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REVIEW

Traditional Fermented Products: Potential Origin for Probiotic Strains

Renata Gomes Caetano[1] · Isabella Bassoto Xavier[1] · Vanessa Feldmann[1] · Inayara Cristina Alves Lacerda[1]

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Abstract

Purpose of Review This review highlights the importance of exploring microorganisms with probiotic potential—mainly lactic acid bacteria and yeasts—which are isolated from traditional fermented products that come from Africa, Asia, and Latin America. We greatly underline the potential these microorganisms have when it comes to conceiving non-dairy foods. After all, these microorganisms resulted in products with greater nutritional value and improved sensory characteristics, such as aroma, texture, and flavor.

Recent Findings Studies indicate that demand for products containing probiotics is increasing in markets as consumers seek healthier options for their diets. In response to this trend, the food industry has strived to produce more fermented products based on cereals, legumes, roots, and tubers so as to serve specific target groups. It is well known that consuming probiotics has several health benefits, including reduced acute inflammation and decreased risk of cardiovascular disease. These benefits occur due to the ability these microorganisms have of reducing cholesterol through the deconjugation of bile salts.

Summary Microorganisms play a fundamental role in our existence, being essential assets in the production of a variety of fermented foods and drinks that are part of our diets. Much research has focused on elucidating the benefits these microorganisms can bestow our health. This study emphasizes the relevance of microorganisms with probiotic potential, which are isolated from various food sources, including cereals, roots, tubers, and vegetables. These sources are of great economic and social importance in African, Asian, and South American countries, as they represent a source of income for thousands of families and small farmers, in addition to comprising the nutritional foundation of these populations. The utilization of these probiotic strains presents a significant economic impact, as it improves the quality and safety of food as well as contributing towards the improvement of human health.

Keywords Potential probiotics · Fermentation · Traditional foods · Yeast · Lactic acid bacteria

Introduction

A wide variety of fermented foods are produced and consumed in different regions of the world [1••]. They are defined as food produced through controlled microbial growth and the enzymatic transformation of major and minor components [2]. Fermented products are important food sources in Asia, Africa, and Latin America due to their sensory properties, high nutritional value, and ease of digestion [3]. Furthermore, these foods can act on the human body, as it is an important vehicle for probiotics [4••].

✉ Inayara Cristina Alves Lacerda
inayarac@farmacia.ufmg.br

1 Department of Food, Faculty of Pharmacy, Federal University of Minas Gerais, Belo Horizonte, MG 31270-901, Brazil

Fermentation is an old food processing method employed throughout the world that emerged with the goal of food conservation. Moreover, it is a part of the cultures of people whose knowledge spans generations. These products serve nutritional sources for many families in which several individuals live on account of the production of these foods [5•]. These fermented foods are produced from local raw materials and develop important products in the overall composition of diets [6], as well as foods with high nutritional value and with more enticing aromas, flavors, and textures [5•]. Fermented foods are produced from a variety of raw materials such as milk, cereals, legumes, roots, fruits, vegetables, meats, and fish [5•]. Africa is one of the continents that rely heavily on fermented foods in order to attain balanced and ideal diets. In Latin America, fermented food has been produced and associated with its tradition since pre-Hispanic times [4••]. Asians consume a variety of vegetables—both domesticated and wild—across different recipes, using indigenous knowledge of bio preservation [7].

A variety of traditional fermented products containing probiotic bacteria are sold in popular establishments in Asia [8]. Among these products, one can highlight fermented soy and vegetables such as cabbage, beet, turnips, cauliflower, green beans, and cucumber [9]. The food found in African culture plays a key role: It is prepared from cereals such as corn, rice, millet, or sorghum. The native population of Latin America produces fermented foods and beverages mainly from maize, rice, and cassava that are important nutritional sources for these communities [10, 11]. Despite the abundance of fermented foods and their microbiological variety, there are still several challenges when it comes to deciphering the real health benefits obtained from the consumption of these products [12].

Preparation, fermentation time, and raw materials differ across the globe [13•]. The fermentation process used to obtain traditional products happens spontaneously and in rustic environments, with a diverse microbiota found in its raw materials and environment (Table 1) [13•, 14]. These fermented foods are also produced via traditional methods which employ pure and mixed cultures of various microorganisms such as lactic acid bacteria, yeasts, and non-lactic acid bacteria and fungi [4••, 8]. Some species of LAB and yeast possess characteristic antibiotic compounds with biotechnological applications. They also have probiotic effects, which result in intestinal modulation, prevention and the treatment of gastrointestinal diseases, hypocholesterolemia effects, and antihypertensive, hypoglycemic, and immunomodulator properties [15••, 16]. To be used in food, these probiotic microorganisms must be able to survive the passage through the digestive tract in order to grow within the intestine. This means that they must either resist gastric fluid and be able to grow in the presence of bile under intestinal conditions, or be consumed in a food vehicle that allows them to survive during the passage through the stomach and exposure to bile (Fig. 1) [17].

Demand for probiotic foods is increasing due to their health benefits and growing consumer preferences. Although most probiotic products are derived from milk, lactose intolerance, milk protein allergy, high cholesterol content, high contents of saturated fatty acids, and vegetarianism limit their consumer population and inspired the idea of developing dairy-free probiotic products [47]. Therefore, non-dairy fermented foods with unique organoleptic properties derived from raw materials (cereals, tubers, legumes, and roots) need to be further explored. The food industry uses probiotic microorganisms isolated predominantly from substrates of animal origin such as dairy fermented food; however, they are also found in non-dairy fermented foods [5•]. Therefore, this review aims to present different microbial strains that have probiotic potential found in non-dairy fermented foods.

Probiotic Potential of Traditional Fermented Food

Microorganisms with probiotic potential are found in traditional fermented foods [4, 7]. Probiotics are defined as live microorganisms that provide health benefits to the host when administered according to specific needs [17, 23, 52, 53]. Strains considered probiotics have various characteristics, including safety and physiological features and technological properties such as antibiotic susceptibility, acid tolerance, bile salt deconjugation, cell surface hydrophobicity, self-aggregation, co-aggregation with pathogens, activity against pathogens, and survival in gastrointestinal conditions which must all be taken into account. In the food matrix, NaCl tolerance, exopolysaccharides, and lipolytic and proteolytic enzyme production should also be considered (Fig. 1) [15••, 54].

In this review, we will introduce some of the main traditional fermented products from Asia, Africa, and Latin America, while highlighting the presence of microbial strains that possess probiotic potential. Among the products described in this study are *gari*, *agbelima*, *lafun*, *fufu*, *jalebi*, *tapuy*, *puba*, *tucupi*, *sour cassava starch*, *calugi*, *yakupa*, *tarubá*, *cauim*, *masato* of *yuca*, *chicha*, *dégué*, *tempe*, among others (Table 1).

Lactic-Acid Bacteria

Products fermented by lactic-acid bacteria (LAB) represent a wide variety of functional foods and can provide probiotic strains. These microorganisms could be attractive for the food industry, mainly for producing gluten-free, lactose-free, and plant-based products [13•]. LABs can produce an active probiotic substance such as BLISs (bacteriocin-like substances)—a cellular complex—that allows the interaction with the host's mucous membranes, modulating the immune system beneficially [5•, 55]. Since they stimulate the interaction between microorganisms and hosts, promoting their survival within the intestine and ensuring intestinal barrier protection through various mechanisms, the adhesion of lactic acid bacteria to epithelial cells and mucosal surfaces has been employed as a potential probiotic marker [26].

Lactobacillus, Lactiplantibacillus, Limosilactobacillus, and *Lacticaseibacillus*

Lactiplantibacillus plantarum stands out among other LABs as one of the microorganisms most frequently found in the vegetable fermentation process. This species is predominant in several products from Africa, such as *gari*, *ogi*, *uji*, *agbelima*, *ting*, *lafun*, and *fufu* [4, 5•, 12, 18, 27]; from Asia,

Table 1 Potential probiotic microrganism in traditional fermented products

	Substrate	Product	Area of production	Potential probiotic microrganism	References
Africa	Maize, sorghum, or millet	Ogi	Nigeria, Benin	*Ped. pentosaceus*, *L. fermentum*, *L. plantarum*, *S. cerevisiae*, *L. casei*, *L. delbrueckii*, *P. kudriavzevii*, *Debaromyces hansenii*	[3, 11, 18–22]
		Uji	East Africa	*L. plantarum*, *L. paracasei*, *L. fermentum*, *Ped. acidilactici*, *Ped. Pentosaceus*	[11, 21, 23]
		Mahewu	South Africa	*L. delbrueckii* subsp. *bulgaricus*, *L. delbrueckii* subsp. *delbrueckii*, *L. brevis*, *Leuconostoc* spp., *L. paracasei*, *L. lactis*	[3, 18, 19, 21, 24, 25]
	Cassava	Agbelima	Ghana	*L. plantarum*, *L. brevis*, *L. fermentum*, *Leuc. mesenteroides*	[18, 21, 26]
		Gari	West Africa	*L. plantarum*, *Leuc. fallax*, *L. fermentum*, *L. brevis*, *Leuc. pseudomesenteroides*, *L. lactis*, *S. cerevisiae*, *P. scutulata*, *Kluyveromyces marxianus*	[3, 18, 19, 21, 26, 27]
		Fufu	Nigeria	*Ped. pentosaceus*, *L. fermentum*, *L. plantarum*, *L. casei*, *L. delbrueckii*, *Leuc. mesenteroides*, *S. cerevisiae*	[18, 20, 24, 26]
		Lafun	Nigeria	*L. fermentum*, *L. plantarum*, *Leuconostoc sp.*, *S. cerevisiae*, *P. scutulata*, *P. kudriavzevii*, *P. rhodanensis*, *K. marxianus*	[18, 23, 26, 28]
	Sorghum	Hussuwa	Sudan	*L. fermentum*, *Ped. acidilactici*, *S. cerevisiae*	[18, 23]
		Ting	Botswana, South Africa	*L. fermentum*, *L. plantarum*	[18]
	Millet, sorghum	Kunu-zaki	Nigeria	*L. fermentum*, *L. casei*, *Ped. pentosaceus*	[18, 20, 24, 29]
	Millet	Dégué	Burkina Faso	*L. gasseri*, *L. fermentum*, *L. brevis*, *L. casei*	[3, 18]
Latin America	Maize, rice	Atole agrio	Mexico	*L. plantarum*, *L. brevis*, *Leuc. pseudomesenteroides*, *Lc. lactis*, *Leuc. pseudomesenteroides*, *Ped. pentosaceus*	[30, 31]
		Chicha	Equador, Argentina, Brazil	*L. plantarum*, *Leuc. lactis*, *Leuc. mesenteroides*, *L. brevis*, *P. acidilactici*, *L. fermentum*, *L. delbrueckii*, *S. cerevisiae*, *P. kluyveri*, *P. kudriavzevii*, *L. paracasei*, *L. casei*	[32–35]
		Champús	Equador	*S. cerevisiase*, *P. fermentans*	[17]
		Pozol	Mexico	*L. plantarum*, *L. casei*, *L. delbrueckii*, *L. fermentum*	[36, 37]
		Calugi	Brazil	*L. plantarum*, *S. cerevisiae*, *P. fermentans*	[38]
	Cassava	Caxiri	Brazil,	*S. cerevisiae*, *Ped. acidilactici*, *L. fermentum*, *P. kluyveri*, *L. fermentum*	[16, 39]
		Tarubá	Brazil	*L. plantarum*, *L. brevis*, *Leuc. lactis*, *Leuc. mesenteroides*	[40]
		Yakupa	Brazil	*L. fermentum*, *L. plantarum*, *S. cerevisiae*, *P. kudriavzevii*	[41]

Table 1 (continued)

	Substrate	Product	Area of production	Potential probiotic microrganism	References
		Sour cassava starch	Brazil	*Lc. lactis*, *L. plantarum*, *Leuc. mesenteroides*, *Leuc. citreum*, *L. fermentum*, *L. brevis*, *Leuc. pseudomesenteroides*, *P. scutulata*	[42–44]
		Puba	Brazil	*L. fermentum*, *L. delbrueckii*, *L. casei*, *L. brevis*, *L. plantarum*	[45]
		Tucupi	Brazil	*L. plantarum*, *L. fermentum*	[46]
	Cassava, rice, peanut, sweet potatoes	Cauim	Brazil	*L. plantarum*, *L. fermentum*, *L. paracasei*, *L. brevis*, *S. cerevisiae*, *P. guilliermondii*	[14, 47, 48•]
	Cassava, sweet potatoes	Masato de yuca	Peru	*L. plantarum*, *L. acidophilus*	[49]
Asia	Rice, glutinous rice, wheat	Idli	India, Sri Lanka	*Leuc. mesenteroides*, *S. cerevisiae*, *D. hansenii*	[4]
		Selroti	India, Himalaia, Nepal, Bhutan	*Leuc. mesenteroides*, *P. pentosaceus*, *S. cerevisiae*, *D. hansenii*	[4]
		Saké	Japan	*S. cerevisiae*, *Leuc. Mesenteroides*	[4]
		Tapuy	Filipinas	*D. hansenii*, *Leuconostoc*	[4, 12]
		Takju	Korea	*S. cerevisiae*	[12]
		Puto	Filipinas	*Leuc. Mesenteroides*	[12]
		Kha nhom Jeen (rice noodle)	Tailandia	*L. delbrueckii*	[12]
		Jalebi	India, Bangladesh, Nepal	*L. fermentum*, *S. cerevisiae*, *L. plantarum*	[4, 50]
		Sourdough	South Kirea	*L. brevis*, *P. pentosaceus*, *Leuc. citreum*	[4, 12, 51]
		Chinese steamed bun (*Comme*)	Vietnã	*L. plantarum*	[51]
		Tape ketan	Indonesia	*P. pentosaceus*	[51]
	Soybean	Tempe	Indonesia	*L. fermentum*, *L. delbrueckii* subsp. *lactis*	[4••]
		Doenjang	Korea	*Leuc. mesenteroides*, *D. hansenii*	[4••]
		Tauco	Indonesia	*L. delbrueckii*	[4••]

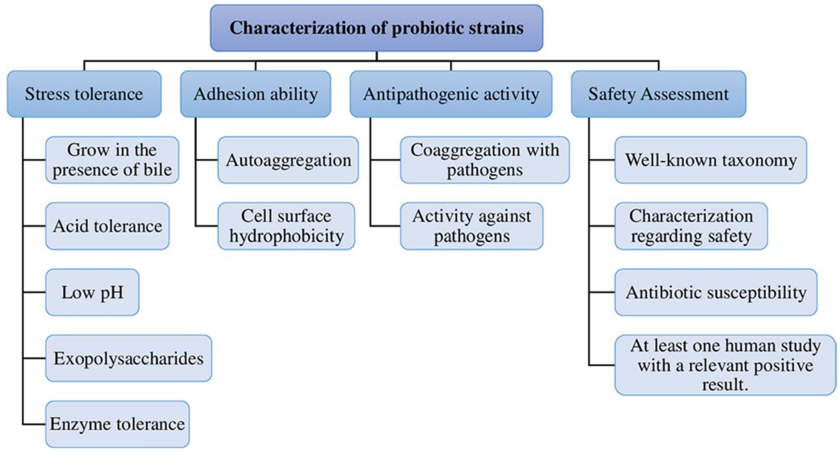

Fig. 1 Characterization of probiotic strains according to FAO/WHO and IPA

such as *jalebi*, *tapuy*, and *chinese steamed bun* (*comme*) [9, 19, 24]; and from Latin America, such as *puba*, *tucupi*, *sour cassava* starch, *calugi*, *yakupa*, *tarubá*, *cauim*, *tocosh*, *pozol*, *masato* of *yuca*, *chicha*, and *atol agrio* [14, 20, 29].

Strains of *L. plantarum* and *Lactobacillus acidophilus* could tolerate the high-temperature thermal treatment (50–56°C) and were selected to verify their probiotic ability. These strains also presented high inhibitory activity against *Salmonella enterica* serovar Enteritidis, *Salmonella enterica* serovar Typhimurium, *Escherichia coli*, *Staphylococcus aureus*, and *Listeria monocytogenes* with a medium inhibition diameter higher than 15 mm. These species also showed tolerances to pH 3.0 and 0.3% (v/v) oxgall bile. Hence, the authors concluded that due to their properties, both strains are potentially probiotic and can be employed in the industrial processing of probiotic products in the future [21].

The CCMA 0743 strain of *L. plantarum* isolated from cassava *cauim*, a beverage produced by indigenous people in the North of Brazil, was able to tolerate pH 2.0 and grow in the presence of 0.3% biliary salts. This resistance is required in order to reach the human intestine and showcases their probiotic potential. In this paper, it was also observed that the *L. plantarum* isolates reached the desirable levels for a product to be considered probiotic (8.0 log UFC/mL) [10]. A probiotic food must contain at least 10^8 UFC/g of viable microorganisms, depending on the microorganism and the consumer's physiological conditions [28, 52]. Rebaza-Cardenas et al. [51] examined different strains of *L. plantarum* isolated from the poli-cereal mixture *chicha*. One of the *L. plantarum* strains showed better resistance to in vitro gastrointestinal traffic and a major ability of adhesion to the intestinal epithelium in comparison to commercial probiotic strains [51].

Limosilactobacillus fermentum strains of these microorganisms were isolated from a wide variety of fermented foods, such as *gari*, *ogi*, *uji*, *hussuwa*, *ting*, *agbelima*, *kunu-zaki*, *dégué*, *lafun*, *fufu* [4••, 5•, 18, 27, 46, 48•, 50], *jalebi* and *tempe* [7, 19], *puba*, *sour cassava starch*, *tucupi*, *yakupa*, *caxiri*, *pozol*, and *cassava's chicha* [14, 30, 32, 36, 38, 40–42, 45, 56].

Nascimento et al. [49] reported that the ingestion of *L. fermentum* strains from different sources, including fermented food, is capable of improving the composition of intestinal microbiota, reducing acute systemic inflammation, enhancing the short-chain fat acid compound in the colon, lowering blood pressure and dyslipidemia, and enhancing antioxidant defenses in the colon, liver, heart, and kidneys [49]. Lacerda et al. [31] evaluated various studies that reported the use of *L. fermentum* strains isolated from different sources, such as Chinese rice noodle wastewater—among others—with probiotic potential concerning the management of diabetes mellitus and observed that the consumption of different strains provided varying effects. Furthermore, some strains showed advantages when handling type 2 diabetes and their daily ingestion could be responsible for mitigating the complications of type 1 diabetes [31].

Strains of *Lactobacillus gasseri* are predominant in the small intestine and are also found in different fermented foods such as *dégué*, *sour cassava starch*, and *puba* [12, 38, 41, 50]. Studies reported that these strains contribute to immunological regulation, preventing bacterial and viral infections, reducing allergic symptoms, inhibiting lipid absorption, and exerting anti-tumor effects [43, 57].

In Africa, *Levilactobacillus brevis* strains are part of the microbial diversity of *dégué*, *mahewu*, *gari*, and *agbelima* [5•, 27, 50, 58, 59]. In Latin products, *L. brevis* strains are found in *agrio*, *rice cauim*, *corn chicha*, *tarubá*, *sour cassava starch*, and *puba* [14, 33, 37, 38, 41, 42, 56, 60, 61]. In Asia, they are present in *sourdough* [24]. Several strains of this species are classified as probiotic because different studies showed that *L. brevis* improves immunity and mind health, relieving gastrointestinal tract irritation and enhancing the natural resistance to pathogens [62, 63].

Lacticaseibacillus casei can be isolated from food, but also from human reproductive and gastrointestinal tracts, which explains its wide implementation as a probiotic [64].

L. casei strains were identified in some fermented foods like *dégué*, *fufu*, *ogi*, and *kunu-zaki* (Africa) [50, 59]; *Chinese steamed bun* (*comme*) (Asia) [24]; and *pozol*, *tocosh*, *rice chicha*, and *puba* (Latin America) [33, 41, 65, 66]. Several strains of this species represent not only potential but actual probiotic bacteria. Studies showed that *L. casei* strains are effective in immunological response modulations, in the protection against diabetes mellitus, in exerting anti-inflammatory effects over intestinal epithelial cells, in reducing time and preventative measures required for respiratory infections, as well as anti-arthritic properties, the modulation of intestinal microbiota [64].

Lacticaseibacillus paracasei compounds the microbiota of *Uji* and *Mahewu* [50, 67]. Recently, new strains were described as potential probiotics due to their ability to inhibit pathogens and functional properties. Hence, this species is a good candidate for a stater culture with probiotic claims [67]. In addition, results pointed out the ability to inhibit the growth of common pathogenic bacteria, highlighting their probiotic potential. Thus, these results can be useful for a deeper comprehension of *L. paracasei* as well as for the development of new starter cultures and probiotic preparations based on this LAB in the future [67].

Lactobacillus delbrueckii are the predominant bacteria during the *mahewu* fermentation process and can be found in *ogi* and *fufu* fermentation [48•, 50, 59, 68]. In Asia, *L. delbrueckii* subsp. *lactis* was isolated in *tempe* and the *L. delbrueckii* species in *kha nhom Jeen* (rice noodle) and *tauco* [7, 24]. Between the Latin American products, *L. delbrueckii* was found in cassava *chicha*, *pozol*, and *puba* [36, 41, 65].

A study performed by Guglielmotti et al. [34] showed that different strains of *L. delbrueckii* presented a limited resistance to bile, while most strains tolerated lysozymes, growing in bile salts and fermenting in prebiotic presence. Moreover, they showed strong antibacterial activity because of the lactic acid production. The studied strains were also capable of joining Caco-2/TC-7 monolayers and significantly inhibited the invasion of *Salmonella enterica* serovar Enteritidis in Caco-2/TC-7cell. Hence, all tested strains presented probiotic characteristics, suggesting an important probiotic potential role for *L. delbrueckii* [34].

Pediococcus spp

Pediococcus spp. are frequently found in foods obtained from vegetable fermentation processes. Among the African and Asian products obtained from vegetable fermentation, *Pediococcus* were isolated from *uji* (*Ped. acidilactici* and *Ped. pentosaceus*); *hussuwa*, *sufu*, *maesura*, and *rabadi* (*Ped. acidilactici*); and *ogi*, *kunu-zaki*, *fufu*, *selroti*, *sourdough*, and *tape ketan* (*Ped. pentosaceus*) [5•, 7, 24, 48•, 50]. In Latin American products, they were found in *atole agrio* (*Ped. pentosaceus*), *caxiri*, *corn chicha* (*Ped. acidilactici*), and *rice cauim* (*Ped. guilliermondii*) [14, 25, 60, 61].

Ped. acidilactici, isolated from milk products, exhibits a probiotic potential due to its ability to reduce high blood sugar levels and low-density lipoprotein and inhibit pathogens. The capacity to reduce blood sugar levels is more effective than metformin. Consequently, this potential probiotic prevents hyperglycemia, hypercholesterolemia, and gastrointestinal infections [69]. Likewise, *Ped. pentosaceus* produces BLISs with antibacterial properties and anti-inflammatory, anticancer, antioxidant, detox, and lipid reducer abilities [39].

Leuconostoc

The probiotic claim for *Leuconostoc* resides in antimicrobial activities due to the production of BLISs [70]. *Leuconostoc* species were already found in Asian products such as *doenjang*, *idli*, *selroti*, *puto*, and *saké* (*Leuc. mesenteroides*) and *sourdough* (*Leuc. citreum*) [7, 9, 24]. *Leuconostoc* strains were also isolated from African foods, such as *mahewu* (*Leuconostoc* spp.), *gari* (*Leuc. fallax* and *Leuc. pseudomesenteroides*), *fufu* (*Leuc. mesenteroides*), *agbelima* (*Leuc. mesenteroides*), and *lafun* (*Leuconostoc* sp.) [4, 5•, 18, 27, 46, 48•, 50]. Across Latin American products, *Leuconostoc* strains were identified in *atole agrio* (*Leuc. pseudomesenteroides*), *corn chicha* (*Leuc. mesenteroides* and *Leuc. lactis*), *rice chicha* (*Leuc. lactis*), *tarubá* (*Leuc. mesenteroides* and *Leuc. lactis*), *sour cassava starch* (*Leuc. mesenteroides*, *Leuc. pseudomesenteroides*, and *Leuc. citreum*), and *puba* (*Leuc. mesenteroides*) [33, 37, 41, 56, 60, 66, 71].

Lactococcus lactis

Lactococcus lactis was identified in Latin-American products, such as *atole agrio*, *sour cassava starch*, and *puba* [33, 38, 41, 56, 61, 71], as well as in African products such as *mahewu* and *gari* [46, 50]. In Asia, this species was isolated from *kha nhom Jeen* (rice noodles) [24].

Lactococcus lactis is an LAB that is widely used for the fermentation of dairy and non-dairy foods, such as cheese, yogurt, and sauerkraut. This LAB species is generally recognized as safe (GRAS) by the Food and Drug Administration (FDA). Beyond the acid production, these bacteria are capable of producing bacteriocin, presenting antagonistic effects against pathogens [70]. *Lc. lactis* has gastrointestinal tract resistance, immunomodulatory activity, anti-allergy, anti-cancer, and healing capabilities [72, 73]. A study with two strains of *Lc. lactis* reported the resistance to bile salts, low pH, osmotic stress, and adhesion to intestinal cells, in addition to presenting antiproliferative effects in colorectal cancer cells [44, 73]. A study with an *Lc. lactis* strain isolated from a fermented product showed healing activities for induced colitis in animal models and inhibited intestinal inflammation through the suppression of inflammatory factors, improvement of the epithelial intestinal barriers and short-chain fat acid concentration regulation. A verified inflammation inhibition mechanism was the inhibition of the NF-κB and MAP, signaling routes that are key regulators during inflammatory processes [44].

Yeasts

Yeasts, due to their natural resistance to antibacterials [74], have advantageous characteristics when used as probiotics. They can help treat gastrointestinal conditions, whether acute, such as retroviral and bacterial diarrhea, or chronic, such as inflammatory diseases. Additionally, yeasts can reinforce humoral, innate immunity, and improve the composition of intestinal microflora in healthy individuals [75].

Saccharomyces

Saccharomyces strains are directly associated to the fermentation of several African, Asian, and Latin American products. *Saccharomyces cerevisiae* ferments foods such as *ogi*, *lafun*, *gari*, *fufu* [4, 5•, 18, 27, 46, 48•, 68], *selroti*, *saké*, *idli*, *jalebi*, *takju* [7, 9], *calugi*, *yakupa*, *cauim*, *chicha*, and *champús* [11, 14, 25, 30, 36, 45, 76, 77].

S. cerevisiae 905, isolated from cachaça, was able to reach potentially functional population levels in the gastrointestinal regions of mice, against the enteropathogenic bacteria *Salmonella Typhimurium* and *Clostridium difficile.* However, antagonism against any pathogenic bacteria was not shown by this yeast in gnotobiotic mices' the digestive tracts. The mortality was lower, and the liver tissue was better preserved in conventional animals treated with yeast against *S. Typhimurium* comparison to the control group. Intestinal histopathological results showed a good protective effect against oral problems with *C. difficile* in gnotobiotic mice [35].

Menezes et al. [78] evaluated the probiotic potential of *S. cerevisiae* strains isolated from cassava *caxiri* with a chewed sweet potato inoculum. The isolated majority showed the capability of co-aggregating with the *Escherichia coli* pathogens, while some also showed this ability with *Salmonella* Enteriditis and *Listeria monocytogenes*. Yeasts reduced pathogen adhesion and bacterial infection in Caco-2 cells [78]. In a previous study performed with *S. cerevisiae* strains isolated from *caxiri*, Menezes et al. [16] reported the capability the isolates showcased of tolerating the gastrointestinal tract conditions (low pH, bile salts, and 37°C temperature). Furthermore, strains were able to produce phytase, increasing nutrient availability. Yeasts showed high hydrophobicity, auto-aggregation, and co-aggregation with *E. coli* and Caco-2 cell adhesion. These characteristics are relevant for new probiotic strain research [16].

Debaryomyces hansenii

Debaryomyces hansenii, involved in the fermentation of *ogi* [46] and Asian products such as *idli*, *selroti*, *doenjang*, and *tapuy* [7, 9], has probiotic properties. Oral administration of these species' strain result in immunostimulatory effects, intestinal microbiota modulation, increases in cell proliferation and differentiation as well as improvements in digestive function [79].

Pichia spp

Pichia strains are part of the microbial diversity of some African and Latin American products such as *P. kudriavzevii* (*ogi* and *yakupa*), *P. scutulata*, *P. kudriavzevii*, *P. rhodanensis* (*lafun*), *P. scutulata* (*gari* and *sour cassava starch*), *P. guilliermondii* (*rice cauim*), *P. fermentans* (champús), *P. kluyveri*, and *P. kudriavzevii* (*rice chicha*) [11, 18, 22, 27, 30, 38, 48•, 50, 68, 77, 80].

Two strains of *P. kudriavzevii* isolated from *ogi* showed the optimal ability of auto-aggregation, capabilities to remove cholesterol and eliminate free radicals on the methanol reaction system, and enhanced co-aggregation for a strain of *P. kudriavzevii*, and *Escherichia coli* [80].

Kluyveromyces marxianus

Kluyveromyces marxianus can be found during the fermentation process of African products such as *gari* and *lafun* [18, 27, 48•, 50].

Five strains of *K. marxianus*, tested in a simulated gastrointestinal environment, showcased the best survival capabilities compared to the probiotic yeast strain *S. boulardii* MYA-796. Additionally, the five strains showed different lactose, xylitol, D-sorbitol and lactate assimilation, great cell surface hydrophobicity, biofilm production, and auto-aggregation capabilities. These characteristics indicate a major survival potential in the host's gastrointestinal tract, suggesting its use as a probiotic [81].

Conclusion

This review focuses on the microbial diversity in fermented foods in Africa, Asia, and Latin America, highlighting the importance of the probiotic potential of the microorganisms involved in these fermentative processes. In this way, fermented foods become vehicles for probiotics and can be considered natural reservoirs of new strains with this potential, providing different health benefits to the consumer. Probiotic abilities include functional properties, nutritional enrichment, immunological effects, and protective properties.

In recent years, interest in and consumption of fermented products has increased due to the natural presence or direct incorporation of probiotics. However, choosing appropriate food systems to deliver probiotics is crucial. Always consider when developing probiotic foods. Although most probiotic products are sold as dairy products, there is growing interest in creating new probiotic foods, mainly plant-based products. Furthermore, despite the strains probiotic potential, they must meet strict safety, functionality, and quality criteria. Although probiotics are GRAS (recognized as safe) organisms, variation in regulatory standards between countries adds another layer of complexity to incorporating probiotics into food products.

It is essential to raise awareness among those producing probiotic foods and teach them about advanced production technologies. Furthermore, adopting policies and guidelines that provide food security and promote sustainability is necessary. During the development of probiotic food, several technological difficulties arise, such as the selection of the food matrix for the probiotic, the appropriate choice of strain for industrial production, the microbial stability of the starter culture, sensory acceptance, the nutritional value of the new product, stability during storage, and the type of packaging, which can also affect the survival of probiotics. Economic aspects, health benefits, and the practicality of developed foods also play a crucial role. Studies point to the feasibility of using probiotic starter cultures derived from plant products, legumes, and cereals.

The future of probiotic foods will lie in product innovation, such as plant-based foods fermented with probiotic starter cultures. Recognizing the potential of these foods is just the beginning. It is equally crucial to dedicate significant efforts to uncovering different probiotic capabilities.

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Declarations

Ethical Approval This article does not contain any studies with human participants or animals carried out by any authors.

Competing Interests The authors declare no competing interests.

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Papers of particular interest, publish recently, have been highlighted as:
• Of importance
•• Of major importance

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