



**FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA**

**UNLOCKING THE POTENTIALS OF
PLANT-BASED FOODS THROUGH
BIOPROCESSING**

BY:

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Preamble

Plant-based foods have long been recognized as rich sources of nutrients, offering a vast array of macro and micronutrients, phytochemicals and bioactive compounds that can be leveraged to promote human health and well-being. However, the full potential of plant-based foods remains untapped due to limitations in processing and utilization. Bioprocessing, a cutting-edge technology that harnesses the power of microorganisms and enzymes, presents a promising solution to unlock the nutritional, bioactive and techno-functional properties and safety of plant-based foods. Bioprocessing, by transforming plant materials into novel, value-added products can reduce antinutritional compounds, improve nutritional, bioactive and techno-functional properties of plant-based foods, making them more appealing to consumers and contributing to a more sustainable food system. This approach has far-reaching implications for the development of innovative, health-promoting foods that can meet the evolving needs of a growing global population, create jobs, improve income and livelihood of rural farmers as well as food processors.

1.0 INTRODUCTION

The World Health Organization (W.H.O, 2023) estimated that 2.4 billion people representing 29.6% of the global population lack consistent access to food. Among them, 900 million are experiencing severe food insecurity. Furthermore, the Food and Agriculture Organization (FAO, 2023) reported that around 633 million people representing 8.9% of the global population do not consume enough calories each day and are therefore classified as undernourished. These underlying scenarios bring about food insecurity, which is a persistent challenge in underdeveloped and developing nations. Food security is in itself defined as a condition that exists where all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life (Moerman, 2018). Accordingly, food security is essential to a nation's overall well-being, and maintaining a reliable supply of nutritious food is a collective responsibility (Yakymchuk and Pomianek, 2023; Iannotti *et al.*, 2024).

Amid the global drive for sustainability and lowering environmental impact, there has been a growing focus on developing sustainable food systems. In this context, plant-based diets have gained attention as a promising alternative that can support and enhance sustainability efforts within the food sector (Boukid, 2024). Growing awareness among consumers about the health and environmental impacts of their food choices has led to significant shifts in

dietary habits, with an increasing preference for plant-based foods. This trend is largely driven by the desire to support healthier lifestyles, protect animal life, and promote environmental sustainability (Tachie *et al.*, 2023). Moreover, numerous studies have demonstrated that adopting plant-based diet as a climate-conscious lifestyle choice can greatly reduce human contributions to climate change. Such diets are also associated with decreased biodiversity loss, lower greenhouse gas emissions, and reduced land use when compared to conventional diets such as animal source food (Springmann *et al.*, 2018; Steg, 2018; Carey *et al.*, 2023). Consequently, plant-based diets, recognized as a more sustainable dietary option, have been gaining momentum and increasing in popularity across the global food industry (Chong *et al.*, 2025).

Although plant-based foods have been considered to promote environmental sustainability and healthy lifestyle, there are several challenges associated with plant foods ingredients employed in the formulation and processing of plant-based foods. Some plant-based foods, including legumes and cereals, contain varying levels of non-nutritional compounds such as phytates, saponins, tannins, protease and amylase inhibitors, and goitrogens. These compounds can restrict the quantity of these ingredients used in food formulations, as they bind to proteins and minerals, reducing protein digestibility and overall nutritional value. Furthermore, they interfere with mineral absorption, cause gastrointestinal discomfort, and become toxic when consumed in excess (Samtiya *et al.*, 2020; Acquah *et al.*, 2021). The challenge of the sensory qualities of plant-based foods is equally important as many consumers express concerns about their flavor and unfamiliar taste, especially when transitioning from traditional animal-based products.

Bioprocessing techniques are affordable and simple traditional food processing methods that help reduce antinutritional compounds in plant-based foods while enhancing their nutritional composition, antioxidant activity, and physicochemical and techno-functional properties for diverse food applications (Chinma *et al.*, 2024). Bioprocessing methods include soaking, germination, fermentation, use of enzymes, and combinations of these methods.

As the global population continues to grow and pressure mounts on available foods, the application of bioprocessing techniques offers a viable pathway for developing nutrient-dense, affordable, and culturally appropriate plant-based foods. This not only addresses nutritional inadequacies but also supports the United Nations (UN) Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production).

This inaugural lecture presents my contribution in unlocking the potentials of plant-based foods through bioprocessing as a strategic tool to combat food insecurity and promote sustainable food systems globally, contribute to Nigeria's quest for addressing UN's SDGs 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-being) and African Union Agenda (2063) goal 3 (towards ensuring healthy and well-nourished citizens).

1.1 Rationale for My Research Interest in Bioprocessing of Plant-Based Foods

The global food system is under pressure from population growth, climate change, and health challenges. There is also an increasing consumer demand for functional or novel foods with potential health properties to ameliorate the burdens of communicable and non-communicable diseases globally. On the hand, malnutrition is one of the major challenges facing the developing regions of the world, including Africa. High rates of chronic malnutrition, micronutrient deficiency and non-communicable diseases have particularly been a major challenge in Nigeria.

Plant-based foods are increasingly recognized as sustainable alternatives to animal-derived products, offering environmental, nutritional, and health benefits (Abu and Chinma, 2022). However, many plant-based foods face limitations such as presence of antinutritional factors. poor digestibility, limited bioavailability of nutrients, and sensory challenges (taste, texture, and aroma). Additionally, high cost of sophisticated food processing machinery and equipment is a major constraint towards achieving food and nutrition security in Africa including Nigeria (Adebisi *et al.*, 2018).

Bioprocessing using biological systems like fermentation, enzymatic treatment, and microbial transformation—can enhance the nutritional, functional, and sensory qualities of plant-based foods. Bioprocessing techniques are simple, affordable and natural means of modifying macromolecules of foods for improved functionality (Abu and Chinma, 2022; Yang *et al.*, 2023; Onwuka *et al.*, 2024). Additionally, bioprocessing techniques do not require sophisticated equipment during food processing (Adebisi *et al.*, 2018). All these aforementioned factors motivated my research interest on bioprocessing of plant-based foods for improved functionality or development of functional ingredients for diverse food applications. The application of bioprocessing technologies in processing numerous underutilized crops in Nigeria that are wasted during seasonal glut will save foreign exchange, increase the utilization of locally available indigenous crops through value addition, promote nutrition and food security, beneficially

contribute to the health of the teaming population by boosting their immune system, improve income and livelihood of the rural farmers, create employment opportunities and reduce post-harvest losses.

2.0 Plant-Based Foods

Plant-based foods are derived from plants and serve as the main energy sources for both animals and humans (Abu and Chinma, 2022). They are rich sources of nutrients (such as dietary fiber, micronutrients), antinutritional compounds, phytochemicals and bioactive compounds (Fadet, 2017). Plant sourced foods are classified into cereals, legumes, nuts, roots, tubers, fruits, vegetables, spices and tea (Fadet, 2017).

Plant source foods such as cereals (especially whole grain cereals), legumes/pulses, and nuts are rich in dietary fiber, β -glucan, resistant starch, minerals, vitamins (B group and vitamin E), bioactive compounds and phytochemicals that have potential health benefits in human (Abu and Chinma, 2022). Fruits and vegetables are excellent sources of nutrients such as dietary fiber, vitamin C, carotenoids, polyphenolic compounds (especially ellagic acid, anthocyanins, condensed tannins and flavonoids) that have health promoting properties. Epidemiological studies have established that fruits (especially raspberries, cherries, grape seeds, blue berries, strawberry, blackberry) and vegetables have been shown to possess anticancer, antidiabetic, anti-inflammatory, cardiovascular effects (Abu and Chinma, 2022). Some African green leafy vegetables are known to be rich sources of nutrients and bioactive compounds with anticancer, anti-inflammatory and antioxidant properties with the potential of reducing the global burden of non-communicable diseases (Abu and Chinma, 2022).

Some plant foods (such as fruits, vegetables and nuts) are consumed with little or no processing while majority of plant foods must undergo processing prior to human consumption or utilization in food systems due to several challenges.

2.1. Factors that Limit the Use of Plant-Based Foods in Food Product Development

Although plant foods are good sources of nutrients and calories, yet their use in food systems is partly constrained by the presence of antinutritional compounds (such as phytic acid, tannins, saponins, protease inhibitors, that limit nutrient digestibility and bioavailability in foods), poor functionality, sensory challenges (many plant-based foods have beany, grassy, or bitter notes

that are hard to mask) and allergenicity (Abu and Chinma, 2022; Yang *et al.*, 2023).

Functional limitations such as lower solubility, emulsification, foaming, and gelling characteristics especially in legumes further restrict their utilization in food systems such as dairy alternatives and plant-based meat analogues (Onwuka *et al.*, 2024). Shelf stability is another factor that constitutes functional limitation. Plant-based ingredients may oxidize faster, affecting flavor and quality.

High cost of sophisticated food processing machinery and equipment required in food product development is a major constraint especially in the developing regions of the world such as Africa (Adebiyi *et al.*, 2018). This has partly influenced the sufficient achievement of nutrition and food security in Africa (Adebiyi *et al.*, 2018). Moreso, consumer perceptions such as cultural preferences, especially in regions where meat and dairy are central to diets, plant-based alternatives face resistance.

Although, traditional and novel food processing techniques have been employed to improve food quality, preserve/extend shelf-life, increase availability, create convenience, ensure sustainability and improve the health properties of plant-based foods; the use of simple, affordable, adoptable, safe and natural means (without the use of chemicals) of processing plant-based foods for improved functionality is trending in the developing regions of the world

2.2 Bioprocessing Techniques Employed in Food Processing

In recent times, there is increasing research interest in the use of bioprocessing techniques as a green technology for the development of functional food ingredients for diverse food applications. Bioprocessing techniques have been established as an affordable, effective and natural means of improving the functionality of plant-based foods for diverse food applications (Chinma *et al.*, 2025).

2.2.1 Soaking treatment

Soaking is a traditional wet processing technique that involves immersing grains, legumes, seeds, or tubers in water or aqueous solutions (such as salt, sugar or acid solution) for a defined period under controlled conditions of time, temperature, and pH (Sharma *et al.*, 2022). It is primarily applied as a pre-treatment step designed for food matrices to reach an equilibrium moisture content that facilitates subsequent further processing such as cooking, germination, fermentation, or milling (Sharma *et al.*, 2022). In modern food

processing, soaking is recognized as a low-cost, environmentally friendly, and scalable bioprocessing strategy capable of inducing biochemical, structural, and functional modifications in plant-based materials, particularly legumes and cereals.

The primary physical mechanism of soaking is a counter-current mass transfer whereby water molecules move from the external solution into the food matrix driven by a concentration gradient, while water-soluble components such as sugars or salts simultaneously leach out (Mari *et al.*, 2024). In addition to these physical processes, soaking acts as a biological switch that triggers the activation of endogenous hydrolytic enzymes such as phytases, proteases and amylases that catalyze the breakdown of complex macromolecules into simpler, more digestible forms (Nkhata *et al.*, 2018).

In food processing, soaking is the most effective first line of defense against compounds that hinder nutrient absorption. In other words, soaking is effective in the reduction of antinutritional factors especially those in legumes, cereals, tubers thereby improving the nutritional quality of foods through mineral bioavailability and digestibility.

2.2.2 Germination

Germination, also known as “sprouting” is a simple bioprocessing technique that serves as the biological evolution of soaking. While soaking initiates hydration, germination drives the seed into a full metabolic state. During germination, dormant seed, grain, or legume resumes metabolic activity, resulting in the emergence of the radicle (root) and plumule (shoot) (Onwuka *et al.*, 2024). Generally, it involves controlled environmental conditions such as temperature, moisture, and oxygen, light and humidity to maximize the synthesis of bioactive compounds while minimizing dry matter loss (Nkhata *et al.*, 2018). The mechanism of germination involves the transition of a dormant seed to a sprout through three (3) distinct phases:

Phase I: Imbibition and Activation: Building on the soaking stage, in this phase, the seed absorbs water rapidly. This triggers the synthesis of gibberellic acid, a plant hormone that signals the aleurone layer in the grains to produce hydrolytic enzymes. In addition, there is a swelling, softening and rupturing of seed coat that enhances seed permeability. This phase is influenced by seed size, seed coat permeability, quantity of available water, chemical composition of the seeds and concentration of solutes (Martí *et al.*, 2020).

Phase II-Metabolic Mobilization: Here lies the core of germination. In this phase, the seed begins to breakdown its internal reserves to fuel growth. There is also the synthesis of regulatory plant hormones that stimulates the

production and release of enzymes – amylases, proteases, and lipases that act on storage compounds in the endosperm and germ, aiding in the liberation of simple sugars, amino acids and fatty acids (Marti *et al.*, 2020).

Phase III: Structural Emergence: In this phase, there is a structural emergence that is seen in the visible growth of sprouts. During this phase, the synthesis of Vitamin C and B-complex vitamins peak as the plant prepares for photosynthesis. The elongation of the radicle through the structures enveloping the embryo signifies the conclusion of germination (Gunathunga *et al.*, 2024).

In terms of its relevance, germination serves as a simple, effective and affordable method that transforms dormant seeds into nutrient-dense foods by activating endogenous enzymes in foods such as amylases and proteases. This metabolic shift significantly reduces anti-nutritional factors, far more effectively than soaking alone, thereby maximizing mineral and protein bioavailability. Beyond simple detoxification, the process triggers a massive synthesis of bioactive compounds, including Vitamin C, B-complex vitamins, and the neuroprotective agent, Gamma-Aminobutyric Acid (GABA) (Nkhata *et al.*, 2018).

2.2.3 Fermentation

Fermentation is one of the bioprocessing methods where microorganisms such as bacteria, yeasts, and fungi metabolize food substrates to create value-added products. Fermentation has been traditionally employed across human cultures to improve food preservation, enhance sensory attributes, and prolong product stability (Yee *et al.*, 2025).

The mechanism is that fermentation is typically carried out via submerged (SmF) and solid-state (SSF) processes. Submerged fermentation (SmF), conducted in liquid systems, is especially appropriate for lactic acid bacteria (LAB) and provides benefits including precise process regulation and straightforward recovery of peptides (Zhou *et al.*, 2025). Conversely, solid-state fermentation (SSF), performed on solid substrates with limited moisture, establishes concentrated, nutrient-rich microhabitats that promote vigorous microbial proliferation and prolonged enzymatic activity (Zhou *et al.*, 2025). Generally, microbial fermentation proceeds through multiple interconnected processes, such as enzymatic breakdown, biochemical conversion, and enhanced release and solubility of previously bound compounds (Arya *et al.*, 2025).

In terms of its relevance, fermentation, through glycemic index reduction emerges as an important strategy for controlling postprandial blood glucose

levels. Through lactic acid production, fermentation alters the cereal matrix and promotes the formation of starch–gluten complexes, which slow enzymatic starch breakdown and consequently lower the glycemic index of the final products (Arya *et al.*, 2025). In addition, for individuals with irritable bowel syndrome (IBS), cereal fermentation offers therapeutic benefits by lowering FODMAPs (fermentable oligo-, di-, monosaccharides, and polyols). These carbohydrates, which are poorly absorbed in the small intestines, are quickly fermented in the colon, frequently causing bloating, gas, and gastrointestinal discomfort. Fermentation also enhances the palatability of foods and beverages by improving texture and flavor, reducing dependence on artificial additives (Arya *et al.*, 2025).

2.2.4 Enzymatic processing

The technique uses enzymes to break down complex molecules into simpler ones, improving food texture, flavors and nutritional value. Examples include the use of amylase in baking and lactase in lactose-free dairy products (Ribas-Agustí *et al.*, 2018).

2.2.5 Dual or combined bioprocessing

This involves a combination of the two or more bioprocessing techniques. This method has been reported to cause significant modification in nutrients and techno-functional properties due to increased activities of enzymes (Sharma *et al.*, 2022).

2.3 Benefits of Bioprocessing of Foods

Bioprocessing offers several benefits, including:

1. Improved food safety

- a. **Reduction of pathogens:** Bioprocessing techniques such as fermentation introduce beneficial microorganisms (e.g., lactic acid bacteria) that inhibit harmful pathogens like *Salmonella* and *E. coli*.
- b. **Detoxification:** Certain microbes can break down naturally occurring toxins in food (e.g., mycotoxins in grains), making them safer for human consumption.
- c. **Natural preservation:** Organic acids and antimicrobial compounds produced during bioprocessing extend shelf life without synthetic preservatives.

2. Increased nutritional value

- a. **Enhanced bioavailability:** Fermentation can break down complex compounds such as antinutritional factors that inhibit mineral absorption, improving uptake of iron, zinc, and calcium (Ribas-Agustí *et al.*, 2018).
- b. **Creation of new nutrients:** Microorganisms produced can synthesize vitamins (such as folate, riboflavin, among others) during bioprocessing, enriching foods naturally (Ribas-Agustí *et al.*, 2018).
- c. **Protein quality improvement:** Germination, fermentation, and enzymatic treatment can increase digestibility of proteins, making them more accessible to the human body (Ribas-Agustí *et al.*, 2018).

3. Improved sensory attributes

- a. **Flavor development:** Fermentation produces organic acids, alcohols, and esters that create complex and desirable flavors (e.g., in cheese, yogurt, sourdough bread) (Onwuka *et al.*, 2024).
- b. **Texture modification:** Enzymes and microbial activity can alter food structure, improving mouthfeel (e.g., tenderizing meat, enhancing creaminess in dairy).
- c. **Novel products:** Bioprocessing enables innovation—such as plant-based meat alternatives with improved taste and texture—meeting consumer demand for diverse food experiences.

4. Beneficial health properties

- a. Fermentation enriches foods with vitamins (e.g., B-complex, vitamin K) and short-chain fatty acids that support gut health (Onwuka *et al.*, 2024).
- b. Bioprocessing can also increase the concentration of polyphenols and flavonoids, enhance antioxidant activity and reducing inflammation (Chinma *et al.* 2024).
- c. Bioprocessed plant-based foods often act as prebiotics, fostering beneficial gut bacteria; this contributes to improved immune function and reduced risk of chronic diseases such as obesity, diabetes, and cardiovascular disorders (Ribas-Agustí *et al.*, 2018).

5. Sustainable Production

- a. **Lowers energy demand:** Bioprocessing often operates at mild temperatures compared to conventional food processing such as heat treatment, reducing energy consumption.
- b. **Waste reduction:** Agricultural by-products such as cereal brans can be converted into valuable food ingredients through fermentation, minimizing food waste (Chinma *et al.*, 2015).

- c. **Eco-friendly alternatives:** Bioprocessing can replace chemical-intensive methods with biological ones, reducing environmental impact and reliance on synthetic additives.

3.0 My Research Contributions

Mr. Vice-Chancellor, Sir, the following are some of my research contributions.

3.1. Unlocking the Potentials of Bioprocessed Plant-Based Foods as Functional or Novel Ingredients

3.1.1 Optimization of rice bran fermentation conditions enhanced by baker's yeast for extraction of protein concentrate (Chinma, Ilowefah and Muhammad, 2014)

The rice bran fermentation conditions for the extraction of protein concentrate were enhanced through the use of baker's yeast under optimized conditions using response surface methodology (RSM). A central composite design with three independent variables—fermentation temperature (25–35 °C), yeast concentration (1–5%), and fermentation time (10–24 h)—was employed to study the response variable (protein yield). The results indicated that the generated regression model adequately represented the relationship between the independent variables and the response. All linear terms, two quadratic terms (fermentation temperature and fermentation time), and all interaction terms had significant effects on protein yield ($p \leq 0.05$). The optimum conditions for yeast pretreatment in rice bran protein extraction were achieved at 30 °C for 17 h using a 3% yeast concentration, yielding a protein content of 23.37%. This value showed no significant difference ($p \geq 0.05$) from the RSM-predicted protein yield of 23.02%. The use of baker's yeast in rice bran fermentation significantly improved protein extraction yield compared with naturally fermented rice bran (15.43%) and untreated rice bran (10.16%).

3.1.2 Effect of germination on the chemical, functional and pasting properties of flour from brown and yellow varieties of tigernut (Chinma, Adewuyi and Abu, 2009).

The chemical, functional and pasting properties of flour processed from germinated (0, 24, 48 and 72 h) brown and yellow varieties of tigernut (*Cyperus esculentus*) seeds were profiled. It was found that germination enhanced tigernut flour quality by improving some chemical constituents, functional (such as foaming, emulsion, water and oil absorption capacities

increased from 7.75% to 12.91%, 14.32–20.25 ml oil/g sample, 2.56–6.97 g water/ g sample and 1.14–1.78 g oil/g sample, respectively) and pasting properties of both brown and yellow tigernut flours, making the germinated tigernut flours suitable for a wider range of food applications such as baked products and complementary food formulations.

3.1.3 Chemical, antioxidant, functional and thermal properties of rice bran proteins after yeast and natural fermentations (Chinma, Ilowefah, Shammugasamy, Ramakrishnan and Muhammad, 2014).

The chemical, antioxidant, functional and thermal properties of rice bran proteins after yeast, natural fermentations and unfermented rice bran were investigated. Protein content of yeast-fermented rice bran protein concentrate (YFRBPC), naturally fermented rice bran protein concentrate (NFRBPC) and unfermented rice protein concentrate (UFRBPC) were 72.50%, 68.92% and 65.73%, respectively. The YFRBPC had higher amino acid content, antioxidant activity (DPPH radical inhibition of YFRBPC, NFRBPC and UFRBPC were 58.62%, 55.29% and 47.14%, respectively, while ferric reducing ability power were 0.73, 0.58 and 0.41 mmol TE/g, respectively) and improved functional properties than NFRBPC, while UFRBPC had the lowest. YFRBPC showed significantly ($p \leq 0.05$) higher denaturation temperature and enthalpy value than NFRBPC, while UFRBPC had the lowest value. FTIR results demonstrated that rice bran protein concentrates have a conformation consisting of β -sheets structures which were more in YFRBPC and NFRBPC than UFRBPC. The higher essential amino acid content and antioxidant activity, water and oil absorption capacities, lighter colour and higher denaturation temperature of YFRBPC and NFRBPC suggest their potentials as functional ingredients in baked products such as wheat bread because these functional attributes are desirable in bread making.

3.1.4 Effect of germination on the physicochemical and antioxidant characteristics of rice flour from three rice varieties from Nigeria (Chinma, Anuonye, Simon, Ohaire and Danbaba, 2015).

In this study, the effect of germination (48 h) on the physicochemical and antioxidant characteristics of rice flour from three rice varieties from Nigeria. Local rice varieties (*Jamila*, *Jeep* and *Kwandala*) were determined and compared to an improved variety (MR 219). Protein (7.78-12.52%), magnesium, phosphorus, potassium and antioxidant properties of rice flour increased after germination while phytic acid and total starch contents decreased. Foaming capacity and stability of rice flours increased after

germination. Germination modified pasting and thermal characteristics of rice flour. Germinated rice flour had improved physicochemical and antioxidant properties with reduced phytic acid and starch contents compared to MR 219, which can be utilized as functional ingredients in the preparation of rice-based complementary formulations and baked products.

3.1.5 Effect of germination on the physicochemical, nutritional, functional, thermal properties and *in vitro* digestibility of Bambara groundnut flours (Chinma, Abu, Asikwe, Sunday, Adebo, 2021).

The physicochemical, functional, thermal properties and *in vitro* digestibility of flours from Bambara groundnut (BGN) germinated at different periods (0, 24, 48 and 72 hours, Plate I) was determined. In a time dependent manner, germination led to significant ($p \leq 0.05$) increases in protein (26.1–28.79 g/100 g), dietary fiber constituents, digestible starch, *in vitro* protein digestibility (73.67–88.9%), minerals, total phenolic content, and majority of the amino acids. Germination significantly decreased antinutrients such as phytic acid, tannin and trypsin inhibitory activity. Functional properties such as protein solubility (81.55–84.90%), oil and water absorption capacity, foaming capacity, emulsion stability and activity of BGN flour increased significantly with germination time. Germination also modified the thermal and pasting properties of the flour. However, scanning electron microscopy did not reveal significant changes in starch granular structure (Figure 1). Significant decreases in relative crystallinity (57.94–20.92%) as observed from the X-ray diffractograms were recorded (Figure 2). This work has demonstrated that germination significantly improved the nutritional, total phenolic content, functional and processing properties of Bambara groundnut flour. This could encourage its utilization in food product development, particularly as a functional food ingredient.



Plate I: Scanning electron microscopy of raw and germinated Bambara groundnut flour: (A) raw Bambara groundnut, (B) 24 h germinated Bambara groundnut, (C) 48 h germinated Bambara groundnut, (D) 72 h germinated Bambara groundnut. Source: **Chinma et al.** (2021).

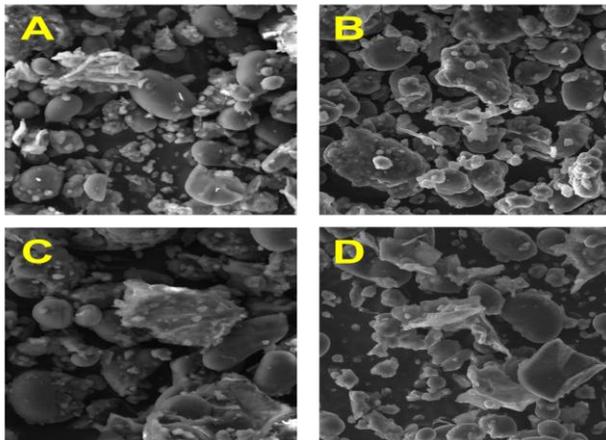


Figure 1: Scanning electron microscopy of raw and germinated Bambara groundnut flour: (A) raw Bambara groundnut flour, (B) 24 h germinated Bambara groundnut flour, (C) 48 h germinated Bambara groundnut flour, (D) 72 h germinated Bambara groundnut flour. Images were captured at a magnification of 1000 \times . Source: **Chinma et al.** (2021).

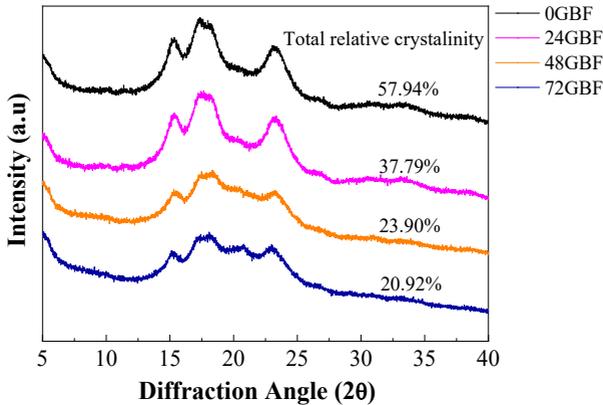


Figure 2: X-ray diffraction of raw and germinated Bambara groundnut flour: Black (0GBF– Raw Bambara groundnut flour), Pink (24GBF – 24 h germinated Bambara groundnut flour), Orange (48GBF – 48 h germinated Bambara groundnut flour), Blue (72GBF – 72 h germinated Bambara groundnut flour). Values on the graph represent the % relative crystallinity

Source: **Chinma et al.** (2021).

3.1.6 Nutritional composition, bioactivity, starch characteristics, thermal and microstructural properties of germinated pigeon pea flour (Chinma, Abu, Adedeji, Aburime, Joseph, Agunloye, Adebo, Oyeyinka, Njobeh and Adebo, 2022).

This study evaluated nutritional composition, physicochemical, bioactivity, *in vitro* digestibility, functional, pasting, thermal and colour characteristics of germinated (24–72 hours) pigeon pea. Germination increased ($p \leq 0.05$) protein, dietary fiber, minerals, vitamins B (B_1 , 0.58–0.93 mg/100 g; B_2 , 0.32–0.75 mg/ 100 g; B_6 , 0.43–0.81 mg/100 g), vitamin C (1.25–8.46 mg/100 g), resistant starch, protein digestibility (72.30–82.66 g/100 g), total phenolic content, antioxidant activities and most amino acids. Antinutritional factors including phytic acid, tannin and trypsin inhibitor activity decreased significantly after germination. Germination also increased functional properties (water absorption capacity, protein solubility, foaming capacity, emulsion stability and activity) of the flours while bulk density decreased. Thermal, pasting (Figure 3) and color characteristics of pigeon pea was modified after germination. The study demonstrated that short-term germination is a natural means for the development of functional pigeon pea flour to promote its application in the food industry.

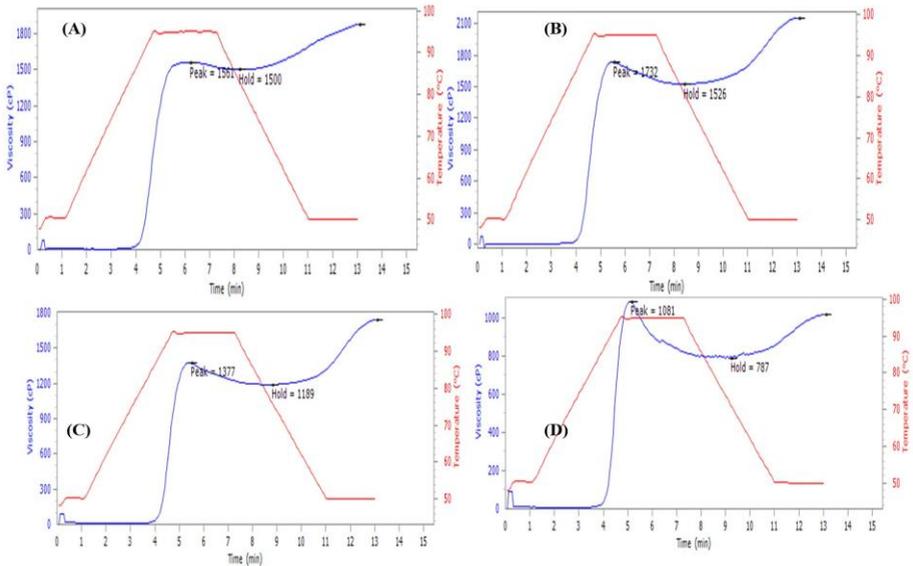


Figure 3: Pasting properties of raw (A), 24 h (B), 48 h (C) and 72 h (D) germinated pigeon pea flour Source: **Chinma et al.** (2022)

3.1.7 Structure, *in vitro* starch digestibility and physicochemical properties of starch isolated from germinated Bambara groundnut (Chinma, Abu, Afolabi, Nwankwo, Adebo, Oyeyinka, Njobeh and Adebo, 2023).

The study investigated the effect of germination time (0, 24, 48 and 72 h) on the physicochemical characteristics, *in vitro* starch digestibility and microstructural changes in Bambara groundnut starch. Raw and germinated Bambara grains are relatively good sources of starch. Extracted starches consist of predominantly oval shaped granules (Figure 4). Bambara groundnut starch showed a reduction in amylose content which significantly influenced their functional properties such as swelling power, solubility, dispersibility and the ability of the starch to absorb water. Germination of the grains did not change the crystallinity pattern (A-type) of the starch but increased their relative crystallinity (Figure 5). Germination time influenced the pasting and thermal properties of Bambara groundnut starch, and these changes indicate that the starches have potential application in food systems requiring higher thermal stability due to increased pasting and gelatinization temperatures. Germination could be employed as a strategy to modify Bambara groundnut starch for better functionality.

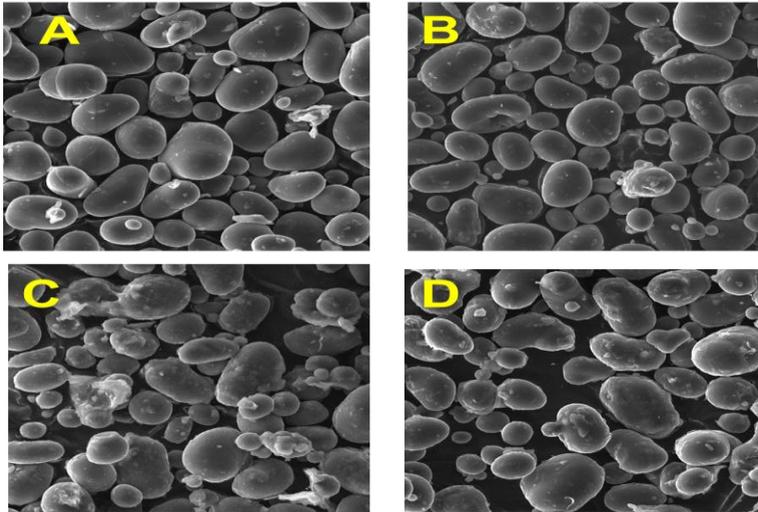


Figure 4: Micrographs of raw and germinated Bambara groundnut starch: (A) raw Bambara groundnut starch, (B) 24 h germinated Bambara groundnut starch, (C) 48 h germinated Bambara groundnut starch, (D) 72 h germinated Bambara groundnut starch.

Source: **Chinma et al. (2023)**

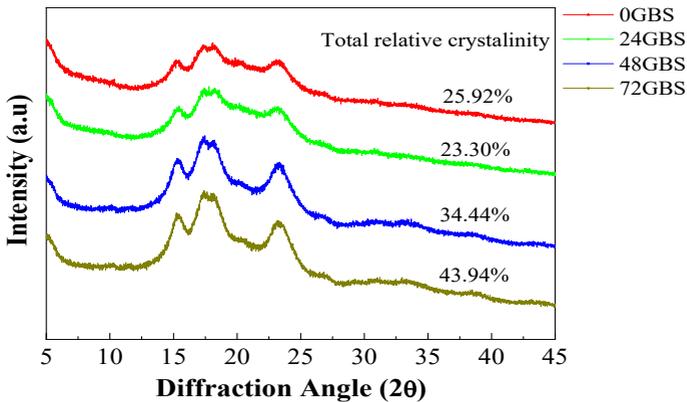


Figure 5: X-ray diffraction of raw and germinated Bambara groundnut starch: Pink (0GBS– Raw Bambara groundnut starch, light green (24GBS – 24 h germinated Bambara groundnut starch), blue (48GBS – 48 h germinated Bambara groundnut starch), black (72GBS – 72 h germinated Bambara groundnut starch). Values on the graph represent the % relative crystallinity.

Source: **Chinma et al. (2023)**

3.1.8 Impact of germination alone or in combination with solid-state fermentation on the physicochemical, antioxidant, *in vitro* digestibility, functional and thermal properties of brown finger millet flours (Azeez, Chinma, Bassey, Eze, Makinde, Sakariyah and Adebo, 2022).

The physicochemical, antioxidant, *in vitro* digestibility, functional, and thermal properties) of brown finger millet were determined. It was found that germination and solid-state fermentation increased the nutrient composition, total phenolic content (122-161 mg/GAE/ 100 g) total flavonoid content (119-155 mg RE/100), antioxidant properties (ABTS, DPPH and FRAP radical scavenging activity), majority of the amino acids as well as *in vitro* protein digestibility (67.72–89.53%), while antinutritional factors and digestible starch (from 45.17 to 35.58 g/100 g) content decreased significantly. Germination and solid-state fermentation increased water absorption capacity and protein solubility, and modified pasting (Figure 6) and thermal characteristics of bioprocessed brown finger millet flour. Combined bioprocessing techniques employed had the highest influence on brown finger millet which led to enhanced functional properties, nutritional composition and bioactivity of the flour. The increased levels of these constituents in the bioprocessed finger millet flours suggest their potentials as functional ingredients in the development of novel bakery products and other food applications.

3.1.9 Physicochemical properties, anti-nutritional and bioactive constituents, *in vitro* digestibility, and techno-functional properties of bioprocessed whole wheat flour (Chinma, Ezeocha, Adebo, Adebo, Sonibare, Abbah, Danbaba, Makinde, Wilkin and Bamidele, 2024).

The impact of bioprocessing methods (germination, solid-state fermentation, and combinations of germination and fermentation, Plate II) on functionality of whole wheat flour (WWF) was determined. Tables 1-2 revealed that germination, fermentation, and their combination enhanced the nutrient composition, amino acids, bioactive properties, resistant starch, and soluble digestible starch content of whole wheat flours with reduced antinutrient factors. Germination, fermentation, and their combination increase the water absorption capacity, water solubility index, and gel consistency of the whole wheat flour (Table 3). The pasting (Figure 6) and thermal characteristics of the bioprocessed whole wheat flour were modified compared to the raw flour. It was observed that the bioprocessing techniques caused molecular interactions among the functional groups, as revealed by the FTIR (Figure 8). The improved functionality of bioprocessed whole wheat flours proposes their potential as novel ingredients in the development of functional food products.

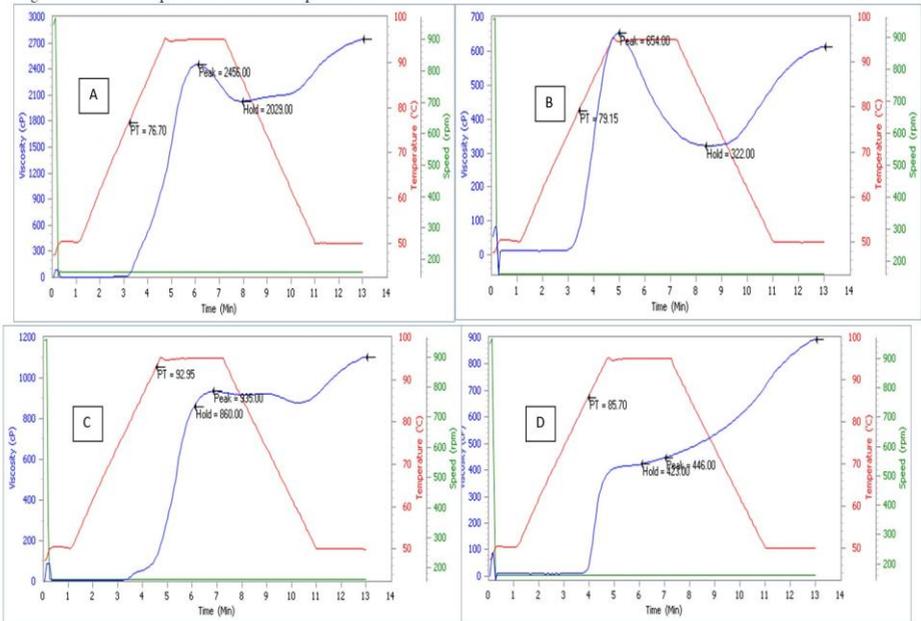


Figure 6: Pasting profiles of raw finger millet flour (A), germinated finger millet flour (B), solid-state fermented finger millet (C) and germinated-solid state fermented finger millet flour (D).

Source: **Chinma et al.** (2024)

Table 1: pH, titratable acidity, proximate composition (dry weight basis), starch characteristics, mineral and phytochemical composition of raw, germinated, fermented, and germinated-fermented whole wheat flour.

Parameters	Raw flour	Germinated flour	Fermented flour	Germinated-fermented flour
pH and proximate composition				
pH	6.80±0.02 ^a	5.60±0.01 ^b	4.30±0.01 ^c	4.00±0.01 ^c
Titratable acidity (%)	2.11±0.01 ^d	2.70±0.01 ^c	3.35±0.01 ^b	4.93±0.01 ^a
Moisture (g/100 g)	9.95±0.01 ^a	8.29±0.03 ^b	8.14±0.01 ^c	8.17±0.02 ^c
Protein (g/100 g)	13.37±0.05 ^d	15.14±0.03 ^c	16.39±0.08 ^b	16.84±0.05 ^a
Fat (g/100 g)	1.65±0.01 ^a	1.42±0.01 ^b	1.27±0.01 ^c	1.13±0.01 ^d
Ash (g/100 g)	1.72±0.03 ^d	2.25±0.02 ^c	2.38±0.01 ^b	2.63±0.02 ^a
Soluble dietary fiber (g/100g)	5.15±0.01 ^c	6.47±0.08 ^a	4.63±0.03 ^d	5.84±0.03 ^b
Insoluble dietary fiber (g/100g)	6.22±0.05 ^c	7.58±0.03 ^a	5.71±0.02 ^d	6.97±0.04 ^b
Total dietary fiber (g/100g)	11.37±0.08 ^c	14.05±0.11 ^a	10.34±0.07 ^d	12.81±0.10 ^b

Starch characteristics					
Amylose content (g/100 g)	25.61±0.08 ^a	24.38±0.05 ^b	23.64±0.10 ^c	22.20±0.07 ^d	
Total starch (g/100 g)	63.27±0.16 ^a	61.56±0.10 ^b	59.86±0.19 ^c	56.44±0.21 ^d	
Resistant starch (%)	7.19±0.12 ^d	8.87±0.14 ^c	9.05±0.10 ^b	9.87±0.14 ^a	
Rapidly digestible starch (%)	55.08±0.23 ^a	50.66±0.19 ^b	47.26±0.17 ^c	44.61±0.21 ^d	
Slowly digestible starch (%)	37.74±0.20 ^d	40.48±0.25 ^c	43.69±0.23 ^b	45.52±0.18 ^a	
Antinutritional factors					
Phytic acid (mg/100g)	388.40±1.05 ^a	121.09±1.17 ^b	73.57±1.03 ^c	24.33±0.84 ^d	
Tannin (mg CE/ g)	220.75±1.63 ^a	118.22±1.35 ^b	105.60±1.17 ^c	62.18±1.20 ^d	
TIA (TIU/mg)	1.82±0.02 ^a	1.35±0.01 ^b	1.16±0.01 ^c	1.10±0.01 ^c	
Mineral composition					
Calcium (mg/100g)	177.63±0.25 ^d	182.40±0.31 ^b	179.16±0.29 ^c	195.28±0.24 ^a	
Iron (mg/100g)	1.40±0.02 ^d	1.73±0.05 ^b	1.66±0.01 ^c	1.95±0.03 ^a	
Magnesium (mg/100g)	55.86±0.11 ^d	64.51±0.13 ^c	70.28±0.15 ^b	78.24±0.10 ^a	
Potassium (mg/100g)	213.19±0.20 ^d	227.75±0.17 ^c	232.76±0.22 ^b	256.80±0.19 ^a	
Zinc (mg/100g)	1.62±0.01 ^d	1.85±0.03 ^c	2.01±0.01 ^b	2.24±0.01 ^a	
Phytochemical composition					
TPC (mg GAE/100g)	76.25±0.17 ^d	89.53±0.14 ^c	93.60±0.12 ^b	105.84±0.16 ^a	
DPPH (mg AA/100 g)	40.78±0.13 ^d	49.36±0.10 ^c	52.29±0.15 ^b	55.45±0.19 ^a	
FRAP (mg TE/ 100g)	55.86±0.11 ^d	64.51±0.13 ^c	70.28±0.15 ^b	78.90±0.10 ^a	

Mean values and standard deviation of triplicate replications. Means with different letters represent significant differences ($p \leq 0.05$) among the sample (across rows).

TIA= Trypsin inhibitor activity; TPC = Total phenolic content; DPPH-DPPH - 1,1-diphenyl-2-picryl-hydrazil radical scavenging activity; FRAP - ferric reducing antioxidant power.

Source: **Chinma et al.** (2024)

Table 2: Amino acid and protein digestibility of raw, germinated, fermented and germinated-fermented whole wheat flours.

Parameters	Raw flour	Germinated Flour	Fermented flour	Germinated-fermented flour
Essential amino acids (mg/g protein)				
Histidine	33.06±0.11 ^d	35.53±0.19 ^c	37.80±0.13 ^b	38.19±0.12 ^a
Isoleucine	38.21±0.17 ^c	40.06±0.11 ^b	41.62±0.14 ^b	43.58±0.10 ^a
Leucine	70.63±0.15 ^d	72.30±0.17 ^c	72.94±0.20 ^b	74.16±0.14 ^a
Lysine	56.40±0.13 ^c	58.27±0.10 ^b	58.79±0.11 ^a	58.91±0.23 ^a
Methionine	10.19±0.18 ^d	11.84±0.21 ^c	13.47±0.16 ^b	13.90±0.14 ^a
Phenylalanine	46.35±0.15 ^d	53.09±0.17 ^c	57.53±0.18 ^b	59.22±0.21 ^a
Threonine	33.82±0.12 ^d	34.61±0.14 ^c	36.90±0.21 ^b	37.14±0.13 ^a

Valine	41.07±0.12 ^c	43.39±0.10 ^b	43.64±0.15 ^b	44.96±0.17 ^a
Non-essential amino acid (mg/g protein)				
Alanine	38.55±0.17 ^d	39.20±0.13 ^c	41.75±0.11 ^b	43.61±0.12 ^a
Arginine	79.84±0.26 ^c	80.31±0.20 ^b	80.42±0.28 ^b	81.53±0.21 ^a
Aspartic acid	105.49±0.35 ^d	107.66±0.25 ^c	108.94±0.20 ^b	111.23±0.27 ^a
Cysteine	19.60±0.14 ^d	21.34±0.11 ^c	22.50±0.16 ^a	21.82±0.19 ^b
Glutamic acid	11.93±0.25 ^d	12.79±0.20 ^c	13.88±0.24 ^b	14.05±0.22 ^a
Glycine	34.25±0.18 ^c	35.90±0.12 ^b	35.16±0.20 ^b	35.94±0.18 ^a
Proline	51.38±0.23 ^d	55.62±0.17 ^c	56.90±0.22 ^b	58.33±0.20 ^a
Serine	45.77±0.16 ^b	43.94±0.21 ^c	45.63±0.17 ^b	46.12±0.14 ^a
Tyrosine	29.42±0.20 ^d	30.11±0.14 ^c	30.85±0.15 ^b	31.26±0.17 ^a
<i>In vitro</i> protein digestibility (g/100 g)	65.27±0.53 ^d	68.40±0.31 ^c	69.72±0.40 ^b	71.08±0.66 ^a

Mean values and standard deviation of triplicate replications.

Means with different letters represent significant differences ($p \leq 0.05$) among the sample (across rows).

Source: **Chinma et al.** (2024)

Table 3: Functional, pasting, thermal and colour properties of raw, germinated, fermented, and germinated-fermented whole wheat flour.

Parameters	Raw flour	Germinated flour	Fermented flour	Germinated-fermented flour
Functional properties				
Bulk density (g/cm ³)	0.62±0.01 ^a	0.50±0.01 ^b	0.38±0.01 ^c	0.33±0.00 ^c
Water absorption capacity (g/g)	2.06±0.02 ^d	2.98±0.04 ^c	3.61±0.02 ^b	5.17±0.03 ^a
Water solubility index (%)	32.26±0.18 ^d	44.90±0.12 ^c	53.54±0.19 ^b	68.35±0.16 ^a
Oil absorption capacity (g/g)	1.24±0.01 ^a	1.10±0.01 ^b	1.05±0.01 ^b	1.08±0.01 ^b
Swelling power (%)	2.16±0.05 ^d	2.74±0.09 ^c	3.29±0.05 ^b	3.64±0.03 ^a
Gel consistency (mm)	31.29±0.21 ^d	37.66±0.19 ^c	45.33±0.24 ^b	51.40±0.28 ^a
Foam capacity (%)	16.57±0.10 ^a	15.04±0.08 ^b	13.46±0.07 ^c	10.62±0.05 ^d
Foam stability (%)	9.24±0.06 ^a	8.10±0.02 ^b	5.63±0.09 ^c	4.35±0.03 ^d
Emulsion capacity (%)	48.60±0.19 ^a	35.92±0.14 ^b	20.11±0.11 ^c	12.57±0.14 ^d
Emulsion stability (%)	51.44±0.13 ^a	30.26±0.10 ^b	19.75±0.18 ^c	11.83±0.10 ^d
Pasting properties				
Peak viscosity (RVU)	123.82±0.00 ^a	107.50±0.01 ^b	93.65±0.04 ^c	90.34±0.01 ^d

Trough (RVU)	viscosity	75.54±0.06 ^a	67.88±0.06 ^b	58.67±0.23 ^c	56.50±1.30 ^d
Break down (RVU)		46.42±2.60 ^a	39.63±0.06 ^b	33.29±2.18 ^c	32.47±0.64 ^c
Final (RVU)	viscosity	194.60±0.02 ^a	168.79±0.06 ^b	148.58±0.11 ^c	138.79±0.06 ^d
Setback (RVU)	viscosity	117.75±1.76 ^a	100.41±0.59 ^b	89.42±0.35 ^c	83.79±0.88 ^d
Pasting (°C)	temperature	71.80±0.07 ^a	70.15±0.00 ^b	71.75±0.00 ^a	70.33±0.27 ^b
Peak time (Min)		5.20±0.00 ^a	5.13±0.00 ^a	5.10±0.04 ^{ab}	5.07±0.01 ^b
Thermal properties					
Onset (°C)	temperature	55.94±0.10 ^d	56.26±0.07 ^c	56.77±0.05 ^b	57.30±0.08 ^a
Peak (°C)	temperature	61.08±0.14 ^d	62.40±0.13 ^c	63.19±0.10 ^b	64.82±0.12 ^a
Conclusion temperature (°C)		68.65±0.09 ^d	68.95±0.04 ^c	69.28±0.10 ^b	69.55±0.06 ^a
Enthalpy of gelatinization (J/g)		3.32±0.01 ^d	3.84±0.03 ^c	4.36±0.01 ^b	4.91±0.05 ^a
Colour properties					
L*		86.28± 0.32 ^a	80.49 ± 0.23 ^b	77.62± 0.28 ^c	74.55± 0.20 ^d
a*		3.15 ± 0.01 ^d	4.36 ± 0.02 ^c	4.90± 0.01 ^b	5.28 ± 0.01 ^a
b*		9.37 ± 0.05 ^d	11.82± 0.05 ^c	13.44± 0.10 ^b	16.10 ± 0.12 ^a

Mean values and standard deviation of triplicate replications. Means with different letters represent significant differences ($p \leq 0.05$) among the sample (across rows). L = Lightness, b= redness and c= yellowness

Source: **Chinma et al.** (2024)

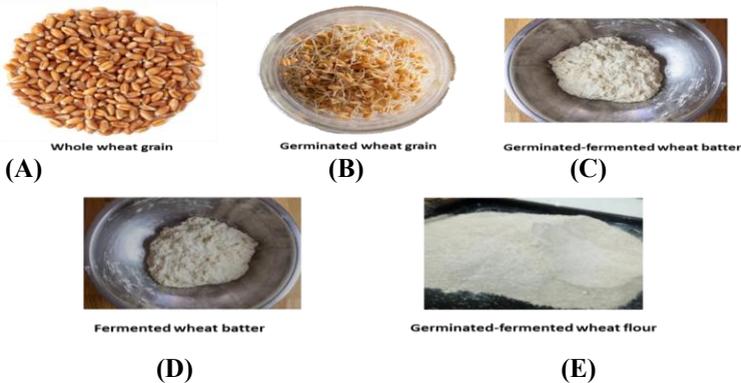


Plate II: Bioprocessed (germinated, fermented and germinated-fermented) whole wheat.

Source: **Chinma et al.** (2024)

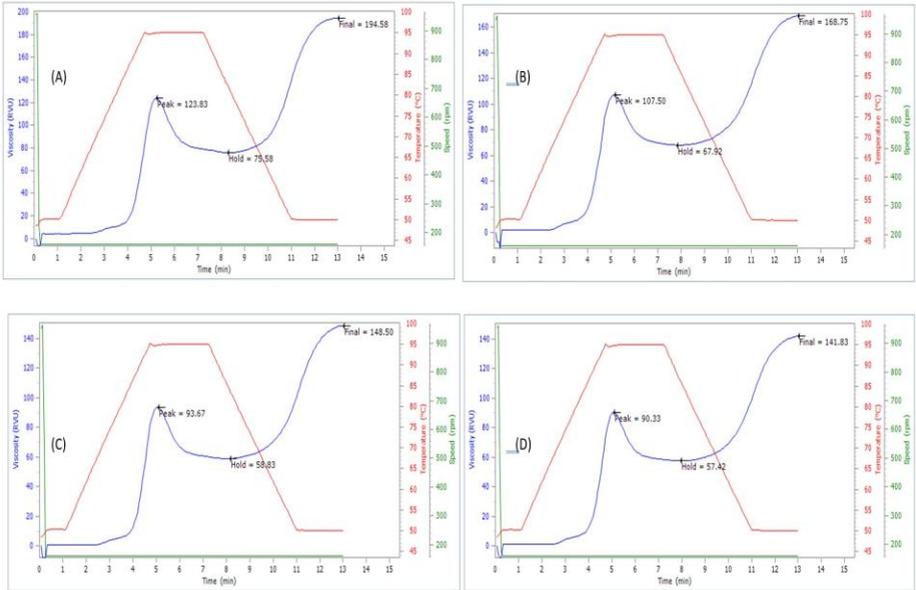


Figure 7: Pasting profiles of raw (A), germinated (B), fermented (C) and (D) germinated-fermented whole wheat flours.
Source: **Chinma et al. (2024)**

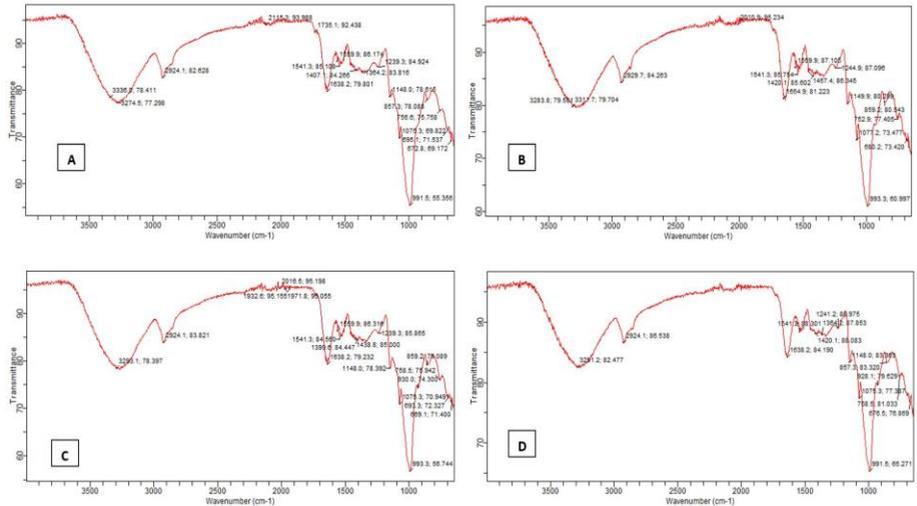


Figure 8: Fourier transform infrared spectroscopy spectra of raw (A), germinated (B), fermented (C) and (D) germinated-fermented whole wheat
Source: **Chinma et al. (2024)**

3.1.10 Gas chromatography–mass spectrometry analysis of metabolites in finger millet and Bambara groundnut as affected by traditional and novel food processing (Mudau, Chinma, Ledbetter, Wilkin and Adebo, 2024).

Traditional (fermentation and malting) and novel (ultrasonication) processing methods significantly altered the metabolite composition of finger millet and Bambara groundnut flours. GC–MS analysis revealed diverse metabolite classes, including amino acids, organic acids, fatty acids, sugars, esters, and volatile compounds, with marked variation across processing methods. Fermentation produced the most pronounced improvements, yielding the highest levels of health-promoting fatty acids such as oleic, linoelaidic, and linoleic acids. Both traditionally and novel-processed flours demonstrated potential for functional food and pharmaceutical applications. The findings provide a scientific basis for optimizing processing methods to enhance nutritional quality and for monitoring and regulating metabolite composition in underutilized crops.

3.1.11 Impact of short-term germination on the nutritional, physicochemical and techno-functional properties of black turtle beans (Chinma, Ezeocha, Shadrach, Onwuka and Adebo, 2025).

The study demonstrated that short-term germination (24-72 hours, Plate III) significantly improved the nutritional quality, antioxidant and techno-functional properties of black turtle beans flour while reducing antinutritional factors (as presented in Tables 4-7). These changes enhanced its suitability for incorporation into functional foods such as bakery products, complementary foods, and plant-based formulations, positioning germination as a low-cost, scalable strategy for developing value-added legume-based food ingredients.



Plate III: Images of raw and germinated black turtle bean seed (A) Raw, (B) 24 h germinated, (C) germinated, (D) 72 h germinated.

Source: **Chinma et al.** (2025)

Table 4: Germination parameters, proximate composition and starch characteristics of raw and germinated black turtle bean flour

Parameter	Raw flour	24 h	48 h	72 h
Germination parameters and proximate composition (dry basis)				
Germination percentage (%)	-	95.27±0.14 ^c	97.84±0.19 ^b	98.66±0.12 ^a
α-amylase activity (U/g)	0.42±0.01 ^d	0.84±0.02 ^c	1.17±0.02 ^b	1.32±0.01 ^a
Moisture (g/100g)	9.43±0.05 ^a	9.25±0.02 ^b	9.04±0.03 ^c	8.86±0.05 ^d
Protein (g/100g)	24.62±0.08 ^d	25.80±0.05 ^c	27.55±0.07 ^b	28.13±0.10 ^a
Ash (g/100g)	2.59±0.04 ^d	2.76±0.05 ^c	3.63±0.01 ^b	4.87±0.02 ^a

Fat (g/100 g)			6.21±0.09 ^a	5.83±0.11 ^b	5.15±0.06 ^c	4.45±0.04 ^d
Soluble dietary fiber (g/100g)			2.06±0.01 ^d	2.16±0.01 ^c	2.48±0.03 ^b	2.76±0.02 ^a
Insoluble dietary fiber (g/100g)			7.07±0.03 ^d	9.10±0.05 ^c	10.92±0.11 ^b	12.03±0.08 ^a
Total dietary fiber (g/100g)			9.13±0.11 ^d	11.26±0.14 ^c	13.40±0.10 ^b	14.79±0.16 ^a
Starch characteristics						
Amylose (g/100 g)			22.42±0.06 ^a	21.91±0.04 ^b	21.46±0.05 ^c	20.15±0.09 ^d
Total starch (g/100 g)			43.70±0.11 ^a	43.06±0.13 ^b	42.94±0.16 ^c	41.62±0.21 ^d
Resistant starch (g/100 g)			33.18±0.17 ^d	34.55±0.10 ^c	35.67±0.18 ^b	35.94±0.05 ^a
Digestible starch (g/100 g)			10.52±0.06 ^a	8.17±0.09 ^b	6.33±0.05 ^c	5.68±0.03 ^a

Mean ± standard deviation of three replications. Means within a row with different superscripts are significantly different ($p \leq 0.05$) from each other.

Source: **Chinma et al. (2025)**

Table 5: Antinutritional constituents, micronutrient composition, phytochemical and antioxidant properties of raw and germinated black turtle bean flour

Parameter	Raw flour	24 h	48 h	72 h
Antinutritional factors				
Phytic acid (mg/100g)	5.11±0.01 ^a	4.62±0.02 ^b	3.40±0.03 ^c	2.05±0.05 ^d
Tannin (mg CE/g)	4.28±0.03 ^a	4.01±0.03 ^b	3.26±0.02 ^c	1.55±0.01 ^d
Trypsin inhibitor activity (TIU/mg)	2.64±0.01 ^a	1.72±0.01 ^b	1.19±0.01 ^c	0.47±0.00 ^d
Micronutrient composition				
Calcium (mg/100 g)	247.50±0.69 ^d	273.10±0.81 ^c	292.74±0.56 ^b	314.66±0.92 ^a
Iron (mg/100 g)	2.38±0.05 ^d	2.80±0.08 ^c	3.53±0.04 ^b	4.98±0.07 ^a
Magnesium (mg/100 g)	95.63±0.49 ^d	113.79±0.61 ^c	144.38±0.42 ^b	162.25±0.30 ^a
Phosphorus (mg/100 g)	316.90±0.85 ^d	384.62±0.77 ^c	425.43±13.64 ^b	482.90±0.24 ^a
Potassium (mg/100 g)	1117.35±1.28 ^d	1175.30±1.46 ^c	1282.90±1.73 ^b	1305.46±1.13 ^a

Selenium (mg/100 g)		18.24±0.04 ^d	18.62±0.07 ^c	18.90±0.08 ^b	19.11±0.05 ^a
Zinc (mg/100 g)		2.49±0.02 ^d	2.75±0.02 ^c	3.81±0.02 ^b	4.03±0.04 ^a
Vitamin (mg/100 g)	B ₁	0.56±0.05 ^d	0.73±0.02 ^b	0.89±0.03 ^a	0.98±0.02 ^a
Vitamin (mg/100 g)	B ₂	0.34±0.01 ^d	0.49±0.01 ^c	0.70±0.02 ^b	0.87±0.01 ^a
Vitamin (mg/100 g)	B ₆	0.47±0.01 ^d	0.75±0.02 ^c	0.83±0.01 ^b	0.89±0.02 ^a
Vitamin (mg/100 g)	C	1.29±0.01 ^d	4.81±0.03 ^c	6.54±0.03 ^b	8.77±0.04 ^a
Phytochemicals and antioxidant activities					
Total phenolic content (µmolTE/g)		1.21 ± 0.03 ^d	1.48 ± 0.02 ^c	1.93 ± 0.01 ^b	2.27± 0.01 ^a
Total flavonoid (µg RE/g)		17.42 ± 0.09 ^d	19.76 ± 0.13 ^c	21.05 ± 0.12 ^b	23.30± 0.15 ^a
Total anthocyanin (mg C3GE/100 g)		28.31 ± 0.16 ^d	45.67 ± 0.24 ^c	62.85 ± 0.19 ^b	76.59 ± 0.22 ^a
FRAP (µmolTE/g)		2.53 ± 0.02 ^d	3.39 ± 0.03 ^c	3.80± 0.01 ^b	4.11± 0.02 ^a
ABTS (mg/100g)		69.81 ± 0.35 ^d	138.40± 0.29 ^c	147.65 ± 0.33 ^b	169.22± 0.57 ^a

Mean ± standard deviation of three replications.

Means within a row with different superscripts are significantly different ($p \leq 0.05$) from each other.

Source: **Chinma et al. (2025)**

Table 6: Amino acid composition (g/100 g) and *in vitro* protein digestibility of raw and germinated black turtle bean flour

Amino acid	Raw flour	24 h	48h	72 h
Essential amino acid				
Histidine	3.40±0.02 ^d	3.51±0.03 ^c	3.74±0.01 ^b	3.83±0.02 ^a
Isoleucine	3.69±0.03 ^d	3.82±0.02 ^c	3.92±0.02 ^b	4.01±0.03 ^a
Leucine	6.47±0.01 ^d	6.98±0.03 ^c	7.25±0.01 ^b	7.37±0.01 ^a
Lysine	6.22±0.02 ^d	6.41±0.01 ^c	6.58±0.03 ^b	6.69±0.02 ^a
Methionine	1.11±0.03 ^b	1.23±0.01 ^a	1.29±0.01 ^a	1.31±0.01 ^a
Phenylalanine	8.84±0.03 ^d	9.17±0.02 ^c	9.35±0.01 ^b	9.47±0.02 ^a
Threonine	3.16±0.01 ^d	3.30±0.01 ^c	3.48±0.01 ^b	3.66±0.01 ^a
Valine	3.97±0.01 ^c	4.24±0.01 ^b	4.36±0.02 ^b	4.53±0.01 ^a
Non-essential amino acid				
Alanine	4.01±0.01 ^d	4.19±0.01 ^b	4.14±0.00 ^b	4.38±0.01 ^a

Arginine	6.13±0.01 ^c	6.27±0.02 ^b	6.35±0.01 ^a	6.49±0.01 ^a
Aspartic acid	8.71±0.03 ^d	8.95±0.02 ^c	9.20±0.03 ^b	9.63±0.02 ^a
Cysteine	1.13±0.01 ^b	1.20±0.01 ^a	1.27±0.01 ^a	1.33±0.01 ^a
Glutamic acid	20.25±0.19 ^d	20.48±0.10 ^c	20.94±0.22 ^b	21.14±0.15 ^a
Glycine	3.17±0.02 ^d	3.32±0.01 ^c	3.57±0.03 ^b	3.79±0.02 ^a
Proline	4.32±0.01 ^d	4.75±0.02 ^c	4.93±0.01 ^b	5.10±0.03 ^a
Serine	4.71±0.02 ^d	4.89±0.01 ^c	5.10±0.03 ^b	5.28±0.01 ^a
Tyrosine	2.60±0.01 ^c	2.77±0.02 ^b	2.93±0.01 ^b	3.14±0.02 ^a
<i>In vitro</i> protein digestibility	71.33±0.29 ^d	73.60±0.42 ^c	76.92±0.31 ^b	78.56±0.38 ^a

Mean and standard deviation of triplicate replications. Values in the same row with different superscripts are significantly ($p \leq 0.05$) different.

Source: **Chinma et al.** (2025)

Table 7: Functional, pasting, thermal and colour properties of raw and germinated black turtle bean flour

Parameter	Raw	24 h	48 h	72 h
Functional properties				
Protein solubility (%)	58.65±0.18 ^d	64.10±0.15 ^c	72.55±0.23 ^b	85.29±0.29 ^a
Water absorption capacity (g/g)	1.04±0.01 ^d	1.33±0.01 ^c	1.81±0.01 ^b	2.24±0.01 ^a
Water solubility index (%)	3.61±0.03 ^d	4.27±0.02 ^c	5.71±0.02 ^b	7.82±0.04 ^a
Oil absorption capacity (g/g)	1.19±0.01 ^d	1.36±0.01 ^c	1.69±0.01 ^b	1.94±0.01 ^a
Bulk density (g/cm ³)	0.73±0.01 ^a	0.60±0.01 ^b	0.54±0.01 ^b	0.41±0.01 ^c
Emulsion capacity (%)	41.09±0.17 ^d	43.36±0.13 ^c	48.60±0.25 ^b	52.30±0.15 ^a
Emulsion stability (%)	48.85±0.26 ^d	52.10±0.24 ^c	56.92±0.19 ^b	60.18±0.27 ^a
Foaming capacity (%)	63.42±0.19 ^d	70.36±0.17 ^c	74.51±0.23 ^b	78.22±0.36 ^a
Foaming stability (%)	46.70±0.22 ^a	43.84±0.26 ^b	38.20±0.16 ^c	30.64±0.19 ^d
Gell consistency (mm)	32.51±0.17 ^d	39.40±0.13 ^c	43.67±0.18 ^b	48.20±0.15 ^a
Pasting properties				
Peak viscosity (cP)	1586±13 ^b	1744±19 ^a	1439±10 ^c	1271±16 ^d
Trough viscosity (cP)	1503±11 ^a	1549±17 ^b	1288±19 ^c	1044±10 ^d
Breakdown viscosity (cP)	83±4 ^d	136±5 ^c	151±3 ^b	227±6 ^a
Final viscosity (cP)	1729±18 ^b	1953±22 ^a	1590±18 ^c	1240±9 ^d
Setback viscosity (cP)	226±4 ^b	481±5 ^a	302±3 ^c	196±5 ^d
Peak time (min)	6.42±0.02 ^a	6.31±0.02 ^b	6.20±0.01 ^c	6.04±0.01 ^d
Pasting temperature (°C)	86.63±0.03 ^a	86.49±0.05 ^b	86.17±0.03 ^c	85.92±0.05 ^d
Thermal properties				
Onset temperature (°C)	65.71±0.09 ^d	65.94±0.04 ^c	66.29±0.03 ^b	66.63±0.04 ^a

Peak temperature (°C)	71.20±0.11 ^d	71.73±0.15 ^c	72.40± 0.12 ^b	73.57 ± 0.13 ^a
Conclusion temperature (°C)	78.42±0.15 ^d	79.08 ± 0.13 ^c	79.93± 0.10 ^b	80.44 ± 0.12 ^a
Enthalpy change (J/g)	5.67±0.01 ^a	5.40 ± 0.02 ^b	5.02± 0.01 ^c	4.86± 0.03 ^d
Colour parameters				
L	58.70± 0.12 ^d	54.16 ± 0.09 ^c	52.84± 0.11 ^b	48.33±0.15 ^a
A	4.25±0.01 ^d	6.43±0.03 ^c	8.06±0.03 ^b	10.59±0.07 ^a
B	2.08±0.01 ^d	2.96±0.05 ^c	3.34±0.02 ^b	4.82±0.03 ^a

Mean and standard deviation of three determinations.

Mean value with different superscripts in a row are significantly ($p \leq 0.05$) different.

L = Lightness, a = redness and b = yellowness

Source: **Chinma et al. (2025)**

3.1.12 Rheological, thermal and physicochemical properties of bioprocessed flour from cowpea, sorghum and orange fleshed sweet potato (Kewuyemi, Chinma, Alabi, Amonsou and Adebo, 2024).

This study examined rheological, physicochemical, and thermal properties of fermented and germinated cowpea, sorghum, and orange-fleshed sweet potato flours. Germination reduced pasting and rheological properties, while fermentation increased hot paste, setback, and final viscosities, improving cooking ease and starch retrogradation. All samples showed viscoelastic, shear-thinning behavior and gelatinization near 80–104°C. Fermented sweet potato exhibited good flowability but high solubility, yielding low pasting viscosities, supporting development of composite bioprocessed flours for the development of complementary foods.

3.1.13 Phenolic composition, functional groups, *in vitro* biological activities, and techno- functional properties of whole and composite bioprocessed cowpea, sorghum, and orange- fleshed sweet potato flours (Kewuyemi, Chinma, Kesa and Adebo, 2025).

This study evaluated blends (50% GCF:25% FSF:25% FSP; 50% GCF:30% FSF:20% FSP; 50% GCF:40% FSF:10% FSP; 50% GCF:20% FSF:30% FSP; 50% GCF:10% FSF:40% FSP and 33.3% GCF:33.3% FSF:33.3% FSP) of germinated cowpea, fermented sorghum, and fermented sweet potato flours for phenolic composition, bioactivity, and techno-functional properties. Increasing sweet potato levels enhanced phenolics, antioxidant capacity, and enzyme inhibition. A blend with 40% fermented sweet potato showed superior

bioactive compounds, improved solubility and flowability, and favorable processing characteristics, indicating synergistic nutritional and functional benefits for food formulations.

3.2 Application of Bioprocessed Functional Ingredients in Food Product Development

3.2.1 Effect of germinated tigernut and *moringa* flour blends on the quality of wheat-based bread (Chinma, Abu and Akoma, 2012)

Wheat flour was substituted with different proportions ((100: 0%; 90:5: 5%; 80:10: 10%; 70:15: 15%) of germinated tigernut and *moringa* flour blends in bread making. It was found that substitution of up to 15% germinated tigernut and *moringa* flours produced bread with higher nutritional quality and sensory attributes compared to 100% wheat bread.

3.2.2 Effect of addition of protein concentrates from natural and yeast fermented rice bran on the rheological and technological properties of wheat bread (Chinma, Ilowefah, M., Shammugasamy, Mohammed and Muhammad, 2015).

The study revealed that substitution of wheat flour with 0%, 5%, 10% and 15% protein concentrates from natural, and yeast fermented rice bran influenced the rheological properties of wheat dough. Overall acceptability score and specific loaf volume of 100% wheat bread were not significantly different from composite bread containing up to 10% rice bran protein; thus, the optimised level of substitution was established (Plate IV). The optimised composite bread contained higher total amino acid content, radical scavenging activity and ferric reducing ability power (43.04–48.87 g/100 g, 182.77–201.65 mmol TEAC/100 g and 613.29–637.81 mmol TE/100 g) than control (33.86 g/100 g, 109.43 mmol TEAC/100 g and 540.13 mmol TE/100 g). Textural properties such as springiness, cohesiveness and resilience values of wheat bread were not significantly different from composite bread. Scanning electron microscopy revealed that composite bread had surfaces with embedded granules like protein deposits with small spores (Figure 9).

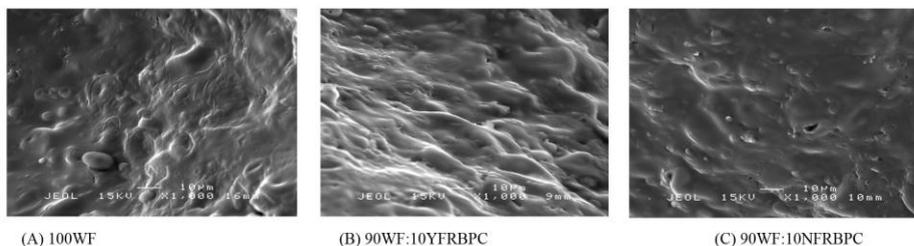


Figure 9: Effect of substituting protein concentrates from natural and yeast fermented rice bran for wheat flour on the microstructure of wheat bread. 100WF= 100%Wheat flour 90WF:10NFRBPC= 90% wheat flour: 10% Natural fermented rice bran protein concentrate 90WF:10YFRBPC= 90% wheat flour: 10% Yeast fermented rice bran protein concentrate

Source: **Chinma et al.** (2015)



100WF

90WF:10YFRBPC

90WF:10NFRBPC

Plate IV: Physical appearance of breadcrumbs prepared from 100WF; 90WF:10NFRBPC and 90WF:10YFRBPC and 100WF= 100%Wheat flour Where 90WF:10NFRBPC= 90% wheat flour: 10% Natural fermented rice bran protein concentrate; 90WF:10YFRBPC= 90% wheat flour: 10% Yeast fermented rice bran protein concentrate

Source: **Chinma et al.** (2015)

3.2.3 Effect of germinated tigernut and moringa flour blends on the quality of wheat-based bread (Chinma, Abu and Akoma, 2014).

The study investigated the potential of germinated tigernut and moringa seed flour in bread making for the purpose of utilization of value-added raw materials and cost reduction. It was found that inclusion of up to 15 %germinated tigernut and moringa flours produced bread with improved nutritional quality and sensory attributes.

3.2.4 Evaluation of fermented African yam bean flour composition and influence of substitution levels on properties of wheat bread (Chinma, Azeez, Sulayman, Alhassan, Alozie, Gbadamosi, Danbaba, Oboh, Anuonye and Adebo, 2020).

The study evaluated the composition of fermented African yam bean flour (FAYBF) and influence of substitution levels on properties of wheat bread. Fermentation significantly ($p \leq 0.05$) increased the levels of nutrients, protein digestibility and bioactivity in the flour (Tables 7), with significant ($p \leq 0.05$) reduction in antinutrients compared to the raw flour. Substitution of wheat flour with different proportions (0, 5, 10, 15 and 20%) of FAYBF influenced the pasting properties of wheat dough. The composite breads had improved nutritional and antioxidant properties compared to 100% wheat bread. Specific volume and crumb color attributes of bread were influenced by the addition of FAYBF (Plate V). The study shows that FAYBF could be explored for the preparation of a functional wheat-based bread.

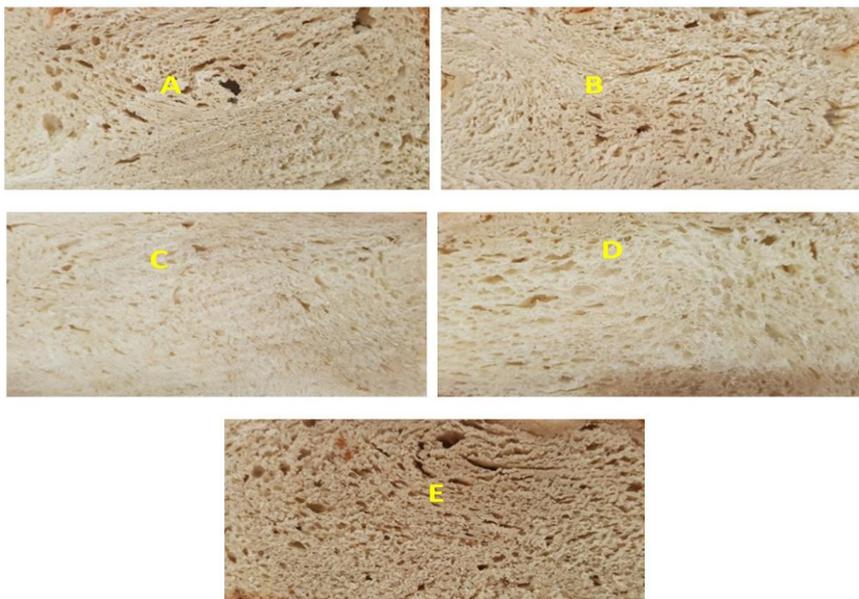


Plate V: Cross-section of bread samples (A) – 100 % wheat bread (control); (B) – 95 % wheat flour : 5 % fermented African yam bean flour; (C) – 90 % wheat flour: 10 % fermented African yam bean flour; (D) – 85 % wheat flour: 15 % fermented African yam bean flour; (E) – 80 % wheat flour: 20 % fermented African yam bean flour.

Source: **Chinma et al.** (2020)

3.2.5 Physicochemical, nutritional, and sensory properties of chips produced from germinated African yam bean (*Sphenostylis stenocarpa*) (Chinma, Adedeji, Etim, Aniaka, Mathew, Ekeh and Anumba, 2021).

Germination (24–72 h) was found to improve African yam bean flour and chip quality. Protein, ash, essential amino acids, minerals, phenolics, antioxidant activity, and in-vitro protein digestibility increased, while phytic acid and trypsin inhibitors decreased. Chips from 72-h germinated African yam bean showed higher protein (24.52 g/100 g) value with adequate quantity of essential amino acids, in vitro protein digestibility (89.50%), minerals, antioxidant activities and improved sensory attributes, with low residual antinutrients compared to the non-germinated AYB chips. Germination improved the physicochemical, nutritional, and antioxidant properties of AYB and the resultant chips.

3.2.6 Physicochemical properties, in vitro digestibility, antioxidant activity and consumer acceptability of biscuits prepared from germinated finger millet and Bambara groundnut flour blends (Chinma, Ibrahim, Adedeji, Ezeocha, Ohuoba, Kolo and Adebo, 2022).

The possibility of producing functional gluten-free biscuits from different proportions (100:0, 90:10, 80:20, 70:30, and 60:40) of germinated finger millet and Bambara groundnut flour was investigated. Increasing the level of germinated Bambara groundnut in the blend significantly improved the nutritional and antioxidant properties, while the glycemic index decreased. Blending 80% germinated finger millet flour with 20% germinated Bambara groundnut flour resulted in biscuits with acceptable sensory properties and enhanced physical characteristics. This suggests that germinated finger millet and Bambara groundnut have strong potential as functional ingredients in gluten-free biscuits.

3.2.7 Germinated Bambara groundnut (*Vigna subterranea*) flour as an ingredient in wheat bread: Physicochemical, nutritional, and sensory properties of bread (Chinma, Ezeocha, Adedeji, Ayo-Omogie, Oganah-Ikujenyo, Anumba, Enimola, Adegoke, Alhassan and Adebo, 2023).

In this study, wheat flour was substituted with different proportions (5, 10, 15, 20, 25 and 30%) germinated Bambara groundnut flour in bread production. Composite doughs showed higher water absorption, gelatinization temperature, and dough development time, with lower peak and setback viscosities. Breads had improved dietary fiber, minerals, total phenolics, antioxidant activity, resistant and slowly digestible starch, and reduced rapidly

digestible starch. Substitution of up to 15% germinated Bambara groundnut flour-maintained loaf volume, while 20% substitution level achieved the highest sensory acceptability, demonstrating germinated Bambara groundnut flour potential as a functional bread ingredient.

3.2.8 Cellulose synthesis from germinated tiger nut residue and its application in the production of a functional cookie (Adedeji, Abiodun, Adedeji, Kang, Istiana, Min, Ayo, Chinma and Jung, 2024).

In this study, cellulose was synthesized from the residue obtained after germinating tiger nuts for 0, 48, 72 or 96 h. The influence of the synthesized cellulose (0%, 2%, or 5%) on the quality of clove extract-laden cookies was determined. The optimum structure, morphology, and thermal properties of cellulose were obtained after germinating tiger nuts for 72 h. Addition of cellulose to the dough stabilized the total phenolic, flavonoid, radical scavenging activity and protein contents during baking. The addition of 2% cellulose generally enhanced the hydration, pasting, and viscoelastic properties of the dough. However, 5% cellulose negatively affected the highlighted properties, culminating in poorer texture and sensory properties of the cookies produced therefrom. Germination proved to be effective in modifying the properties of cellulose from tiger nuts; thus, enhancing its application in the production of a functional cookie.

3.2.9 Impact of germination on the techno-functional properties, nutritional composition, and health-promoting compounds of brown rice and its products: A review (Chinma, Adedeji, Jolayemi, Ezeocha, Ilowefah, Rosell, Adebo, Wilkin, and Adebo, 2024).

This paper reviewed the techno-functional, nutritional, and health-promoting properties of germinated brown rice and its products. The applications of germinated brown rice in the development of functional brown rice products were documented. The paper highlighted gaps in knowledge in germinated brown rice flour functionality. Further work is also needed to determine the optimum germination conditions of some underutilized rice varieties for improved nutritional quality, health-promoting constituents, and low residual antinutrients to produce functional rice-based products. There is also the need to investigate the impact of germination on the physicochemical, nutritional, and techno-functional properties some underutilized brown rice varieties in Africa.

3.2.10 Short- term germinated legume flours as functional ingredients in food products (Onwuka, Chinma, Ezeocha, Otegbayo, Oyeyinka, Adebo, Wilkin, Bamidele and Adebo, 2024).

This paper reviewed the potential of germinated legume flours as functional ingredients in food products. It highlighted that germination triggers biochemical changes in legumes that significantly enhanced their nutritional quality, digestibility, and functional properties when processed into flour. The review paper also emphasized that germinated legume flours can be successfully incorporated into various food formulations, expanding their usefulness in food product development. The review underscores the potential of germinated legume-based products to be nutritious, affordable, and sustainable, making them suitable for addressing malnutrition and food insecurity across the globe. The review highlighted the need for extensive research on short-term germination of African traditional legumes to generate data that will support wider and more effective food applications.

3.2.11 Germinated/fermented legume flours as functional ingredients in wheat-based bread: A review (Chinma, Ezeocha, Adedeji, Jolayemi, Onwuka, Ilowefah, Adebo, Rosell, Bamidele, and Adebo, 2025).

This paper reviewed the influence of germinated and fermented legume flours on the rheological, nutritional, health, and technological properties of wheat bread. The paper documented in detail how enzymatic activity and macroconstituent changes during processing alter dough functionality and bread quality. It also highlighted that substitution of up to 20% germinated legume flour reduced technological quality, whereas substitution of up to 20% fermented legume flour improved it. Furthermore, such breads provide high-quality protein, dietary fiber, micronutrients, and phytochemicals, and exhibit a lower glycemic index with enhanced sensory properties. However, information on the bioavailability of nutrients in breads containing germinated or fermented legumes, based on *in vivo* studies, as well as metabolite profiling, remains scarce in the literature.

3.2.12 Impact of fermentation periods on the nutritional composition and antioxidant activities of *ogi* (gruel) from two sorghum (*Sorghum bicolor* (L.) Moench) varieties (Adebowale, Chinma, Adebo and Makun, 2025).

The impact of fermentation on the nutritional composition and antioxidant properties of *ogi* (gruel) from red and white sorghum varieties was determined. It was found that nutritional composition and antioxidant properties varied significantly ($p \leq 0.05$) with sorghum type and fermentation

duration. White sorghum contained higher mineral levels, while fermentation reduced antinutrients, thereby enhancing mineral bioavailability, protein digestibility, and overall nutritional quality of *ogi*.

3.3 Other Food Products

3.3.1 Development of cassava starch and protein concentrate edible films (Chinma, Ariaahu and Abu, 2012).

Edible films were developed from cassava starch and soy protein concentrate using varying levels (10-30%) of glycerol as a plasticizer. It was found that addition of SPC and glycerol up to 30% and 20%, respectively, reduced stickiness and improved colour and appearance of the films. Tensile strength (TS), elastic modulus (EM) and elongation at break (EAB) of films increased, while film solubility (FS) and WVP decreased with SPC and glycerol up to 50% and 20% level, respectively, ranging from 20.33 to 26.94 MPa (TS), 41.33 to 72.76 MPa (EM), 7.90 to 12.28 MPa (EAB), 15.07 to 31.90% (FS) and 2.62 to 4.13g H₂O mm⁻² day kPa (WVP). The TS, EAB and WVP were higher for the biofilms than for low-density polyethylene and cellophane films. The findings indicates that the edible films have excellent flexibility, barrier and mechanical properties suitable for food packaging and preservation.

3.3.2 Moisture sorption and thermodynamic properties of cassava starch and soy protein concentrate based edible films (Chinma, Ariaahu, Alakali, 2013).

In this study, moisture sorption isotherms and thermodynamic properties of cassava starch-soy protein concentrate-based edible films were evaluated. Equilibrium moisture content was measured at various temperatures (10, 20, 30 and 40 °C) and relative humidities (17–83%) using gravimetric method, and the results were analysed using four sorption isotherm models (BET, GAB, Henderson and Oswin) models. The equilibrium moisture of edible films (both adsorption and desorption modes) decreased with soy protein concentrate addition and temperature at constant water activity. The monolayer moisture content values of cassava starch–soy protein concentrate edible films decreased with increase in temperature and soy protein level. GAB and Oswin models (% root mean square, RMS ≤10) best described the isotherms of the biofilms with the monolayer moisture contents, isosteric enthalpy and entropy higher for adsorption with significant kinetic compensations. The moisture sorption and thermodynamic properties of cassava starch–soy protein concentrate edible films indicate suitability for food packaging applications.

3.3.3 Effect of addition of germinated *moringa* seeds flour on the quality attributes of wheat-based cake (Chinma, Gbadamosi, Ogunsina, Oloyede and Salami, 2014).

Substituting germinated *moringa* seed flour for wheat flour altered modified pasting properties and improved cake nutritional value. Significant differences in physical properties of the cakes were recorded, but crust/crumb color, aroma, texture, taste, and acceptability remained comparable to wheat cakes up to 30% substitution, showing nutritional gains without compromising sensory quality.

3.3.4 Effect of tigernut (*Cyperus esculentus*) flour addition on the quality of wheat-based cake

The effect of tigernut (*Cyperus esculentus*) flour substitution for wheat flour on cake quality was investigated. Addition of tigernut flour modified the pasting properties of wheat flour. Increasing tigernut levels enhanced proximate composition, increasing protein (22.30–26.93%) and fat (4.17–7.21%), thereby increasing energy value (342.09–390.93 kcal). Mineral content improved, Sensory evaluation showed acceptable taste and texture up to 30% substitution levels, indicating tigernut flour's potential for nutritionally enriched cakes.

3.3.5 Chemical, functional and pasting properties of starches from brown and yellow tigernuts (*Cyperus esculentus*) (Chinma, Abu and Ojo, 2010).

Starch was isolated from brown and yellow varieties of tigernuts and compared with conventional starch, cassava starch in terms of their chemical, functional and pasting properties. Results showed varietal differences in amylose content. Pasting characteristics such as breakdown, peak and final viscosities were significantly higher in tigernut starch than cassava starch. Tigernut starch displayed higher syneresis and low stability under refrigerated and freezing temperatures than cassava starch. Brown and yellow varieties of tigernut starches may find useful application in food systems requiring high temperature processing such as baked goods but not cold products like ice creams.

3.3.6 Physiochemical properties of flours from five Nigerian rice cultivars (Chinma, Azeez, Olaitan, Anuonye, Danbaba and Oloyede, 2018).

The study evaluated five Nigerian rice cultivars (*Bisalachi*, *Ebagichi*, *Lamiyatu*, *Majalisa*, *Walue*) for grain dimensions, weight, color, proximate composition, amino acid profile, minerals, B-vitamins, and phytic acid.

Results showed variations in protein (5.82–11.48%), carbohydrate (74.57–80.90%), amylose (20.56–23.84%), and amino acids (7.29–8.06 g/100 g). These rice cultivars offer diverse physicochemical profiles, enabling targeted product development for both mainstream and specialized markets.

3.4 Manpower Development Through Research and Training

Vice-Chancellor, Sir, and distinguished audience, I am pleased to report that, as of today, I have successfully supervised twelve (12) PhD candidates, seventeen (17) M.Tech students, and two hundred and thirteen (213) B.Tech students. I am currently supervising several PhD and M.Tech candidates whose programmes are ongoing. Many of the students whom I have taught and supervised at both undergraduate and postgraduate levels are now serving as managers in various national and international food companies. In addition, two of my PhD graduates currently serve as Director and Permanent Secretary at the Federal Ministry of Agriculture, Abuja. Furthermore, one of my mentees is a Professor of Food Science and Technology at Michael Okpara University of Agriculture, Umudike, Nigeria.

3.5 Service to the University and Community

Vice-Chancellor, Sir and distinguished audience, I am pleased to report that I have served the University in various capacities, both as a member and as Chairman of several committees. These roles include Deputy Director of Academic Planning (2018–2019), Deputy Director of Research, Innovation and Development (2019–2022), Academic Coordinator of the World Bank-supported Africa Centre of Excellence for Mycotoxin and Food Safety (2018–2020), and Head of the Department of Food Science and Technology (2022–2024).

I also served as Chairman of the University Policies and Manuals Advisory Committee (2020–2024) at the Federal University of Technology Minna and as a Visiting Professor at the University of Johannesburg, South Africa (2022–date). I am currently serving as the Director of the Directorate for Research, Innovation and Development (DRID) and a member of the 14th Governing Council of the Federal University of Technology, Minna.

In addition, I served as the Zonal Coordinator (North Central, Nigeria) of the African Network of Food Data Systems, a Regional Data Centre of the Food and Agriculture Organization (FAO), which was responsible for the development of the Nigerian Food Composition Table. I have also served as

an undergraduate and postgraduate External Examiner in several national and international Universities. Furthermore, I am actively involved in several nutrition intervention programmes in Nigeria and have participated in the review of standard manuals for food products developed by the Standard Organization of Nigeria.

I served as Secretary of the Nigerian Institute of Food Science and Technology NIFST Committee that evaluated the food safety quality bill from 2021 to 2022.

4.0 CONCLUSION

Vice-Chancellor Sir, distinguished academics, ladies and gentle men, permit me to conclude this lecture by saying that bioprocessing represents a powerful, affordable, and sustainable strategy for unlocking the full nutritional, bioactive, and techno-functional potential of plant-based foods. Through systematic application of traditional and novel bioprocessing techniques—particularly soaking, germination, fermentation, enzymatic treatment, and their combinations—significant improvements were achieved in nutrient density, mineral bioavailability, protein and starch digestibility, antioxidant activity, and functional properties of a wide range of cereals, legumes, tubers, and underutilized indigenous crops.

The findings from the works so far in this lecture consistently show that bioprocessing effectively reduces antinutritional factors while simultaneously enhancing essential amino acids, dietary fiber, resistant starch, vitamins, and health-promoting phytochemicals. Beyond nutritional enhancement, bioprocessing markedly improved techno-functional attributes including water and oil absorption, emulsification, foaming, gelling, pasting, and thermal properties—qualities that are critical for successful incorporation of plant-based ingredients into diverse food systems such as baked products, complementary foods, gluten-free products, snacks, and functional foods.

Importantly, the application of bioprocessed plant-based ingredients in food product development confirmed their practical relevance, consumer acceptability, and industrial potential. Composite foods developed from bioprocessed flours not only exhibited superior nutritional and functional quality but also maintained desirable sensory attributes, demonstrating that health promotion and consumer appeal can be achieved simultaneously. These outcomes provide strong scientific justification for the substitution of imported raw materials with locally available, value-added plant resources, thereby supporting food sovereignty, reducing foreign exchange expenditure, and strengthening local food value chains.

Bioprocessing plays a critical role as a low- cost, scalable, and culturally adaptable technology for addressing food insecurity, malnutrition, and sustainability challenges, particularly in developing regions such as Sub- Saharan Africa, including Nigeria. By encouraging the utilization of underexploited crops and the adoption of simple, accessible processing methods, bioprocessing aligns closely with the United Nations Sustainable Development Goals, the African Union Agenda 2063, and national priorities related to nutrition, public health, poverty reduction, and sustainable economic development. Continued research, optimization, and industrial translation of bioprocessing technologies are essential for transforming plant- based foods into functional, health- promoting products capable of meeting the nutritional demands of a rapidly growing global population.

5.0 RECOMMENDATIONS

Mr Vice-Chancellor Sir, distinguished academics, ladies and gentlemen, based on the research findings presented in this lecture, I wish to recommend that bioprocessing should be strategically integrated into plant-based food research, development, and policy frameworks as a sustainable approach to improving food and nutrition security. There is a need to scale up simple, low-cost bioprocessing techniques such as soaking, germination, fermentation, enzymatic treatment, and their combinations for processing crops, particularly in developing regions like Africa. Stronger linkages between researchers, food processors, policymakers, and rural farmers are recommended to facilitate technology transfer, value addition, and commercialization of bioprocessed functional ingredients. Further research should focus on process optimization, product standardization, consumer acceptability, and long-term health impacts of bioprocessed plant-based foods. Investment in capacity building, small-scale processing infrastructure, and supportive policies will enhance adoption, reduce post-harvest losses, lower dependence on imported raw materials, and contribute meaningfully to achieving food security, improved livelihoods, and sustainable development goals.

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A BRIEF PROFILE OF THE INAUGURAL LECTURER

Professor Chiemela Enyinnaya Chinma was born on 23rd February 1976 in Okpuala Amapu Isiala Ngwa North Local Government Area of Abia State, Nigeria. He attended Apu Na Ekpu Primary School and Umuoha Secondary School, both in Isiala Ngwa of Abia State. He obtained his Bachelor of Science (B.Sc.), Master of Science (M.Sc.) and Doctor of Philosophy (PhD) degrees in Food Science and Technology from the University of Agriculture, Makurdi. He undertook a Postdoctoral Fellowship at the UPM-BERNAS Research Laboratory, Faculty of Food Science and Technology, Universiti Putra Malaysia, between 2012 and 2013.

Professor Chinma joined the services of the Federal University of Technology, Minna, in 2005 as a Lecturer II and was promoted to the rank of Professor of Food Science and Technology in October 2018. He has been serving as a Visiting Professor in the Department of Biotechnology and Food Technology, University of Johannesburg, South Africa, since 2022.

Professor Chinma has served the University in various capacities, both as a member and Chairman of several committees. His administrative appointments include Deputy Director, Academic Planning Unit (2018–2019); Deputy Director, Directorate for Research, Innovation and Development (2019–2022); Head, Department of Food Science and Technology (2022–2024); and Chairman, University Policies and Manuals Advisory Committee (2019–2024). During his tenure as Chairman of the Committee, several institutional policies currently in use at the University were developed and approved by the 13th and 14th University Governing Council of the Federal University of Technology Minna. He is currently the Director, Directorate for Research, Innovation and Development (DRID), and a member of the 14th University Governing Council.

Professor Chinma leads the Food Product Development Research Group at the Federal University of Technology, Minna. His research focuses on improving the functionality of underutilized grains through conventional and innovative food processing methods. He has successfully attracted several research grants to the University through collaborations with national and international institutions. Notably, he played a key role in securing the One Billion Naira (₦1,000,000,000.00) Tertiary Education Trust Fund (TETFund) Agricultural Commercial Farm project, where he served as Chairman of the Research Proposal Drafting Committee and currently serves as Chairman of the Commercial Farm Committee.

He has supervised about two hundred and thirteen (213) undergraduate projects, seventeen (17) master's theses and twelve (12) PhD dissertations. Many of his former students now occupy managerial positions in national and international food companies, while others serve as academic staff in various Nigerian Universities, including the Department of Food Science and Technology, Federal University of Technology, Minna. In addition, two of his PhD graduates currently serve as Director and Permanent Secretary at the Federal Ministry of Agriculture, Abuja. Furthermore, one of his mentees is a Professor of

Food Science and Technology at Michael Okpara University of Agriculture, Umudike, Nigeria.

Professor Chinma has over one hundred and twenty-four (124) scientific publications to his credit, including peer-reviewed journal articles, book chapters published by reputable publishers such as Elsevier and Springer, as well as conference proceedings.

He has participated in numerous local and international conferences, workshops and technical meetings. He served as Zonal Coordinator (North Central, Nigeria) of the African Network of Food Data Systems, a Regional Data Centre of Food and Agriculture Organization (FAO), which developed the Nigerian Food Composition Table. Professor Chinma is actively involved in several nutrition intervention programmes in Nigeria and has contributed to the review of standard manuals for food products developed by the Standards Organization of Nigeria (SON).

Professor Chinma is a Fellow of the Nigerian Institute of Food Science and Technology and a Member of the Nutrition Society of Nigeria, among other professional bodies. He serves on the Editorial Boards of several academic journals, including Food Bioscience (an Elsevier Q1 Journal), Nigerian Food Journal, and the Nigerian Journal of Technological Research (NJTR). He has also served on numerous occasions as Chairman of the National Universities Commission (NUC) Ad-hoc Accreditation Panels for Food Science and Technology Programmes in Nigerian Universities. Additionally, he has acted as an External Examiner at both undergraduate and postgraduate levels in several national and international Universities and Professorial Assessor for many institutions. He is a recipient of numerous awards from Universities, Professional bodies and student associations.

Professor Chinma is happily married and blessed with four children.