouraging the formation of more potent antioxidant compounds in fermented *Iru* products. This demonstrates that the effect of fermentation on antioxidant properties is dependent on the food matrix and the specific microbial interactions involved.

Table 4.5: Antioxidant properties of raw and fermented food

Raw Foods				
Samples	TPC (g/100 g GAE)	DPPH (% Inh./mg DM)	FRAP (mmol/100 g)	ABTS (mM 100 g⁻¹ DW)
Cassava	30.69±0.00 ^c	34.86±0.00 ^a	2.98±0.00 ^b	3.55±0.00 ^a
Corn	3.46±0.00 ^b	62.93±0.00 ^b	8.11±0.00 ^c	7.17±0.00 ^b
<i>Iru</i> seed	0.69±0.00 ^a	77.82±0.00 ^c	1.53±0.00 ^a	9.15±0.00 ^c
Fermented Foods				
<i>Garri</i>	0.46±0.00 ^b	55.89±0.00 ^b	0.80±0.00 ^c	0.03±0.00 ^a
<i>Fufu</i>	0.04±0.00 ^a	51.24±0.00 ^a	0.58±0.00 ^b	0.12±0.00 ^b
<i>Ogi</i>	14.35±0.00 ^c	81.45±0.00 ^c	0.11±0.00 ^a	4.45±0.00 ^c
<i>Iru Woro</i>	0.82±0.00 ^c	83.12±0.00 ^d	3.81±0.00 ^d	12.16±0.00 ^d
<i>Iru pete</i>	0.92±0.00 ^d	87.93±0.00 ^e	5.12±0.00 ^e	15.12±0.00 ^e

Mean values with different superscripts within the same column are significantly different ($p < 0.05$). TPC: Total Phenolic Content, DPPH: 1, 1-Diphenyl-2-picrylhydrazyl, FRAP: Ferric Reducing Antioxidant Power, ABTS: 2,2'-Azinobis[3-ethylbenzthiazoline]-6-sulfonic acid

Microbial Counts of Raw and Fermented Foods

Microbial counts are presented as $\log_{10}$ CFU/g, indicating the relative levels of different microbial groups present in raw and fermented foods. The analysis includes total viable counts (TVC), lactic acid bacteria (LAB), *Bacillus* species, yeasts and moulds, as well as members of the Enterobacteriaceae family.

The raw foods exhibited moderate counts of different microbial groups. Cassava, corn, and *Iru* seeds each contained measurable levels of microorganisms, reflecting the natural flora associated with plant-based substrates. Cassava tuber showed the lowest TVC, while corn and *Iru* seed recorded higher values, indicating a richer microbial load before fermentation. Lactic acid bacteria (LAB) were present in small quantities across all raw samples, while *Bacillus* species were more abundant in *Iru* seed than in cassava or corn. Yeasts and moulds were detected in moderate amounts, and the Enterobacteriaceae family occurred in relatively high numbers, suggesting environmental contamination from soil or handling.

Following fermentation, microbial activity increased notably in most products. In cassava-based foods, *Fufu* and *ogi* exhibited much higher TVC than their raw counterparts, showing intense microbial proliferation during fermentation. Conversely, *garri* displayed reduced counts due to roasting and drying, which limit microbial survival. Fermented *Iru* products—*Iru woro* and *Iru pete*—showed the highest microbial loads overall, signifying the rich microbial activity and enzymatic processes associated with traditional condiment fermentation.

LAB populations rose sharply in *Fufu* and *ogi*, confirming the dominance of lactic acid bacteria during fermentation and their role in acid production and preservation. *Garri*, *Iru woro*, and *Iru pete* contained moderate LAB counts, reflecting differences in fermentation conditions.

Bacillus species became highly dominant in fermented *Iru*, emphasising their importance in protein breakdown and flavour development. In contrast, their levels remained lower in fermented cassava and corn products, where other microorganisms predominate.

Yeasts and moulds also increased during fermentation, especially in *ogi*, which is characterised by its sour taste and pleasant aroma resulting from yeast metabolism. Moderate yeast growth was observed in *Fufu* and *Iru* products, contributing to desirable sensory attributes without causing spoilage.

Enterobacteriaceae counts decreased substantially after fermentation, signifying an improvement in microbial safety. The lowest counts were recorded in *garri*, *ogi*, and *Iru pete*, due to acidification, heat, and drying processes that inhibit pathogenic growth. *Fufu* and *Iru woro* retained slightly higher counts but remained within acceptable safe limits.

These findings indicate that fermentation leads to marked changes in microbial composition and load, enhancing beneficial groups such as LAB and *Bacillus* while suppressing undesirable bacteria. This microbial shift contributes to the improved safety, stability, and nutritional quality of traditionally fermented foods.

Table 4.6: Microbiological Counts of Raw and Fermented Foods ($\log_{10}$ CFU/g, mean $\pm$ SD)

Sample	TVC	LAB	Bacillus spp.	Yeasts & Moulds	Enterobacteriaceae
Raw Samples					
Cassava Tuber (raw)	4.20 ± 0.20^a	2.10 ± 0.10^a	3.00 ± 0.20^a	2.30 ± 0.10^a	3.80 ± 0.20^a
Corn Grain (raw)	5.80 ± 0.30^b	2.50 ± 0.10^b	3.60 ± 0.20^b	3.20 ± 0.20^b	4.00 ± 0.20^b
Iru Seed (raw)	6.50 ± 0.20^c	3.10 ± 0.20^c	5.20 ± 0.30^c	3.00 ± 0.20^b	4.30 ± 0.20^c
Fermented Samples					
Garri	3.80 ± 0.20^a	3.50 ± 0.20^c	3.10 ± 0.20^a	3.00 ± 0.20^a	2.00 ± 0.10^a
Fufu	7.20 ± 0.30^b	6.50 ± 0.20^d	3.80 ± 0.20^c	4.20 ± 0.20^d	3.50 ± 0.20^e
Ogi	8.10 ± 0.20^c	8.00 ± 0.10^e	3.50 ± 0.20^b	6.90 ± 0.20^e	2.60 ± 0.20^b
Iru Woro	8.60 ± 0.20^e	3.20 ± 0.20^b	8.40 ± 0.20^e	3.80 ± 0.20^c	3.00 ± 0.10^d
Iru Pete	8.20 ± 0.20^d	3.00 ± 0.20^a	7.80 ± 0.20^d	3.50 ± 0.20^b	2.80 ± 0.20^c

Mean values with different superscripts within the same column are significantly different ($p < 0.05$). TVC: Total viable count, LAB: Lactic acid bacteria.

Microbial Identification of Raw and Fermented Foods

The microbial identification of raw and fermented foods revealed diverse organisms, including bacteria, yeasts, and moulds, which play important roles in fermentation and spoilage. In raw samples, cassava harboured yellow yeast, *Lactobacillus plantarum*, and *Aspergillus niger*, indicating the presence of both beneficial fermentative microbes and spoilage fungi. Corn was dominated by *Lactobacillus plantarum*, a lactic acid bacterium known for acid production and preservation. Raw *Iru* seed showed the presence of *Syncephalastrum spp.* (a mould related to *Aspergillus*) and *Bacillus subtilis*, highlighting the natural microbial flora associated with African locust beans.

In fermented products, microbial populations were more specific to the type of food. *Garri* contained white yeast and *Aspergillus niger*, while Fufu was dominated by white yeast and *Bacillus subtilis*, reflecting their importance in starch breakdown and protein modification. *Ogi* fermentation was driven mainly by white yeast and *Lactobacillus plantarum*, consistent with its acidic and sour taste. Both *Iru woro* and *Iru pete* were dominated by *Bacillus subtilis*, confirming its role as the primary fermenter in African locust bean fermentation, where it contributes to the strong flavour, aroma, and breakdown of complex proteins into simpler amino acids.

Table 4.7: Microbial Identification of Raw and Fermented Foods

Samples	Microorganisms Identified
Raw	
Cassava	Yellow yeast, <i>Lactobacillus plantarum</i> , <i>Aspergillus niger</i>
Corn	<i>Lactobacillus plantarum</i>
<i>Iru seed</i>	<i>Syncephalastrum</i> spp. (<i>Aspergillus</i>), <i>Bacillus subtilis</i>
Fermented	
<i>Garri</i>	White yeast, <i>Aspergillus niger</i>
<i>Fufu</i>	White yeast, <i>Bacillus subtilis</i>
<i>Ogi</i>	White yeast, <i>Lactobacillus plantarum</i>
<i>Iru Woro</i>	<i>Bacillus subtilis</i>
<i>Iru Pete</i>	<i>Bacillus subtilis</i>

4.2 Discussion of Findings

Proximate Composition of Raw and Fermented Foods

The moisture contents of the raw foods varied significantly ($p < 0.05$), with cassava having the highest moisture content, while the least moisture content was observed in corn. Moisture content serves as an indicator of the storage, shelf stability, and safety of food products, with $\leq 15\%$ moisture content being considered ideal for long shelf stability ². Therefore, the corn and *Iru* seed samples may have longer storability than cassava roots. High moisture content observed in the cassava sample could be attributed to the inherent high moisture in cassava root varieties ³. The low moisture levels recorded in both the corn and *Iru* seed samples are consistent with previous studies, which reported moisture contents ranging from 10.39% to 14.02% in maize and approximately 18.64% in raw *Iru* seeds ^{1, 4}. The dry matter contents of the raw foods revealed that corn had the highest value, while cassava had the lowest. There were significant differences at a 95% confidence level between the dry matter contents of the raw foods. Higher dry matter content has been linked to larger flour particle sizes and higher fibre but lower ash content; hence, the corn sample could have the low ash content but higher fibre and larger particle size, respectively ⁵. Similar findings had been reported for dry matter, 70.2 – 93.4% of corn ⁶. The dry matter contents observed for *Iru* seeds and cassava roots in the current study are consistent with previously reported values—88.79% for African locust bean seeds and 24.64–37.96% for cassava ^{7, 8}. Higher dry matter content has been linked to larger flour particle sizes and higher fibre but lower ash content ⁸. The crude fat contents of the raw foods varied significantly ($p < 0.05$) with the highest crude fat content being observed in *Iru* seed while cassava had the lowest crude fat content. Highest crude fat content shown in the *Iru* seed could be attributed to the high fat content in African locust bean seeds; however, the lower crude fat content for the *Iru* seeds in

the current study is a pointer to agronomical differences, which could play a significant role in levels of nutritional contents in raw food materials ⁴. The low crude fat content (1.68–3.06%) previously reported for cassava supports the findings of the current study, which observed similarly low-fat levels in the cassava root sample ⁹. The slightly higher fat content observed in the corn sample, relative to the cassava root, aligns with the report that fat levels ranging from 3.53% to 4.47% in maize harvested at various growth stages ¹⁰. However, the low-fat content of the raw foods in the current study suggested that they could be less prone to oxidative rancidity; hence, an indication of long shelf stability ². The mean results for the total ash contents of the raw foods varied significantly ($p < .05$). *Iru* seed had the highest total ash content, while the lowest total ash content was observed in cassava. The ash content serves as an indicator of the total mineral composition in a food sample, offering insight into its nutritional value ^{11, 12}. Accordingly, the higher ash content observed in *Iru* seeds suggests they may possess greater mineral density compared to corn and cassava root samples. The higher ash content observed in *Iru* seeds is expected, as it has previously been reported that locust bean seeds contain approximately 4.24% ash, along with elevated levels of essential minerals such as potassium, magnesium, calcium, iron, and phosphorus nutrients vital for metabolic processes and physiological functions ⁷. The total ash content reported for raw maize, ranging from 2.22% to 2.61% at various growth stages, is higher than the 1.26% observed in the corn sample analysed in the current study ¹⁰. Similarly, it was reported that crude fat content ranged from 1.38% to 3.06% in cassava root, values that exceed those observed in the present study ⁹. Agronomical differences or stages in crop maturity may have influenced differences or variation in values in the current study and the cited literature. The crude fibre contents of the raw foods showed that corn had the highest value, while cassava recorded the lowest. Significant differences ($p < 0.05$)

were observed between the crude fibre contents of the raw foods. The highest crude fibre observed in the corn is an indication of characteristic coarseness, while the less fibrous nature of *Iru* seed and cassava, respectively, is a pointer to finer inherent fibre. This is expected, as previous studies have shown that corn contains higher crude fibre levels ranging from 2.3% to 22.8% compared to African locust bean seeds (3.29%) and cassava (1.58–2.96%)^{6, 4, 9}. For human digestive health and healthy bowel movement, dietary fibre is essential. Additionally, it helps keep the stomach full for longer periods, lowers blood sugar and cholesterol, and helps treat conditions including diabetes, heart disease, and bowel cancer¹².

The crude protein contents of the raw foods varied significantly at a 95% confidence level. *Iru* seed had the highest crude protein, while the lowest value was observed in cassava. The highest crude protein content observed in *Iru* seeds aligns with the 39.59% previously reported, while lower protein values of 1.32–1.90% for cassava and 9.14–13.02% for various corn varieties have also been documented^{4, 9, 1}. Therefore, high protein content in the *Iru* seed sample of the current study makes it a subtle means of delivering protein needed development and repair of damaged tissues; besides, its utilisation has been comprehensively reviewed in literature¹⁵. Proteins are vital nitrogenous substances that both humans and animals require for tissue growth, development, and repair. They accomplish this by supplying vital nutrients, preserving bodily fluid balance, and supporting immunological response and enzyme synthesis^{13, 14}.

The total carbohydrate contents of the raw food samples showed that corn had the highest value whereas cassava recorded the lowest. There were significant differences ($p < 0.05$) between the total carbohydrate contents of the raw food samples. The carbohydrate content results from the current study align with earlier findings, which reported 41.10% in African locust bean, 23.14–

31.28% in various cassava varieties, and 69.7–75.74% in different corn cultivars ^{7, 3, 1}. High carbohydrate content in the corn could suffice for provision of energy needed to do work ^{2, 12}.

Foods' moisture content tells us about their safety and shelf life ¹⁶.

The moisture contents of the fermented foods varied significantly at a 95% confidence level, with *Fufu* having the highest moisture content while *Garri* had the lowest level of moisture. The highest moisture content observed in the *Fufu* sample is an indication that it could be prone to microbial spoilage, especially as it will create an enabling environment for bacteria, yeast, mould, as well as the development of off flavours, short shelf life and textural degradation. The moisture content of the *Fufu* sample in the current study is higher than 52.6 – 59.4% reported for the moisture contents of *Fufu* dough sold in different markets of Akwa Ibom and Rivers state, Nigeria, ¹⁷. However, the lowest moisture content observed in the *Garri* sample is advantageous as the fermented food product will have long shelf stability and retain its quality, provided that better packaging material is employed. The moisture contents of the *Garri* samples are lower than 12.55 – 15.74% reported for *Garri* samples ¹⁸. The moisture contents of the *Iru woro* and *Iru pete* in the current study are lower than 11.63 – 22.09% for the moisture contents of *Iru woro* and *Iru pete* studied ¹⁹. Similarly, the moisture contents of the *Ogi* sample in the current investigation is higher than 8.31 – 8.98% reported for the moisture content of maize *Ogi* enriched with defatted baobab seed ²⁰. Variation in values could be attributed to differences in processing operations employed in the respective studies.

The highest dry matter content was observed in *Garri*, while the lowest value was observed in the *Fufu* sample. There were significant differences ($p < 0.05$) between the dry matter contents of the fermented food samples. Higher dry matter content is generally linked to reduced ash levels, suggesting that the *Garri* sample may possess lower ash content compared to the other fermented

food samples ¹⁸. On the flip side, given that it is a crucial component in determining the marketability of foods, the *Garri* sample's best dry matter content may be a sign of a desirable quality trait ¹⁷. High dry matter contents, 88.7 – 95.6% of *Garri*, have also been reported ⁴⁵. The result obtained for the dry matter content of *Fufu* dough in the current study is lower than 45.4 – 48.3% reported for *Fufu* dough sold in different markets of Akwa Ibom and Rivers States, Nigeria ¹⁷. The dry matter content of the *Ogi* sample in the current study is lower than the 93.4% reported for *Ogi* supplemented with date flour and the 91.37% reported for *Ogi* powder supplemented with termite flour ^{21, 22}. Similar dry matter contents ranging from 83.78% to 89.67% were reported for *Iru* fermented both spontaneously and using *Bacillus subtilis* as a starter culture ²³. Variation in values of the current study and those in the cited previous studies could be attributed to differences in raw materials or the medium of fermentation used in the cited literature. Dry matter is the substance that remains in a meal sample after the water has been removed, and it serves as a gauge for the quantity of nutrients present ¹⁷.

The crude fat contents of the fermented food samples showed that *Iru woro* had the highest value, while the *Ogi* sample recorded the lowest. Significant ($p < 0.05$) differences were observed between the crude fat contents of the fermented foods. The highest fat content observed in *Iru woro* is consistent with the 13.82–14.06% reported for *Iru* fermented with *Bacillus subtilis* A₂ and falls within the 13.62–19.6% range observed for *Iru* made from locust bean and soybean fermented with *Bacillus subtilis* A₂, but it is higher than the 5.915–9.895% reported for *Iru* produced from locust bean seeds and mesquite/okpehe, and the 3.00–5.30% lipid content recorded for *daddawa* produced by local fermentation of African locust bean, soybean, and *Hibiscus sabdariffa* seeds ^{23, 28}. The reported crude fat content of the *Garri* sample in the current study is higher than 0.09 – 0.33% for lipid contents of yellow and white *Garri* researched ¹⁸. The

findings of the current study for the fat content of *Ogi* are lower than 2.14 – 8.96% reported for the fat contents of *Ogi* and date flour blends ²¹. The fat content of the *Fufu* sample in the current study falls within the 1.20–5.40% range reported for stiff dough made from blends of pearl millet, white maize, and cassava, but is higher than the 0.51–1.22% range reported for the fat content of *Fufu* flour derived from various cassava varieties ^{22, 24}. Cassava and its products are well recognised for their naturally low fat content, thereby supporting the findings of low-fat levels in the fermented cassava-based products examined in the present study ²².

The total ash contents of the fermented food samples varied significantly ($p < 0.05$), with the highest total ash content being observed in *Garri*, while the lowest value for total ash was observed in the *Ogi* sample. Ash is an index of minerals in foods; thus, the *Garri* sample may contain higher mineral contents than other fermented food samples. The ash content of the *Garri* sample in the present study falls within the 0.33–3.61% range reported for *Garri* derived from various cassava varieties, but it is higher than the 1.44–1.99% reported for *Garri* from white and yellow cassava roots and the 0.09–0.18% reported for *Garri* made from cassava varieties across five local government areas in Ekiti State, Nigeria ^{34, 22, 33}. The ash content of the *Fufu* sample is in line with 0.33 – 0.54% for ash contents of *Fufu* powder, but lower than 0.63 – 0.85% reported for ash content of *Fufu* dough sold in different markets in Akwa Ibom and Rivers States, Nigeria ^{25, 17}. The findings of the current study for total ash content of the *Ogi* are lower than 0.95 – 1.27% for ash contents of maize *Ogi*-almond nut flour blends by 1.55 – 1.70% for ash contents of fermented yellow and white *akamu* ^{26, 27}. However, a similar report for the ash content of the *Iru woro* and *Iru pete* had been documented for ash contents 2.6 – 3.69% of *Iru* produced from locust bean and soybean with *Bacillus subtilis* A₂ ²³. It is anticipated that food items with a high

percentage of ash contain significant concentrations of mineral elements, which will accelerate metabolic processes and enhance human growth and development ¹⁷.

The crude fibre contents of the fermented food samples revealed that *Garri* had the highest crude value (5.57%) while the *Ogi* sample recorded the lowest (2.29%). Significant differences at 95% confidence level were observed between the crude fibre contents of the fermented food samples.

The value reported for the crude fibre content of the *Garri* sample is lower than 8.018 – 9.12% for fibre contents of yellow and white *Garri*, but higher than 1.21 – 1.42% for fibre contents of *Garri* produced from cassava varieties from five local government areas in Ekiti state, Nigeria ¹⁸,

³³. Fibre contents ranging from 2.3% to 8.2% were reported for stiff dough prepared from composite flour of pearl millet, white maize, and cassava in Enugu State, Nigeria, which aligns with the range observed in the present study ²⁴. The reduction in crude fibre content observed in

the fermented *Iru woro* and *pete* does not align with previous findings, which reported an increase ranging from 5.10% to 15.60% in crude fibre content of *Iru* following fermentation ²⁸.

On the flip side, Laba *et al.* (2024) reported 1.59 – 1.965% for crude fibre contents of *Iru woro* and *Iru Pete*, which are lower than the findings of the current study for crude fibre content of similar fermented food samples (*Iru woro* and *pete*). The raw material composition, microbial activity, fermentation conditions and duration, pre- or post-fermentation processing techniques, and other factors can all affect the crude fibre content of the fermented food samples.

The crude protein contents of the fermented food samples varied significantly ($p < 0.05$) with the highest crude protein content (25.74%) being observed in *Iru woro*, while the least crude protein content (1.45%) was observed in the *Fufu* sample. The highest protein content observed in *Iru woro* could be attributed to the high protein content 11.70% inherent in *Iru* seed; therefore, its inclusion as a condiment in soups serves as a nutritional advantage, especially in developing

countries such as Nigeria, where protein-rich diets are expensive ²⁸. Additionally, fermentation has been reported to improve the crude protein content of *Iru* seeds ^{28,19}. However, the protein contents of the *Iru woro* and *Iru pete* samples are lower than 32.2 – 44.70% for the protein contents of *Iru* produced from locust bean and soybean with *Bacillus subtilis* A₂ ²³. The reduction in protein content from 9.14% in raw corn to 1.81% in *Ogi* observed in the current study supports the claims of Sinay and Harijati that while raw corn of various varieties contains 9.14–13.02% protein, fermentation significantly decreases the protein content to between 1.771% and 2.373% when processed into *Ogi* ^{1, 30}. Cassava-based fermented products such as *Fufu* have been reported to contain low proteins, 0.96 – 1.49% and 0.17 – 0.88%; hence, corroborating the low protein content observed in the *Fufu* sample of the current study ^{17,22}.

The total carbohydrate contents of the fermented food samples showed that *Garri* sample had the highest value (86.26%) while *Iru pete* sample recorded had the least value (10.09%). Significant differences ($p < .05$) were observed between the total carbohydrate contents of the fermented food samples. The carbohydrate content of the *gari* sample aligns with 77.55 – 83.27% reported for the carbohydrate content of *Garri* from white and yellow cassava roots studied by Joel *et al.* (2019) and 74.91 – 76.91% for the carbohydrate contents of yellow and white *Garri* ¹⁸. The carbohydrate contents of the *Iru woro* and *pete* samples are lower than 33.36 – 36.88% for the carbohydrate contents of *Iru* fermented with *Bacillus subtilis* A₂ and 36.995 – 51.655% for the carbohydrate contents of *Iru woro* and *Iru pete* from African locust beans and okpehe ¹⁹. The current study's *Iru* samples' lower carbohydrate contents may be the result of bacteria, particularly *Bacillus subtilis*, using the carbohydrates in locust bean seeds to break down the sugar and produce CO₂ and organic acids. Enzymatic hydrolysis and conversion, loss of water-soluble carbohydrates are also contributors to reduced carbohydrate contents of the *Iru pete* and

Ogi samples. Similar observations had been reported for unfermented 70.00% and fermented 58.30% *Iru* condiments²⁸. The carbohydrate contents of the *Fufu* and *Ogi* samples in the current study are lower than the 60.52–81.74% reported for fermented maize-defatted baobab seed, and also lower than the 67.50–86.36% reported for Fufu dough sold in different markets across Akwa Ibom and Rivers States, Nigeria^{20, 17}. However, they align with the 41.68–50.003% reported for different varieties of pap sold in Owo market³⁰. The high energy values recorded for the *Garri*, *Fufu*, and *Ogi* samples could suffice where high energy diets are required.

Selected Mineral Composition of Raw and Fermented Foods

Minerals, a vital class of inorganic nutrients, must be consumed in daily amounts ranging from 1 to 2500 mg depending on the type⁵⁸. The calcium content of the raw food samples revealed that *Iru* seed exhibit the highest value (495.82 mg/100 g), while corn had the lowest (8.26 mg/100 g). These differences were statistically significant at the 95% confidence level. The calcium levels observed in the raw food samples are lower than the 933.45–1388.15 mg/100 g reported for selected legumes such as brown cowpea, black-eyed pea, soybean, and groundnut, and also lower than the 414–9747 mg/kg range reported for various root and tuber crops including sweet potato, purple yam, cassava, taro, cocoyam, and giant swamp taro^{57, 58}. Nonetheless, the high calcium content recorded for *Iru* seed aligns with previous findings, as earlier studies reported values of 222.2 mg/100 g and 103.25 mg/kg (equivalent to 10.325 mg/100 g), respectively—differences that may be attributed to varietal composition, geographic origin, or analytical methodology^{7, 56}. The calcium content of cassava in the current study (18.92 mg/100 g) is comparable to the 12.80–17.75 mg/100 g range reported for various sweet potato varieties, including Cardinal, Chipsona, Desiree, Lady Rosetta, and Satellite⁴⁵. The notably high calcium content in *Iru* seed highlights its potential to help meet daily calcium requirements. This is

especially significant considering calcium's essential role in supporting bone development during infancy and childhood, where adequate intake promotes optimal skeletal growth and density. Furthermore, calcium contributes to the prevention of osteoporosis and is involved in muscle contraction and nerve transmission, all of which are essential for maintaining overall health and physiological function ^{59, 60}.

The magnesium contents of the raw food samples varied significantly ($p < 0.05$) with *Iru* seed having the highest value (324.19 mg/100 g), while the lowest value (20.69 mg/100 g) was observed in the cassava sample. The highest magnesium content observed in the *Iru* seed is higher than 280.2 mg/100 g reported for the magnesium content of African locust bean, 96.34 mg/100 g for the magnesium content of *Parkia biglobosa* seeds and 2.49 mg/100 g for unfermented parkia seeds ^{7, 56, 40}. On the flip side, the magnesium content of the corn sample 38.64 mg/100 g is lower than 1578.50 – 2320.50 mg/kg reported for magnesium contents of some legumes (brown cowpea, black-eyed pea, soybean and groundnut) but higher than 14.15 – 21.19 ppm reported for magnesium contents of some cereal varieties (Reyna, Atilla, Norman B., Samsorg -41, Samsorg-45, Samsorg -46, Smz- 15, Smz -39, Evdt -2009) available in Kano ^{57, 62}. The magnesium content 20.69 mg/100 g of the cassava sample is lower than 313 – 896 mg/kg reported for magnesium contents of different root and tuber crops (sweet potato, purple yam, cassava, taro, cocoyam, and giant swamp taro) ⁵⁸.

The highest iron content (10.37 mg/100 g) was observed in *Iru* seed, while the cassava sample had the lowest iron content (0.26 mg/100 g). The result showed significant variations ($p < .05$) between the iron contents of the raw food samples. The findings of the current study for the iron content of the *Iru* seed aligns with 10.31 mg/100 g for the iron content of *Parkia biglobosa* seeds, slightly in line with 9.3 mg/100 g reported for African locust bean seed, but higher than 1.46

mg/100 g reported for the iron content of *Parkia biglobosa* ^{56, 7, 63}. The iron contents of other raw food samples (cassava and corn) are slightly in consonance with 0.04 – 0.27 mg/100 g reported for iron contents of selected root and tuber crops (sweet potato, purple yam, cassava, taro, cocoyam and giant swamp taro) but lower than 1.68 – 2.19 mg/100 g reported for iron contents of different potatoes studied ^{58, 45}. Except for the *Iru* seed sample in the current sample which meets the recommended dietary requirement for male 8 mg/day, the iron contents of other raw food samples are below this benchmark; hence, indicating that corn and cassava may not be a good source of iron ⁵⁸. The zinc contents of the raw food samples varied significantly at 95% confidence level. *Iru* seed had the highest value (1.35 mg/100 g) while cassava sample recorded the lowest value (0.38 mg/100 g). The results are in tandem with values reported for zinc content of some cereals (0.49–1.44 ppm), such as Reyna, Attila, Norman B., Samsorg-41, Samsorg-45, Samsorg-46, Smz-15, Smz-39, and Evdt-2009, available in Kano ⁶². They are higher than 0.17 mg/kg for African locust bean seed, but lower than 3.8 mg/100 g reported for African locust bean, 7.6–100 mg/kg for various root and tuber crops like sweet potato, purple yam, cassava, taro, cocoyam, and giant swamp taro, and 294.39 mg/100 g for raw locust bean ^{56, 7, 58, 38}. The zinc contents of the raw food samples in the current study are below the recommended daily intake for zinc of 500 mg/100 g; hence, they may not suffice as a valuable source of zinc ^{38, 64}.

The calcium contents of the fermented food samples varied significantly ($p < 0.05$), however, *Iru pete* had the highest value (847.69 mg/100 g), while *Ogi* sample had the lowest value (14.87 mg/100 g). The findings of the current study fall within the range of 19.68–20.94 mg/100 g reported for calcium content in fermented soybean and locust bean. They are also higher than the 0.50–1.30 mg/kg reported for *daddawa* produced by local fermentation from seeds of *Parkia biglobosa*, *Glycine max*, and *Hibiscus sabdariffa*, and the 6.84–9.33 mg/100 g reported for

calcium content in *Ogi* enriched with date flour ^{21, 28}. However, they are lower than the 55.84–57.81 mg/100 g reported for partially and fully fermented locust bean seeds, and the 40.13–60.11 mg/100 g reported for *lafun* made from refrigerated cassava root ^{31, 40}. Together with phosphorus, calcium promotes bone growth and strength and supports proper muscle function ²¹.

The magnesium contents of the fermented food samples showed that *Iru woro* had the highest value (213.81 mg/100 g), while *Garri* had the lowest (8.67 mg/100 g). Significant differences ($p < .05$) were observed among the magnesium contents of the fermented food samples. The values obtained for *Iru woro* and *Iru pete* in the current study are higher than the 0.30–0.80 mg/kg reported for *daddawa* produced by local fermentation of *Parkia biglobosa*, *Glycine max*, and *Hibiscus sabdariffa* seeds, and the 0.17–0.24 mg/100 g reported for fermented locust bean and sorrel seed condiments ^{28, 65}. The magnesium content of the *Fufu* sample aligns with the 20.12–40.99 mg/100 g range reported for *Fufu* made from refrigerated cassava root ³¹. Magnesium is an essential nutrient for healthy metabolism and bone mineral density, serving as a co-factor in numerous enzymatic processes involved in critical metabolic pathways ⁶¹.

The iron contents of the fermented food samples varied significantly at 95% confidence level, however, *Iru pete* had the highest iron content (17.32 mg/100 g) while *Ogi* had the lowest iron content (0.18 mg/100 g). The iron content of the *Ogi* sample is lower than 1.64 – 7.63 mg/100g reported for the iron content of *Ogi* supplemented with date fruit flour studied by ²¹. Variation in values could be attributed to differences in raw materials used in their study. The findings of the current study for the iron content of *Fufu* are lower than 1.20 –1.80 mg/100 g reported for the iron content of *lafun* ³¹. The values of 0.14–2.19 mg/100 g for iron content reported for dried fermented locust bean and sorrel seed condiments are lower than the 14.92–17.32 mg/100 g observed for *Iru woro* and *Iru pete* in the current study ⁶⁵. The iron contents of 41.53–44.72

mg/100 g in dried fermented locust bean and soybean condiments are higher than the values reported for Iru woro and Iru pete in the current study ⁵⁴. The zinc contents of the fermented food samples varied significantly ($p < 0.05$). *Iru pete* had the highest zinc content (5.31 mg/100 g), while the lowest zinc content (0.31 mg/100 g) was observed in the *Fufu* sample. The results fall within the range of 3.40–7.65 mg/100 g reported for the zinc content of *lafun* from refrigerated cassava root ³¹. They are also comparable to the 0.19–1.20 mg/100 g reported for zinc content of dried *Ogi* supplemented with date flour as a sugar substitute, the 2.89–3.21 mg/100 g reported for *Ogi* powder supplemented with termite flour, and the 0.80–1.07 mg/100 g reported for *Ogi* powder made from yellow and white maize, finger millet, popcorn maize, and white and red sorghum ^{21, 22, 66}. Zinc is essential for numerous physiological functions, including growth, cell replication, fertility, reproduction, and hormone production ²².

Vitamin Composition of Raw and Fermented Foods

Vitamins can be divided into two groups: water-soluble and fat-soluble. Acid, base, heat, oxygen, and salt are some of the elements that can break down organic compounds like vitamins ⁶⁷. The vitamin A contents of the raw food samples varied significantly ($p < .05$), with the corn sample exhibiting the highest value (10.86 mg/100 g) and cassava the lowest (1.86 mg/100 g). These findings are consistent with the 1248–2303 $\mu\text{g}/100\text{ g}$ range reported for pigeon pea seeds and the 3.36–4051.98 $\mu\text{g}/100\text{ g}$ range observed in green spinach, red amaranth, barley, corn, and pineapple ^{68, 69}. The values are notably higher than the 0.00002 mg/100 g reported for whole grain cowpea, but lower than the 13.69 mg/kg reported for African locust bean and the 15 mg/100 g reported for raw and matured cowpea seeds ^{70, 76, 71}. Conversely, the vitamin A levels in the current study exceed the recommended dietary intake of 600 $\mu\text{g}/\text{day}$ ^{72, 61}. Vitamin A is

known to support growth and enhance immune function, making its presence in these foods nutritionally significant ⁷³.

The highest vitamin B₁ content (0.58 mg/100 g) was observed in *Iru* seed while cassava had the least vitamin B₁ content (0.08 mg/100 g). Significant variations ($p < 0.05$) were observed between the vitamin B₁ contents of the raw food samples. The results are slightly in consonance with reported values of 0.08–0.11 mg/100 g for some roots and tuber crops (potato, sweet potato, taro, cassava, and yam), 0.08–0.19 mg/100 g for selected cereals (guinea corn, maize, rice, and wheat), and 0.03 mg/100 g for African locust bean seeds, but are lower than 3.37–9.01 mg/100 g for purple sweet potato, green spinach, red amaranth, and barley ^{73, 69, 74, 76}.

The vitamin B₂ (riboflavin) contents of the raw food sample revealed that cassava sample had the highest vitamin B₂ content (0.09 mg/100 g), while the least vitamin B₂ content (0.04 mg/100 g) was observed in *Iru* seed. No significant difference ($p > 0.05$) was observed between the vitamin B₂ contents of cassava and *Iru* seed while the vitamin B₂ content of the corn sample differed significantly ($p < 0.05$) from other raw food samples. The vitamin B₂ contents reported in the current study are lower than those documented in earlier research. Reported values include 0.11–0.2 mg/100 g for selected whole cereal grains such as wheat, rice, and corn; 88.25–672.45 µg/100 g for purple sweet potato, green spinach, red amaranth, and barley; and 0.16 mg/100 g for African locust bean seeds. These higher values may be due to differences in the raw materials used, varietal composition, or agronomic and post-harvest practices ^{69, 75, 76}. The differences in raw materials and or agronomical practices may have resulted in variation in values.

The vitamin B₃ (niacin) contents of the raw food samples revealed that *Iru* seed had the highest vitamin B₃ content (0.58 mg/100 g) while cassava had the least vitamin B₃ content (0.08 mg/100 g). Significant variations ($p < .05$) were observed between the vitamin B₃ contents of the raw

food samples. The findings of the current study are higher than 0.56 mg/100 g reported for vitamin B₃ contents of African locust bean seeds, 0.00206 mg/100 g for vitamin B₃ contents of raw cowpea seeds and 0.05 – 0.55 mg/100 g for vitamin B₃ contents of selected cereals (guinea corn, rice and wheat) but slightly in line with 2.075 mg/100 g for niacin contents of raw and matured cowpea seeds and 3.6 – 4.62 mg/100 g for vitamin B₃ contents of selected cereals (wheat, rice and corn) reported by ^{73, 70, 75, 71}. The vitamin B₃ contents of the raw food samples are below the recommended daily dose of niacin: 5 – 6 mg for infants, 9 – 13 mg for children, 13 – 20 mg for adults, and 17 – 20 mg for pregnant and lactating mothers, respectively ⁷⁷.

The highest value for vitamin B₆ content (0.58 mg/100 g) was observed in *Iru* seed while corn had the lowest value for vitamin B₆ content (0.58 mg/100 g). Significant variations ($p < .05$) were observed between the vitamin B₆ contents of the raw food samples. The findings of the current study fall within the range of 0.24–10.7 mg/100 g reported for vitamin B₆ contents in purple sweet potato, green spinach, red amaranth, and barley ⁶⁹. They also align with the 0.119–0.443 mg/100 g range reported for raw barley, Eikorn, Kamut, millets, and oats, and the 0.08–0.293 mg/100 g range observed in root and tuber crops such as potato, sweet potato, taro, cassava, and yam ^{74, 78}. Except for the cassava sample, the vitamin B₆ contents of the corn and *Iru* seed samples in the current study are consistent with the recommended dietary allowance of 0.1–2.0 mg/day ⁷⁷.

The vitamin B₁₂ (Cyanocobalamin) contents of the raw food samples varied significantly ($p < .05$), the *Iru* seed exhibited the highest vitamin B₁₂ content (381.01 mg/100 g), while the corn sample had the lowest (0.01 mg/100 g). These values are in line with the 31.25 µg/100 g reported for purple sweet potato ⁶⁹. However, aside from the *Iru* seed, the vitamin B₁₂ contents of corn and cassava were lower than the 3.39 mg/100 g reported for African locust bean seeds ⁷⁶. Among

all the raw food samples analyzed, only the *Iru* seed exceeded the recommended dietary level of 2–5 mg/day for vitamin B₁₂ ⁷⁹. Therefore, corn and cassava may not be considered rich sources of this vitamin. Notably, vitamin B₁₂ deficiency has been associated with several disorders, including megaloblastic anemia, subacute combined degeneration of the spinal cord, methylmalonic acidemia, and pernicious anemia ⁸⁰.

The vitamin C contents of the raw food samples revealed that *Iru* seed had the highest vitamin C content (113.81 mg/100 g) while the least vitamin C content (8.13 mg/100 g) was observed in the corn sample. The vitamin C contents of the *Iru* seed sample is higher than 25.13 – 28.21 mg/100 g reported for vitamin C contents of pigeon pea seeds, 67.89 mg/100 g for vitamin C contents of African locust bean seeds by Enoch *et al.* (2025) but lower than 135.76 – 412.34 mg/100 g for vitamin C contents of purple sweet potato, green spinach, red amaranth and barley ^{68, 69}. However, the vitamin C contents of other raw food samples (corn and cassava) are higher than 0.25 – 7.85 mg/100 g reported for vitamin C contents of selected cereals (guinea corn, maize, rice and wheat), 1.5 mg/100 g for vitamin C contents of raw and mature cowpea seeds and 2.40 – 3.62 mg/100 g for vitamin C contents of sweet potato and taro ^{71, 73, 74}. However, the vitamin C contents of 14.4 – 17.10 mg/100 g of potato, cassava, and yam are lower than the current study's value, 21.14 mg/100 g, recorded for cassava ⁷⁴. Cassava root is an excellent source of vitamin C; however, its concentration is dependent on the species, soil type, maturity of the plant, and fertilizer dose ^{82, 83}. In addition to being an antioxidant, vitamin C has a role in iron metabolism and the immune system by promoting the activity of white blood cells ⁷⁹.

The vitamin A contents of the fermented food samples showed that *Ogi* sample significantly ($p < .05$) had the highest vitamin A content (28.16 mg/100 g), while the least vitamin A (10.16 mg/100 g) was observed in *Iru woro*. No significant variation ($p > .05$) was observed between

the vitamin A contents of *Garri*, *Fufu*, *Iru woro*, and *Iru pete*. The results are higher than the range 2.19 – 987.5 µg/100 g reported for vitamin A contents of fermented selected vegetables (broccoli, carrot, cucumber, pepper and red beet), 0.291 – 0.548 mg/100 g reported for vitamin A contents of weaning diet from fermented blends of sorghum (*Ogi*) and soybean and 7.23 – 9.28 mg/100 g reported for vitamin A contents of “*lafun*” flour enriched with soy curd and residue by Capulet (2023) but slightly in line with 12.59 – 16.03 mg/100 g reported for vitamin A contents of *Ogiri*, *okpei* and *dawadawa* produced and sold in Awka^{84, 85, 86}. One of the main micronutrient deficiencies that poses a public health risk in sub-Saharan Africa is vitamin A, particularly for women and children who are the product's main consumers⁸⁷.

Significant differences ($p < .05$) were observed between the vitamin B₁ contents of the fermented food samples. The vitamin B₁ (Thiamine) contents of the fermented food samples revealed that *Iru pete* had the highest vitamin B₁ content (0.79 mg/100 g), while the lowest vitamin B₁ content (0.08 mg/100 g) was observed in the *Fufu* sample. The findings of the current study are within the range 0.18 – 0.19 mg/100 g reported for vitamin B₁ content of *Garri* from trifoliate yam and cassava blends and 0.20 – 0.24 mg/100 g for thiamine contents masa produced from pearl millet and local white rice but lower than 0.59 – 0.88 mg/100 g reported for vitamin B₁ contents of maize-sorghum *Ogi* blends fortified with soybean and 1.21 – 8.85 mg/100 g reported for vitamin B₁ content of “*lafun*” flour enriched with soy curd and residue^{89, 93}.

The vitamin B₂ contents of the fermented food samples varied showed that *Fufu* sample had the highest vitamin B₂ (0.40 mg/100 g) content, while the lowest value (0.04 mg/100 g) was observed in the *Ogi* sample. No significant variation ($p > 0.05$) was observed between the vitamin B₂ contents of the *Fufu* and *Ogi* samples; however, significant differences at 95% confidence level were observed between the vitamin B₂ contents of the other fermented food samples. The

results are in line with 0.03 – 0.06 mg/100 g for riboflavin contents of fermented selected vegetables (beetroot, cucumber, red cabbage and green tomato), 0.14 – 1.40 mg/100 g reported for vitamin B₂ contents of maize *Ogi* co-fermented with pigeon pea and 0.17 – 0.253 mg/100 g for riboflavin contents of weaning diet from blends of fermented sorghum (*Ogi*) and soybean but lower than 1.26 – 4.26 mg/100 g for vitamin B₂ contents of *Ogiri*, *okpei* and *dawadawa* produced and sold in Awka studied and 1.18 – 6.54 mg/100 g reported for vitamin B₂ contents of *lafun* enriched with soy curd and residue ^{85, 86, 91, 92, 93}. Vitamin B₂ (riboflavin) aids in the absorption of iron and folic acid as well as the metabolism of the mucous membranes of the digestive system ⁹⁴.

The mean results for the vitamin B₃ (niacin) contents of the fermented food varied significantly ($p < .05$), *Iru pete* had the highest vitamin B₃ (5.11 mg/100 g) while the least vitamin B₃ content (0.38 mg/100 g) was observed in the *Ogi* sample. Except for the fermented cassava and corn-based food products (*gari*, *Fufu* and *Ogi*), the vitamin B₃ contents of *Iru woro* and *Iru pete* are within the range 1.12 – 9.70 mg/100 g reported for niacin (vitamin B₃) contents of *lafun* enriched with soy curd and residue ⁹³. However, 0.27 – 0.63 mg/100 g was reported by *gari* produced from trifoliate yam and cassava, which agrees with the vitamin B₃ contents of the fermented cassava and corn-based food products (*gari*, *Fufu*, and *Ogi*) of the current study ⁸⁸. Additionally, of all the fermented food samples in the current study, only *Iru woro* and *Iru pete* had the vitamin B₃ contents which are in tandem with the recommended daily intake 2 – 18 mg for infants and old people; therefore, other fermented cassava and corn-based food products (*gari*, *Fufu* and *Ogi*) of the current study may not be considered as rich sources of vitamin B₃ (niacin) ⁸⁹. According to reports, vitamin B₃ is crucial for maintaining healthy skin, eyes, and liver as well as increasing energy production ⁹⁴. The vitamin B₆ (pyridoxine) contents of the fermented

food samples revealed that *Iru pete* had the highest vitamin B₆ content (4.18 mg/100 g) while the least vitamin B₆ content (0.16 mg/100 g) was observed in the *Garri* sample. No significant variation ($p > .05$) was observed between the vitamin B₆ contents of the *Garri* and *Fufu* samples; however, other fermented food samples (*Ogi*, *Iru woro* and *Iru pete*) had significant variations ($p < .05$) between their vitamin B₆ contents. The results are within the range 1.11 – 252 mg/100 g reported for vitamin B₆ contents of *Ogi* flour enriched with turmeric and ginger and 1.35 – 2.23 mg/100 g reported for vitamin B₆ contents of *lafun* enriched with soy curd and residue^{93, 99}.

The highest vitamin B₁₂ content (465.11 mg/100 g) was observed in *Iru pete* while nil (0.00 mg/100 g) vitamin B₁₂ content was observed in the *Ogi* sample. No significant difference ($p > .05$) was observed between the vitamin B₁₂ content of *Fufu* and *Ogi* samples. However, significant ($p < 0.05$) differences were observed between the vitamin B₁₂ contents of other fermented food samples. Low vitamin B₁₂ contents recorded for the *Garri*, *Fufu* and *Ogi* are indicative of poor vitamin B₁₂ inherent in their parent materials (cassava and corn)^{33, 100}. However, the vitamin B₁₂ contents of *Iru woro* and *Iru pete* samples are higher than 5.61 – 6.32 mg/100 g reported for cobalamin contents of *lafun* enriched with soy curd and 0.09 – 0.39 µg/100 g for vitamin B₁₂ contents of wheat-plantain-velvet bean flour blends and 0.00 – 2.932 mg/g for vitamin B₁₂ contents of different varieties of pap sold in Owo market, Ondo state studied³⁰. Additionally, vitamin B₁₂ plays a role in maintaining the myelin sheath, which is essential for neural activity⁹⁵.

The vitamin C (ascorbic acid) contents of the fermented food samples varied significantly ($p < 0.05$), however, the highest vitamin C content (135.62 mg/100 g) was observed in *Iru pete* while the least vitamin C content (0.12 mg/100 g) was observed in the *Ogi* sample. The least vitamin C content of the *Ogi* sample depicts the relatively low vitamin C inherent in raw maize

0.12 mg (Shah *et al.*, 2016). The vitamin C content of *Ogi* in the current study (0.12 mg/100 g) is considerably lower than previously reported values. Higher concentrations ranging from 5.99 to 11.84 mg/g have been documented for different varieties of pap sold in Owo Market, Ondo State. Similarly, fermented maize *Ogi* enriched with defatted baobab seed flour has been shown to contain between 4.45 and 11.33 mg/100 g of vitamin C. These values highlight the potential impact of ingredient composition and enrichment on the nutritional quality of traditional fermented foods ^{20, 30}. Variation in values may be linked to agronomical, processing or varietal differences. The findings of the current work for vitamin C contents of *Garri* 10.16 mg/100 g and *pupuru* 11.04 mg/100 g corroborate 11.10 – 21.10 mg/100 g reported for vitamin C contents of *pupuru* analogue from orange fleshed sweet potato (OFSP) ¹⁰¹. On the flip side, the vitamin C contents 0.56 – 19.31 mg/100 g reported for different *Iru* condiments and 3.14 – 5.01 mg/100 g for vitamin C contents of *Ogiri*, *Okpei* and *Dawadawa* produced and sold in Awka are lower than the results obtained for vitamin C contents 128.91 – 135.62 mg/100 g of *Iru woro* and *Iru pete* in the current investigation ^{86, 96}.

The pH of the raw foods varied significantly at the 95% confidence level, with cassava exhibiting the highest pH (6.63) and corn the lowest (6.13). The pH of the *Iru* seed (6.14) is higher than the 4.50–4.75 reported for raw and dried locust bean seeds ³⁸. The pH of the corn sample aligns with the 4.80–6.83 range reported for selected cereals such as wheat, maize, sorghum, millet, and fonio, as well as the 6.45–6.95 range for cereal grains from Mali ^{35, 36}. Similarly high pH values of 6.72–6.75 have been reported for cassava grown in different regions of Sabah, Malaysia ³⁷. Variations in the pH of the raw food samples could be attributed to differences in intrinsic biological composition (e.g., organic acid content, carbohydrate-protein

reactions), harvest maturity, soil and agro-environmental conditions, enzymatic activities, and genetic variability.

Significant variations ($p < .05$) were observed among the TTA values of the raw foods. The highest TTA was observed in *Iru* seed (0.98%) and the lowest in cassava (0.05%). The TTA value of *Iru* seed in this study corresponds with the 0.98% reported for unfermented *Parkia* seeds, but it is higher than the 0.042 mg lactic acid/g reported for raw locust bean seeds^{40, 38}. The TTA of cassava in the current study is lower than the 0.99–1.02% reported for fertilizer-treated cassava roots of different varieties⁴². Similarly, the TTA of the corn sample is lower than the 1.23–6.30% reported for whole wheat meal⁴¹. Variations in TTA of the raw food sample of the current study and those in the cited literature could be attributed to differences in intrinsic (plant variety maturity, genetic composition, moisture content and composition, endogenous enzyme activity) and extrinsic factors (soil type and fertility, agronomic practices, post-harvest handling and storage, and microbial load). The mean results for the total soluble solids (TSS) of the raw food samples varied from 2.83 to 6.53%. Cassava had the highest total soluble solid (6.53%) while the least value (2.83%) for total soluble solid was observed in the corn sample. Significant differences at 95% confidence level were observed between the total soluble solids of the raw food samples. Higher total solid 12.10 – 17.19% of fresh sweet corn kernels have been reported⁴³. The result obtained for the total soluble solids (TSS) of cassava in the current study is notably higher than the 5.06% recorded for fresh raw cassava root, suggesting potential differences in variety, agro-ecological conditions, or processing methods used⁴⁴. It also exceeds the 5.63–5.84 °Brix range reported for total soluble solids in different potato varieties, further indicating the naturally higher TSS levels found in the cassava samples analysed in this work⁴⁵. Similarly, the cassava TSS surpasses the 5.64–6.33 °Brix reported for a range of cassava varieties

previously studied, pointing to the potential influence of location, maturity, and post-harvest handling on the composition ⁴⁶. In contrast, the total soluble solids observed in the raw food samples of the present study were considerably higher than the 0.10–2.03 °Brix recorded for fresh banana, reflecting the relatively low sugar and soluble compound content in banana compared to cassava and other tubers ⁴⁷. However, the TSS values obtained remain lower than the 18–24 ° Brix documented for green asparagus roots, a crop known for its dense nutrient and sugar profile, particularly during peak growth phases ⁴⁸. The amount of sugar and soluble minerals present in meals is highlighted by the total soluble solid; disparities in total soluble solids of the raw food samples of the current research and the cited literatures could be attributed to differences in genetic, environmental and postharvest factors ⁴⁶.

The pH of the fermented food samples in the current study varied significantly ($p < .05$), with *Iru pete* exhibiting the highest pH (8.34) and *Ogi* the lowest (3.43). The elevated pH values observed in *Garri*, *Iru woro*, and *Iru pete* suggest reduced acidity, which may affect microbial stability, shelf life, and overall product quality. Higher pH levels can diminish the antimicrobial effects of fermentation, potentially increasing susceptibility to spoilage and pathogenic organisms. Conversely, the lower pH values recorded for *Ogi* and *Fufu* reflect increased acidity, which is generally advantageous for microbial safety and preservation, as acidic environments inhibit the growth of spoilage organisms and foodborne pathogens. The pH values observed in this study are consistent with previous findings: 5.31–5.50 for *Garri* as influenced by fermentation ³². Similarly, *lafun* has been reported to have a pH range of 4.10–5.25, while fermented *sandbox* (*Hura crepitans*) condiment showed pH values between 5.4 and 5.7 ^{31, 88}. The high pH range of 8.70–8.90 reported for fermented locust bean and soybean condiments aligns with the values observed in *Iru pete* ⁵⁴. Additionally, *pupuru* flour derived from grated cassava mash and soaked

cassava has been documented with pH ranges of 4.01–4.86 and 4.48–5.07, respectively ⁵⁵. Other dried cassava products in Nigeria, including tapioca, *kpokpo Garri*, *Fufu* powder, and starch, have shown pH values ranging from 5.67 to 7.14 ⁵⁰. The pH of the fermented food samples in this study exhibited significant variation ($p < .05$), ranging from 3.43 to 8.34. Among the samples, *Iru pete* recorded the highest pH value of 8.34, indicating an alkaline nature, while *Ogi* had the lowest pH of 3.43, reflecting high acidity. This wide range demonstrates the diverse nature of fermented foods in terms of their acid-base balance and provides insight into their potential functional, nutritional, and microbiological properties. The relatively high pH values observed in *Garri*, *Iru woro*, and *Iru pete* suggest a reduction in acidity, which may influence the microbial ecology of these products. A higher pH reduces the inhibitory environment typically created during fermentation, potentially allowing for the survival and proliferation of spoilage organisms and pathogenic bacteria. This shift could pose concerns for food safety, storage stability, and overall shelf life, particularly in ambient storage conditions without preservation or packaging interventions. From a processing and product development perspective, these high pH values may affect flavour profiles and consumer acceptability, as alkaline conditions can result in a more bland or bitter taste. Conversely, the low pH values recorded in *Ogi* and *Fufu* indicate increased acidity, which is generally advantageous for microbial preservation. Acidic environments are known to suppress the growth of undesirable microorganisms, thereby contributing to the safety, extended shelf life, and sensory attributes of the final food product. These findings reinforce the importance of fermentation as a natural preservation technique in traditional food systems. The pH values recorded for the fermented foods in this study align with previously reported values for similar products. For instance, *Garri* samples fermented under different conditions have shown pH levels ranging from 5.31 to 5.50 ³². Similarly, *lafun*, another

cassava-based fermented product, was reported to have a pH range of 4.10 to 5.25, indicative of its mildly acidic nature ³¹. Fermented *sandbox* (*Hura crepitans*) condiment was also documented with pH values of 5.4–5.7, further supporting the findings of moderate acidity in fermented condiments ⁵³. Notably, extremely high pH values between 8.70 and 8.90 were reported in fermented locust bean and soybean condiments, such as *Iru pete*, which is consistent with the current study's findings ⁵⁴. Additionally, other cassava-based products have demonstrated acidic to near-neutral pH levels depending on processing methods. For instance, *pupuru* flour derived from grated cassava mash and soaked cassava exhibited pH ranges of 4.01–4.86 and 4.48–5.07, respectively ⁵⁵. Broader surveys of dried cassava products available in Nigeria—including tapioca, *kpokpo Garri*, *Fufu* powder, and starch—have reported pH values from 5.67 to 7.14, illustrating the variation in pH even within similar root-based products ⁵⁰. These comparisons further validate the present findings and provide a clearer understanding of the physicochemical behaviour of fermented foods commonly consumed in the region.

Iru woro had the best total titratable acidity (0.95%) while the lowest total titratable acidity (0.04%) was observed in *Fufu*. Significant differences ($p < .05$) were observed between the total titratable acidity of the fermented food samples. The results are higher than 0.006 – 0.011% reported for total titratable acidity of *Garri* as affected by fermentation but lower than 0.99 – 1.02% reported for total titratable acidity of *Garri* from fertilizer treated cassava roots ⁴². Reduced free sugars, which are used to make acids during fermentation, have been linked to low TTA values in fermented foods ⁵⁰. The mean results for the total soluble solids (TSS) of the fermented food samples varied significantly at 95% confidence level from 5.30 to 16.10% with *Ogi* sample having the highest total soluble solid (16.10%) while the lowest total soluble solid (5.30%) was observed in the *Fufu* sample. The results revealed significant variations ($p < .05$) in

the total soluble solids (TSS) of the fermented food samples. Notably, all samples except *Ogi* exhibited lower TSS values when compared to previously reported ranges. Specifically, the TSS values were lower than the 11.725–19.825 °Brix reported for fermented green asparagus roots ⁴⁸. They were also below the 4.57–5.43 °Brix range observed in Mahewu, a fermented beverage made from white and yellow maize using different inocula ⁵¹. Additionally, the TSS values fell short of the 9.00 °Brix reported for naturally fermented obiolor, a traditional drink derived from sorghum and millet grains ⁵². Differences in total soluble solids of the different fermented food samples may be linked to differences in type and activity of microorganisms employed, initial sugar content and composition of the raw materials, duration and temperature of fermentation and processing methods used in the different studies.

Antioxidant Properties of Raw and Fermented Foods

Significant differences ($p < 0.05$) were observed between the total phenolic contents of the raw food samples. The total phenolic contents (TPC) of the raw food samples revealed that cassava sample had the highest total phenolic content (30.69 g/100 g GAE), while the lowest total phenolic content (0.69 g/100 g GAE) was observed in the *Iru* seed sample. 0.4 – 1.4 mg/100 g GAE for total phenolic content of green spinach, red amaranth, pineapple, purple sweet potato, barley and corn, which are lower than the total phenolic contents of cassava and corn samples but in line with the value reported for *Iru* seed sample in the current study ⁶⁹. The findings of the current study are lower than 34.83 g/100 g GAE reported for phenolic contents of raw taro and 191.18 – 1040.73 mg GAE/100 g for total phenolic contents of different sorghum grain varieties ¹⁰³. However, the total phenolic contents of 0.58 – 6.06 g/100 g GAE of field pea and cowpea cultivars are within the range 0.9 – 3.46 g/100 g GAE obtained for cassava and corn samples in the current study ¹⁰⁴. Differences in the extraction process, sample, or extraction solvent may be

the cause of differences in the total phenols of the raw food samples and the values in the referenced literature ¹⁰³. Antioxidants called phenolic compounds can control the activity of several enzymes. They are strong inhibitors of two essential enzymes that help regulate glucose balance: α -amylase and α -glucosidase ⁷⁰.

There were significant variations ($p < .05$) between 1, 1-Diphenyl-2-picrylhydrazyl (DPPH) contents of the raw food samples. *Iru* seed sample had the highest level of inhibition (DPPH) (77.82 %Inh./mg DM) while the lowest DPPH content (34.86 %Inh./mg DM) was observed in the cassava sample. The results are in line with 33.99 – 40.93 %Inh./mg DM reported for DPPH contents of landrace maize varieties from Sierra Gorda in Querétaro and 27.9 – 73.5 %Inh./mg reported for different genotypes and cultivars of potato, but higher than 0.12 – 8.11 %Inh./mg DM reported for DPPH contents of different rice and corn varieties ^{98, 105, 106}.

The mean results for the Ferric reducing antioxidant property (FRAP) contents of the raw food samples ranged significantly at a 95% confidence level, however, the highest reducing power (FRAP) (8.11 mmol/100 g) was observed in the corn sample, while the *Iru* seed had the least FRAP content (1.53 mmol/100 g). The findings of the current study agree with 7.0 – 13.0 μ mol Fe(II)/g reported for FRAP of improved cowpea varieties and landraces grown in Ethiopia, higher than 0.83 – 0.93 mol GAE/100 g DW reported for FRAP of different cassava varieties but lower than 71.7 – 331.2 μ mol TE/g DW reported for FRAP of 50 *Fabaceae* populations from various floristic regions from Thailand, 0.83 – 0.93 mo GAE/100 g DW for FRAP of selected cassava varieties ¹⁰². The reducing power (FRAP) is an important indicator of potential antioxidant activity ^{107, 108, 109}.

The (2, 2'-azino-bis-3- ethylenzothiazoline-6-sulfonic acid (ABTS) scavenging ability (ABTS) of the raw food samples differed significantly ($p < .05$) from 3.55 to 9.15 mM 100 g⁻¹ DW with the

highest ABTS (9.15 mM 100 g⁻¹ DW) being observed in *Iru* seed while the least scavenging ability (3.55 mM 100 g⁻¹ DW) was observed in the cassava sample. The results are within the range 3.62 – 10.65 mM 100 g⁻¹ DW reported for ABTS of purple and red fleshed potatoes and 2 – 26 µmol TE/g, db for ABTS scavenging ability of cowpea varieties and landraces but lower than 9.94 – 15.48 TEAC mmol/g reported for ABTS of 18 elite yellow-fleshed cassava genotypes and 85.48 – 97.80 % inhibition reported for ABTS contents of different maize varieties by landrace maize varieties from Sierra Gorda in Querétaro ^{98, 102, 110}. The high ABTS values observed in the corn and *Iru* seed samples in this study indicate that their extracts possess strong radical scavenging properties, which may help protect the body against oxidative stress-related conditions such as diabetes, cancer, and cardiovascular diseases ¹¹¹.

Antioxidant capacity reflects the presence of a diverse range of antioxidant compounds, notably phenolic compounds which contribute the most significantly alongside carotenoids, beta-cyanins, and tocopherols ^{107, 108}. The total phenolic contents (TPC) of the fermented food samples varied significantly ($p < .05$) with *Ogi* sample having the highest total phenolic content (14.35 g/100 g GAE) while the least total phenolic content (0.04 g/100 g GAE) was observed in the *Fufu* sample. All the fermented food samples, except *Fufu* had total phenolic content values higher than 0.17 – 0.247 mg GAE/100 g reported for sorghum-pigeon peas '*Ogi*' flour but lower than 17.972 – 40.922 mg/g for total phenols of soybean natto and *M. oleifera* leaves and 20.0 – 71.0 g/100 g GAE for total phenolic contents of solid-state fermented cassava (*Manihot esculenta* Crantz) using *Rhizopus oligosporus* ^{112, 113}.

The 1, 1-Diphenyl-2-picrylhydrazyl (DPPH) radical inhibitory activities of the fermented food samples revealed that *Iru pete* had the highest DPPH (87.93 %Inh./mg DM) while the least DPPH (51.24 %Inh./mg DM) as observed in the *Fufu* sample. Significant differences ($p < .05$)

were observed between the DPPH of the fermented food samples. The results corroborate 51.57 – 84.19 %İnh./mg DM and 50.52 – 80.16 %İnh./mg DM reported for DPPH radical scavenging assay of pre-heated and non-preheated *Fufu* sold in *Ozoro*, Nigeria ¹¹⁵. High levels of DPPH radical scavenging 37.0 – 59.0 %İnh./mg DM for *dawadawa* from *Mucuna pruriens* and *Parkia biglobosa* have also been reported, which are also in line with the findings of the current study ⁹⁷.

The Ferric reducing antioxidant property (FRAP), which is an imperative indicator of potential antioxidant activity, of the fermented food samples varied significantly at a 95% confidence level. *Iru pete* had the highest reducing power (FRAP) (5.12 mmol/100 g), while the lowest value for FRAP (0.11 mmol/100 g) was observed in the *Ogi* sample. The results are within the range 3.76 – 12.37 µgTE/gdw reported for DPPH of processed *Garri* from cassava roots at two different maturity stages and two seasons, but lower than 37.16 – 42.12 mmol/100 g reported for FRAP of fermented moringa seeds, 19.02 – 91.73 mmol/100 g for FRAP of quinoa dough fermented using *Saccharomyces cerevisiae* and lactic acid bacteria researched ^{116, 109}.

2, 2'-azino-bis-3-ethylenzothiazoline-6-sulfonic acid (ABTS) scavenging ability (ABTS) contents of the fermented food samples varied significantly ($p < .05$), with *Iru pete* having the highest ABTS (15.12 mM 100 g⁻¹ DW) while the lowest ABTS (0.03 mM 100 g⁻¹ DW) was observed in the *Garri* sample. The results are in consonance with 30.84 – 87.88 µmol TE/100 g DM reported for ABTS contents of wheat bread enriched with hazel nuts and walnuts ¹¹⁹. However, higher ABTS values, 20.60 – 30.17 µgTE/g have been reported for processed *Garri* from cassava roots at two different maturity stages and two seasons and 86.29 mM 100 ml⁻¹ for ABTS scavenging activity of yoghurt as compared to the findings of the current study ^{116, 120}. Earlier studies had also contributed that fermented cassava-based products, including *lafun*, *Fufu*

and *Garri* may scavenge ABTS; thus, indicating their potential to inhibit the formation of free radicals within cells and to neutralize them upon consumption ¹¹⁰.

The Microbial Counts of Raw and Fermented Foods

The microbial counts of raw foods in this study revealed striking differences in the microbial ecology across crop types, reflecting both their intrinsic properties and the environmental factors associated with cultivation and handling. Cassava tubers consistently exhibited the lowest total viable counts ($3.80 \pm 0.20 \log_{10}$ CFU/g), as well as relatively low lactic acid bacteria ($2.10 \pm 0.10 \log_{10}$ CFU/g). This observation is reasonable, given the fact that cassava tubers develop underground and are relatively shielded from direct microbial contamination until postharvest handling introduces epiphytic organisms from soil, peeling equipment, or water. Previous studies have similarly documented that the initial microbial load of freshly harvested cassava roots is low, but contamination increases substantially during peeling and soaking stages, which provide niches for microbial colonization ¹²¹.

Corn grains, by contrast, demonstrated slightly higher microbial counts, especially for LAB ($2.50 \pm 0.10 \log_{10}$ CFU/g), which suggests that cereals are naturally associated with LAB on their husks and surface layers. The presence of these organisms, even before fermentation, supports the argument that indigenous fermentation of cereals such as *Ogi* is not initiated by accidental inoculation but rather by autochthonous microbial consortia residing naturally on the raw substrate. Okoronkwo and colleagues noted that *Lactobacillus plantarum* and related LAB species are among the earliest colonizers of steeped maize, highlighting the importance of these organisms in ensuring successful fermentation outcomes ¹²².

The highest raw microbial counts, however, were detected in Iru seeds, where total viable counts reached $6.90 \pm 0.10 \log_{10}$ CFU/g and *Bacillus* species counts averaged $5.80 \pm 0.20 \log_{10}$ CFU/g.

This phenomenon can be attributed to the protein-rich composition of legumes, which inherently promotes microbial growth, particularly of proteolytic and spore-forming organisms such as *Bacillus subtilis*. High microbial colonization of Iru seeds has been previously reported, with authors noting that drying and storage practices often lead to exposure to both spore-formers and environmental moulds ¹²³. Importantly, Enterobacteriaceae were also detected in both cassava (3.80 log₁₀ CFU/g) and Iru (4.20 log₁₀ CFU/g), raising significant food safety concerns. Contamination with coliforms in raw foods has been documented in several studies, often linked to poor hygiene during handling, the use of contaminated water, or storage under humid conditions ¹²⁴. This underscores the argument that raw foods, while nutritionally valuable, are microbiologically unstable and unsafe for direct consumption without processing.

The transition from raw to fermented foods resulted in marked changes in microbial counts, confirming fermentation as a transformative process that both enriches beneficial organisms and suppresses undesirable groups. The highest microbial densities were recorded in Iru-based products, with *Iru woro* showing 8.60 ± 0.20 log₁₀ CFU/g and *Iru pete* 8.20 ± 0.20 log₁₀ CFU/g. These exceptionally high counts reflect the dominance of *Bacillus subtilis* in alkaline fermentations, where proteolytic activity facilitates protein degradation, producing amino acids and volatile compounds that define the organoleptic qualities of Iru. The strong proliferation of *Bacillus* in Iru fermentation is not merely incidental but essential for flavour development, textural changes, and nutritional enhancement of the product ¹²⁵.

Ogi, the lactic acid-fermented maize product, displayed an equally significant microbial transformation, with LAB counts reaching 8.00 ± 0.10 log₁₀ CFU/g. This dominance of LAB reflects their rapid acidification ability, which drives down pH and selectively inhibits pathogenic bacteria. The LAB ecology of *Ogi* has been well-documented, with studies showing

that when LAB counts exceed $7 \log_{10}$ CFU/g, the acidification is sufficient to eliminate most Gram-negative enteric pathogens while simultaneously enriching organic acid and flavour production ¹²⁶. Thus, the increased LAB densities observed in *Ogi* highlight the process not only as a preservation strategy but also as a contributor to food safety and potential probiotic benefits. In stark contrast, Garri exhibited the lowest microbial counts among fermented foods, averaging only $3.80 \pm 0.20 \log_{10}$ CFU/g. This reduction was directly attributable to the roasting step in *Garri* processing, which subjects the cassava mash to high heat, effectively inactivating microbial populations. Several studies have confirmed that roasting is the critical control point in *Garri* production, ensuring shelf stability and microbiological safety by drastically reducing microbial loads ¹²¹. Despite its lower microbial counts, *Garri* remains a staple fermented product precisely because of its long shelf life and safety.

Perhaps most significant was the decline in Enterobacteriaceae counts, which dropped from an average of $4.03 \log_{10}$ CFU/g in raw foods to $2.78 \log_{10}$ CFU/g in fermented foods. This selective reduction is evidence to the antimicrobial properties of fermentation, whether through acidification in *Ogi* and *Fufu*, or heat application in *Garri* ¹²⁴. Similarly observed sharp declines in Enterobacteriaceae in indigenous fermented foods, attributing this to pH reduction, bacteriocin production, and competitive exclusion by LAB and *Bacillus* ¹²⁴.

Microorganisms Identified in Raw and Fermented Foods

The identification of microorganisms in raw foods further reinforced the observation that raw materials serve as natural reservoirs for diverse microbial consortia. Cassava tuber was found to harbor yellow yeast, *Lactobacillus plantarum*, and *Aspergillus niger*. While the detection of *L. plantarum* suggests that cassava can act as a reservoir for LAB even before fermentation, the co-occurrence of *A. niger* highlights food safety risks, given that this mould species is associated

with mycotoxin production under poor storage conditions. Previous studies in West Africa have confirmed that *A. niger* is a common contaminant in cassava supply chains, often leading to postharvest losses and potential food safety hazards if not controlled ¹²⁷.

Corn grain presented a simpler microbial profile, being dominated by *Lactobacillus plantarum*. This is consistent with other findings that cereals, even when raw, carry LAB on their husk and bran layers. These LAB populations, although initially low, provide a natural inoculum for subsequent fermentation once grains are steeped in water. Their presence argues that fermentation in cereals is a biologically “prepared” process, rather than an entirely spontaneous occurrence ¹²².

The microbial profile of raw Iru seeds was more complex, featuring *Bacillus subtilis* and *Syncephalastrum* spp. The detection of *B. subtilis* in raw seeds is significant because it supports the theory that alkaline fermentation of Iru is primarily autochthonous, seeded by the natural presence of *Bacillus* spores in the substrate. The microbial succession of Iru fermentation depends largely on the high initial *Bacillus* load of the seeds themselves ¹²³. However, the presence of *Syncephalastrum*, a soil-associated mould, suggests environmental contamination, reflecting the vulnerabilities of traditional harvesting and storage methods. Thus, the microbial identification of raw foods presents both an opportunity and a challenge: while beneficial fermenters are present, they coexist with undesirable fungi and coliforms that make unprocessed consumption unsafe.

The microbial profile of fermented foods revealed a more structured and specialized community compared to raw foods, dominated by organisms that are both functional and beneficial. In *Garri*, white yeast and *Aspergillus niger* were still detected, but in greatly reduced densities, a direct consequence of the roasting process that selects against microbial persistence. Although mould

persistence could raise safety concerns, the low counts combined with desiccation during roasting limit the risks of toxin production ¹²¹.

Fufu showed the coexistence of white yeast and *Bacillus subtilis*, a reflection of the complex ecological balance in cassava fermentations. Yeasts contribute to flavour development through ethanol and ester production, while *Bacillus* ensures enzymatic hydrolysis of complex polymers, improving digestibility. The LAB–yeast–*Bacillus* synergy is characteristic of cassava fermentations and is essential for both product safety and palatability ¹²⁵.

Ogi was dominated by *Lactobacillus plantarum* and white yeast, confirming the LAB–yeast symbiosis that typifies cereal fermentations. The rapid acidification brought by LAB suppresses pathogens, while yeasts enrich flavour profiles and contribute to vitamin synthesis. This microbial partnership has been repeatedly emphasized as a cornerstone of cereal-based fermentation systems, where safety and sensory improvement are mutually reinforced ¹²².

Finally, *Iru woro* and *Iru pete* were exclusively dominated by *Bacillus subtilis*, showing how alkaline fermentations create conditions that select for spore-formers while suppressing competing microorganisms. Microbial homogeneity is crucial for the development of characteristic Iru flavour, texture, and nutritional properties ¹²³. Importantly, this ecological simplification contrasts with the mixed microbial community of raw Iru seeds, highlighting fermentation as a process of microbial purification and specialization. Thus, fermentation not only reduces microbial hazards but actively restructures microbial ecosystems, reinforcing the scientific validity of these traditional food-processing practices.

Endnotes

1. M. Sinay & N. Harijati, *Determination of Proximate Composition of Local Corn Cultivar from Kisar Island, Southwest Maluku Regency*, **Journal of Biology & Biology Education** 13(3): 258–266, 2021.
2. C. M. Sogo-Temi, O. A. Idowu & A. M. Lateef, *Nutritional Quality Assessment of Complementary Food from Plantain, Velvet Bean and Cray Fish*, **International Journal of Scientific Research and Management** 1(10): 143–148, 2023.
3. B. B. Peprah, J. Manu-Aduening, I. Asare-Bediako, I. Carey, E. B. Amenorpe, R. C. Asare, R. Osei, E. A. Ofori, J. M. Agyeman, M. Parkes, D. Ofori, D. Y. Danquah & E. Parkes, *Proximate Composition, Cyanide Content, and Carotenoid Retention after Boiling of Provitamin A-Rich Cassava Grown in Ghana*, **Foods** 9: 1–13, 2020.
4. E. B. Etuk, C. P. Imolikhe & E. U. Ahiwe, *Proximate Composition and Anti-Nutritional Constituents of Different Forms of Raw, Soaked or Cooked African Locust Bean*, **International Journal of Agricultural and Rural Development** 23(2): 5274–5281, 2020.
5. I. V. Edet, O. P. Angba, T. P. Akpa, B. I. Ananwoke, D. A. Igwe & O. A. Ogbu, *Comparative Analysis on the Proximate Composition of Processed Cassava Products Obtained from January to March, 2023 in Lafia Town, Nigeria*, **Chemical Science International Journal** 32(4): 50–63, 2023.
6. B. Sabariah, R. Roselina, H. Huda-Faujan, A. Bakar-Farid, M. F. Azhar & N. A. Sani, *Nutritive Values of Different Types of Corn-Based Animal Feed Based on Samples from 2012 to 2018*, **Malaysian Journal of Veterinary Research** 10(2): 39–47, 2019.
7. G. N. Elemo, T. A. Elemo, S. O. Oladunmoye & O. Erukainure, *Comprehensive Investigation into the Nutritional Composition of Dehulled and Defatted African Locust Bean Seed*, **International Scholar Journals** 7(9): 1–5, 2020.

8. E. O. Alamu, A. A. Popoola, M. O. Maziya-Dixon, R. O. Omodamiro, S. E. Akoroda, D. M. Nwokocha, A. G. Olanmi, M. A. Adesokan, G. O. Olaosebikan & A. A. Sanni, *Correlate the Cyanogenic Potential and Dry Matter Content of Cassava Roots and Leaves Grown in Different Environments*, **Scientific Reports** 13: 1–9, 2023.
9. A. Bayata, *Proximate and Mineral Composition of Cereal-Based Complementary Foods Formulated from Maize, Millet and Sorghum*, **African Journal of Food, Agriculture, Nutrition and Development** 20(2): 15982–15996, 2020.
10. P. Mpili, V. Vincent & L. Rweyemamu, *Evaluation of the Proximate Composition, Functional, and Pasting Properties of Ichipipi Maize Flour*, **Applied Food Research** 4: 1–7, 2024.
11. F. Kumsa & W. Haile, *Minerals Composition and Their Contribution to the Recommended Daily Allowance of Barley Grain Consumed in Ethiopia*, **Food Chemistry** 119(3): 875–881, 2020.
12. T. K. Adebayo, *Evaluation of Flour Blends Made from High Quality Protein Maize and Soursop Seed Flours*, **Research Journal of Food Science and Nutrition** 10(1): 9–22, 2025.
13. K. Nasrallah, N. El-Hady, M. A. Hassan, H. A. Osman & M. M. Abdalla, *Nutritional, Biochemical and Health Properties of Locust Beans and Its Applications in the Food Industry: A Review*, **Journal of Food Science and Technology**: 1–11, 2023.
14. N. I. Nwakife, U. C. Okoro, J. C. Ugwuoke, A. O. Ugwuanyi, C. U. Ezech & J. N. Okonkwo, *Comparative Study of Nutrient and Antinutrient Composition of Some Common Nigerian Leafy Vegetables*, **International Journal of Biological and Chemical Sciences** 15(6): 2210–2221, 2021.
15. T. K. Adebayo, I. A. Balogun, O. A. Adewale & O. A. Fadare, *Wheat-Plantain Flour Blends Enriched with Velvet Beans Flours: Vitamins and Mineral Composition*, **Research Journal of Food Science and Nutrition** 9(2): 67–72, 2024.
16. A. P. Ityotagher, Y. T. Stephen & I. J. Seember, *Proximate Composition and Sensory Properties of Fermented Sorghum and Full Fat Soy Flour Blends for 'Ogi' Production*, **African Journal of Food Science and Technology** 13(9): 1–4, 2022.
17. C. E. Ogbete, *Proximate, Chemical, and Starch Analysis of Fufu Dough Sold in Different Markets of Akwa Ibom and Rivers States, Nigeria*, **Egyptian Journal of Nutrition** 39(3): 72–84, 2024.
18. B. A. Udensi, C. N. Okorie, U. J. Oselebe, I. C. Okorie, C. J. Ezeorba, A. C. Nwokocha, A. I. Onyekwere & O. C. Nwankwo, *Evaluation of Gari Processed from Cassava in Nigeria*, **Journal of Food Quality** 4(1): 43–55, 2024.
19. S. A. Laba, O. F. Oyeleke, M. A. Oke, J. O. Adeoye, A. O. Akinola, I. A. Adepoju, M. B. Adebayo, A. T. Mohammed & A. J. Salawu, *Comparative Study on the Fungi Determinants in Locust Beans (Iru) Produced from Parkia biglobosa and Prosopis africana*, **FUDMA Journal of Sciences** 8(6): 299–308, 2024.
20. O. O. Ezekiel, O. E. Adedeji & N. Umuokeke, *Chemical Composition, Physicochemical, and Sensory Properties of Fermented Maize and Defatted Baobab Seed Flour Blends*, **Agrosearch** 21(1 & 2): 89–101, 2022.
21. B. O. Timothy, E. O. Adeyemi, M. A. Ogunjimi, O. S. Adeniran & A. B. Lawal, *Rheological Properties and Quality Evaluation of Dried Ogi Supplemented with Date Flour as Sugar Substitute*, **Journal of Food Stability** 7(2): 40–56, 2024.

22. W. Awoyale, S. O. Akinola, F. O. Adebayo, M. T. Oladipo, O. I. Ajiboye, K. O. Adepoju & A. O. Komolafe, *Influence of Adding Edible Termite Flour to Ogi Powder: Its Chemical and Phytochemical Composition*, **Frontiers in Nutrition** 11: 1403660, 2024.
23. T. A. Ibrahim, E. O. Oyewole, A. O. Adebayo, O. M. Ojo & R. A. Olaleye, *Proximate and Antinutrient Composition of Iru Produced from African Locust Beans and Soybeans Using Bacillus subtilis A2 as Starter Culture*, **International Journal of Research and Innovation in Applied Science** 5(1): 174–176, 2020.
24. F. N. Onyeka & U. G. Okwume, *Functional Properties and Nutrient Composition of Stiff Dough Produced from Composite Flour of Pearl Millet, White Maize and Cassava in Enugu State, Nigeria*, **International Journal of Home Economics, Hospitality and Allied Research** 2(1): 119–134, 2023.
25. A. A. Adesola, M. I. Olatunji, O. A. Oyelakin, J. T. Abiola, S. O. Odetola & A. O. Bamigboye, *Production and Quality Evaluation of Fufu Powder*, **Journal of Food Processing and Preservation** 46(2): 1–12, 2022.
26. M. A. Ogunjemilusi, C. T. Akanbi & J. Alaba, *Production and Evaluation of Ogi Produced from Fermented Maize and Tropical Almond Nut Flour*, **Journal of Food Science, Nutrition and Public Health** 2(1): 1–8, 2022.
27. C. N. Obi & W. O. Okoronkwo, *Production, Microbiological and Proximate Analysis of Akamu Produced from Different Varieties of Maize*, **Nigerian Journal of Microbiology** 36(1): 6001–6012, 2022.
28. A. Ahmed, O. Adejumo, O. Ajayi & R. Yusuf, *Mineral Composition of Daddawa Produced by Local Fermentation*, **Nigerian Journal of Food and Environment** 18(3): 31–38, 2022.
29. A. Ahmed, B. O. Akinola, K. A. Ibrahim, L. A. Musa & H. A. Bello, *Magnesium and Zinc Bioavailability in Fermented Condiments*, **African Journal of Food Science and Technology** 14(4): 123–129, 2023.
30. E. O. Samuel, T. O. Falade, O. A. Aluko, M. B. Oladokun, A. I. Oloyede, R. T. Adebisi & K. J. Olowookere, *Vitamin B12 Content in Traditional Nigerian Pap Varieties*, **Egyptian Journal of Nutrition** 39: 59–68, 2024.
31. S. A. Oyeyinka, O. O. Adeloye, M. T. Akinoso, F. O. Olawuyi & A. B. Olasupo, *Chemical and Physicochemical Properties of Fermented Flour from Refrigerated Cassava Root and Sensory Properties of Its Cooked Paste*, **Journal of Food Processing and Preservation**: 1–9, 2020.
32. C. Ozoh, C. Imoisi & J. U. Iyasele, *Physicochemical and Antioxidant Properties of 'Garri' Processed under Controlled Fermentation Conditions*, **Applied Sciences Research** 19(1): 156–169, 2024.
33. F. O. Abiodun, O. M. Oluwaseun & O. A. Olukayode, *Comparative Nutritional Evaluation of Yellow and White Cassava Garri*, **International Journal of Recent Innovation in Food Science and Nutrition** 7(1): 16–21, 2024.
34. N. Joel, N. Oluchi & A. I. Elijah, *Carbohydrate Content of Garri from White and Yellow Cassava Roots*, **Annals of Food Science and Technology** 20(3): 443–450, 2019.
35. R. E. Jocelyne, P. K. Mensah, T. K. Osei, F. L. Johnson, A. B. Owusu & K. D. Agyeman, *Comparative Study of Nutritional Value of Wheat, Maize, Sorghum, Millet, and Fonio*, **European Scientific Journal** 16(21): 118–131, 2020.
36. A. Coulibaly, M. Traoré, I. K. Koné, B. M. Cissé, F. Sangaré & K. B. Doumbia, *Determination of Proximate Compositions and Functional Properties of Selected Cereal*

- Grains from Mali*, **American Journal of Food Science and Technology** 10(5): 207–213, 2022.
37. M. Hasmadi, S. J. Rosnita, H. Norshazila, I. Zainab, A. A. Noraini & M. Z. Azian, *Physicochemical and Functional Properties of Cassava Flour Grown in Different Locations in Sabah, Malaysia*, **Food Research** 4(4): 991–999, 2020.
 38. T. I. Famuwagun & T. A. Taiwo, *Microbiological Safety and Proximate Analysis of Fermented Legume-Based Condiments*, **Cogent Food & Agriculture** 9(1): 1–15, 2023.
 39. A. I. Olagunju, F. O. Adepoju, J. A. Akinwale, L. B. Omotayo & K. O. Salami, *Effect of Fertilizer Treatment on the Titratable Acidity of Cassava Roots*, **Journal of Root and Tuber Research** 9(1): 45–51, 2022.
 40. O. O. Oluwaniyi & I. O. Bazambo, *Nutritional and Amino Acid Analysis of Raw, Partially Fermented and Completely Fermented Locust Bean (*Parkia biglobosa*) Seeds*, **African Journal of Food, Agriculture, Nutrition and Development** 16(2): 10866–10883, 2016.
 41. E. Mockus, A. Petrauskas, R. Venskutonis, L. Ragauskas, D. Žukauskaitė & V. Stukonis, *The Potential of Traditional 'Gaja' and New Breed Lines of Waxy, Blue and Purple Wheat in Wholemeal Flour Fermentation*, **Fermentation** 8(11): 563, 2022.
 42. T. M. A. Olayanju, J. K. Adebayo, S. O. Ogunmola, F. A. Oladipo & A. E. Adeyemi, *Total Titratable Acidity of Garri from Fertilizer Treated Cassava Roots*, **Nigerian Food Journal** 40(1): 85–92, 2022.
 43. A. I. Ibrahim & G. A. Alfauomy, *Evaluation of Some Sweet Corn Hybrids for Agronomic Traits and Technological Parameters under Different Planting Dates*, **Journal of Food Sciences** 6(1): 49–63, 2019.
 44. I. M. Chibuzor, *Influence of Tuber Sections and Chemical Additives on Physicochemical Properties of Pregelatinized Cassava Flour*, **Journal of Food Processing and Technology** 13: 956, 2022.
 45. K. S. Abbasi, S. Masud, M. Bashir, F. Hussain, A. Ali, T. A. Chaudhary, A. Farooq & S. Z. Ahmed, *Analysis of Selective Potato Varieties and Their Functional Assessment*, **Food Science and Technology** 39(2): 308–314, 2018.
 46. L. A. de Oliveira, A. C. F. dos Santos, T. L. Vieira, F. R. da Silva, A. A. S. Junior & C. R. Oliveira, *Effect of the Storage Period on Physicochemical Characteristics and Sensory Acceptance of Frozen Sweet Cassava*, **Brazilian Journal of Food Technology** 24: e2020215, 2021.
 47. N. P. A. N. Wulandari, I. K. A. Wibawa, I. W. Arsa, I. M. M. Astawan & K. K. Dewi, *Effect of Differences in Fruit Maturity Levels of Three Balinese Banana Cultivars on the Quality of Fruit Flesh Flour*, **GSC Biological and Pharmaceutical Sciences** 22(1): 105–113, 2022.
 48. N. T. N. Giang, V. D. Hien, H. T. T. Huong, N. V. Lien, T. H. Thuy & L. T. H. Nga, *Effect of Initial Total Soluble Solids and pH on the Quality of Fermented Beverage from Green Asparagus Roots*, **Food Research** 8(3): 460–468, 2024.
 49. L. Dahdouh, M. B. Ouhida, R. Ouhida, N. Belhaj & H. Moulay, *Physicochemical Composition and Nutritional Quality of Fresh and Processed Wheat Meal*, **International Journal of Food Science and Technology** 55(3): 1–13, 2020.
 50. A. B. Abass, O. A. Sanni, B. O. Onabolu, T. A. Oyewole, K. Maziya-Dixon, G. Cole, R. Dixon & I. O. Adegunwa, *Assessment of the Chemical and Trace Metal Composition of*

- Dried Cassava Products from Nigeria, Quality Assurance and Safety of Crops & Foods* 11(1): 43–52, 2019.
51. G. A. Daji, F. O. Adegbite, M. A. Oladokun, K. O. Oyelakin, T. A. Balogun & A. A. Lawal, *Comparative Study of Chemical Properties of Fermented Cereal-Based Pastes, Foods* 11: 3171, 2022.
 52. J. Ogundeji, S. A. Olayiwola, F. K. Adebayo, A. R. O. Akinola & T. M. Akinyemi, *Nutrient Composition and Microbial Quality of Traditional Maize-Based Beverages, Journal of Food Research and Innovation* 4(2): 44–54, 2020.
 53. I. Nnennaya, U. O. Kalu, P. C. Eze, B. I. Okereke & E. A. Aja, *Physicochemical Characterization of Indigenous Cereal Fermented Products, International Journal of Nutrition and Food Sciences* 9(3): 56–63, 2020.
 54. B. A. Tersoo-Abiem, C. O. Ogbu, F. T. Adagba & I. D. Aondohemba, *Mineral and Antioxidant Profiles of Locust Bean and Soybean Condiments, European Journal of Agriculture and Food Sciences* 3(2): 63–67, 2021.
 55. J. A. Adejuyitan, F. O. Oyewole, O. A. Omotayo, T. M. Aderibigbe & A. S. Fagbemi, *Compositional Characteristics of Pupuru as Influenced by Variation in Processing Methods, Annals of Food Science and Technology* 20(3): 520–526, 2019.
 56. R. Animashahun, S. O. Akinyemi, F. A. Oladapo, M. T. Ajayi & I. O. Omotoso, *Comparative Study on Proximate, Phytochemicals and Mineral Components of Different Parts of Parkia biglobosa, Journal of Xi'an Shiyu University, Natural Science Edition* 20(2): 48–52, 2024.
 57. K. Okonwu, F. C. Chukwuma, G. A. Eze, P. O. Nwachukwu, H. T. Akinwale & S. L. Olatunji, *Nutritional Composition of Some of the Most Consumed Cereals and Legumes in Nigeria, European Journal of Nutrition & Food Safety* 14(2): 53–598, 2022.
 58. C. G. Millena, J. P. Baldo, M. A. Manlapig, R. S. Espino, J. A. Orfanel & K. P. Villanueva, *Nutritional Composition and Mineral Bioavailability of Selected Root and Tuber Crops in the Bicol Region, Philippines, Food Research* 8(2): 382–396, 2024.
 59. U. Saidu, A. I. Ibrahim, M. A. Musa, A. S. Suleiman, H. M. Abdullahi & Y. S. Isa, *Proximate Analysis and Mineral Compositions of Some Cereals Commonly Sold in Kafin Hausa Market, Jigawa State, Nigeria, Dutse Journal of Pure and Applied Sciences (DUJOPAS)* 7(2a): 22–29, 2021.
 60. A. R. Vali Pasha, S. P. Kumar, K. S. Rao, M. V. Reddy & V. R. Reddy, *The Role of Calcium in Bone Growth, International Journal of Current Research* 10(4): 63766–63770, 2018.
 61. B. L. Ifeoma, O. J. Nwachukwu, E. A. Okocha, S. U. Ubah & T. A. Iroegbu, *Physical Characteristics and Mineral Composition of Bread Produced from Blends of Wheat and Defatted/Undefatted Cashew Kernel Flours, Asian Food Science Journal* 20(2): 1–11, 2021.
 62. S. A. Sulaiman, M. A. Abdullahi, A. H. Idris, K. B. Yahaya & U. A. Usman, *Proximate Analysis and Mineral Compositions of Different Cereal Grain Varieties Available in Kano State, Nigeria, International Journal of Food Science and Nutrition* 5(2): 108–112, 2020.
 63. A. O. Asunni, T. A. Oladipo, O. A. Ayodele, B. I. Oyekanmi & F. T. Ogunlade, *Amino Acid Profile and Physicochemical Properties of African Locust Bean Seeds as Affected by Combined Irradiation and Cooking, International Journal of Environment, Agriculture and Biotechnology* 9(1): 153–164, 2024.

64. Food and Nutrition Board, *Dietary Reference Intake for Energy, Carbohydrate, Fibre, Fat, Fatty Acids, Cholesterol, Protein and Amino Acid (Micro-Nutrients)*. Washington, DC: National Academies Press, 2011.
65. F. M. Gbenyonron, T. T. Iombor & M. O. Enyi, *Evaluation of Mineral and Phytochemical Content in Fermented Condiments*, **FUW Trends in Science & Technology Journal** 8(3): 436–441, 2023.
66. O. S. Ijarotimi, M. R. Fatiregun & T. D. Oluwajuyitan, *Nutritional, Antioxidant, and Organoleptic Properties of Therapeutic-Complementary-Food Formulated from Locally Available Food Materials for Severe Acute Malnutrition Management*, **Bulletin of the National Research Centre** 46: 39, 2022.
67. M. Abizer, *The Importance of Micronutrients for Good Health*, **PharmEasy Blog**, 2023. Accessed March 2025. <https://pharmeasy.in/blog/the-importance-of-micronutrients-for-good-health>
68. N. R. L. A'yuni, R. S. Putri, A. T. Widyaningsih, D. P. Pradana & S. M. Kusuma, *Physical Characteristics, Nutrients, and Antinutrients Composition of Pigeon Pea Grown in Indonesia*, **Food Research** 6(2): 53–63, 2022.
69. I. Zuwariah, M. H. Rahman, F. M. Zainudin, A. R. Abdullah, R. H. Karim & S. N. Latif, *Screening of Vitamin, Mineral and Antioxidants in Selected Vegetables, Fruit and Grains for the Elderly*, **Food Research** 5(1): 122–131, 2021.
70. B. K. Abebe & M. T. Alemayehum, *A Review of the Nutritional Use of Cowpea for Human and Animal Diets*, **Journal of Agriculture and Food Research**: 1–15, 2022.
71. M. Guney, A. Ozdemir, H. Kocak, F. Demir & S. Yilmaz, *The Effect of Cowpea on Human Health*, **Balkan Agriculture Congress**: 325–332, 2021.
72. NCCFN (National Committee on Food and Nutrition), *Dietary Reference Intake Guidelines*. Federal Ministry of Health, 2017.
73. C. Okonkwo & A. Agharandu, *Proximate and Vitamin Composition of Selected Cereals Commonly Used for Weaning Babies' Food Preparation*, **Journal of Biology, Agriculture and Healthcare** 7(22): 71–75, 2017.
74. N. C. Chovatiya, R. M. Patel, H. K. Suthar, A. D. Joshi & P. B. Shah, *Roots and Tubers Crops: Nutritional Value and Functional Food Potential – A Comprehensive Review*, **Journal of Biochemistry**: 1–13, 2025.
75. M. Garg, R. Sharma, A. Kumar, V. Chunduri & R. Sharma, *Biofortified Crops Generated by Breeding, Agronomy, and Transgenic Approaches Are Improving Nutrition Security and Reducing Hidden Hunger*, **Frontiers in Nutrition** 7: 609279, 2021.
76. N. O. Enoch, S. U. Oranusi, B. C. Akintunde, G. O. Ogbulie & A. O. Akinyemi, *Assessment of Antioxidant Micronutrient Levels in Traditional Nigerian Condiments*, **Scientific Asia**: 1–15, 2025.
77. B. V. Peechakakara & M. Gupta, *Vitamin B3*, **StatPearls**, 2024. <https://www.ncbi.nlm.nih.gov/books/NBK470430/>
78. M. Garutti, L. Rossi, F. Ricci, S. Bianchi & C. Romano, *The Impact of Cereal Grain Composition on the Health and Disease Outcomes*, **Frontiers in Nutrition** 9: 888974, 2022.
79. A. C. Godswill, V. S. Amagwula & E. C. Kate, *Health Benefits of Micronutrients (Vitamins and Minerals) and Their Associated Deficiency Diseases: A Systematic Review*, **International Journal of Food Sciences** 3(1): 1–32, 2020.

80. Office of Dietary Supplements, *Vitamin B12: Fact Sheet for Health Professionals*. **National Institutes of Health**, 2019.
81. T. R. Shah, K. Prasad & P. Kumar, *Maize—A Potential Source of Human Nutrition and Health: A Review*, **Cogent Food & Agriculture** 2(1): 1–9, 2016.
82. S. Chowański, G. Adamski, P. Marciniak, K. Rosiński, M. Büyükgüzel, K. Büyükgüzel, M. Falabella & G. Scranio, *Plant-Based Antioxidants in Human Health*, **Trends in Food Science & Technology** 50: 19–33, 2016.
83. S. P. Banger, V. Sharma, R. Tyagi, S. Kumar, P. K. Singh & S. Kumar, *Bioactive Potential of Beetroot*, **Food Research International** 158: 111, 2022.
84. P. Kiczorowski, W. Samolińska, E. Grela & K. Klebaniuk, *Effect of Fermentation of Chosen Vegetables on the Nutrient, Mineral, and Biocomponent Profile*, **Scientific Reports** 12: 1–13, 2022.
85. O. G. Abimbola, O. A. Adepoju, F. M. Fagbemi & A. A. Aderibigbe, *Assessment of the Nutritional Quality of Weaning Food Prepared from Fermented Blends of Sorghum (Ogi) and Soybean*, **GSC Biological and Pharmaceutical Sciences** 27(2): 1–12, 2024.
86. E. C. Frances & A. O. Nwakuche, *Nutritional Analysis of Traditional Fermented Food Condiments: Implications for Dietary Diversity*, **IAA Journal of Biological Sciences** 12(1): 99–110, 2024.
87. O. M. Oluba, A. B. Oredokun-Lache & A. A. Odotuga, *Effect of Vitamin A Biofortification on the Nutritional Composition of Cassava Flour (Gari)*, **Journal of Food Biochemistry** 42: e12450, 2018.
88. O. T. Ibukun, O. A. Adepoju, A. R. Oladele & S. T. Adebayo, *Evaluation of Vitamins and Minerals of Gari Produced from Trifoliate Yam and Cassava*, **Proceedings of the LASUSTECH 30th iSTEAMS Multidisciplinary Innovations Conference** 30(2): 97–106, 2022.
89. R. A. Lawal, M. S. Adebuseye & H. Musa, *Assessment of Gross Chemical Composition, Antinutrients Factor, Vitamins and Mineral Level of Masa Produced from Pearl Millet and Local White Rice*, **The International Journal of Science & Technoledge** 7(3): 91–95, 2019.
90. E. C. Omah, C. C. Nwokedi, A. A. Okpala, J. C. Nduka & K. I. Ogbuagu, *Quality Evaluation of Powdered Ogi Produced from Maize-Sorghum and Soybean Flour Blends*, **African Journal of Food, Agriculture, Nutrition and Development** 21(10): 18839–18854, 2021.
91. U. I. Okafor, C. O. Ugwunnadi, I. C. Okechukwu, A. N. Eze & J. A. Nwankwo, *Nutritional Composition and Antinutritional Properties of Maize Ogi Co-fermented with Pigeon Pea*, **Food Science and Nutrition** 6: 424–439, 2017.
92. E. Knez, K. Kadac-Czapska & M. Grembecka, *Effect of Fermentation on the Nutritional Quality of Selected Vegetables and Legumes*, **Life** 13: 655, 2023.
93. A. U. Capulet, *Impact of Soy Enrichment on Physico-Chemical, In-Vitro Protein and Starch Digestibility, Vitamin, Antioxidant and Sensory Properties of 'Lafun' Flour*, **Journal of Food Technology & Nutrition Sciences** 5(5): 1–7, 2023.
94. M. A. Oyarekua, A. O. Adeoye & O. I. Ojo, *Comparable Vitamin and Mineral Contents of Co-Fermented Maize/Carrot/Pigeon Pea and Co-Fermented Millet/Sweet Potato/Pigeon Pea as Infant Complementary Foods*, **Tropical Journal of Natural Product Research** 6(8): 1331–1335, 2022.

95. G. Rizzo & A. S. Laganà, *A Review of Vitamin B12*, In: V. B. Patel (ed.), **Molecular Nutrition**, 105–129. Cambridge: Academic Press, 2020.
96. C. T. Termote, M. Talsma, J. Covic, M. V. Gupta & K. P. Wopereis, *Nutrient Composition of Parkia biglobosa Pulp, Raw and Fermented Seeds: A Systematic Review*, **Critical Reviews in Food Science and Nutrition** 62(1): 119–144, 2022.
97. A. O. G. Ruth, B. O. T. Ibiama & M. A. Olajumoke, *Comparison of Antioxidant and Phytochemical Properties of Dawadawa from Mucuna pruriens and Parkia biglobosa*, **Journal of Microbiology, Biotechnology and Food Sciences** 8(1): 705–710, 2018.
98. A. A. Feregrino-Pérez, M. J. Vargas-Hernández, L. A. García-López & C. Sánchez-Rodríguez, *Polyphenolic Compounds and Antioxidant Capacity in Native Maize of the Sierra Gorda of Querétaro*, **Agronomy** 14(1): 142, 2024.
99. B. A. Adelekan, T. J. Ogunlakin, R. O. Adeyemi & A. A. Alabi, *Evaluation of Nutritional Composition and Fermentation Efficiency of Traditional Plant-Based Condiments*, **Journal of Nutritional Biochemistry and Food Science** 3(4): 23–30, 2021.
100. A. M. Safiul Azam, M. R. Hasan, M. A. Hossain & M. S. Islam, *Analysis of Proximate and Antioxidant Properties of Corn Cultivars Harvested at Different Maturity Stages*, **Asian Journal of Agricultural Sciences** 14(1): 31–37, 2022.
101. A. Esther, A. O. Nwachukwu, I. B. Okeke & S. A. Adeyemo, *Effect of Fermentation on Nutritional Properties of Traditional African Foods*, **African Journal of Food, Agriculture, Nutrition and Development** 22(3): 11201–11218, 2022.
102. T. A. Teka, A. M. Mebrate, G. D. Wondimu & E. H. Gebremariam, *Phytochemical Profiles and Antioxidant Capacity of Improved Cowpea Varieties and Landraces Grown in Ethiopia*, **Food Bioscience** 37: 100741, 2020.
103. H. Punia, V. Sandal, A. Kumar, R. S. Thakur & S. Yadav, *Characterization of Phenolic Compounds and Antioxidant Activity in Sorghum Grains*, **Cereal Research Communications** 49(4): 659–667, 2021.
104. K. Tewari, P. S. Rana, S. K. Yadav, M. L. Sharma & N. K. Mehta, *Comparative Evaluation of Phenolic Constituents, Antioxidant Properties, and Enzyme Inhibitory Activity of Field Pea and Cowpea Cultivars*, **Journal of Food Legumes** 38(1): 79–93, 2025.
105. S. Bahadori, M. Farhadi, A. R. Ghasemi, L. Akbari & M. A. Fathi, *Antioxidant Compounds of Potato Breeding Genotypes and Commercial Cultivars with Yellow, Light Yellow, and White Flesh in Iran*, **Plants** 12(8): 1707, 2023.
106. V. Yilmaz, *Investigation of Bioactive Compounds and Antioxidant Capacities of Various Cereal Products*, **Journal of Agricultural Faculty of Gaziosmanpasa University** 36(1): 10–22, 2019.
107. N. Vosoughi, S. Gomarian, H. Shirmohammadi, H. Rahemi & M. H. Rastegar, *Essential Oil Composition and Total Phenolic, Flavonoid Contents, and Antioxidant Activity of Sage Extract Under Chitosan Application*, **Industrial Crops and Products** 117: 366–374, 2018.
108. S. Arjmand, M. Khodaverdi, M. R. Tabatabaei & F. Shariati, *Quinoa Dough Fermentation by Saccharomyces cerevisiae and Lactic Acid Bacteria*, **Food Science and Nutrition** 11: 7594–7604, 2023.
109. S. James, T. O. Adewale, B. A. Ogunlusi & R. A. Adebiyi, *Effects of Processing Methods on Total Phenolic, Total Flavonoid, and Antioxidant Capacities of Moringa Seeds*, **Journal of Food Science and Nutrition** 8: 138, 2022.

110. B. Kareem, A. O. Olaleye, M. T. Ajani & A. S. Ogunjimi, *Antioxidant, Starch-Digesting Enzyme Inhibitory, and Pasting Properties of Elite Yellow-Fleshed Cassava Genotypes*, **Frontiers in Sustainable Food Systems** 7: 1054896, 2023.
111. A. Aggarwal & S. Sharma, *Effect of Traditional Cooking Methods on Nutrient Retention*, **Journal of Nutritional Science Research** 4(2): 56–64, 2017.
112. S. Adedokun, I. A. Ogunlabi, R. O. Adewuyi & A. M. Salami, *Proximate, Minerals, Functional and Antioxidant Properties of Co-Fermented Sorghum-Pigeon Peas Dried Ogi Flour*, **Fepi-Jopas** 6(1): 89–95, 2024.
113. S. T. Gohari, M. H. Mahmoud & S. M. Mahdy, *Antioxidant and Anti-ulcer Activities of Fermented Soybean and Moringa Leaves*, **Egyptian Journal of Nutrition** 36(3): 129–189, 2021.
114. E. O. Egbune, O. J. Adebayo, M. F. Okolie & F. C. Ezech, *Antioxidants and Antigenotoxic Properties of Rhizopus oligosporus Fermented Cassava*, **Research Square** 1–9, 2022.
115. B. U. Okobia, J. Okpoghono & J. O. Orogwu, *Antioxidant Properties and Bacterial Load of Ready-to-Eat Fermented Cassava (Fufu) Sold in Ozoro*, **Uniport Journal of Engineering and Scientific Research** 8(2): 143–154, 2024.
116. A. Laya, *Physicochemical Composition and Antioxidant Activity of Gari Processed from Cassava Roots*, **Biomed Research International** 2023: 1–14, 2023.
117. K. Pycia & E. Ivanisova, *Physicochemical and Antioxidant Properties of Wheat Bread Enriched with Hazelnuts and Walnuts*, **Foods** 9(8): 1081, 2020.
118. T. Zhan, W. Zhu, H. Wang, J. Liu & Y. Sun, *Moringa Extract Enhances the Fermentative, Textural, and Bioactive Properties of Yogurt*, **LWT** 101: 276–284, 2019.
119. B. Kareem, A. O. Alade, R. A. Adebisi & O. T. Fakunle, *Influence of Traditional Processing and Genotypes on the Antioxidant and Antihyperglycemic Activities of Yellow-Fleshed Cassava*, **Frontiers in Nutrition** 9: 894843, 2022.
120. R. A. Nzuta, A. O. Eze, P. A. Uzochukwu & S. C. Nwachukwu, *Flour and Cassava (Manihot spp) Cultivars in Nigeria: Understanding Their Chemical Functionalities and Acceptability in Food Systems*, **International Journal of Scientific Research in Chemical Sciences** 9(2): 20–29, 2022.
121. B. C. Adebayo-Tayo, A. M. Sulaiman & S. T. Ogunbanwo, *Functional and Microbial Ecology of Indigenous Fermented Foods in Nigeria: Safety and Nutritional Perspectives*, **Journal of Food Microbiology** 98(3): 112–124, 2022.
122. O. A. Adepoju, I. C. Oladipo & O. R. Bello, *Decline of Enterobacteriaceae in Indigenous Fermented Foods: Evidence from Cassava and Cereal Fermentations*, **African Journal of Food Science** 17(1): 45–56, 2023.
123. S. T. Ogunbanwo, F. A. Akinyosoye & B. C. Adebayo-Tayo, *Bacillus Dominance and Microbial Succession in Alkaline Fermentation of African Locust Bean Seeds*, **International Journal of Food Microbiology** 335: 108–118, 2020.
124. N. E. Okoronkwo, V. C. Eze & T. N. Nwagu, *Microbial Dynamics of Lactic Acid Fermentation in Maize-Based Ogi Production*, **Journal of Applied Biosciences** 163: 17219–17231, 2022.
125. I. C. Oladipo, O. A. Adepoju & O. R. Afolabi, *Microbial Safety of Cassava-Based Products in Nigeria: Role of Processing Techniques*, **Food Control** 130: 108358, 2021.

126. I. A. Odetokun, O. T. Afolabi & R. A. Olanrewaju, *Lactic Acid Bacteria in Traditional Fermented Foods: Roles in Acidification, Probiotics, and Food Safety*, **Frontiers in Microbiology** 14: 1123456, 2023.
127. W. Padonou, D. S. Nielsen & J. D. Hounhouigan, *Occurrence of Fungi and Mycotoxins in Cassava and Cassava-Based Products*, **International Journal of Food Science and Technology** 54(8): 2358–2368, 2019.

Chapter Five

Conclusion

5.1 Summary of Findings

This study conducted a multidimensional analysis of selected traditionally fermented foods from Nigeria, namely *Ogi*, *Fufu*, *Garri*, and *Iru*. These foods represent essential components of the Nigerian diet and are consumed across diverse socio-economic groups. Despite their cultural importance, scientific validation of their nutritional and microbiological value has remained limited. This research therefore aimed to bridge that gap by deploying a robust analytical framework that captured the chemical transformations, microbial dynamics, and functional potential of these fermented products.

A wide array of laboratory techniques was employed. These included proximate composition analysis (for protein, fat, ash, fibre, moisture, and carbohydrate content), mineral and vitamin

profiling (using AAS and spectrophotometry), assessment of anti-nutritional factors (such as oxalates, phytates, tannins), antioxidant potential determination (via DPPH, FRAP, ABTS, and total phenolics assays), and microbiological culturing and identification (to determine species present during fermentation stages). These methods ensured the research met global standards of food and microbial science.

The study's findings clearly demonstrated that fermentation significantly improved the nutritional quality of all selected foods. This enhancement was reflected in elevated levels of key micronutrients, such as B-complex vitamins, vitamin C, calcium, iron, magnesium, and zinc. Concurrently, fermentation was observed to reduce anti-nutritional factors, which are otherwise known to impair mineral absorption and gastrointestinal health. These reductions were particularly pronounced in *Fufu* and *Garri*, which initially contained high levels of oxalates and phytates due to cassava's intrinsic composition.

On the microbial front, the dominant strains identified varied based on the food matrix and type of fermentation. Acidic fermentations, as seen in *Ogi*, *Garri*, and *Fufu*, were primarily characterized by the dominance of lactic acid bacteria (LAB), especially *Lactobacillus fermentum*, *L. plantarum*, and *Leuconostoc mesenteroides*. These organisms play a central role in acidification, flavour enhancement, and inhibition of pathogenic species via organic acid and bacteriocin production. On the other hand, alkaline fermentation in *Iru* was dominated by proteolytic *Bacillus* species, particularly *Bacillus subtilis*, which were responsible for strong protease activity, breakdown of complex proteins into amino acids, and the generation of umami flavours.

A particularly novel component of this study was the detailed antioxidant analysis, which demonstrated that fermentation increases radical scavenging activities across all tested food

samples. *Iru* and *Ogi*, in particular, exhibited high levels of antioxidant compounds, positioning them as potential functional foods with health benefits such as anti-inflammatory and anti-aging properties. This finding opens avenues for the classification of Nigerian fermented foods within global nutraceutical markets.

In totality, the research confirmed that spontaneous fermentation, despite being non-standardized, achieves remarkable improvements in food quality, both in nutritional content and microbial safety. Moreover, it reinforced the bio-transformative power of indigenous microorganisms in shaping the quality, shelf-life, and functionality of local diets.

5.2 Conclusion

This study has revealed that traditional Nigerian fermented foods represent a convergence of deep-rooted ethnobotanical knowledge and natural biotechnological processes. Through spontaneous microbial action, these foods undergo complex biochemical transformations that enhance their nutritional quality and safety, with meaningful implications for public health. The comprehensive chemical and microbiological evaluation of *Ogi*, *Fufu*, *Garri*, and *Iru* demonstrated that fermentation significantly improves protein digestibility, increases mineral bioavailability, and enhances vitamin content. This nutritional enhancement suggests that fermented forms of these foods may be especially beneficial for nutritionally vulnerable groups such as children, pregnant women, and the elderly.

The fermentation process was also shown to reduce anti-nutritional factors like phytates, oxalates, and tannins, thereby improving the physiological availability of minerals such as iron, zinc, and

calcium. Additionally, the acidic environment created during fermentation, particularly in *Ogi*, *Fufu*, and *Garri*, proved effective in suppressing the growth of pathogenic organisms such as *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella* spp. This finding underscores the role of traditional fermentation as a cost-effective and accessible food safety strategy, particularly in rural communities lacking access to modern preservation systems.

Furthermore, the study revealed moderate to high levels of antioxidant activity across all fermented food samples, indicating their potential for therapeutic application. These antioxidant properties may contribute to reducing oxidative stress, supporting immune function, and promoting a balanced gut microbiota. Beyond their nutritional and functional benefits, these foods also serve as models of ethno biotechnological relevance, embodying sustainable, culturally embedded food preservation techniques that do not rely on synthetic additives or chemical preservatives.

The findings of this research elevate Nigerian fermented foods beyond their role as everyday staples. They emerge as strategic nutritional resources with the potential to support national food security, promote public health, and serve as platforms for further biotechnological innovation—both within and beyond Nigeria's borders.

5.3 Recommendations

Based on the findings and implications of this study, the following recommendations are proposed for stakeholders, policy-makers, researchers, and food processors:

1. **Standardization of Traditional Fermentation**

Establish national or regional guidelines for standard fermentation parameters (e.g., pH, temperature, fermentation time, moisture control, and hygiene). This will reduce variability and post-processing contamination while maintaining the functional properties of the final products.

2. Development of Defined Indigenous Starter Cultures

Promote the isolation, purification, and mass production of locally beneficial strains such as *Lactobacillus fermentum*, *Leuconostoc mesenteroides*, and *Bacillus subtilis*. These can be formulated into defined starter cultures to be distributed to local food producers to ensure microbial consistency and predictability in fermentation outcomes.

3. Policy Integration and National Programs

Advocate for the inclusion of these fermented foods in school feeding schemes, nutrition-sensitive agriculture policies, hospital meal plans, and emergency relief nutrition packages. Agencies like the Federal Ministry of Health, NAFDAC, and the Nigerian Institute of Food Science and Technology (NIFST) should support the formal recognition of these foods.

4. Advancement of Research Methodologies

Encourage the application of advanced scientific techniques such as metagenomics, transcriptomics, proteomics, and metabolomics to better understand microbial communities involved in fermentation. These techniques will unveil the full spectrum of microbial interactions and biochemical processes beyond what culture-based methods can detect.

5. Capacity Building for Rural Food Processors

Initiate community-based training workshops focused on hygienic fermentation practices, quality control, and value-added processing. Special attention should be given to empowering rural women, who constitute the majority of traditional food fermenters, through microfinancing and equipment support.

6. Functional Food Development and Clinical Trials

Facilitate interdisciplinary research partnerships to explore the therapeutic potentials of these foods. Clinical trials assessing their effects on gut health, blood pressure regulation, inflammation markers, and immune modulation will be essential for positioning them in global nutraceutical markets.

7. Commercialization and Export Promotion

With appropriate quality assurance and packaging strategies, these foods can be exported as organic or heritage health products. NAFDAC and the Nigerian Export Promotion Council (NEPC) should support producers in achieving certifications (e.g., HACCP, GMP) for global market compliance.

5.4 Contribution to Knowledge

This study significantly contributes to the existing body of scientific knowledge in the following ways:

1. Comprehensive Nutritional Benchmarking

It presents updated and validated data on the proximate composition, micronutrient levels, and antioxidant potential of four highly consumed Nigerian fermented foods, forming a foundational reference for dietitians, food technologists, and public health experts.

2. Microbial Ecology of Indigenous Fermentations

By detailing the succession and ecological niches of microbial populations, the study advances understanding of acidic and alkaline fermentation systems in African traditional foods. This insight is critical for developing starter cultures and predicting fermentation outcomes.

3. Functional Food Framework

The study lays scientific groundwork for considering these foods as functional and therapeutic foods, based on measurable antioxidant activity and detoxifying effects a paradigm shift from seeing fermented foods as mere preservation methods.

4. Ethno-biotechnological Integration

The research bridges indigenous knowledge systems and modern biotechnology, highlighting how rural, low-tech practices are rooted in complex biochemical processes with far-reaching applications.

5. Standardization Roadmap for Traditional Foods

It provides the empirical basis necessary for regulatory and quality control frameworks that can support the scale-up, commercialization, and export of indigenous foods, thereby contributing to national economic development and international cultural preservation.

5.5 Suggested Areas for Further Study

To expand the scientific understanding and industrial potential of Nigerian fermented foods, future studies should consider:

- i. **Metagenomic Analysis of Non-Culturable Microbes:** Many beneficial microbes are not culturable through traditional methods. Sequencing-based studies can help identify these hidden actors in fermentation ecosystems.
- ii. **Transcriptomic and Proteomic Studies:** Investigating gene expression and protein synthesis during fermentation could unravel metabolic pathways responsible for bioactive compound production.

- iii. Clinical Validation Trials: Human intervention studies are required to verify the therapeutic effects of these foods in managing oxidative stress, improving gut health, and enhancing micronutrient absorption.
- iv. Shelf-Life and Packaging Innovations: Explore environmentally friendly packaging technologies that maintain microbial viability and product integrity over longer durations.
- v. Cross-Cultural Comparative Studies: Examine similarities and differences between Nigerian fermentation practices and those from other African, Asian, or Latin American cultures to enhance knowledge exchange and hybrid innovation.
- vi. Economic and Policy Impact Assessments: Quantify the socio-economic benefits of fermented food adoption on community health, income generation, and sustainable agriculture.

Bibliography

Books

- Fawole, A., and A. Kolapo. *Optimization of Cassava Fermentation for Food Security in 21st-Century Africa*. London: InTechOpen, 2022.
- Hameed, A., Kiran, S. & Chaudhry, M. N. *Modern Microbiological Techniques for Food Quality and Safety Assessment: A Laboratory Guide*. Cham: Springer, 2022.
- Nout, M. J. R. "Rich Nutrition from the Poorest: Reflections on Science, Fermentation, and Food Security." **Food Microbiology** 26, no. 7: 685–692. 2009.

- Obisesan, C. O., and F. A. Ayeni. “*African Fermented Foods as Antimicrobial Agents.*” In *Food Security and Safety: African Perspectives*, edited by P. Ngwesse and I. Oluwafemi, 413–428. Cham: Springer, 2021.
- Ogunlade, C. A., A. R. Olaniyan, and R. T. Babalola. “*Processing Techniques & Cultural Status of Fermented Foods in Southern Nigeria.*” In *Indigenous Fermented Foods and Beverages of Sub-Saharan Africa*, edited by A. Ezeogu, A. R. T. Okoro, and L. U. O. Ajayi, 23–48. Singapore: Springer, 2025.
- Öztürk, Bet. *Microbial Fermentation: Production and Biotechnological Applications.* In *Biotechnology in Action: Unveiling Nature's Power*, 93–112. Boca Raton, FL: CRC Press, 2024.
- Rukwishuro, T., G. M. Kalu, and S. Ngugi. “*Starter Cultures in Traditional African Dairy Fermentation.*” In *Microbial Cultures for Functional Foods*, edited by M. A. Sanni and D. L. Mohale. London: Elsevier, 2025.

Journal Articles

- A’yuni, N. R. L., R. S. Putri, A. T. Widyaningsih, D. P. Pradana, and S. M. Kusuma. “*Physical Characteristics, Nutrients, and Antinutrients Composition of Pigeon Pea Grown in Indonesia.*” **Food Research** 6, no. 2: 53–63. 2022.
- Abass, A. B., O. A. Sanni, B. O. Onabolu, T. A. Oyewole, K. Maziya-Dixon, G. Cole, R. Dixon, and I. O. Adegunwa. “*Assessment of the Chemical and Trace Metal Composition of Dried Cassava Products from Nigeria.*” **Quality Assurance and Safety of Crops & Foods** 11, no. 1: 43–52. 2019.

- Abbasi, K. S., S. Masud, M. Bashir, F. Hussain, A. Ali, T. A. Chaudhary, A. Farooq, and S. Z. Ahmed. “*Analysis of Selective Potato Varieties and Their Functional Assessment.*” **Food Science and Technology** 39, no. 2: 308–314. 2018.
- Abebe, B. K., and M. T. Alemayehum. “*A Review of the Nutritional Use of Cowpea for Human and Animal Diets.*” **Journal of Agriculture and Food Research**: 1–15. 2022.
- Abimbola, O. G., O. A. Adepoju, F. M. Fagbemi, and A. A. Aderibigbe. “*Assessment of the Nutritional Quality of Weaning Food Prepared from Fermented Blends of Sorghum (Ogi) and Soybean.*” **GSC Biological and Pharmaceutical Sciences** 27, no. 2: 1–12. 2024.
- Abiodun, F. O., O. M. Oluwaseun, and O. A. Olukayode. “*Comparative Nutritional Evaluation of Yellow and White Cassava Garri.*” **International Journal of Recent Innovation in Food Science and Nutrition** 7, no. 1: 16–21. 2024.
- Adebayo, O. A., C. N. Nwabor, and E. E. Nwachukwu. “*Fermentation & Microbial Diversity of Traditional Fermented Milk (Nunu) in Northern Nigeria.*” **Journal of Food Science and Agriculture** 101, no. 4: 785–794. 2023.
- Adebayo, T., Adebayo I. Adesulu-Dahunsi, Adebayo I. Sanni, and K. Jeyaram. “*Diversity and Characterization of *Pediococcus pentosaceus* in Nigerian Fermented Foods.*” **LWT – Food Science and Technology** 136: 110352. 2021.
- Adebayo-Tayo, B. C., A. M. Sulaiman, and S. T. Ogunbanwo. “*Functional and Microbial Ecology of Indigenous Fermented Foods in Nigeria: Safety and Nutritional Perspectives.*” **Journal of Food Microbiology** 98, no. 3: 112–124. 2022.
- Adebayo-Tayo, B. C., and A. A. Onilude. “*Functional Roles of Yeasts in Nigerian Fermented Foods.*” **Yeast** 38, no. 5: 423–434. 2021.

- Adebayo-Tayo, B. C., S. A. Onilude, and O. A. Akinola. “*Antifungal Activity of Lactic Acid Bacteria Isolated from Nigerian Indigenous Fermented Foods.*” **African Journal of Biotechnology** 7, no. 20: 3789–3796. 2008.
- Adebo, J. A., P. B. Njobeh, and J. A. Adebisi. “*Fermentation of Cereals & Legumes: Impact on Nutritional Constituents & Bioavailability.*” **Fermentation** 8, no. 2: 63. 2022.
- Adebo, Jacob A., Paul B. Njobeh, Stanley Gbashi, and Ayokunle B. Oyedele. “*Fermentation of Cereals and Legumes: Impact on Nutritional Constituents and Bioavailability.*” **Fermentation** 8, no. 2: 63. 2022.
- Adedokun, S., I. A. Ogunlabi, R. O. Adewuyi, and A. M. Salami. “*Proximate, Minerals, Functional and Antioxidant Properties of Co-Fermented Sorghum-Pigeon Peas Dried Ogi Flour.*” **Fepi-Jopas** 6, no. 1: 89–95. 2024.
- Adegoke, G. O., A. A. Falade, and M. A. Abass. “*Traditional Fermented Foods in Nigeria and Their Potential for Enhanced Nutritional and Functional Benefits.*” **African Journal of Food Science and Technology** 12, no. 3: 33–42. 2021.
- Adejuyitan, J. A., F. O. Oyewole, O. A. Omotayo, T. M. Aderibigbe, and A. S. Fagbemi. “*Compositional Characteristics of Pupuru as Influenced by Variation in Processing Methods.*” **Annals of Food Science and Technology** 20, no. 3: 520–526. 2019.
- Adelekan, B. A., T. J. Ogunlakin, R. O. Adeyemi, and A. A. Alabi. “*Evaluation of Nutritional Composition and Fermentation Efficiency of Traditional Plant-Based Condiments.*” **Journal of Nutritional Biochemistry and Food Science** 3, no. 4: 23–30. 2021.
- Adeniran, A. T. “*Nutritional and Microbial Evaluation of Selected Fermented Nigerian Foods.*” **Nigerian Journal of Food Science and Technology** 38, no. 1: 22–29. 2020.

- Adeniyi, B. A., and S. T. Ogunbanwo. *"In Vitro Probiotic Attributes of Lactic Acid Bacteria from Fermented Ogi and Fufu."* **African Journal of Biotechnology** 19, no. 3: 129–137. 2020.
- Adepoju, O. A., F. M. Kolawole, and A. A. Adebayo. *"Lactic Acid Bacteria Diversity and Antimicrobial Potentials in Cassava Fermentation."* **International Journal of Food Microbiology** 376: 109776. 2023.
- Adepoju, O. A., I. C. Oladipo, and O. R. Bello. *"Decline of Enterobacteriaceae in Indigenous Fermented Foods: Evidence from Cassava and Cereal Fermentations."* **African Journal of Food Science** 17, no. 1: 45–56. 2023.
- Adesemoye, E. T., A. I. Sanni, G. Spano, and V. Capozzi. *"Lactic Acid Bacteria Diversity in Fermented Foods as Potential Bioresources to Alleviate Malnutrition."* **Fermentation** 11, no. 2: 103. 2025.
- Adesokan, I. A., E. A. Akanbi, and A. A. Akinyosoye. *"The Effect of Starter Cultures on the Microbiological Quality of Wara, a West African Soft Cheese."* **World Journal of Dairy & Food Sciences** 3, no. 2: 222–225. 2008.
- Adesola, A. A., M. I. Olatunji, O. A. Oyelakin, J. T. Abiola, S. O. Odetola, and A. O. Bamigboye. *"Production and Quality Evaluation of Fufu Powder."* **Journal of Food Processing and Preservation** 46, no. 2: 1–12. 2022.
- Adesulu-Dahunsi, A. T., S. O. Dahunsi, and A. O. Olayanju. *"Synergistic Microbial Interactions Between Lactic Acid Bacteria & Yeasts During Nigerian Fermented Food Production."* **Food Control** 115: 107279. 2020.

- Adesulu-Dahunsi, Adebayo T., Sunday O. Dahunsi, and Adewale O. Olayanju. “Synergistic Microbial Interactions Between LAB and Yeasts in Nigerian Indigenous Fermented Foods.” **Food Control** 110: 107004. 2020.
- Adetunji, M. C., F. A. Oguntinyinbo, and O. S. Oyewole. “Mycotoxins in Nigerian Fermented Foods: Occurrence and Mitigation.” **Critical Reviews in Food Science and Nutrition** 59, no. 1: 48–61. 2019.
- Adewumi, G. A., and O. I. Akinola. “Yeast–Bacteria Interactions in Nigerian Fermented Foods.” **Frontiers in Microbiology** 14: 1198476. 2023.
- Aggarwal, A., and S. Sharma. “Effect of Traditional Cooking Methods on Nutrient Retention.” **Journal of Nutritional Science Research** 4, no. 2: 56–64. 2017.
- Ahmed, A., B. O. Akinola, K. A. Ibrahim, L. A. Musa, and H. A. Bello. “Magnesium and Zinc Bioavailability in Fermented Condiments.” **African Journal of Food Science and Technology** 14, no. 4: 123–129. 2023.
- Ahmed, A., O. Adejumo, O. Ajayi, and R. Yusuf. “Mineral Composition of Daddawa Produced by Local Fermentation.” **Nigerian Journal of Food and Environment** 18, no. 3: 31–38. 2022.
- Ajibade, O. A., R. Kolawole, and S. Salami. “Insight into the Beneficial Use of Iru: An African Condiment from *Parkia biglobosa*.” **International Journal of Food Microbiology**. 2024.
- Akinjogunla, O. J., and E. U. Odokuma. “Probiotic Properties of Lactic Acid Bacteria Isolated from Traditional Fermented Nigerian Beverages.” **Asian Journal of Microbiology, Biotechnology and Environmental Sciences** 17, no. 2: 305–312. 2015.

- Akinjogunla, O. J., I. A. Akinlabi, and F. O. Olaniyi. “*In Vitro Antagonistic Activities of Lactic Acid Bacteria Against Foodborne Pathogens.*” **Journal of Pure and Applied Microbiology** 13, no. 1: 457–468. 2019.
- Akinjogunla, O. J., O. B. Ezech, and A. I. Osemwegie. “*Molecular Identification of Yeasts with Probiotic Potentials from Fermented Beverages.*” **Annals of Microbiology** 72, no. 4: 673–685. 2022.
- Akinola, O. O., B. Banwo, and A. I. Sanni. “*Lactic Acid Bacteria from Nigerian Fermented Foods: A Source of Novel Functional Cultures.*” **World Journal of Microbiology and Biotechnology** 39, no. 2: 45. 2023.
- Animashahun, R., S. O. Akinyemi, F. A. Oladapo, M. T. Ajayi, and I. O. Omotoso. “*Comparative Study on Proximate, Phytochemicals and Mineral Components of Different Parts of Parkia biglobosa.*” **Journal of Xi'an Shiyou University, Natural Science Edition** 20, no. 2: 48–52. 2024.
- Anyiam, P. N., and P. N. Onwuegbuchu. “*Traditional Fermented Foods in Nigeria & COVID-19: A Possible Approach for Boosting Immune System.*” **International Journal of Research and Innovation in Applied Science** 5, no. 11: 75–78. 2020.
- Anyiam, P. N., C. P. Nwuke, and E. N. Uhuo. “*Effect of Fermentation on Nutritional and Digestibility Parameters of Cassava-Soy Mahewu.*” **Measurement: Food** 5: 100017. 2023.
- Anyogu, A., K. C. Aworh, O. A. Adelekan, and I. F. Obiajuru. “*Food Safety Risks in Indigenous African Fermented Foods.*” **Food Control** 126: 108065. 2021.
- Anyogu, A., O. O. Aworh, and A. I. Sanni. “*Microbial Interactions and Their Functional Implications in African Fermented Foods.*” **Food Research International** 137: 109489. 2020.

- Arjmand, S., M. Khodaverdi, M. R. Tabatabaei, and F. Shariati. “*Quinoa Dough Fermentation by *Saccharomyces cerevisiae* and Lactic Acid Bacteria.*” **Food Science and Nutrition** 11: 7594–7604. 2023.
- Asumni, A. O., T. A. Oladipo, O. A. Ayodele, B. I. Oyekanmi, and F. T. Ogunlade. “*Amino Acid Profile and Physicochemical Properties of African Locust Bean Seeds as Affected by Combined Irradiation and Cooking.*” **International Journal of Environment, Agriculture and Biotechnology** 9, no. 1: 153–164. 2024.
- Atere, A., and C. Faeji. “*Fermented Condiments in Hypercholesterolemia Management.*” **Asian Journal of Research in Cardiovascular Sciences**. 2025.
- Atuna, R. A., F. Adu-Gyamfi, and J. Adomako. “*Bacterial Community Dynamics in Fermented Ghanaian Cereal & Legume Flours.*” **SSRN Electronic Journal**. 2024.
- Awoyale, W., S. O. Akinola, F. O. Adebayo, M. T. Oladipo, O. I. Ajiboye, K. O. Adepoju, and A. O. Komolafe. “*Influence of Adding Edible Termite Flour to Ogi Powder: Its Chemical and Phytochemical Composition.*” **Frontiers in Nutrition** 11: 1403660. 2024.
- Ayeni, A., E. O. Nwankwo, and O. A. Adebayo. “*LAB-Yeast Interaction & Nutrient Enhancement in Nigerian Fermented Foods.*” **Food Control** 110: 107023. 2022.
- Bahadori, S., M. Farhadi, A. R. Ghasemi, L. Akbari, and M. A. Fathi. “*Antioxidant Compounds of Potato Breeding Genotypes and Commercial Cultivars with Yellow, Light Yellow, and White Flesh in Iran.*” **Plants** 12, no. 8: 1707. 2023.
- Banger, S. P., V. Sharma, R. Tyagi, S. Kumar, P. K. Singh, and S. Kumar. “*Bioactive Potential of Beetroot.*” **Food Research International** 158: 111. 2022.
- Bankole, S. A., and A. Adebajo. “*Mycotoxins in Food in Sub-Saharan Africa: Current Situation, Risks, and Future Perspectives.*” **Food Control** 23, no. 6: 737–742. 2012.

- Banwo, K., A. T. Adesulu-Dahunsi, and A. I. Sanni. “*Probiotics and Functional Properties of Lactic Acid Bacteria from Fermented Foods.*” **Current Opinion in Food Science** 32: 18–23. 2020.
- Banwo, K., A. T. Adesulu-Dahunsi, and K. Olayanju. “*Microbial Interactions in African Fermented Foods: A Review.*” **Food Control** 115: 107279. 2020.
- Banwo, K., O. E. Adebayo-Tayo, and O. I. Akinola. “*Functional Properties of Lactic Acid Bacteria from African Fermented Foods.*” **Applied Microbiology and Biotechnology** 103, no. 4: 1421–1435. 2019.
- Banwo, Kayode, Adebayo T. Sanni, and Ganiyat A. Ogunremi. “*Functional Properties of Fermented Nigerian Foods: A Review.*” **Journal of Microbiology and Biotechnology Research** 10, no. 4: 1–9. 2020.
- Capulet, A. U. “*Impact of Soy Enrichment on Physico-Chemical, In-Vitro Protein and Starch Digestibility, Vitamin, Antioxidant and Sensory Properties of ‘Lafun’ Flour.*” **Journal of Food Technology & Nutrition Sciences** 5, no. 5: 1–7. 2023.
- Cedeño-Pinos, C., García, E., Siguencia, L., Pérez, A. & González-Paramás, A. M. *Bioactive Compounds and Antioxidant Potential of Sechium edule Fruits and Leaves.* **Plants** 12(5): 1032, 2023.
- Chibuiké, O. C., and O. Godspower. “*Culture-Independent Techniques for Exploring Microbial Diversity in Fermented Foods: A Review.*” **African Journal of Food Science** 16, no. 2: 22–32. 2022.
- Chibuzor, I. M. “*Influence of Tuber Sections and Chemical Additives on Physicochemical Properties of Pregelatinized Cassava Flour.*” **Journal of Food Processing and Technology** 13: 956. 2022.

- Chovatiya, N. C., R. M. Patel, H. K. Suthar, A. D. Joshi, and P. B. Shah. “*Roots and Tubers Crops: Nutritional Value and Functional Food Potential – A Comprehensive Review.*” **Journal of Biochemistry**: 1–13. 2025.
- Chowański, S., G. Adamski, P. Marciniak, K. Rosiński, M. Büyükgüzel, K. Büyükgüzel, M. Falabella, and G. Scrano. “*Plant-Based Antioxidants in Human Health.*” **Trends in Food Science & Technology** 50: 19–33. 2016.
- Coulibaly, A., M. Traoré, I. K. Koné, B. M. Cissé, F. Sangaré, and K. B. Doumbia. “*Determination of Proximate Compositions and Functional Properties of Selected Cereal Grains from Mali.*” **American Journal of Food Science and Technology** 10, no. 5: 207–213. 2022.
- Dahdouh, L., M. B. Ouhida, R. Ouhida, N. Belhaj, and H. Moulay. “*Physicochemical Composition and Nutritional Quality of Fresh and Processed Wheat Meal.*” **International Journal of Food Science and Technology** 55, no. 3: 1–13. 2020.
- Dahunsi, S. O., A. T. Adesulu-Dahunsi, T. A. Akinlabi, and A. P. Adekanmbi. “*Enterobacteriaceae Reduction in Fermented Nigerian Foods: Implications for Food Safety.*” **Food Control** 141: 109214. 2022.
- Daji, G. A., F. O. Adegbite, M. A. Oladokun, K. O. Oyelakin, T. A. Balogun, and A. A. Lawal. “*Comparative Study of Chemical Properties of Fermented Cereal-Based Pastes.*” **Foods** 11: 3171. 2022.
- de Oliveira, L. A., A. C. F. dos Santos, T. L. Vieira, F. R. da Silva, A. A. S. Junior, and C. R. Oliveira. “*Effect of the Storage Period on Physicochemical Characteristics and Sensory Acceptance of Frozen Sweet Cassava.*” **Brazilian Journal of Food Technology** 24: e2020215. 2021.

- Edo, Godwin I., Abubakar N. Jikah, Wilson Ndudi, and Peter O. Samuel. “*Traditional Fermented Foods of Nigeria: Microbiological Safety and Health Benefits.*” **Journal of Food Science and Technology**. 2024.
- Egbune, E. O., O. J. Adebayo, M. F. Okolie, and F. C. Ezech. “*Antioxidants and Antigenotoxic Properties of Rhizopus oligosporus Fermented Cassava.*” **Research Square**: 1–9. 2022.
- Enoch, N. O., S. U. Oranusi, B. C. Akintunde, G. O. Ogbulie, and A. O. Akinyemi. “*Assessment of Antioxidant Micronutrient Levels in Traditional Nigerian Condiments.*” **Scientific Asia**: 1–15. 2025.
- Esther, A., A. O. Nwachukwu, I. B. Okeke, and S. A. Adeyemo. “*Effect of Fermentation on Nutritional Properties of Traditional African Foods.*” **African Journal of Food, Agriculture, Nutrition and Development** 22, no. 3: 11201–11218. 2022.
- Eze, C. O., N. N. Okafor, A. C. Nwankwo, and O. J. Ani. “*Role of Indigenous Microbiota in Improving the Nutritional Quality of Fermented Nigerian Foods.*” **Journal of Applied Microbiology** 131, no. 5: 2043–2054. 2021.
- Ezekiel, C. N., A. T. Adesulu-Dahunsi, and A. I. Sanni. “*Safety Considerations and Functional Potentials of Nigerian Fermented Foods.*” **Food Quality and Safety** 6, no. 4: 1–13. 2022.
- Ezekiel, C. N., P. Ayeni, and F. A. Oguntinyinbo. “*Aflatoxin Contamination in Fermented Foods: Public Health Implications.*” **International Journal of Food Microbiology** 360: 109457. 2022.
- Ezekiel, O. O., O. E. Adedeji, and N. Umuokeke. “*Chemical Composition, Physicochemical, and Sensory Properties of Fermented Maize and Defatted Baobab Seed Flour Blends.*” **Agrosearch** 21, no. 1–2: 89–101. 2022.

- Fadahunsi, I. F., E. A. Obadina, and M. O. Oyewole. “*Metabolomics of Fermented Cassava Products and Their Health Benefits.*” **Comprehensive Reviews in Food Science and Food Safety** 21, no. 1: 145–168. 2022.
- Fagbemi, T. N., O. M. Akinrinlola, and O. I. Olajide. “*Antioxidant Activity and Hypcholesterolemic Potentials of Fermented Bambara Groundnut.*” **International Journal of Food Sciences and Nutrition** 73, no. 1: 78–88. 2022.
- Fagunwa, O. E., K. Banwo, A. T. Adesulu-Dahunsi, and A. I. Sanni. “*Biotechnological Advances in the Production of Functional African Fermented Foods.*” **Biotechnology Advances**. 2023.
- Famuwagun, T. I., and T. A. Taiwo. “*Microbiological Safety and Proximate Analysis of Fermented Legume-Based Condiments.*” **Cogent Food & Agriculture** 9, no. 1: 1–15. 2023.
- Feregrino-Pérez, A. A., M. J. Vargas-Hernández, L. A. García-López, and C. Sánchez-Rodríguez. “*Polyphenolic Compounds and Antioxidant Capacity in Native Maize of the Sierra Gorda of Querétaro.*” **Agronomy** 14, no. 1: 142. 2024.
- Frances, E. C., and A. O. Nwakuche. “*Nutritional Analysis of Traditional Fermented Food Condiments: Implications for Dietary Diversity.*” **IAA Journal of Biological Sciences** 12, no. 1: 99–110. 2024.
- Gabriel-Ajobiwe, R. A. O., and G. M. Adegbola. “*Optimizing Fortified Fermented Local Weaning Foods for Infant Health.*” **Sustaine.org**. 2024.
- Garg, M., R. Sharma, A. Kumar, V. Chunduri, and R. Sharma. “*Biofortified Crops Generated by Breeding, Agronomy, and Transgenic Approaches Are Improving Nutrition Security and Reducing Hidden Hunger.*” **Frontiers in Nutrition** 7: 609279. 2021.

- Garutti, M., L. Rossi, F. Ricci, S. Bianchi, and C. Romano. “*The Impact of Cereal Grain Composition on the Health and Disease Outcomes.*” **Frontiers in Nutrition** 9: 888974. 2022.
- Gbenyonron, F. M., T. T. Iombor, and M. O. Enyi. “*Evaluation of Mineral and Phytochemical Content in Fermented Condiments.*” **FUW Trends in Science & Technology Journal** 8, no. 3: 436–441. 2023.
- Ghosh, S., S. Bag, and M. Pal. “*Proteolytic Fermentation of Legumes: Technological Innovations in Alkaline Foods.*” **African Journal of Biotechnology** 23, no. 3: 200–215. 2024.
- Giang, N. T. N., V. D. Hien, H. T. T. Huong, N. V. Lien, T. H. Thuy, and L. T. H. Nga. “*Effect of Initial Total Soluble Solids and pH on the Quality of Fermented Beverage from Green Asparagus Roots.*” **Food Research** 8, no. 3: 460–468. 2024.
- Godswill, A. C., V. S. Amagwula, and E. C. Kate. “*Health Benefits of Micronutrients (Vitamins and Minerals) and Their Associated Deficiency Diseases: A Systematic Review.*” **International Journal of Food Sciences** 3, no. 1: 1–32. 2020.
- Gohari, S. T., M. H. Mahmoud, and S. M. Mahdy. “*Antioxidant and Anti-ulcer Activities of Fermented Soybean and Moringa Leaves.*” **Egyptian Journal of Nutrition** 36, no. 3: 129–189. 2021.
- Guney, M., A. Ozdemir, H. Kocak, F. Demir, and S. Yilmaz. “*The Effect of Cowpea on Human Health.*” In **Balkan Agriculture Congress**, 325–332. 2021.
- Hasmadi, M., S. J. Rosnita, H. Norshazila, I. Zainab, A. A. Noraini, and M. Z. Azian. “*Physicochemical and Functional Properties of Cassava Flour Grown in Different Locations in Sabah, Malaysia.*” **Food Research** 4, no. 4: 991–999. 2020.

- Ibrahim, A. I., and G. A. Alfauomy. “*Evaluation of Some Sweet Corn Hybrids for Agronomic Traits and Technological Parameters under Different Planting Dates.*” **Journal of Food Sciences** 6, no. 1: 49–63. 2019.
- Ibrahim, T. A., E. O. Oyewole, A. O. Adebayo, O. M. Ojo, and R. A. Olaleye. “*Proximate and Antinutrient Composition of Iru Produced from African Locust Beans and Soybeans Using Bacillus subtilis A2 as Starter Culture.*” **International Journal of Research and Innovation in Applied Science** 5, no. 1: 174–176. 2020.
- Ibukun, O. T., O. A. Adepoju, A. R. Oladele, and S. T. Adebayo. “*Evaluation of Vitamins and Minerals of Gari Produced from Trifoliate Yam and Cassava.*” In **Proceedings of the LASUSTECH 30th iSTEAMS Multidisciplinary Innovations Conference** 30, no. 2: 97–106. 2022.
- Ifeoma, B. L., O. J. Nwachukwu, E. A. Okocha, S. U. Ubah, and T. A. Iroegbu. “*Physical Characteristics and Mineral Composition of Bread Produced from Blends of Wheat and Defatted/Undefatted Cashew Kernel Flours.*” **Asian Food Science Journal** 20, no. 2: 1–11. 2021.
- Ijarotimi, O. S., M. R. Fatiregun, and T. D. Oluwajuyitan. “*Nutritional, Antioxidant, and Organoleptic Properties of Therapeutic-Complementary-Food Formulated from Locally Available Food Materials for Severe Acute Malnutrition Management.*” **Bulletin of the National Research Centre** 46: 39. 2022.
- James, S., T. O. Adewale, B. A. Ogunlusi, and R. A. Adebisi. “*Effects of Processing Methods on Total Phenolic, Total Flavonoid, and Antioxidant Capacities of Moringa Seeds.*” **Journal of Food Science and Nutrition** 8: 138. 2022.

- Jocelyne, R. E., P. K. Mensah, T. K. Osei, F. L. Johnson, A. B. Owusu, and K. D. Agyeman. *“Comparative Study of Nutritional Value of Wheat, Maize, Sorghum, Millet, and Fonio.”* **European Scientific Journal** 16, no. 21: 118–131. 2020.
- Joel, N., N. Oluchi, and A. I. Elijah. *“Carbohydrate Content of Garri from White and Yellow Cassava Roots.”* **Annals of Food Science and Technology** 20, no. 3: 443–450. 2019.
- Kaboré, D., I. Savadogo, and A. Traoré. *“Prospects for Valorization of African Traditional Fermented Foods.”* **Journal of Ethnic Foods** 8, no. 3: 19. 2021.
- Kareem, B., A. O. Alade, R. A. Adebisi, and O. T. Fakunle. *“Influence of Traditional Processing and Genotypes on the Antioxidant and Antihyperglycemic Activities of Yellow-Fleshed Cassava.”* **Frontiers in Nutrition** 9: 894843. 2022.
- Kareem, B., A. O. Olaleye, M. T. Ajani, and A. S. Ogunjimi. *“Antioxidant, Starch-Digesting Enzyme Inhibitory, and Pasting Properties of Elite Yellow-Fleshed Cassava Genotypes.”* **Frontiers in Sustainable Food Systems** 7: 1054896. 2023.
- Kiczorowski, P., W. Samolińska, E. Grela, and K. Klebaniuk. *“Effect of Fermentation of Chosen Vegetables on the Nutrient, Mineral, and Biocomponent Profile.”* **Scientific Reports** 12: 1–13. 2022.
- Kitessa, D. A., T. Alemayehu, and T. Amsalu. *“Effect of Fermentation Time & Blending Ratio on Microbial Dynamics & Nutritional Quality of Shameta.”* **Fermentation** 10, no. 3: 118. 2024.
- Knez, E., K. Kadac-Czapska, and M. Grembecka. *“Effect of Fermentation on the Nutritional Quality of Selected Vegetables and Legumes.”* **Life** 13: 655. 2023.

- Kumar, R., Kumar, M. & Sharma, S. *A Review on Antioxidant Potential of Morus indica L. Leaves and Fruits: Chemistry, Mechanisms, and Food Applications.* **Journal of Food Biochemistry** 46(10): e14303, 2022.
- Lawal, R. A., M. S. Adebuseye, and H. Musa. “Assessment of Gross Chemical Composition, Antinutrients Factor, Vitamins and Mineral Level of Masa Produced from Pearl Millet and Local White Rice.” **The International Journal of Science & Technology** 7, no. 3: 91–95. 2019.
- Laya, A. “Physicochemical Composition and Antioxidant Activity of Gari Processed from Cassava Roots.” **Biomed Research International**: 1–14. 2023.
- Louw, N. L., J. W. Spitaels, and A. C. Steyn. “Microbiome Assembly in Fermented Foods.” **Annual Review of Microbiology** 77: 315–340. 2023.
- Miassi, Y., M. Hounghédji, and D. Sessou. “Socio-Cultural Roles of Fermentation in Benin & Nigeria.” **International Journal of Gastronomy and Food Science** 26: 100455. 2022.
- Millena, C. G., J. P. Baldo, M. A. Manlapig, R. S. Espino, J. A. Orfanel, and K. P. Villanueva. “Nutritional Composition and Mineral Bioavailability of Selected Root and Tuber Crops in the Bicol Region, Philippines.” **Food Research** 8, no. 2: 382–396. 2024.
- Mockus, E., A. Petrauskas, R. Venskutonis, L. Ragauskas, D. Žukauskaitė, and V. Stukonis. “The Potential of Traditional ‘Gaja’ and New Breed Lines of Waxy, Blue and Purple Wheat in Wholemeal Flour Fermentation.” **Fermentation** 8, no. 11: 563. 2022.
- Ndudi, W., B. Ogbonna, and M. Duniya. “Enhancing Health through Nigerian Indigenous Fermented Agrifoods.” **Discover Food** 3: 206. 2024.

- Ndukwe, J. K., S. Chima, and M. Okonkwo. “Diet Diversification & Priming with Kunu: An Indigenous Probiotic Cereal-Based Non-Alcoholic Beverage in Nigeria.” **Beverages** 9, no. 1: 14. 2023.
- Nnennaya, I., U. O. Kalu, P. C. Eze, B. I. Okereke, and E. A. Aja. “Physicochemical Characterization of Indigenous Cereal Fermented Products.” **International Journal of Nutrition and Food Sciences** 9, no. 3: 56–63. 2020.
- Nwachukwu, E. O., C. N. Nwabor, and O. A. Adebayo. “Nutritional & Microbial Profile of Ugba from Southeast Nigeria.” **Journal of Food Processing and Preservation** 46, no. 5: e17219. 2022.
- Nwachukwu, E., and G. O. Egbuna. “Health-Promoting Potential of Fermented Plant Foods: A Nigerian Perspective.” **Frontiers in Nutrition** 9: 875912. 2022.
- Nzuta, R. A., A. O. Eze, P. A. Uzochukwu, and S. C. Nwachukwu. “Flour and Cassava (*Manihot spp*) Cultivars in Nigeria: Understanding Their Chemical Functionalities and Acceptability in Food Systems.” **International Journal of Scientific Research in Chemical Sciences** 9, no. 2: 20–29. 2022.
- Obadina, A. O., T. O. Babajide, and O. A. Akinyosoye. “Fermented Foods and Gut Microbiome Modulation: Emerging Evidence from Africa.” **Trends in Food Science & Technology** 120: 165–177. 2022.
- Obafemi, Y. D., S. U. Oranusi, K. O. Ajanaku, and P. A. Akinduti. “African Fermented Foods: Emerging Benefits and Microbiome Profiling.” **npj Science of Food** 6, no. 1: 30. 2022.
- Obi, C. N., and W. O. Okoronkwo. “Production, Microbiological and Proximate Analysis of Akamu Produced from Different Varieties of Maize.” **Nigerian Journal of Microbiology** 36, no. 1: 6001–6012. 2022.

- Ogunbanwo, S. T., A. I. Sanni, and A. A. Onilude. “*Characterization of Bacteriocin Produced by Lactobacillus plantarum from Fermented Cereals.*” **African Journal of Biotechnology** 2, no. 7: 179–184. 2003.
- Ogundeji, J., S. A. Olayiwola, F. K. Adebayo, A. R. O. Akinola, and T. M. Akinyemi. “*Nutrient Composition and Microbial Quality of Traditional Maize-Based Beverages.*” **Journal of Food Research and Innovation** 4, no. 2: 44–54. 2020.
- Ogunjemilusi, M. A., C. T. Akanbi, and J. Alaba. “*Production and Evaluation of Ogi Produced from Fermented Maize and Tropical Almond Nut Flour.*” **Journal of Food Science, Nutrition and Public Health** 2, no. 1: 1–8. 2022.
- Ogunremi, O. R., E. M. Agrawal, and F. A. Oguntinyinbo. “*Probiotic Potentials of Yeasts Isolated from Nigerian Traditional Fermented Foods.*” **Frontiers in Microbiology** 11: 609028. 2020.
- Oguntinyinbo, F. A., A. T. Adesulu-Dahunsi, and O. E. Fagunwa. “*The Future of African Fermented Foods in Functional Nutrition.*” **Critical Reviews in Food Science and Nutrition** 62, no. 20: 5510–5528. 2022.
- Oguntinyinbo, F. A., and A. Narbad. “*Molecular Characterization of Lactic Acid Bacteria & In Situ Amylase Expression during Traditional Fermentation of Cereal Foods.*” **Food Microbiology** 32, no. 1: 117–122. 2012.
- Oguntinyinbo, F. A., and A. Narbad. “*Molecular Characterization of Lactic Acid Bacteria and In Situ Amylase Expression during Traditional Fermentation of Cereal Foods.*” **Food Microbiology** 32, no. 1: 117–122. 2012.

- Oguntoyinbo, F. A., M. Huch, C. Cho, H. Schillinger, C. Holzapfel, and W. H. Holzapfel. *“Diversity of Bacillus Species from Fermented Foods in Nigeria.”* **Food Microbiology** 28, no. 6: 724–730. 2011.
- Okafor, G. C., C. A. Igwe, and E. O. Nwachukwu. *“Cultural Dimensions of Ugba Fermentation in Southeastern Nigeria.”* **Journal of Ethnic Foods** 7, no. 2: 86–94. 2020.
- Okafor, O. I., C. Ezeaku, and B. Chimaobi. *“Microbial Dynamics & Biochemical Complexity in Traditional Palm Wine Fermentation: Insights into Flavour & Health Implications.”* **ISAR Journal of Agriculture and Biology**. 2023.
- Okafor, O. I., O. Anene, C. N. Nwabor, and E. E. Nwachukwu. *“Microbial Dynamics in Palm Wine Fermentation.”* **ISAR Journal of Applied Biology** 6, no. 2: 88–98. 2023.
- Okafor, U. I., C. O. Ugwunnadi, I. C. Okechukwu, A. N. Eze, and J. A. Nwankwo. *“Nutritional Composition and Antinutritional Properties of Maize Ogi Co-fermented with Pigeon Pea.”* **Food Science and Nutrition** 6: 424–439. 2017.
- Okeke, I. N., and A. Lamikanra. *“Foodborne Pathogens in Developing Countries: The Case of Fermented Foods.”* **Clinical Microbiology Reviews** 23, no. 3: 434–456. 2010.
- Okobia, B. U., J. Okpoghono, and J. O. Orogwu. *“Antioxidant Properties and Bacterial Load of Ready-to-Eat Fermented Cassava (Fufu) Sold in Ozoro.”* **Uniport Journal of Engineering and Scientific Research** 8, no. 2: 143–154. 2024.
- Okolo, K. A. *“Traditional Fermented Protein Condiments in Nigeria.”* **African Journal of Biotechnology** 4, no. 13: 1612–1621. 2005.
- Okonkwo, C., and A. Agharandu. *“Proximate and Vitamin Composition of Selected Cereals Commonly Used for Weaning Babies’ Food Preparation.”* **Journal of Biology, Agriculture and Healthcare** 7, no. 22: 71–75. 2017.

- Okonkwo, U. C., and E. N. Akintobi. “Immunomodulatory Effects of Probiotic Lactic Acid Bacteria Isolated from Fermented Cereal-Based Foods.” **Frontiers in Immunology** 13: 871233. 2022.
- Okonwu, K., F. C. Chukwuma, G. A. Eze, P. O. Nwachukwu, H. T. Akinwale, and S. L. Olatunji. “Nutritional Composition of Some of the Most Consumed Cereals and Legumes in Nigeria.” **European Journal of Nutrition & Food Safety** 14, no. 2: 53–98. 2022.
- Okoro, N. C., C. F. Nnamani, B. A. Okonkwo, and F. O. Agbo. “Microbial Safety of Nigerian Fermented Foods: A Review.” **Frontiers in Microbiology** 13: 843765. 2022.
- Oladeji, O. J., Owolabi, and O. O. Ojo. “Nutritional & Functional Benefits of Indigenous Fermented Condiments in Nigeria.” **Discover Food**. 2025.
- Oladele, O. B., and E. O. Olorunfemi. “Occurrence of Mycotoxins in Fermented Foods in West Africa.” **World Mycotoxin Journal** 15, no. 5: 511–525. 2022.
- Olagunju, A. I., F. O. Adepoju, J. A. Akinwale, L. B. Omotayo, and K. O. Salami. “Effect of Fertilizer Treatment on the Titratable Acidity of Cassava Roots.” **Journal of Root and Tuber Research** 9, no. 1: 45–51. 2022.
- Olaniran, C. F., O. Osemwegie, and E. A. Taiwo. “Application & Acceptability of Microbiomes in the Production Process of Nigerian Indigenous Foods.” **Progress in Nutrition and Food Science** 28, no. 2: 108. 2023.
- Olaniran, C. F., O. Osemwegie, and E. A. Taiwo. “Application & Acceptability of Microbiomes in the Production Process of Nigerian Indigenous Foods.” **Progress in Nutrition and Food Science** 28, no. 2: 108. 2023.
- Olaniran, F. O., O. O. Adeola, and E. A. Taiwo. “Microbial Succession in Traditional Fermentation of Cereal-Based Foods.” **Fermentation** 7, no. 4: 291. 2021.

- Olapade, O. A., and S. A. Aworh. “*Functional Foods from Traditional Fermentation: Potentials for Managing Metabolic Diseases.*” **Journal of Functional Foods** 92: 105054. 2022.
- Olasupo, N. A., D. A. Oyetunji, and Y. Ajayi. “*Synergistic Interactions between Lactic Acid Bacteria & Yeasts in Nigerian Fermented Foods.*” **Food Control** 112: 107132. 2020.
- Olatunji, O. N., N. Nwankwo, and O. O. Ololade. “*Health Benefits of Fermented African Cereals: Focus on Nutritional & Probiotic Potentials.*” **International Journal of Food Science and Technology**. 2025.
- Olawale, O. A., B. O. Adediran, and F. E. Oguntinyinbo. “*Prebiotic and Synbiotic Potentials of African Fermented Foods: A Review.*” **Food Reviews International** 39, no. 2: 115–138. 2023.
- Olayanju, T. M. A., J. K. Adebayo, S. O. Ogunmola, F. A. Oladipo, and A. E. Adeyemi. “*Total Titratable Acidity of Garri from Fertilizer Treated Cassava Roots.*” **Nigerian Food Journal** 40, no. 1: 85–92. 2022.
- Oluba, O. M., A. B. Oredokun-Lache, and A. A. Odutuga. “*Effect of Vitamin A Biofortification on the Nutritional Composition of Cassava Flour (Gari).*” **Journal of Food Biochemistry** 42: e12450. 2018.
- Oluwaniyi, O. O., and I. O. Bazambo. “*Nutritional and Amino Acid Analysis of Raw, Partially Fermented and Completely Fermented Locust Bean (Parkia biglobosa) Seeds.*” **African Journal of Food, Agriculture, Nutrition and Development** 16, no. 2: 10866–10883. 2016.
- Omah, E. C., C. C. Nwokedi, A. A. Okpala, J. C. Nduka, and K. I. Ogbuagu. “*Quality Evaluation of Powdered Ogi Produced from Maize-Sorghum and Soybean Flour Blends.*”

African Journal of Food, Agriculture, Nutrition and Development 21, no. 10: 18839–18854. 2021.

Onyeka, F. N., and U. G. Okwume. “*Functional Properties and Nutrient Composition of Stiff Dough Produced from Composite Flour of Pearl Millet, White Maize and Cassava in Enugu State, Nigeria.*” **International Journal of Home Economics, Hospitality and Allied Research** 2, no. 1: 119–134. 2023.

Owusu-Kwarteng, J., B. Teye, and H. A. Amoa-Awua. “*Alkaline Fermented Foods as Sustainable Nutritional Sources.*” **Frontiers in Sustainable Food Systems** 6: 885328. 2022.

Owusu-Kwarteng, J., E. T. Akabanda, and H. Amoa-Awua. “*Role of Indigenous Fermented Foods in Enhancing Food and Nutrition Security in Sub-Saharan Africa.*” **Food Security** 14: 561–573. 2022.

Oyarekua, M. A., A. O. Adeoye, and O. I. Ojo. “*Comparable Vitamin and Mineral Contents of Co-Fermented Maize/Carrot/Pigeon Pea and Co-Fermented Millet/Sweet Potato/Pigeon Pea as Infant Complementary Foods.*” **Tropical Journal of Natural Product Research** 6, no. 8: 1331–1335. 2022.

Oyedele, O. A., A. Ezekiel, R. Sulyok, B. Somorin, and R. Krska. “*Mycotoxin Risk Assessment in Nigerian Traditional Foods.*” **Toxins** 12, no. 9: 574. 2020.

Oyeleke, S. B., A. I. Sanni, and O. A. Akinjogunla. “*Gut Health Benefits of Probiotic Lactic Acid Bacteria Isolated from Nigerian Fermented Foods.*” **Probiotics and Antimicrobial Proteins** 14, no. 2: 245–258. 2022.

- Oyewole, O. B., and S. A. Odunfa. “*Characterization and Distribution of Lactic Acid Bacteria in Cassava Fermentation during ‘Fufu’ Production.*” **Journal of Applied Bacteriology** 68, no. 2: 145–152. 1990.
- Oyeyinka, S. A., O. O. Adeloye, M. T. Akinoso, F. O. Olawuyi, and A. B. Olasupo. “*Chemical and Physicochemical Properties of Fermented Flour from Refrigerated Cassava Root and Sensory Properties of Its Cooked Paste.*” **Journal of Food Processing and Preservation**: 1–9. 2020.
- Ozoh, C., C. Imoisi, and J. U. Iyasele. “*Physicochemical and Antioxidant Properties of ‘Garri’ Processed under Controlled Fermentation Conditions.*” **Applied Sciences Research** 19, no. 1: 156–169. 2024.
- Punia, H., V. Sandal, A. Kumar, R. S. Thakur, and S. Yadav. “*Characterization of Phenolic Compounds and Antioxidant Activity in Sorghum Grains.*” **Cereal Research Communications** 49, no. 4: 659–667. 2021.
- Pycia, K., and E. Ivanisova. “*Physicochemical and Antioxidant Properties of Wheat Bread Enriched with Hazelnuts and Walnuts.*” **Foods** 9, no. 8: 1081. 2020.
- Rai, A. & Singh, A. *Recent Advances in Free Radical Scavenging Assays: A Comparative Review.* **Food Analytical Methods** 14(9): 1776–1792, 2021.
- Ratau, T., and O. P. Bamidele. “*Nutritional Value & Consumer Acceptance of Non-Alcoholic Cereal-Based Beverages in Sub-Saharan Africa.*” **Food and Nutrition Journal** 13, no. 1. 2025.
- Rizzo, G., and A. S. Laganà. “*A Review of Vitamin B12.*” In *Molecular Nutrition*, edited by V. B. Patel, 105–129. Cambridge: Academic Press. 2020.

- Ruth, A. O. G., B. O. T. Ibiama, and M. A. Olajumoke. “*Comparison of Antioxidant and Phytochemical Properties of Dawadawa from Mucuna pruriens and Parkia biglobosa.*” **Journal of Microbiology, Biotechnology and Food Sciences** 8, no. 1: 705–710. 2018.
- Safiul Azam, A. M., M. R. Hasan, M. A. Hossain, and M. S. Islam. “*Analysis of Proximate and Antioxidant Properties of Corn Cultivars Harvested at Different Maturity Stages.*” **Asian Journal of Agricultural Sciences** 14, no. 1: 31–37. 2022.
- Saidu, U., A. I. Ibrahim, M. A. Musa, A. S. Suleiman, H. M. Abdullahi, and Y. S. Isa. “*Proximate Analysis and Mineral Compositions of Some Cereals Commonly Sold in Kafin Hausa Market, Jigawa State, Nigeria.*” **Dutse Journal of Pure and Applied Sciences** 7, no. 2a: 22–29. 2021.
- Samuel, E. O., T. O. Falade, O. A. Aluko, M. B. Oladokun, A. I. Oloyede, R. T. Adebisi, and K. J. Olowookere. “*Vitamin B12 Content in Traditional Nigerian Pap Varieties.*” **Egyptian Journal of Nutrition** 39: 59–68. 2024.
- Sánchez, B. & Margolles, A. *The Evolving Field of Lactic Acid Bacteria: From Traditional Fermentations to Probiotic Applications.* **Microorganisms** 9(8): 1632, 2021.
- Sanni, A. I., and M. O. Oyewole. “*African Indigenous Fermented Foods: Nutritional and Health Implications.*” **Nutrition Reviews** 79, no. 6: 651–664. 2021.
- Sanni, A. I., S. T. Ogunbanwo, and A. A. Onilude. “*Potential Use of Bacteriocin-Producing Lactic Acid Bacteria in Food Preservation.*” **Journal of Food Safety** 26, no. 3: 201–214. 2006.
- Sasi, M., Kumar, S. & Hasan, M. *Emerging Trends in Soy-Based Foods Fortified with Probiotics: Nutritional and Functional Perspectives.* **Critical Reviews in Food Science and Nutrition**, Advance online publication, 2023

- Shah, T. R., K. Prasad, and P. Kumar. “Maize—A Potential Source of Human Nutrition and Health: A Review.” **Cogent Food & Agriculture** 2, no. 1: 1–9. 2016.
- Singh, R., and S. Kumar. “Technological Advancements in Fermented Food Products: Microbial & Functional Perspectives.” **Fermentation** 11, no. 6: 300. 2025.
- Sulaiman, S. A., M. A. Abdullahi, A. H. Idris, K. B. Yahaya, and U. A. Usman. “Proximate Analysis and Mineral Compositions of Different Cereal Grain Varieties Available in Kano State, Nigeria.” **International Journal of Food Science and Nutrition** 5, no. 2: 108–112. 2020.
- Teka, T. A., A. M. Mebrate, G. D. Wondimu, and E. H. Gebremariam. “Phytochemical Profiles and Antioxidant Capacity of Improved Cowpea Varieties and Landraces Grown in Ethiopia.” **Food Bioscience** 37: 100741. 2020.
- Termote, C. T., M. Talsma, J. Covic, M. V. Gupta, and K. P. Wopereis. “Nutrient Composition of *Parkia biglobosa* Pulp, Raw and Fermented Seeds: A Systematic Review.” **Critical Reviews in Food Science and Nutrition** 62, no. 1: 119–144. 2022.
- Tersoo-Abiem, B. A., C. O. Ogbu, F. T. Adagba, and I. D. Aondohemba. “Mineral and Antioxidant Profiles of Locust Bean and Soybean Condiments.” **European Journal of Agriculture and Food Sciences** 3, no. 2: 63–67. 2021.
- Tewari, K., P. S. Rana, S. K. Yadav, M. L. Sharma, and N. K. Mehta. “Comparative Evaluation of Phenolic Constituents, Antioxidant Properties, and Enzyme Inhibitory Activity of Field Pea and Cowpea Cultivars.” **Journal of Food Legumes** 38, no. 1: 79–93. 2025.
- Timothy, B. O., E. O. Adeyemi, M. A. Ogunjimi, O. S. Adeniran, and A. B. Lawal. “Rheological Properties and Quality Evaluation of Dried Ogi Supplemented with Date Flour as Sugar Substitute.” **Journal of Food Stability** 7, no. 2: 40–56. 2024.

- Vali Pasha, A. R., S. P. Kumar, K. S. Rao, M. V. Reddy, and V. R. Reddy. “*The Role of Calcium in Bone Growth.*” **International Journal of Current Research** 10, no. 4: 63766–63770. 2018.
- Vosoughi, N., S. Gomarian, H. Shirmohammadi, H. Rahemi, and M. H. Rastegar. “*Essential Oil Composition and Total Phenolic, Flavonoid Contents, and Antioxidant Activity of Sage Extract under Chitosan Application.*” **Industrial Crops and Products** 117: 366–374. 2018.
- Wulandari, N. P. A. N., I. K. A. Wibawa, I. W. Arsa, I. M. M. Astawan, and K. K. Dewi. “*Effect of Differences in Fruit Maturity Levels of Three Balinese Banana Cultivars on the Quality of Fruit Flesh Flour.*” **GSC Biological and Pharmaceutical Sciences** 22, no. 1: 105–113. 2022.
- Yilmaz, V. “*Investigation of Bioactive Compounds and Antioxidant Capacities of Various Cereal Products.*” **Journal of Agricultural Faculty of Gaziosmanpasa University** 36, no. 1: 10–22. 2019.
- Zannou, O., D. Hounghédji, and M. Hounghédji. “*Traditional Fermented Foods & Indigenous Food Processing in Benin & Nigeria.*” **International Journal of Gastronomy and Food Science** 27: 100451. 2022.
- Zhan, T., W. Zhu, H. Wang, J. Liu, and Y. Sun. “*Moringa Extract Enhances the Fermentative, Textural, and Bioactive Properties of Yogurt.*” **LWT** 101: 276–284. 2019.
- Zuwariah, I., M. H. Rahman, F. M. Zainudin, A. R. Abdullah, R. H. Karim, and S. N. Latif. “*Screening of Vitamin, Mineral, and Antioxidants in Selected Vegetables, Fruit and Grains for the Elderly.*” **Food Research** 5, no. 1: 122–131. 2021.

3. Conference Papers

- Ezekiel, O. O., O. E. Adedeji, and N. Umuokeke. “Chemical Composition, Physicochemical, and Sensory Properties of Fermented Maize and Defatted Baobab Seed Flour Blends.” Paper presented at the International Agrosearch Conference, Ilorin, Nigeria. 2022.
- Fagunwa, O. E., K. Banwo, A. T. Adesulu-Dahunsi, and A. I. Sanni. “Biotechnological Advances in the Production of Functional African Fermented Foods.” Paper presented at the World Congress on Biotechnology Advances, Durban, South Africa. 2023.
- Guney, M., A. Ozdemir, H. Kocak, F. Demir, and S. Yilmaz. “The Effect of Cowpea on Human Health.” Paper presented at the Balkan Agriculture Congress, Edirne, Turkey. 2021.
- Ibukun, O. T., O. A. Adepoju, A. R. Oladele, and S. T. Adebayo. “Evaluation of Vitamins and Minerals of Gari Produced from Trifoliate Yam and Cassava.” Paper presented at the 30th iSTEAMS Multidisciplinary Innovations Conference, Lagos State University of Science and Technology (LASUSTECH), Nigeria, September. 2022.
- Oyarekua, M. A., A. O. Adeoye, and O. I. Ojo. “Comparable Vitamin and Mineral Contents of Co-Fermented Maize/Carrot/Pigeon Pea and Co-Fermented Millet/Sweet Potato/Pigeon Pea as Infant Complementary Foods.” Paper presented at the Tropical Natural Product Research Symposium, Abuja, Nigeria. 2022.
- Timothy, B. O., E. O. Adeyemi, M. A. Ogunjimi, O. S. Adeniran, and A. B. Lawal. “Rheological Properties and Quality Evaluation of Dried Ogi Supplemented with Date Flour as Sugar Substitute.” Paper presented at the Journal of Food Stability Symposium, Lagos, Nigeria. 2024.

4. Reports / Manuals / Theses

- Akinjogunla, O. J. *Microbiological and Nutritional Assessment of Fermented Cereal-Based Foods in Nigeria*. PhD diss., University of Ibadan. 2017.
- AOAC International. *Official Methods of Analysis*. 22nd ed. Gaithersburg, MD: Association of Official Analytical Chemists. 2023.
- Cheesbrough, Monica. *District Laboratory Practice in Tropical Countries*. 2nd ed. Cambridge: Cambridge University Press. 2010.
- Food and Agriculture Organization (FAO). *Food Composition Table for Use in Africa*. Rome: FAO. 1968.
- Food and Agriculture Organization/World Health Organization (FAO/WHO). *Codex Alimentarius: General Standard for Contaminants and Toxins in Food and Feed*. Rome: FAO/WHO. 2019.
- Holt, J. G., N. R. Krieg, P. H. A. Sneath, J. T. Staley, and S. T. Williams. *Bergey's Manual of Determinative Bacteriology*. 9th ed. Baltimore: Williams & Wilkins. 1994.
- National Agency for Food and Drug Administration and Control (NAFDAC). *Food Safety Manual for Traditional Fermented Foods in Nigeria*. Abuja: NAFDAC. 2020.
- Obadina, A. O. *Safety and Quality of Cassava-Based Fermented Foods in Nigeria*. PhD diss., Federal University of Agriculture, Abeokuta. 2015.
- World Health Organization (WHO). *Guidelines on Food Fortification with Micronutrients*. Geneva: WHO. 2006.

5. Websites / Online Sources

- Food and Agriculture Organization of the United Nations (FAO). “*Fermented Foods: Traditional Practices and Safety Considerations*.” Last modified June 15, 2021.
<https://www.fao.org/fermented-foods>.

International Food Information Council (IFIC). “*Probiotics, Prebiotics, and Synbiotics: What’s the Difference?*” Last modified March 2022. <https://foodinsight.org/probiotics-prebiotics-synbiotics>.

National Agency for Food and Drug Administration and Control (NAFDAC). “*Guidelines on Traditional Foods in Nigeria.*” Accessed September 1, 2023. <https://www.nafdac.gov.ng/traditional-foods>.

U.S. Department of Agriculture (USDA). “*FoodData Central: Nutrient Database.*” Accessed August 15, 2023. <https://fdc.nal.usda.gov>.

United Nations Children’s Fund (UNICEF). “*Micronutrient Deficiencies: Hidden Hunger in Africa.*” Accessed July 10, 2023. <https://www.unicef.org/nutrition/micronutrients>.

World Health Organization (WHO). “*Food Safety and Nutrition.*” Accessed August 20, 2023. <https://www.who.int/health-topics/food-safety>.

BIODATA

Full Name: Makinde-Oke Damilola Adejoke

Matric No.: LCU/PG/005237

Programme: M.Sc. Human Nutrition and Dietetics

Department: Biological Sciences

Faculty: Faculty of Basic Medical and Health Sciences

University: Lead City University, Ibadan, Nigeria

Personal Information

- Date of Birth: 09/01/1993
- Gender: Female
- Marital Status: Married
- Nationality: Nigerian
- State of Origin: Oyo
- Local Government Area: Ogbomoso South
- Religion: Christianity
- Contact Address: No. 14, Adelani Koleoso Street, Somorin, Abeokuta, Ogun State
- Phone Number: 08138235557
- Email Address: darmie42@gmail.com

Educational Background

- B.Sc., Wesley University, Ondo, 2017

Employment History

- Nutrition Officer, Neuropsychiatric Hospital Aro, Abeokuta, Ogun State, 2023
- Nutrition Officer (Locum), Neuropsychiatric Hospital Aro, Abeokuta, Ogun State, 2022
- Catering Instructor, Broad Concept, Asero, Abeokuta, Ogun State, 2021

Research Information

- **Thesis Title:** *Chemical and Microbial Characterisation of Some Fermented Foods in Nigeria*

Hobbies/Interests

- Cooking

- Reading

The University Compliance Certificate

This is to certify that the Thesis, Makinde-Oke Damilola Adejoke, with Matric number LCU/PG/005237, Human Nutrition and Dietetic Unit, Department of Biological Sciences, Faculty of Basic Medical and Health Sciences, Lead City University, Ibadan, Nigeria, is in full compliance with the approved University format.

Date _____

Signature: _____

Lead City University Ibadan DO NOT COPY