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Review

Lactic Acid Bacteria Diversity in Fermented Foods as Potential Bio-Resources Contributing to Alleviate Malnutrition in Developing Countries: Nigeria as a Case Study

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Abstract: Fermented products represent ecological niches for developing microorganisms of interest as bio-resources for improving human well-being. Lactic acid bacteria (LAB) are frequently associated with food fermentations and represent relevant biotechnological resources for enhancing the overall quality of foods and beverages. Among the other potential applications, LAB isolated from traditional fermented foods can play a significant role in addressing malnutrition in developing countries, positively modulating the finished products' nutritional quality. Nigeria represents an excellent model region to explore this topic as (i) it is a country where the magnitude of phenomena associated with malnutrition is high; (ii) there is a significant effort linked to the achievement of Sustainable Development Goals (SDGs) of the Food and Agriculture Organization (FAO) of the United Nations (UN); and (iii) there is an interesting diversity of traditional fermented foods and beverages. In nations such as Nigeria, fermented foods are integral to infant and young child nutrition, often serving as complementary foods. This review proposes a detailed overview of traditional Nigerian fermented products, including *ogi*, *gari*, *fufu*, *lafun*, *kunu-zaki*, *masa*, *wara*, *kobele*, *abacha*, *pito*, and *burukutu*. An overview of the microbial diversity associated with these matrices is also provided, considering a specific focus on LAB responsible for the spontaneous fermentation of various Nigerian foods. We underlined the potential of different LAB species/stains to produce vitamins naturally, particularly B-group vitamins, suggesting strategies that can be followed for in situ biofortification, enhancing the nutritional value of fermented products. In general, the review, summarizing data on microbial diversity presented in principal traditional fermented foods and beverages in Nigeria, supports future studies to exploit the potential of LAB species/strains from fermented foods to combat micronutrient deficiencies in developing countries, such as Nigeria, with the objective to mitigate hidden hunger and alleviate malnutrition in vulnerable populations.

Keywords: fermentation; microbial diversity; fermented beverages; lactic acid bacteria (LAB); malnutrition; sustainable development goals (SDGs); vitamins; riboflavin; cobalamin; biofortification

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1. Introduction

Malnutrition is a condition caused by an imbalance between the nutrients required by the body and those provided through diet: "Malnutrition refers to deficiencies, excesses, or imbalances in a person's intake of energy and/or nutrients" [1–3]. The two major forms of malnutrition are undernutrition and overnutrition. Signs of undernutrition include stunting, wasting, being underweight, acute malnutrition, chronic malnutrition, and deficiencies or excesses of vitamins and minerals. Conversely, overweight, obesity, and diet-related non-communicable diseases (NCDs) such as diabetes mellitus, heart disease, certain types of cancer, and stroke are associated with overnutrition [4–6]. Recent statistics from the 2024 Global Nutrition Report revealed that almost 282 million people "experienced high levels of acute food insecurity requiring urgent food and livelihood assistance" [7]. Furthermore, the report emphasizes that poor diet-driven malnutrition is one of the most pressing health and socioeconomic challenges of our time. Despite modest progress in combating malnutrition, its prevalence remains unacceptably high worldwide [7,8]. In developing countries, undernutrition persists as a dominant issue, alongside a rising trend in overweight and obesity. This phenomenon, referred to as the double burden of malnutrition (DBM), signifies the simultaneous occurrence of undernutrition and overnutrition within different population groups in these regions. Since 2015, the prevalence of malnutrition has steadily increased, particularly in Africa, west Asia, and Latin America [9]. According to the Food and Agriculture Organization (FAO), "Africa remains the region with the largest estimated proportion of the population facing hunger", followed by Asia, Oceania, Latin America, and the Caribbean [9]. Undernutrition deprives many children of the energy and nutrients essential for healthy growth, contributing to significant mortality rates among children under five years old. Hidden hunger, caused by deficiencies in vitamins and minerals such as vitamins A and B, iron, and zinc, further impairs children's health, vitality, and development. If left unaddressed, hidden hunger can have severe and long-lasting consequences, including increased mortality rates in children under five [10,11]. Nigeria is one of the countries with the highest burden of malnutrition on a global scale [7,12–14].

Food is fundamental to human life, and fermentation represents one of the oldest and most significant food processing methods. There is evidence that fermentation has been used to prepare food and beverages since 7000 BC; however, its exact beginnings are unknown. In the past, people exploited fermentation in addition to other preservation techniques like sun-drying food to lower moisture and prevent microbial development as they moved from hunting to a more structured and semi-stable way of life (Sulieman, 2022). Many civilizations and geographical areas have varied fermentation methods, reflecting their inventiveness in using natural processes to produce wholesome, tasty, and safe meals. For ages, this technique has been employed to boost the nutritional value, preserve food, and enhance flavours [15]. Through the use of microorganisms like bacteria, yeasts, or moulds in anaerobic environments, fermentation transforms carbohydrates into alcohol or organic acids [16]. Microbial metabolism can improve the bioavailability of macro/micronutrients and phytochemicals during fermentation, which also increases the digestibility of macromolecules. Fermentation is regarded as one of the best processing techniques for getting rid of toxins, allergies, and anti-nutrients [17,18]. According to Ekwem and Okolo [19], fermented foods have a long history and are present in many civilizations worldwide. This method of producing and preserving food is economically important and popular in developing and underdeveloped countries in Africa because it has solved the problems of food security in many African regions and is affordable for people experiencing poverty [20], which directly addresses the issue of malnutrition and improves socio-economic status. In Nigeria, with its diverse ethnic, cultural, and religious backgrounds, various fermented foods exist, varying by raw materials, processing methods, and localities [20]. Lactic acid bacteria (LAB)—Gram-positive, non-spore-forming, catalase-negative cocci or rods—play a central role in the spontaneous or natural fermentation of many Nigerian foods, alongside yeasts and *Bacillus* species [21]. Common fermented foods in Nigeria can be categorized based on their raw materials. Examples include maize, sorghum, or millet-based products such as *ogi*, *ogi baba*, *kunu-zaki*, *masa*, *pito*, and *burukutu*; cassava-based products such as *gari*, *fufu*, and *lafun*; fermented products from African locust beans and soybeans, such as *iru* and *dawadawa*; melon seed-based *ogiri*; and oil bean-based *ugba*. Palm wine, a naturally fermented beverage, is also widely consumed in Nigeria. Most of these products are produced using traditional fermentation techniques at the household level [20]. Nigerians place a high value on fermented foods because of their many benefits to the country's economy, including job creation, poverty alleviation, industrialization, food security, market expansion, food supplementation, and lower mortality rates. Fermented foods are an essential part of the Nigerian economy because of these elements, which together improve the socio-economic environment of the country [22].

The primary objective of this review is to highlight research from developed countries overviewing the microbial diversity of traditional fermented foods and beverages from Nigeria as a model country. Subsequently, the potential of the LAB diversity is discussed in order to support future studies on micronutrient biofortification, particularly B vitamins. This evidence supports the need for studies intending to mitigate micronutrient deficiencies in Nigeria and across Africa/developing countries. This review activity included a systematic approach to synthesize existing knowledge on the diversity and lactic acid bacteria (LAB) in Nigerian fermented food. A comprehensive literature search was conducted using databases such as PubMed and Google Scholar, employing keywords like "Nigeria", "fermented foods", "fermented beverages", "traditional fermented foods", "lactic acid bacteria", and all the traditional names of the reported fermented foods and beverages. Articles and books detailing the microbiological composition of Nigerian fermented foods, LAB diversity, and their nutritional impacts were included. Data reporting focused on identifying types of fermented foods, LAB species, their biofortification potential (e.g., folate, riboflavin, and thiamine production), and their health-enhancing properties. To ensure review quality, selected studies were assessed for the clarity of experimental design and relevance to the topic.

2. Nigerian Traditional Fermented Foods

Food fermentation technologies have evolved significantly over time and now contribute to one-third of global food consumption [23]. This ancient method of food preservation is especially prevalent in rural households and village communities. It preserves desirable biochemical changes and the unique properties of raw materials while producing wholesome and nutritious foods for daily consumption [24]. Nigerian diverse population and cultural heritage make selecting a single national dish challenging, as each region boasts its favourite foods shaped by customs, traditions, and religious practices [20,21,25–28]. The fermentation processes used for these foods are a crucial component of indigenous knowledge, developed through observation and experience and passed down through generations. Microbial diversity associated with food and beverage fermentation profoundly influences the food flavour and other organoleptic properties [29–31]. The indigenous production of fermented foods in Nigeria dates back centuries [20,21,25–28]. Lactic acid bacteria (LAB), traditionally derived from milk fermentation, play a central role in this process [23]. These bacteria are also present in legume-based foods, alcoholic and non-alcoholic beverages, and other milk-based products [32]. Other microorganisms associated with fermented foods in Nigeria include yeasts, moulds, and *Bacillus* species [20,21,25–28]. Fermented foods are vital components of the global human diet and are especially significant in regions like Africa, including Nigeria (Figure 1), where people use fermented matrices to prepare complementary foods for infants and young children [20,21,25–28].

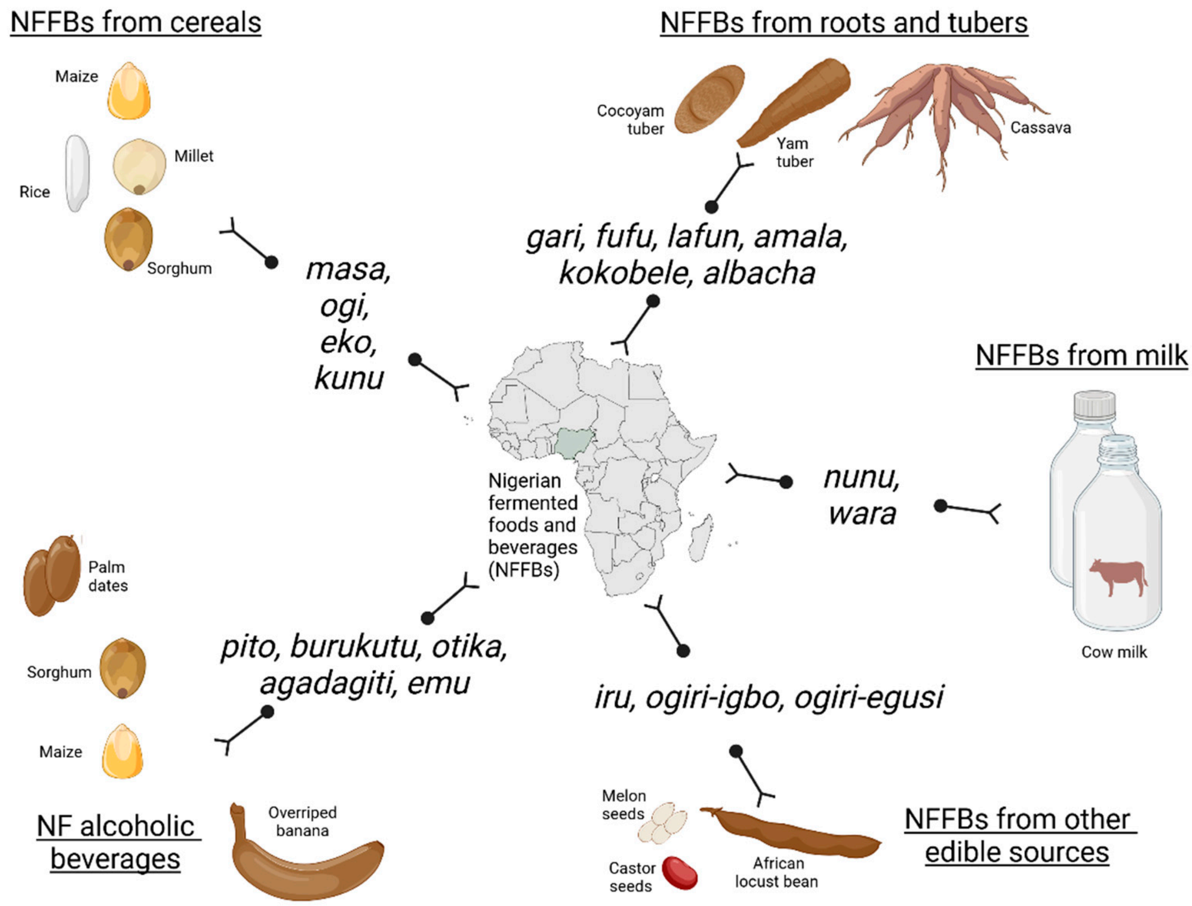

Figure 1. General overview of the diversity of traditional Nigerian fermented foods, associating each product with the principal categories of raw materials used in the preparation. The image was created using BioRender.com (accessed on 6 January 2025).

In the broader context, development involves overcoming natural challenges, equipping citizens to succeed with limited resources, eradicating poverty, ignorance, and disease, and enabling a nation to live with dignity. In Nigeria, fermented foods contribute significantly to the national economy by addressing malnutrition, poverty, disease, and hunger [33]. They also enhance food security, sustainable development, and economic growth by creating job opportunities, empowering unemployed women, scaling up traditional food processing methods, and distributing the resulting products [34]. Fermented foods are a rich source of nutrients due to the 'pre-digestion' of food substrates during fermentation. This process increases the bioavailability of associated nutrients and can even eliminate allergens and antinutritional substances [18]. LAB isolated from traditional fermented foods has demonstrated probiotic properties, including hypolipidemic, hepatoprotective, and antibacterial effects. They have also proven effective as metal chelators in treating gastroenteritis in humans and animals [23].

2.1. Nigerian Fermented Foods and Beverages from Cereals

2.1.1. *Masa*

The cereal used for this fermented food, also known as *waina*, is rice, sorghum, maize, or millet. Depending on the substrate used to make the snack, there are several distinct kinds of masa, including *masa shinkafa*, *masa masara*, *masa gero*, and *masa dawa*. An excellent *masa* is brown and rounded in shape, and it should have a smooth surface [35]. *Masa* has a shelf life of about four to five days and is widely consumed in the northern and south-western parts of Nigeria. In order to improve the organoleptic properties and nutritional quality of the food, peanuts, soybean flour, or cowpeas are sometimes added to the rice flour [36]. The rice is initially soaked for 8 to 12 h, then washed and milled together with already precooked rice while diluting the mixture with water to control the texture and thickness. Yeast is added and kept in a cool place for 5–12 h. After this phase, the fermented product is fried in batches with oil in a pan till it turns golden brown [37,38]. The organisms associated with the fermentation of *masa* are *Lactiplantibacillus plantarum*, *Pediococcus acidilactici*, *Saccharomyces cerevisiae*, *Fructilactobacillus sanfranciscens*, *Limosilactobacillus pontis*, *Limosilactobacillus fermentum*, *Limosilactobacillus frumenti*, and *Levilactobacillus brevis* [37,38].

2.1.2. *Ogi*

Ogi, also known as *akamu* or *pap*, is a traditional fermented cereal-based food widely consumed in the western and northern regions of Nigeria. It is particularly popular as a weaning food for babies. Maize serves as the primary staple for its preparation, although sorghum or a combination of maize and sorghum is also used. The preparation process begins with steeping maize in water for 48 to 72 h, during which fermentation occurs. The fermented maize is then wet-milled and sieved to remove the fibrous tissue. The resulting filtrate is left to settle, after which the excess water is decanted. The sediment, a pure starch called *ogi*, is collected and can be stored in a cool place. For consumption, *ogi* is boiled to form a thick gruel [21] (detailed flow chart in Figure S1). *Cephalosporium* and *Fusarium* are responsible for the fermentation within the first 24 h, after which organisms such as *L. plantarum*, *Leuconostoc mesenteroides*, *S. cerevisiae*, *Rhodotorula* spp., and *Candida mycoderma* take over the fermentation process and still present during wet milling of the corn [21]. Recent studies have found some other organisms associated with *ogi* fermentation are: *L. fermentum*, *Lentilactibacillus buchneri*, *Lacticaseibacillus pantheris*, *Paucilactobacillus vaccinostercus*, *Pediococcus acidilactici*, *Pediococcus pentasaceus*, *Corynebacterium* spp., *Aerobacter* spp., *Candida krusei*, *Candida tropicalis*, *Geotrichum candidum*, *Geotrichum fermentum*, *Clavispora lusitaniae*, *Aspergillus* spp., *Penicillium* spp., *Cephalosporium* spp., *Fusarium* spp., and *Candida mycoderma* [21,39].

2.1.3. *Eko*

Eko is a local gel-like fermented starchy dish made from maize (*Zea mays*), though millet and sorghum can also be used as raw materials. The colour of the food is determined by the cereal used; maize is cream to glassy white, sorghum is light brown, and millet is grey to greenish. It is known by various names in different regions, including "eko" (Yoruba), "akasan" (Benin), "komu" (Hausa), and "Agidi" (Ibo). *Eko* has popularity, with acceptance spanning multiple ethnic groups and socioeconomic classes. Its ease of consumption alone or with soup, stew, bean cake (*akara*), and *moi-moi*, as a light meal, especially among post-operative patients and other hospital patients, makes it very popular. The production process is the same as that of *ogi*, but the cooking method differs in that *eko* is cooked longer to gelatinize and form a smooth paste [20,40]. The microorganisms associated with this Nigerian fermented food are *P. acidilactici*, *L. plantarum*, *Lactobacillus acidophilus*, *Leuconostoc* spp., *Streptococcus* spp., and *Bacillus* spp. [40].

2.1.4. *Kunu*

Kunu is a non-alcoholic fermented beverage with a shelf life of 24 hours and is mostly consumed in the northern part of Nigeria [41]. It can be made from many plants such as sorghum, millet, maize, rice, wheat, or *acha*; hence, there are different types of *kunu*, which are *kunu gyada*, *kunu tsamiya*, *kunu akamu*, *kunu baule*, *kunu jiko*, *kunu gayamba*, and *kunu-zaki* which is the most common [41]. The millet is pounded using mortar and pestle in order to release the kernels and eliminate the husk. The kernels are washed and spread on the mat for 8–12 h under the sun, milled into flour, and mixed with a little cold water. The liquid is then poured into hot water and stirred continuously until a paste is formed, which is then left to ferment for 1–3 days. The milled flour can also be made into a watery gruel known as *kunu-zaki*. Organisms that have been associated with the fermentation of *kunu* are *L. plantarum*, *Lactiplantibacillus pentosus*, *L. fermentum*, *L. mesenteroides*, *Candida mycoderma*, *and S. cerevisae* [41].

2.2. Nigerian Fermented Foods and Beverages from Plant Roots and Tubers

2.2.1. *Gari*

Gari, also known as cassava flakes, is a popular food consumed across Nigeria, especially in the Southern regions. Renowned for its sour taste, gari is processed locally from cassava tubers into creamy-white granular flour. It can be consumed directly by adding water to the flakes or prepared as a paste with hot water and served alongside various homemade soups [42]. Nigeria, the world's leading producer of cassava, cultivates over 40 varieties of the crop. However, consuming raw cassava tubers without fermentation poses significant health risks due to the presence of hydrogen cyanide [42]. The processing of *gari* begins by peeling the outer layer of cassava tubers to expose the inner white portion, which is then thoroughly washed and milled. The milled cassava is placed in a sack and left for 4–7 days to ferment. Excess water is extracted by applying pressure to the sack with a heavy object for 8–12 h. The fermented mash is then sieved and dry-roasted in an iron pan, with continuous stirring, until fully dried [43] (detailed flow chart in Figure S2). Some of the predominant microorganisms associated with the fermentation of *gari* are *Corynebacterium manihot* which breaks down the starch to acid, *L. mesenteroides*, *L. plantarum*, *Bacillus subtilis*, and *Candida krusei* produces linamarase, which breaks down linamarin and removes the cyanide in the gari. Some other organisms associated with the fermentation of *gari* from recent studies are *Carynebacterium manihot*, *Geotrichum candidum*, *L. plantarum ULAG11. L. plantarum ULAG24*, *L. plantarum*, *L. fermentum*, *S. cerevisiae*, *Candida krusei*, *Corynebacterium* spp., *Acetobacter* spp., *Aspergillus niger*, *Rhodotorula* spp., *Penicillium* spp., *Leuconostoc* spp., and *Streptococcus* spp. [24,42].

2.2.2. *Fufu*

Fufu is a traditional fermented food widely consumed in the eastern and western regions of Nigeria. Although it is also made from cassava, its processing method differs significantly from that of gari. The preparation begins with peeling and washing cassava tubers, which are then cut into thick chunks, approximately 20 cm long, and soaked in water within a large plastic container for 3–5 days [24]. The tubers soften and ferment during this period, releasing the toxic hydrogen cyanide. The softened cassava tubers are next fragmented into clean water, sieved to remove fibrous material, and allowed to settle for one to two hours. The water is then decanted, and the sediment is packed into a sack. A heavy object is placed on the sack to extract excess water. The resulting cassava mash is cooked in boiling water for 30–40 min and then pounded to form a smooth paste. This paste, known as fufu, is typically eaten with soup or stew [20,43]. The retting process begins as soon as the cassava tubers are steeped in water and is facilitated primarily by *Bacillus* spp. These bacteria break down the pectin in the cassava root's cell walls, a crucial step in softening the tubers and enabling their fermentation [44]. *Schizophyllum commune* (*MK 431022*), *Aspergillus oryzae* (*MK434151*), *Aspergillus sydowii* (*MK434152*), *Bacillus* spp. (*MK450345*), *Bacillus* spp. (*MK 449018*), *Lactobacillus*, *Weisssela*, *Leuconostoc*, *Lactococcus*, *Bacillus*, *Clostridium*, *Staphylococcus*, *Serratia*, *Acinetobacter*, *Neurospora crassa*, *Aspergillus fumigatus*, *Saccharomyces* spp., and *Raoutella* are the microorganisms associated with fermentation of *fufu* [27,45,46].

2.2.3. *Lafun*

Lafun is a fermented cassava-based dish processed into a white, powdery form. It is a staple food widely consumed in the south-western region of Nigeria, particularly among the Yoruba people. The preparation involves a submerged fermentation process similar to that used in making *fufu*. Cassava tubers are selected, peeled, washed, and cut into cubes before being soaked in water for 2–3 days to ferment. After fermentation, the cassava is sun-dried and milled into fine flour. The flour is prepared as a dough by stirring it into boiling water [25]. *Lafun* is typically served with indigenous soups such as *gbegiri* and *ewedu*, which are particularly popular among the Oyo tribe in south-western Nigeria (6). Microorganisms that play an important role in the fermentation of *lafun* are *Bacillus* spp., *Corynebacterium* spp., *Candida* spp., and lactobacilli [47]. A recent study reveals other microorganisms associated with *lafun* fermentation; *L. brevis*, *L. plantarum*, *L. mesenteroides*, *Secundilactobacillus collinoides*, and *L. lactis* [48].

2.2.4. *Amala*

Amala, a popular dish among the *Yoruba* people of western Nigeria, is made from yam tubers (*Dioscorea* spp.). The preparation process involves peeling, washing, and slicing the yam tubers into small portions, which are then spread out on a tray or mat to ferment and dry in the sun for three days. Once dried, the yam is milled into flour and cooked in hot water while being continuously stirred until it forms a thick, dark brown paste [31]. *Amala*'s distinctive flavour and dark colour result from enzymatic and non-enzymatic browning reactions, as well as the presence of polyphenols in the yam. However, these characteristics can be unappealing to some people. To reduce or completely prevent the browning reactions, the yam slices can be blanched in boiling water for two minutes before fermentation or drying. This process inactivates the enzymes responsible for the browning. The microorganisms associated with the fermentation of *amala* are lactobacilli, *Weissella* spp., *Leuconostoc* spp., *Lactococcus* spp., *Bacillus subtilis* (MK448227), *Bacillus pumilus* (MK446418), *Aspergillus flavus* (MK433604), *Aspergillus niger* (MK430926)., *Fusarium oxysporum*, *Rhizopus* spp., and *Neurospora* spp. [46,49–51].

2.2.5. *Kokobele*

Kokobele is a fermented Nigerian food widely consumed in Ondo State in western Nigeria. It is traditionally produced from Cocoyam tuber (*Xanthosoma sagittifolium*, *Colocasia esculenta*). The production process involves peeling, washing, slicing, and steeping the cocoyam tubers in water for 2–3 days, during which fermentation takes place. After this, the fermenting liquid is discarded, and the cocoyam is sundried for 3–5 days and then milled into powdery form. The *kokobele* flour is boiled in water with the addition of pepper, fish, palm oil, tomatoes, and spices [24]. The microorganisms associated with the fermentation of this Nigerian food are *Aspergillus niger*, lactobacilli, and *Streptococcus* spp. [8,34].

2.2.6. *Abacha*

Abacha, a popular snack in Nigeria's south-east, is made from cassava tuber. The cassava is harvested, peeled, washed, and then boiled in water for an hour before slicing into tiny long slices. After this, it is soaked in water for 1–2 days, changing the water twice to remove cyanogen, then cleaned twice or thrice and eaten with coconut or palm kernel/groundnuts [44]. Some of the microorganisms associated with the fermentation of *abacha* are lactobacilli, *Saccharomyces* spp., *Bacillus* spp., and *Candida* spp. [52].

2.3. Nigerian Dairy Fermented Foods and Beverages

2.3.1. *Nunu* (nono)

Nunu is a yoghurt-like, naturally fermented milk drink made from cow's milk and is commonly consumed within 4 to 5 days in northern Nigeria. However, if stored in a refrigerator at 4 °C, it can last for several weeks [36]. The process of making *nunu* starts with fresh cow's milk, which is sieved to remove impurities. The milk is then left to ferment naturally for 18 to 24 h at room temperatures between 25 °C and 35 °C. Once the fermentation is complete, the excess whey is drained off, and the milk is stirred to achieve the final product (detailed flow chart in Figure S3). In Nigeria, the *Fulani* people are known for producing *nunu* at home on a small scale. They usually rely on traditional methods, either fermenting raw or boiled milk naturally or using a back-slopping technique—where a portion of an already fermented batch is used to start the fermentation of a new one [53]. The microorganisms associated with the fermentation of *nunu* are LAB (*L. fermentum*, *L. brevis*, *L. plantarum*, *L. bulgaricus*, *L. acidophilus*, *L. mesenteriodes*, *S. thermophilus*, *L. lactic*, *Pediococcus cerevisiae*), and yeast (*Candida parapsilosis*, *Candida tropicalis*, *Candida rugosa*, *Galactomyces geotrichum*, *Pichia kudrivzevil*, *S. cerevisiae*) [54,55].

2.3.2. *Wara*

Wara is a Nigerian unripe soft cheese curd commonly consumed in the northern part of the country. It is locally processed using fresh cow milk curdled with juice extract of Sodom apple leaves (*Calostropis procera*). The liquid part (water and whey) is removed from the solid part (protein and fats), which is pressed together [44]. Although *wara* has a shelf life of 24 h and can be eaten as snacks either raw or fried, it has a plethora of nutrients such as protein, fat, small amount of carbohydrates, minerals (calcium, vitamin B12, phosphorus, selenium, sodium, zinc) and vitamins (riboflavin, vitamins A, K2, and B12), hence, suitable for the growth of microorganisms [56]. According to [57], organisms isolated from *wara* are able to regulate the microbes in the gut. LAB (lactobacilli, *Lactococcus* spp., *Leuconostoc* spp., and *Pediococcus* spp.) are the dominant microorganisms in *wara.* Also, Enterobacteria and Staphylococci have been isolated from this fermented food [58].

2.4. Nigerian Fermented Foods from Other Edible Sources

2.4.1. *Iru*

Iru, also known as *dawadawa*, is a fermented food condiment from the African locust bean (*Parkia biglobosa*), which is widely consumed in all parts of Nigeria to spice up soups and other cuisines. Naturally, the African locust bean cannot be consumed due to the presence of high anti-nutrients; however, it is processed into a soft, tasty, and delicious condiment with an enriched vitamin and great flavour [59]. The production process involves boiling the locust bean seeds for 24–48 h to make the hard seed coat soft, which are then removed by finger pressure, hence releasing the cotyledons. The cotyledon is heated again for two hours, excess water is decanted, and the cotyledons are spread in a blanched banana leaves-lined basket. Many layers of banana leaves are used to cover up the seed in the basket and left for 2–3 days for fermentation to take place. Wood ash is sometimes added and sundried for two days before consumption [20] (detailed flow chart in Figure S4). The major microbes associated with this condiment are *B. subtilis*, *Bacillus licheniformis*, *Bacillus firmus*, *Bacillus megaterium*, and *S. epidermis* [60].

2.4.2. *Ogiri-Igbo/Ogiri-Agbor/Ogiri-Isi*

Ogiri-Igbo is used in Nigeria as a condiment in stews or soups. It is locally produced from castor seeds (*Ricinus communis*), which are high in oil and protein. These seeds cannot be eaten raw due to their toxic constituents like ricin and trypsin inhibitors; however, when fermented, they detoxify into a seasoning agent. The production process of *Ogiri-Igbo* includes removing the seeds' outer layer, then wrapping them in balanced plantain leaves and boiling them for 6–9 h. After this, it is left to ferment for 4–5 days; the seeds are mixed with ash from burnt palm leaves and milled into a paste. It is further wrapped again and left for another three days near the fire. The microorganisms associated with the fermentation of *Ogiri-Igbo* are *L. acidophilus*, *L. fermentum*, *L. plantarum*, *Enterococcus* spp., *B. subtilis*, *B. megaterium*, *B. firmus*, *Proteus* sp., *Alcaligenes* spp., and *P. aeroginosa* [60,61].

2.4.3. *Ogiri Egusi*

Ogiri egusi, traditionally produced from melon seeds (*Cucumeropsis manni*) using an uncontrolled solid-state fermentation method, is a condiment widely consumed in the south-western part of Nigeria, especially among the *Ijebu* and *Ondo* tribes of the country [20]. The local production process involves dehulling and boiling the melon seeds for 3–4 h, after which it is mashed, wrapped tightly in banana leaves, and left to ferment for 5–7 days. The fermented mashed melon is then placed in an earthen well pot and covered with jute sacks to keep the oxygen tension low. Before it can be used in cooking, the fermenting mashed melon is covered in leaves, placed on a wire mesh, smoked over charcoal heat at a distance for about two hours, and pulverized [59]. The predominant microorganisms involved in the fermentation of *ogiri egusi* are *Bacillus* spp., lactobacilli, *Corynebacterium* spp., and *Saccharomyces* [62].

2.5. Nigerian Fermented Alcoholic Beverages

2.5.1. *Pito*

Pito is a cereal-based fermented alcoholic beverage with a bitter taste, made locally from a blend of maize and sorghum grains. It is a dark brown liquid consumed by all age groups and widely sold among middle-aged women in various markets in Nigeria [20,59]. The local method of production involves steeping the grains in water for two days; the next stage of the process is malting for five days, after which the grains are wet-milled and then boiled for 12 h. It is allowed to cool and then filtered. The filtrate is left to ferment overnight; previously brewed *pito* is added and allowed to ferment overnight again [20]. It contains lactic acid, sugars, and amino acids with a 3% alcohol content. The microorganisms associated with the fermentation of *pito* are *Pediococcus halophylus*, *L. plantarum*, *L. casei*, *S. cerevisae*, *Candida utilis*, *Rhodotorula glutinis*, *Candida pelliculosa*, *Cryptococcus albidus*, and *Geotrichum candidum* [41].

2.5.2. *Burukutu*

Burukutu, which is usually consumed in the northern part of Nigeria, is a fermented alcoholic beverage produced from malted sorghum [6]. The first stage of the production of *burukutu* is the steeping of sorghum grains in water overnight, after which it is malted and allowed to germinate for 4–5 days. The malted grains are sun-dried for two days and then milled to powdery form. An adjunct (usually *gari*) and water are added to it, and the mixture is boiled for 12 h, filtered using a sieve, then allowed to cool and left to ferment for 48 h [41] (detailed flow chart in Figure S5). The acetic acid content in a fully matured *burukutu* beer varies between 0.4 and 0.6%, while the pH of the fermenting mixture decreases from about 6.0 to 4.2 within 24 h of fermentation and further decreases to 3.7 after two days [40]. The microorganisms associated with the fermentation of *burukutu* are lactobacilli., *L. mesenteroides*, *Acetobacter* spp., *S. cerevisiae*, *Saccharomyces chavelieri*, *Rhodotorula glutinis*, *Cryptococcus aldidis*, and *Candida* spp. [41,63].

2.5.3. *Otika*

Otika, drunk in some parts of Nigeria, is an alcoholic beverage locally made from sorghum malt. It is brewed traditionally by malting grains of the red variety of sorghum, ground to powder using mortar and pestle, after which water is added to the flour and boiled for 3 h, cooled, and filtered. The filtrate is left at room temperature to ferment for three days or inoculated with previously fermented liquor [64]. The fermented beverage is filtered again using a sieve cloth before consumption. Some of the microorganisms associated with the fermentation of *otika* are *L. plantarum*, *L. fermentum*, *L. mesenteroides*, and *S. cerevisiae* [64].

2.5.4. *Agadagidi*

Agadagidi, a cloudy, effervescent, sweet-sour-tasting alcoholic drink, is a local beverage commonly consumed in the southern part of Nigeria [6]. It is produced from overripe plantain/banana, and the process includes peeling, slicing, and soaking the plantain in an adequate quantity of water for 3–5 days; then, the mixture is sieved, and the filtrate is served as *agadagidi* [20]. The dominant microorganisms involved in the fermentation of this traditional beverage are *L. plantarum*, *L. mesenteroides*, *B. subtilis*, *S. cerevisiae*, *A. niger* and *C. utilis* [65].

2.5.5. *Emu* (Palm Wine)

Palm wine which is also called *Emu* in *Yoruba*, *Nkwu ocha* in *Igbo*, and *Bammi* in *Hausa* is a whitish alcoholic fermented beverage obtained from the sap of Raphia palm and left to ferment for a few hours. It has a shelf life of 24 h and is consumed widely in all parts of Nigeria [66]. The microorganisms associated with palm wine fermentation are *Lactobacillus* spp., *Micrococcus* spp., *Streptococcus* spp., *Leuconostoc* spp. *S. cerevisiae*, *Candida ethanolica*, and *Pichia* spp. [66].

3. Nigerian Fermented Products: A Transdisciplinary Point of View

Scientific studies have been concentrating more on these conventional techniques in recent years in an effort to comprehend, improve, and broaden their uses. Modern scientific analysis combined with traditional knowledge has facilitated the creation of new technologies, enhanced food security, and raised awareness of the possible health advantages of fermented foods on a global scale [67]. Generation after generation has carried on with traditional fermenting methods that have their roots in environmental and cultural conditions. Nigerian *ogi* and *fufu*, Korean *kimchi*, European sauerkraut, and Japanese *natto* are a few examples. These techniques frequently rely on spontaneous fermentation, in which starter cultures are not necessary because the process is driven by native microbial communities [15]. In order to preserve this priceless knowledge, scientific study has started methodically recording these traditions. For instance, Oyewole and Isah [22] investigated traditional fermentation methods in Nigeria, highlighting their contribution to the production of reasonably priced and nutrient-dense foods while identifying the important microbes at play. These investigations guarantee that, even in the face of modernization, traditional practices are not forgotten. Scientists are now able to detect and describe the microbial communities that drive conventional fermentation, thanks to the development of sophisticated molecular methods like metagenomics and next-generation sequencing (NGS). For example, research on some Nigerian fermented foods has identified a variety of lactic acid bacteria (LAB) species that contribute to the nutritional qualities, safety, and shelf life of a coconut-fermented drink [68]. These discoveries make it possible to create starter cultures and choose particular microbial strains for regulated fermentations.

Although they have a longer shelf life and are more nutritious, fermented foods do have some microbial dangers. Their safety may be jeopardized by industrial contamination, unsuitable fermentation conditions, and the generation of hazardous by-products. Poor hygiene, dirty equipment, or contaminated raw materials can all lead to contamination from pathogens like *Salmonella*, *Listeria monocytogenes*, or *Escherichia coli*. Inadequate acidity or unregulated conditions during fermentation can foster the growth of dangerous microbes [25]. Adesemoye et al. [17] reported the presence of some *Enterobacter* and *Aspergillus* spp. in *gari* (a fermented food from cassava), Adekoya et al. [69] also reported the dominance of *Sphingomonas paucimobilis* and *Escherichia coli* some selected foods in Nigeria and South Africa; Adekoya et al., [70] reported the dominance of *Aspergillus flavus* and the presence of *Fusarium verticillioides* in some selected fermented foods in Nigeria; Adedeji et al. [71] found pathogenic species such as *Alcaligenes faecalis*, *Bacillus anthracis*, *Proteus mirabilis* and *Staphylococcus sciuri* subsp. *sciuri* occurred in some samples of *iru* and *ogiri*. Maintaining hygiene, employing strong starting cultures, keeping an eye on fermentation parameters (such as pH and temperature), and screening for harmful substances are all crucial steps in ensuring the safety of fermented foods in Nigeria.

At the moment, Nigeria's food safety regulatory structure is a multi-agency sectoral food safety control system. In Nigeria, the federal, state, and municipal governments all share responsibility for enforcing food safety laws. The Ministries of Health, Environment, Science and Technology, Agriculture, and Trade and Investment are the main federal agencies in charge of promoting food safety. Notable organizations under these ministries include the Nigerian Institute of Food Science and Technology (NIFST), the Nigeria Customs Service, the National Biotechnology Development Agency (NABDA), the Standards Organization of Nigeria (SON), the National Agricultural Seeds Council, the Consumer Protection Council, the National Biosafety Management Agency, and the National Agency for Food Drug Administration and Control (NAFDAC). One of the Federal Ministry of Health's agencies, NAFDAC, is in charge of overseeing and managing the usage, sale, and distribution of food. Similarly, the Federal Ministry of Environment's specific job is to ensure that organic pollutants, environmental pollution, waste disposal, and environmental food contaminants are properly controlled [72]. Nigerian food safety issues have prompted the passage of several laws, including the NAFDAC Act 57. The NAFDAC Act 57 has emerged as the most important food safety law. In this Act, NAFDAC establishes guidelines for the monitoring of food irradiation, additives, marketing of food products for infants and young children, pesticide registration, fortification, cocoa, milk, and dairy products, and pre-packaged food (labelling) [73]. Regretfully, traceability requirements for food handlers and food business operators, especially the production of fermented foods in Nigeria, were not covered by any laws or regulations under the NAFDAC Act.

4. LAB Diversity in Nigerian Fermented Foods

Table 1 reveals the several types of LAB associated with the fermentation of Nigerian traditional foods. The common LAB found in most fermented foods is *L. plantarum*, which is closely followed by *Leuconostoc* spp. These common species of bacteria in traditional Nigerian fermented foods have been revealed to produce one or more vitamins, as discussed in the next section of this article.

Table 1. Several LAB are associated with traditional Nigerian fermented foods.

Substrate	Product	Commonly Consumed	Microorganisms Associated	References
Cereals				
Maize (*Zea mays*) or Rice (*Oryza sativa*) Millet (*Pennisetum typhoideum*) Sorghum (Sorghum vulgare)	Massa	Northern and western parts of Nigeria	*Lactiplantibacillus plantarum*, *Pediococcus acidilactici*, *Fructilactobacillus sanfranciscensis*, *Limosilactobacillus pontis*, *Limosilactobacillus fermentum*, *Limosilactobacillus frumenti*, and *Levilactobacillus brevis*	[37,38]
Maize or Millet or Sorghum	*Ogi*	South and west of Nigeria	*Limosilactobacillus fermentum*, *Lentilactobacillus buchneri*, *Lactiplantibacillus plantarum*, *Leuconostoc mesenteroides*, *Lacticaseibacillus pantheris*, *Paucilactobacillus vaccinostercus*, *Pediococcus acidilactici*, and *Pediococcus pentasaceus*	[39,47,74]
Maize or Sorghum	Eko "eko" (Yoruba), "akasan" (Benin), "komu" (Hausa), and "Agidi" (Ibo).	All ethnic groups in Nigeria	*Lactiplantibacillus plantarum Pediococcus acidolactic*, *Lactobacillus acidophilus*, *Leuconostoc* spp. and *Streptococcus* spp.	[40]
Roots and Tubers				
Cassava Tuber (*Manihot esculenta*)	*Gari*	Southern and western parts of Nigeria	*Lactiplantibacillus plantarum* ULAG11. *Lactiplantibacillus plantarum* ULAG24, *Limosilactobacillus fermentum*, *Leuconostoc* spp. and *Streptococcus* spp.	[24,42]
Cassava Tuber	*Fufu*	Eastern and western parts of Nigeria	Lactobacilli, *Weisssela* spp., *Leuconostoc* spp., *Lactococcus* spp.	[45,46,49]
Cassava Tuber	*Lafun*	South-western part of Nigeria	*Levilactobacillus brevis*, *Lactiplantibacillus plantarum*, *Leuconostoc mesenteroides*, *Secundilactobacillus collinoides*, and *Lactococcus lactis*.	[47,48]

Table 1. *Cont.*

Substrate	Product	Commonly Consumed	Microorganisms Associated	References
Yam Tuber (*Dioscorea rotundata*)	*Amala*	South-western part of Nigeria	Lactobacilli, *Weissella* spp., *Leucostoc* spp., *Lactococcus* spp.	[45,49–51]
Cocoyam Tuber (*Xanthosoma sagittifolium; Colocasia esculenta*)	*Kokobele*	South-western (Ondo state) part of Nigeria	Lactobacilli, and *Streptococcus* spp.	[24]
Cassava Tuber	*Abacha*	South-Eastern part of Nigeria	Lactobacilli	[52]
Dairy				
Cow Milk	*Nunu*	Northern part of Nigeria	*Limosilactobacillus fermentum*, *Levilactobacillus brevis*, *Lactiplantibacillus plantarum*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Lactobacillus acidophilus*, *Leuconostoc mesenteroides*, *Streptococcus. thermophilus*, and *Lactococcus lactis*	[54]
Cow Milk	*Wara*	Northern part	lactobacilli, *Lactococcus* spp., *Leuconostoc* spp., and *Pediococcus* spp.	[58]
Legumes and Seeds				
Castor Seeds (*Ricinus Communis*)	*Ogiri Igbo*	Southern part of Nigeria	*Lactobacillus acidophilus*, *Limosilactobacillus fermentum*, and *Lactiplantibacillus plantarum*	[42,43]
Melon Seed	*Ogiri-egunsi*	South-western part of Nigeria	Lactobacilli	[8,44]
Fluted Pumpkin Bean Seeds (*Telfairiax occidentalis*)	*Ogiri-ugu/ogiri nwan*	Southern part of Nigeria	*Lactobacillus acidophilus*, *Limosilactobacillus fermentum* and *Lactiplantibacillus plantarum*	[8,43]
Cereals				
Maize or Sorghum	*Pito*	Mid-western part of Nigeria	*Lactiplantibacillus plantarum* and *Lacticaseibacillus casei*	[41,63]
Sorghum	*Burukutu*	Northern part	Lactobacilli and *Leuconostoc mesenteroides*,	[63]

Table 1. *Cont.*

Substrate	Product	Commonly Consumed	Microorganisms Associated	References
Sorghum	*Otika*	South-western part of Nigeria	*Lactiplantibacillus plantarum*, *Limosilactobacullus fermentum* and *Leuconostoc mesenteroides*	[64]
Maize or Rice or Millet or or Sorghum or Wheat or Acha	*Kunu*	Northern part of Nigeria	*Lactiplantibacillus plantarum*, *Lactiplantibacillus pentosus*, *Limosilactobacullus fermentum* and *Leuconostoc mesenteroides*	[41]
Overripe Plantain/Banana	*Agadagidi*	South-western part of Nigeria	*Lactiplantibacillus plantarum* and *Leuconostoc mesenteriodes*	[65]
Palm Tree	*Emu*	All parts of Nigeria	Lactobacilli, *Micrococcus* spp., *Streptococcus* spp., *Leuconostoc* spp.	[66]

This broad bacterial biodiversity represents a significant panel of bio-resources with numerous potentials in terms of improving the safety and overall quality of production through the development of tailored fermentation processes, the design of starter cultures, and the development of biotechnological solutions.

5. Alleviating Malnutrition (Hidden Hunger) Using LAB from Fermented Foods

Selected lactic acid bacteria strains (including some probiotic strains) isolated from fermented foods have been shown to increase the quantity, availability and/or absorbability of macro- and, mainly, micro-nutrients such as B vitamins, vitamin A, zinc, and iron as discussed below [75]. The production of B vitamins received particular attention in the scientific literature, demonstrating the potential of LAB in alleviating malnutrition in developing countries [76,77]. For this reason, an extensive overview of this topic is dedicated to this aspect.

5.1. Alleviating B Vitamins Malnutrition Using LAB from Fermented Foods

5.1.1. Folate

Folate, also known as vitamin B9, is an essential cofactor in various metabolic processes, particularly those involving one-carbon transfer reactions. These processes are critical for DNA replication, repair, and methylation, as well as for the synthesis of nucleic acids, certain amino acids, and vitamins. A lack of folate in the diet can have serious health consequences, including neural tube defects and an increased risk of colon cancer and cardiovascular diseases [78]. Research by [79] revealed that a novel lactic acid bacterium from the *Weissella* genus, isolated from fermented fish, produces both antibacterial compounds and natural folate. Among the strains studied, *Weissella cibaria* showed the highest folate production, reaching 4.14 µg/mL, suggesting its potential for use in enhancing the nutritional value of functional foods. Other lactic acid bacteria, such as species from *Lactococcus*, lactobacilli, *Propionibacterium*, *Bifidobacterium*, *Streptococcus thermophilus*, and *Leuconostoc*, have also been found to naturally produce folate in concentrations ranging from 0.08 µg/mL to 43 µg/mL in various fermented foods [80–84]. One of the highest folate concentrations reported came from amaranth sourdough fermented with *Lactiplantibacillus plantarum* strains CRL 2106 and CRL 2107, highlighting the potential of lactic acid bacteria (LAB) to boost the nutritional and functional properties of foods made from pseudocereals [80,85]. Similarly, when *Lactobacillus rhamnosus* LGG and *Streptococcus thermophilus* TH-4 were used as starter cultures in fermentation soymilk, they produced significant amounts of folate. Interestingly, the addition of passion fruit by-products and fructooligosaccharides during fermentation further enhanced folate production by these strains [84]. The ability of certain LAB strains to increase folate levels in soymilk is linked to the presence of fructooligosaccharides and passion fruit by-products, which act as fermentation enhancers [84]. Likewise, *L. plantarum* CRL 2106 and CRL 2107 were found to produce high folate concentrations in amaranth sourdough, further demonstrating the role of LAB in improving the nutritional profile of pseudocereal-based products [80]. A recent study showed that combining five *Streptococcus thermophilus* strains with *L. plantarum* 16cv yielded the highest folate levels in bio-enriched fermented milk. This product was created under controlled conditions (pH 6.0, 42 °C, 70 rpm, for 24 h) and demonstrated both high folate bioavailability and positive effects on gut health in a mouse model [86]. Another interesting finding came from fermenting a blend of cauliflower and white beans with *L. plantarum* strains, which significantly increased the folate content of the mixture [87]. While most of these studies were conducted in developed countries, there is strong potential to replicate this research in Nigeria, where incorporating folate-producing LAB into local fermented foods could help address nutritional deficiencies. The species of LAB investigated for the production of natural folate whose strains were further used as a starter culture for the production of folate-enriched foods could also be found in fermented food in Nigeria, such as *massa*, *ogi*, *eko*, *gari*, *fufu*, *lafun*, *amala*, *kokobele*, *nunu*, *abacha*, *wara*, *pito*, and *burukutu*. The common LAB species in Nigeria fermented food is *L. plantarum*; hence, they can be screened with other LAB for folate production and used as a starter culture to alleviate folate deficiency in developing countries like Nigeria. Scaling up this intervention will also be highly effective in combating folate deficiency, especially in women of reproductive age and pregnant women.

5.1.2. Riboflavin

Riboflavin (vitamin B2) is an essential nutrient required by all aerobic organisms. It serves as a precursor to two important coenzymes, flavin mononucleotide (FMN), and flavin adenine dinucleotide (FAD), both of which play key roles in metabolism by acting as hydrogen carriers in redox reactions. Riboflavin is crucial for normal cellular function and growth, and a deficiency can lead to several health issues, including vision problems, anaemia, skin disorders, preeclampsia, cardiovascular risks, and impaired brain glucose metabolism [78,88]. Riboflavin-producing lactic acid bacteria (LAB) have been identified in a variety of fermented foods and have shown the potential to naturally enhance the riboflavin content in products such as milk, soymilk, whey, and pseudocereals [88,89]. For example, two naturally occurring strains of *Lactiplantibacillus plantarum*—UNIFGPL104 and UNIFGPL209—were adapted to produce higher levels of riboflavin by exposing them to roseoflavin, a toxic analogue of riboflavin. These modified strains were then used successfully to create riboflavin-enriched bread and pasta [78,90]. In another study, *L. plantarum* M5MA1-B2 was used to ferment a maize-based kefir-like beverage, while *L. plantarum* M9MA1-B2 was used to produce an oat-based kefir-like drink. A 100 g serving of the oat-based kefir-like beverage provided 11.4% of the Recommended Dietary Allowance (RDA) for riboflavin, demonstrating the potential of fermentation to boost the nutritional value of foods [90]. Soymilk, which is already rich in protein and unsaturated fatty acids, can also be transformed into a more nutritious, biofortified product by fermenting it with riboflavin-producing LAB. This process not only enhances the nutritional profile but also improves the taste and texture of the final product, making it more appealing to consumers [78]. A recent in vivo study using a mouse model explored the impact of LAB on increasing the bioavailability of vitamins B2 and B9. The study found that pasta fermented with a combination of *L. plantarum* CRL 2107 and *L. plantarum* CRL 1964 significantly increased riboflavin and folate levels in the blood of mice. Additionally, the mice fed with this fermented pasta showed higher levels of key minerals such as iron, calcium, magnesium, and phosphorus, further highlighting the nutritional benefits of LAB-fermented foods [54]. These findings suggest that LAB from fermented foods could offer a natural alternative to chemical fortification for enhancing the nutritional quality of everyday meals. Notably, various strains of *L. plantarum* have been shown to boost riboflavin levels naturally in fermented foods, and this species is commonly found in many traditional Nigerian fermented products. While there is limited research on riboflavin deficiency in Nigeria, anemia remains a significant public health issue, particularly among pregnant women and women of reproductive age. This highlights the potential for replicating studies on riboflavin-enriched foods in Nigeria and other developing countries, where micronutrient deficiencies remain a pressing health concern [80]. Utilizing riboflavin-producing LAB in local fermented foods could be a practical, sustainable way to improve nutrition and health outcomes in vulnerable populations.

5.1.3. Thiamin

Thiamine, also known as vitamin B1, is crucial in various biochemical and physiological processes essential for human growth and development. It is crucial for the proper functioning of the heart and nervous system and for the metabolism of carbohydrates to release energy. A thiamine deficiency, often caused by inadequate intake or malabsorption, can lead to serious neurological and metabolic disorders, including neuroinflammation, impaired mitochondrial function, disrupted oxidative metabolism, and selective neuronal death [91]. In high-income countries, thiamine intake is largely ensured through the consumption of fortified foods such as wheat flour, breakfast cereals, and infant formula. However, in low-income countries like Nigeria, where food fortification is less common, thiamine deficiency is primarily driven by a lack of dietary diversity and heavy reliance on staple foods that are naturally low in thiamine [92]. Recent research has shown that certain lactic acid bacteria (LAB) can produce significant amounts of thiamine. For instance, *Lactobacillus brevis* CRL2013 and *Streptococcus thermophilus* CRL986 were identified as the most efficient extracellular producers, yielding 3.42 ng/mL and 2.64 ng/mL of thiamine, respectively. Meanwhile, the highest intracellular production was observed in *Lactococcus lactis* ssp. *cremoris* CRL462, with a yield of 4.03 ng/mL. Notably, three LAB strains—*L. brevis* CRL2013, *L. casei* 238, and *L. plantarum* CRL725 demonstrated the ability to produce intracellularly and extracellularly thiamine [93]. Despite these promising findings, there is still a limited number of published studies on the biofortification of fermented foods with thiamine using LAB. Thiamine deficiency remains prevalent in many parts of Asia and Africa, affecting up to one-third of children and women of reproductive age. Diagnosis is often based on clinical suspicion, particularly in cases involving infants, encephalopathy in individuals of any age, and peripheral neuropathy in older children and adults [94]. Several species of LAB that have been shown to produce thiamine—such as *S. thermophilus* and *L. plantarum*—have also been isolated from a variety of traditional Nigerian fermented foods. This suggests that these LAB strains could potentially be used to naturally enhance the thiamine content of local fermented foods, thereby addressing thiamine deficiency in developing countries like Nigeria. Implementing such biofortification strategies could significantly contribute to reducing the prevalence of thiamine deficiency and improving public health outcomes in vulnerable populations.

5.1.4. Cobalamin

The cobalamin family, which includes vitamin B12 (cyanocobalamin), is a group of substances characterized by a corrinoid ring with upper and lower ligands. The top ligand can vary, consisting of an adenosine, methyl, hydroxy, or cyano group. Vitamin B12 is produced exclusively by prokaryotes and plays a critical role in preventing pernicious anaemia in animals [95]. Humans rely on dietary sources like milk, meat, and eggs for their vitamin B12 needs, as our bodies cannot produce it on their own. Despite this, vitamin B12 is essential for maintaining good health. A deficiency can result in serious health conditions, including pernicious anaemia, nerve damage, coronary disease, stroke, and even heart attack [96]. Historically, pernicious anaemia earned its name because of its severe, potentially fatal effects on blood and nerve function. It was once thought to be a condition caused by poor vitamin absorption, primarily affecting older individuals of north European ancestry. However, we now understand that vitamin B12 deficiency is a widespread global issue, often stemming from poor dietary intake, especially among children and women of reproductive age [97]. Alarmingly, vitamin B12 deficiency affects as much as 40% of people in Latin America, 70% in Africa, and 70–80% in South Asia, making it a significant public health challenge worldwide [98]. The main sources of vitamin B12 for humans are microorganisms, either free-living or associated with animal digestive systems, which we access by consuming animal-based foods. Recent studies show that vitamin B12 deficiency is more prevalent in developing countries, such as India, where rates can reach as high as 46%, compared to wealthier nations [97,99]. Interestingly, certain strains of lactic acid bacteria (LAB) have been found to produce vitamin B12. For instance, *Lactobacillus plantarum* (95 μg/L), *Lactobacillus reuteri* (132 μg/L), and *Lactobacillus rhamnosus* (101.7 μg/L) are known cobalamin producers, with *L. reuteri* and *L. rhamnosus* even being used to biofortify soymilk [96,100,101]. This discovery opens up exciting possibilities for addressing vitamin B12 deficiency. Since only a few LAB strains have been identified as cobalamin producers, exploring their use as starter cultures in fermented food production could be a practical way to improve vitamin B12 intake globally. Moreover, *L. plantarum*, commonly found in traditional Nigerian fermented foods, has also been reported to produce vitamin B12 naturally [102]. This raises the need for further research, especially in developing countries like Nigeria, to confirm whether *L. plantarum* or other LAB strains in fermented foods can reliably produce cobalamin. If confirmed, this could provide an affordable and locally adaptable strategy to tackle vitamin B12 deficiency in regions where dietary inadequacies are most severe.

5.1.5. Pyridoxine

Mammals cannot produce pyridoxine, a type of vitamin B6, making it an essential part of their diet. After being absorbed in the intestine, pyridoxine is converted in the liver into its active form, pyridoxal 5′-phosphate (PLP). This active form plays a crucial role as a cofactor for over 140 metabolic processes, especially those related to amino acid metabolism. PLP is particularly important in the production of serotonin (5-hydroxytryptamine, 5-HT), which is linked to mood regulation and anxiety, as well as dopamine (3,4-dihydroxyphenethylamine, DA), which supports hippocampal neurogenesis. Additionally, PLP helps regulate GABA levels in the brain, making it essential for healthy fetal and postnatal development [77]. Studies show that pyridoxine can be effective in treating several neurological conditions, including brain injuries, ischemia, and toxin-induced nerve damage. Moreover, pyridoxine promotes the dimerization of PKM2, which increases glutathione production—a protective mechanism against Parkinson's disease [103]. One promising discovery is the natural production of pyridoxine by *Lactobacillus paracasei* subsp. *tolerans* JCM 1171, a strain isolated from traditional Iranian yoghurt. This strain produces pyridoxine at a remarkable concentration of 1566.17 μg/mL and could be used to fortify new types of fermented foods, offering a potential solution to vitamin B6 deficiency [104]. Although this specific strain has not yet been associated with Nigerian traditional fermented foods, exploring the potential of LAB strains from these foods could lead to significant findings. Identifying LAB capable of producing pyridoxine could provide a practical way to improve dietary intake, helping to combat vitamin B6 deficiency and its related health issues. This approach could be particularly valuable in regions where dietary gaps contribute to widespread deficiencies.

5.1.6. Niacin

The "4 Ds" (dermatitis, dementia, diarrhea, and death) are used to describe the symptoms of pellagra, which is caused by a severe niacin shortage in humans. Human epidemiology implies that niacin deficiency increases cancer risk, notwithstanding the lack of research in this area. Due to the high amounts of tryptophan and nicotinamide produced during the digestion of NAD/NAD(P), fish and meat are excellent sources of NEs (Meyer-Ficca and Kirkland, 2016). Niacin (vitamin B3) has been reported to be produced naturally by an *L. acidophilus* strain KU (522.7 ug mL^{-1}), which was isolated from traditional Iranian yoghurt [104]. This species of LAB has been isolated from Nigerian traditional fermented foods, such as *ogiri-ugu*, *ogiri igbo*, *eko*, *agidi*, and *nunu.* However, other LAB isolated from Nigeria's traditional fermented food should also be screened for the production of niacin and can be used as starter culture for the fermentation of other fermented foods in other to alleviate niacin deficiency.

5.2. The Potential of Alleviating Other Vitamins and Minerals Malnutrition Using LAB from Fermented Foods

The production of B vitamins using specially selected lactic acid bacteria is a very promising application area that deserves extensive coverage. This area is a good model for the overall potential of lactic acid bacteria to improve the overall quality of foods and beverages in developing countries. A positive effect can also be obtained at the level of nutritional attributes connected to macronutrients, in particular, with reference to the proteolysis carried out on proteins associated with the food matrix [105,106]. Other vitamin targets are also potentially affected. Vitamin K deficiency has been linked to intracranial hemorrhage in newborn infants and possible bone fracture resulting from osteoporosis as this vitamin is essential for the formation of γ-carboxyglutamic acid residues in proteins, which binds calcium ions and influences blood coagulation and tissue calcification. *Lactococcus lactis* ssp. *cremoris* YIT 2011; *L. lactis* ssp. *cremonis* strain MG1363 and *Leuconostoc lactis* YIT 3001 have been reported to synthesize vitamin K2 (menaquinones) and these strains can be used to reconstitute a novel fermented food in order to alleviate the deficiency of this vitamin [107,108]. LAB from Nigerian traditional fermented foods could also have the potential to produce this vitamin. Thus, this research can be replicated in order to reduce the deficiency of vitamin K and other micronutrients. Carotenoids, which are precursors of vitamin A, have health benefits such as the prevention of cancer and reduction in coronary heart disease risk. *Lactobacillus fermentum* and *L. plantarum* have been reported as producers of carotenoids in which *L. plantarum* synthesized carotenoids in a cereal-fermented food [109]. Finally, lactic acid bacteria have the potential to complex and bioaccumulate metals, a biological phenomenon that may be of interest for biofortifying food matrices in specific metals [110].

6. Conclusions

Fermented foods offer a unique space for beneficial microorganisms to grow, many of which can play a key role in improving human health. Lactic acid bacteria (LAB) are particularly important in food fermentations, helping to boost the quality and nutritional value of foods and drinks. These bacteria, mainly when sourced from traditional fermented foods, can help combat malnutrition by enriching the nutritional content of everyday meals. Nigeria stands out as an excellent example for exploring this idea. The country faces serious challenges with malnutrition, is actively working towards the Sustainable Development Goals (SDGs) of the United Nations, and has a rich variety of traditional fermented foods that are part of daily life. Some of these foods, like *ogi*, *gari*, *fufu*, *lafun*, *kunu-zaki*, *masa*, *wara*, *kobele*, *abacha*, *pito*, and *burukutu*, are essential to the diets of infants and young children, especially as complementary foods during weaning. The review highlights the wide range of microbes, particularly LAB, found in these Nigerian foods. The overview of the microbiodiversity in light of the knowledge about biofortification paths using LAB indicated emerging opportunities to exploit LAB's ability to produce essential vitamins, particularly B vitamins. Using selected LAB strains as starter cultures it would be possible to enrich fermented foods, making them more nutritious naturally. This study supports the LAB from traditional fermented foods as powerful tools in the fight against malnutrition. Preserving the traditions linked to fermentations, studying spontaneous fermentations and specifically enhancing microbial resources represent elements of resilience to support economic, social, and environmental sustainability in developing countries. All the aspects covered in the present review contribute to underlining the relevance of dedicating resources to microbial biotechnology and microbial collections as strategic factors for sustainable progress in these geographical contexts.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/fermentation11020103/s1. Figure S1: Flow chart of *Ogi* production; Figure S2: Flow chart of *Gari* production; Figure S3: Flow chart of *Nunu* production; Figure S4: Flow chart of *Iru* production; Figure S5: Flow chart of *Burukutu* production.

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