

Fermented nondairy functional foods based on probiotics

Pınar Şanlıbaba

Department of Food Engineering, Faculty of Engineering, Ankara University, Ankara, Turkey

*Corresponding Author: Pınar Şanlıbaba, Department of Food Engineering, Faculty of Engineering, Ankara University, Ankara, Turkey. Email: sanlibab@ankara.edu.tr

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Abstract

Functional foods containing probiotic bacteria are consumed worldwide. According to the Food and Drug Administration (FDA), probiotics are living microorganisms that contribute to the host's overall health when provided in adequate amounts. Fermented dairy products, especially yogurt and other dairy-based products, are good substrates for probiotic delivery. However, recently, consumers have begun to seek alternatives due to lactose intolerance and high fat and cholesterol contents. Moreover, the growing vegetarianism has increased the demand for nondairy probiotic foods. Thus worldwide, researchers are studying probiotic bacteria feasibility in nondairy products, including fruits, vegetables, and cereals. This study aims to give an overview of various nondairy based products that contain probiotic bacterial strains available worldwide based on fruits, vegetables, cereals, chocolate-based products, and meat products. Moreover, the latest globally available commercial products are also summarized.

Keywords: functional foods, nondairy-based products, probiotic

Introduction

Functional food was introduced in the mid 1980s by the Japanese government (Min *et al.*, 2019; Zamfir *et al.*, 2022). In 1991, the Japanese Ministry of Health, Welfare, and Labor established a systematic regulatory system for functional foods, and "Food for Specified Health Uses" (FOSHU) became the legal term (Iwatani and Yamamoto, 2019; Gomes *et al.*, 2021). However, the interest in functional foods in Europe started in the 1990s. Later, the European Commission established a commission called Functional Food Science in Europe (FuFoSE) to explore functional foods (Perricone *et al.*, 2015). Functional foods are used to maintain or regulate specific health conditions, such as decreased cancer risk, improve heart health, enhancement of the immune system, to reduce menopause symptoms, improvement of gastrointestinal health, preservation of urinary tract health, anti-inflammatory influences, decrease in blood pressure and cholesterol levels, reduced osteoporosis, and anti-obesity influences

(Al-Sheraji *et al.*, 2013; Aspri *et al.*, 2020). Functional food is classified into four different categories by The American Dietetic Association (ADA): (1) conventional foods, (2) modified foods, (3) medical foods, and (4) foods for special dietary use. Of these functional foods, probiotic foods have currently received maximum attention as health promoters, accounting for approximately 60–70% of the total functional food market (Aspri *et al.*, 2020; Misra *et al.*, 2019; Küçükgöz and Trzaskowska, 2022). Generally, three main ingredients designed for gut health are added to functional foods. They are living microorganisms (probiotics), nondigestible carbohydrates (prebiotics), and secondary plant metabolites (polyphenol compounds) (Panghal *et al.*, 2018).

Elie Metchnikoff, a Russian-born Nobel Prize winner and professor at the Pasteur Institute in Paris, first expressed the probiotic concept. He suggested that some selected bacteria may have positive effects on the human gastrointestinal tract. He observed that many Bulgarian

peasants had long and healthy lives as they consumed large quantities of fermented dairy products, including beneficial organisms. Therefore, he suggested the possibility to direct the microflora in human bodies to replace harmful microorganisms with beneficial ones (Shorkryazdan *et al.*, 2017). Research on this concept has been developed further to date. This study summarizes some characteristics of probiotics as a functional ingredient in food and nondairy-based probiotic foods.

Probiotics, Prebiotics, and Synbiotics

Probiotics, prebiotics, and synbiotics have attracted attention for developing balance in gastrointestinal microflora (Küçükgöz and Trzaskowska, 2022). The term “probiotic” comes from the Greek meaning “for life”. In 1954, Ferdinand Vergin first used this term in his article entitled “Anti-und Probiotika,” comparing the beneficial effects of antibiotics and other antibacterial agents of some useful bacteria. Later, Lilly and Stillwell, in 1965, determined that probiotics were substances produced by microorganisms that support the growth of other organisms. Subsequently, the definition of probiotics was modified several times and changed by many scientists till today. In 1989, Fuller emphasized that these organisms must be viable and have some beneficial health effects on humans. The current definition of 2002, by FAO (Food and Agriculture Organization of the United Nations) and WHO (World Health Organization), stated that “probiotics are living strains of strictly selected microorganisms that, when administered in sufficient quantities, provide a health benefit to the host” (Markowiak and Slizewska, 2017). The last updated definition was made in 2013 by a panel of expert teams from the International Scientific Association for Probiotics and Prebiotics, and FAO/WHO’s definition was reinforced with some minor grammatical corrections. The final definition is “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host.” Three main key aspects, such as viable, microbial, and beneficial to health, were included in this definition (Kumar *et al.*, 2022; Shorkryazdan *et al.*, 2017). Generally, the level of viable probiotic organisms should be at least a minimum of 10^6 CFU (Colony Forming Units)/g of viable cells during the food shelf life to show the minimum therapeutic effect on the human body. It was also suggested that a daily intake of 10^8 – 10^9 CFU/g probiotic microorganisms could pass the upper ingestion to show their beneficial physiological effects on the human body. A daily intake of approximately 100 g of probiotic food products should be consumed to reach these counts of viable probiotic cells (Küçükgöz and Trzaskowska, 2022; Terpou *et al.*, 2019).

The most important probiotic microorganisms are lactic acid bacteria (LAB) that include *Lactobacillus* spp. and

Bifidobacterium spp. In addition, *Bacillus*, *Pediococcus*, *Clostridium*, and some yeasts such as *Saccharomyces* (e.g., *Saccharomyces cerevisiae* and *Saccharomyces boulardii*) have also been used as probiotic candidates (Kumar *et al.*, 2022; Soccol *et al.*, 2010). Most probiotic cultures are gram-positive, usually catalase-negative, non-motile, non-spore-forming, and non-flagellated. Most probiotics grow optimum at 37°C and pH of 6.5–7.5, but some prefer 30°C, for example, *Lactobacillus casei* (Song *et al.*, 2012). WHO, FAO, and EFSA (The European Food Safety Authority) suggested that before using them as a probiotic in food application, safety, technological, and functional characteristics of probiotic organisms must be considered (Markowiak and Slizewska, 2017). Hence, some criteria need to be fulfilled. Some of the safety properties of probiotics are summarized as; (1) must be isolated from healthy human or animal gastrointestinal tract, (2) have a history of safe use, (3) must have diagnostic identification traits (phenotype and genotype traits), (4) no adverse effects, (5) absence of genes responsible for antibiotic resistance, (6) nonpathogenic and nontoxic, ability to interact or send signals to immune modulator activity, and (7) survive in the presence of administered drugs and other antimicrobial compounds. Functional criteria are defined as (1) resistance to low pH for surviving and processing in the gut condition, (2) the ability to resist gastric juices, enzymes and the exposure to bile acid, which is crucial for oral administration, (3) ability to pass through gastrointestinal tract at low pH and in contact with bile salts, (4) antimicrobial activity against pathogenic bacteria such as *Salmonella* spp., *Listeria monocytogenes*, *Clostridium* spp., (5) ability to influence local metabolic activity, (6) health effects on human bodies such as anti-carcinogenicity and anti-mutagenic activity, and cholesterol-lowering effect, (7) to create a beneficial effect on the host by increasing disease resistance, and (8) to have the power of restore and replace the intestinal microflora (Kumar *et al.*, 2022; Pimentel *et al.*, 2021). Finally, technological aspects are detailed: (1) to have excessive cell viability, (2) to have genetic stability, (3) must be stable, safe, effective, and equipped for staying viable under storage conditions, (4) ability to be viable and stable during the food processes and (5) ability to have large scale production (Abatenh *et al.*, 2018; Kumar *et al.*, 2022; Markowiak and Slizewska, 2017). Table 1 shows the frequently used probiotic cultures applied in food systems, some of which are produced commercially. As an example, *Lactobacillus acidophilus* LA-1, *Lactobacillus acidophilus* LA-5, *Lactobacillus paracasei* CRL 431, *Bifidobacterium animalis* Bb-12, *Bifidobacterium bifidum* Bb-11, *Lactobacillus paracasei* CRL 431, and *Bifidobacterium lactis* Bb-12 from Chr. Hansen (Horsholm, Denmark); *Lactobacillus casei* Shirota and *Bifidobacterium breve* strain Yakult from Yakult (Tokyo, Japan); *Lactobacillus acidophilus* R0011

Table 1. Commonly used probiotic organisms in food application, both dairy and non-dairy foods. (*)

<i>Lactobacillus</i> spp.	<i>Lactobacillus acidophilus</i> , <i>Lactobacillus amylovorus</i> , <i>Lactobacillus brevis</i> , <i>Lactobacillus casei</i> , <i>Lactobacillus rhamnosus</i> , <i>Lactobacillus crispatus</i> , <i>Lactobacillus delbrueckii</i> subsp. <i>bulgaricus</i> , <i>Lactobacillus fermentum</i> , <i>Lactobacillus gasseri</i> , <i>Lactobacillus helveticus</i> , <i>Lactobacillus johnsonii</i> , <i>Lactobacillus lactis</i> , <i>Lactobacillus paracasei</i> , <i>Lactobacillus plantarum</i> , <i>Lactobacillus reuteri</i> , <i>Lactobacillus salivarius</i> , <i>Lactobacillus gallinarum</i> , <i>Lactobacillus cellobiosus</i> , <i>Lactobacillus curvatus</i> , <i>Lactobacillus gasseri</i>
<i>Bifidobacterium</i> spp.	<i>Bifidobacterium adolescentis</i> , <i>Bifidobacterium animalis</i> , <i>Bifidobacterium breve</i> , <i>Bifidobacterium bifidum</i> , <i>Bifidobacterium infantis</i> , <i>Bifidobacterium lactis</i> , <i>Bifidobacterium longum</i> , <i>Bifidobacterium thermophilum</i>
<i>Bacillus</i> spp.	<i>Bacillus coagulans</i> , <i>Bacillus cereus</i> , <i>Bacillus subtilis</i> , <i>Bacillus lentus</i> , <i>Bacillus licheniformis</i> , <i>Bacillus cereus</i> var. <i>toyoi</i> , <i>Bacillus clausii</i> , <i>Bacillus laterosporus</i> , <i>Bacillus pumilus</i> , <i>Bacillus racemilacticus</i>
<i>Pediococcus</i> spp.	<i>Pediococcus acidilactici</i> , <i>Pediococcus cerevisiae</i> , <i>Pediococcus pentosaceus</i>
<i>Streptococcus</i> spp.	<i>Streptococcus salivarius</i> subsp. <i>thermophilus</i> , <i>Streptococcus intermedius</i>
<i>Bacteriodes</i> spp.	<i>Bacteriodes capillus</i> , <i>Bacteriodes suis</i> , <i>Bacteriodes ruminicola</i> , <i>Bacteriodes amylophilus</i>
<i>Propionibacterium</i> spp.	<i>Propionibacterium freudenreichii</i> , <i>Propionibacterium shermanii</i>
<i>Leuconostoc</i> spp.	<i>Leuconostoc mesenteroides</i> subsp. <i>dextranicum</i>
<i>Lactococcus</i> spp.	<i>Lactococcus lactis</i> subsp. <i>cremoris</i> , <i>Lactococcus lactis</i> subsp. <i>lactis</i>
<i>Enterococcus</i> spp.	<i>Enterococcus faecalis</i> , <i>Enterococcus faecium</i> , <i>Enterococcus durans</i>
Other bacteria	<i>Clostridium butyricum</i> , <i>Escherichia coli</i> Nissle 1917
Yeast and mold	<i>Aspergillus niger</i> , <i>Aspergillus oryzae</i> , <i>Saccharomyces boulardii</i> , <i>Candida torulopsis</i> , <i>Candida pintolopesii</i>

Adapted from Abatenh *et al.*, 2018; Žuntar *et al.*, 2020.

and *Lactobacillus rhamnosus* R0052 from Institut Rosell (Montreal, Canada); *Lactobacillus johnsonii* La1 (same as Lj1) from Nestle' (Lausanne, Switzerland); *Lactobacillus plantarum* 299V, *Lactobacillus plantarum* Lp01 and *Lactobacillus rhamnosus* 271 from Probi AB (Lund, Sweden); *Lactobacillus rhamnosus* GG from Valio Dairy (Helsinki, Finland); *Saccharomyces boulardii* from Biocodex Inc. (Seattle, WA); *Bifidobacterium longum* BB536 from Morinaga Milk Industry Co., Ltd (Zama-City, Japan); *Lactobacillus casei* DN014001 and *Bifidobacterium essencis* from Danone Le Plessis Robinson (Paris, France); *Lactobacillus salivarius* from UCC118 University College (Cork, Ireland); *Bacillus lactis* DR10 from Danisco (Copenhagen, Denmark) (Nagpal *et al.*, 2012; Pimentel *et al.*, 2021; Socol *et al.*, 2010).

The health benefits of probiotics depend on the specific strain and dosage. One strain cannot show all positive health effects. Foods containing probiotic strains from different species rather than a single strain show better success in providing human health benefits and broader efficacy (Žuntar *et al.*, 2020). Probiotic cultures differ in health effects on humans. The mechanism of probiotics on human health is still unclear (Küçükğöz and Trzaskowska, 2022). However, some of the potential effects of probiotic microorganisms are summarized in Table 2.

Nowadays, three different types of food products supplemented with probiotic cells are available for direct or indirect human consumption. These are (1) fermented or nonfermented form, (2) dried or deep-frozen for industrial or home uses, and (3) drugs in powder, capsule, or tablet meaning pharmaceutical form (Misra *et al.*, 2019).

In pharmaceutical and food systems, the selection of probiotic cells and their differentiation are crucial. Food-based probiotic products are classified into two distinct groups: dairy products and nondairy products (Dahiya and Singh-Nee Nigam, 2022; Terpou *et al.*, 2019). The purpose of this study was to provide information about nondairy probiotic foods.

Two terms entitled “prebiotics” and “synbiotics” are also significant. Prebiotics are short-chain carbohydrates (SCCs), mostly nondigestible food ingredients, which positively affect the host's health by selectively stimulating the growth and/or activity of specific microorganisms in the colon such as *Lactobacillus* spp. and *Bifidobacterium* spp. (Aladeboyeje and Sanli 2021; Al-Sheraji *et al.*, 2013). When prebiotics passes from the small intestine to the lower gut, health-promoting bacteria such as probiotics selectively ferment and use these fibers as an energy source by breaking them down. In addition, they also boost the human immune response by increasing the gut microbial activity and the production of short-chain fatty acids (SCFA), particularly acetic acid, propionic acid, and butyric acid (Priya, 2020). Among the beneficial effects of prebiotics, SCFA production stimulation is essential (Nagpal *et al.*, 2012). These products have some positive impact on the human body. They participate in different host signaling mechanisms, affect T-helper 2 cells in the airways and macrophages, decrease the colon pH, stimulate gut hormone release, shape the gut environment, and influence the colon physiology. They are also used as energy sources by colonic epithelial cells and the intestinal microflora (Lockyer and Stanner, 2019). The term “prebiotic” was first defined by Glenn

Table 2. Potential health effect of probiotics and prebiotics.(*)

Probiotics	Prebiotics
1. Reduction of food allergy symptoms such as atopic dermatitis	1. Helping increase the count of useful organisms in intestines, hence possibly help in preventing gastroenteritis
2. Lowering cholesterol level	2. Decreasing inflammatory bowel disease related to the intestinal microbiota pathogenesis
3. Elimination of pathogens or decrease in pathogenic adherence by lactic acid and bacteriocin	3. Reduction of colorectal cancer risk (decreasing the activity of genotoxic enzyme via the administration of prebiotics)
4. Pediatric gastroprotection	4. Prevention and treatment of allergy
5. Increasing the body's immunity (Immune stimulation and immunomodulatory activity)	5. Effective in bone mineralization (prebiotics play a crucial role in adult bone mass depending on the bioavailability of calcium)
6. Elimination of <i>Helicobacter pylori</i> , inflammatory bowel disease (Crohn's disease, pouchitis, and ulcerative colitis)	6. Plays an active role in preventing atherosclerosis and cardiovascular disease
7. Reduction of irritable bowel syndrome	7. Selectively stimulating the growth and/or activity of certain types of organisms in the colon
8. Treatment of diseases such as obesity, insulin-resistant syndrome, and type-2 diabetes	8. Improving immune response by increasing the gut microbial activity
9. Having anti-carcinogenic effects such as colorectal cancer and anti-mutagenic activities	9. Treatment of hepatic encephalopathy
10. Decreasing incidence and duration of antibiotic-induced diarrhea	10. Lowering serum lipid concentration
11. Decreasing blood pressure	11. Insulin sensitivity improvement
12. Improving child growth	12. Laxative agent
13. Formation of useful compounds, such as vitamins, short-chain fatty acids, and conjugated linoleic acid	13. Lowering the glycemic index and body weight
14. Showing antioxidant activity	
15. Reducing symptoms related to lactose intolerance	
16. Reduction of toxin-binding and detoxification activity	
17. Effective in nutrient absorption	
18. Pathogen interference, exclusion, and antagonism	
19. Having neuropsychiatric disorders via the enteric and central nervous system	
20. Maintenance of mucosal integrity	

Adapted from Markowiak and Slizewska, 2017; Priya, 2020; Shorkryazdan *et al.*, 2017; Younis *et al.*, 2015.

Gibson and Marcel Roberfroin in 1995. A compound should have several requirements to be prebiotic. These are summarized as: (1) not be hydrolyzed by mammalian enzyme, (2) not be absorbed in the upper part of the gastrointestinal tract, (3) fermented selectively by intestinal flora, (4) promote the growth of selected beneficial bacteria, (5) resistant to gastric acidity, and (6) not confer negative consequences to the host, such as excess gas production or the growth of pathogenic organisms (Lockyer and Stanner, 2019; Younis *et al.*, 2015). The ways of isolating the most commonly known prebiotics and its candidates are summarized as follows: (1) extraction from plants (such as chicory root, onions, whole grains, bananas, and garlic), (2) enzymatic hydrolysis (like oligofructose from inulin), (3) synthesis from mono- or disaccharides (such as fructo-oligosaccharides [FOS] from sucrose, or galactooligosaccharides [GOS] and transgalactosylated oligosaccharides from lactose), or (4) microbiological production. Among prebiotics, inulin and

oligosaccharides are most recognized as dietary fibers in the world. In addition, FOS, GOS, inulin, isomaltoligosaccharide (IMO), and beta-glucan are also commonly used as prebiotics in food applications (Singla and Chakkaravarthi, 2017; Younis *et al.*, 2015). Some health effects of prebiotics are summarized in Table 2. Enhancing organoleptic characteristics and improving both taste and mouthfeel are among the positive effects of prebiotics in food applications. Prebiotics must also be chemically stable in food processing, such as high temperature, low pH, and Maillard reaction conditions. When prebiotics are broken down into their components, such as mono- and disaccharides, or chemically altered, they no longer provide selective stimulation of beneficial microorganisms called as probiotics (Gomes *et al.*, 2021; Younis *et al.*, 2015). In 2015, The United Kingdom Scientific Advisory Committee on Nutrition's (SACN) recommended an average intake of approximately 30 g/day for adults, 15 g/day for children aged

2–5 years, 20 g/day for children aged 5–11 years, 25 g/day for children aged 11–16 years, and 30 g/day for adolescents aged 16–18 years of fiber from natural dietary sources (Lockyer and Stanner, 2019).

Formulating a probiotic product with prebiotics gives synbiotics properties to the food item. In 1995, Gibson and Roberfroid introduced this term to describe a combination of probiotics and prebiotics. Synbiotics means synergistically acting probiotics and prebiotics. For example, *Lactobacillus rhamnosus*, *Bifidobacterium* spp., *Lactobacillus acidophilus*, and *Lactobacillus casei*, when combined with prebiotics such as Raftiloses P95, improve their viabilities at 4°C on 4 weeks of storage. Pear and apple fibers combined with raffinose also increased the activity and viability of probiotic bacteria. It is recommended that 10 g/day of GOS is sufficient to improve fecal bifidobacteria levels. Moreover, xylo-oligosaccharides 2 g/day are necessary for the bifidogenic effect. Similarly, 2–10 g/day FOS intake is essential as a bifidogenic stimulus (Al-Sheraji *et al.*, 2013). European milk and yogurt producers such as Aktifit (Emmi, Switzerland), Proghurt (Ja Naturlich Naturprodukte, Austria), Vifit (Belgium, UK), and Fysiq (Netherlands) are the widely used synbiotics concept to produce probiotic foods (Dahiya and Singh-Nee Nigam, 2022; Nagpal *et al.*, 2012).

Why Nondairy Probiotics?

Traditionally for about a century, probiotic foods have been commonly recognized as dairy-based derived products due to more demand and easy availability. Besides, yogurt has always been the top probiotic food preference. Some other examples of dairy-based products are fermented milk, milk powder, sour cream, cheese, fermented dairy beverage, buttermilk, dairy desserts, flavored liquid milk, baby foods, and ice cream (Misra *et al.*, 2019).

Consumer vegetarianism, dyslipidemia, lactose intolerance, milk protein allergies (casein, cholesterol phobia), the requirement of cold storage, and economic reasons associated with dairy-based probiotic products are the main causes restricting their consumption (Chaudhary, 2019; Zamfir *et al.*, 2022). Lactose intolerance is the most important health problem, which accounts for 75% of the world's population, according to the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK). The absence of lactase enzyme activity, which hydrolyses lactose into glucose and galactose, is the leading cause of this disease. Lactose, known as milk sugar, is a crucial carbohydrate for the health of a newborn. During the postnatal period, this intestinal enzyme is at the highest in infants. However, two distinct groups, entitled lactose nonpersistence, and lactose persistence occurred among 2–12-year-old children. Bloating gastric pain and cramps,

gas production in the gastrointestinal tract, and diarrhea are common symptoms of lactose intolerance (Gomes *et al.*, 2021; Panghal *et al.*, 2018). Moreover, vegetarianism is increasing in both developed and developing countries, thus demanding plant-based probiotic products. High cholesterol level in human is another important health problem. Milk contains 4–5% fat. Consuming high-fat dairy products causes an increase in total cholesterol and low-density lipoprotein (LDL) cholesterol contents in the blood, thereby leading to coronary heart disease. This can be eliminated by lowering the consumption of high LDL-cholesterol foods (Hassan *et al.*, 2010; Kumar *et al.*, 2022). These reasons make investigating the potential of nondairy foods in supporting probiotic cultures of immense importance. Therefore, in recent years, probiotic cultures have been successfully applied to other types of food matrices, including meats, beverages, cereals, vegetables, and fruit (Aspri *et al.*, 2020). The first nondairy probiotic food, named ProViva, was formulated and manufactured by a Swedish company, Skane Dairy, in 1994. The main substrate in this product is oatmeal gruel fermented by *Lactobacillus plantarum* 299v. Then, malted barley was added to improve the liquefaction of this product. Finally, fermented food was mixed at a concentration of 5% with different fruit juices such as strawberry, blueberry, rosehip, or any tropical fruit. ProViva contains approximately 5×10^{10} CFU/L of viable *Lactobacillus plantarum* 299v. Like ProViva, GoodBelly prepared from oatmeal and fermented with *Lactobacillus plantarum* 299v was the first nondairy probiotic drink in the US market in 2006. Today, many nondairy-based probiotic products are commercially available (Table 3).

Cereal-based probiotic products

Recently interest in cereal-based probiotic foods has been increasing. Cereals are the most important sources of nutrients and bioactive compounds in people's diets. Moreover, they are an excellent resource for nondigestible carbohydrates such as fiber and oligosaccharides, which stimulate probiotic culture growth (Kockova and Valik, 2014; Küçüköz and Trzaskowska, 2022). Dietary fibers are divided into two groups according to their solubility in water, namely insoluble and soluble fibers. Cereals usually have insoluble fiber, including cellulose, hemicellulose, and lignin (Fernandes *et al.*, 2018). However, some cereals also contain water-soluble fiber, such as β -glucan and arabinoxylan (Vasudha and Mishra, 2013). Consumption of whole grains also has some positive effects on human health. These effects are reducing the risk of type-2 diabetes, cardiovascular disease, obesity, and certain types of cancer (Lamsal and Faubion, 2009). Rice, millets, rye, barley, sorghum, maize, and wheat are the most consumed cereals, while buckwheat,

Table 3. Commercially available nondairy probiotic foods.*

Product Name	Manufacturer	Probiotic strains	Major characteristics
Fruit-based			
Biola R	TINE BA, Norway	<i>Lactobacillus rhamnosus</i> GG	Mixture of apple-pear and orange-mango juice, 95% fruit, no sugar.
Bravo Friscus	Probi AB, Sweden	<i>Lactobacillus plantarum</i> HEAL+ and <i>Lb. paracasei</i> 8700:2	Orange apple and tropical fruit juices
KEVITA	KEVITA, USA	<i>Lactobacillus rhamnosus</i> , <i>Lactobacillus plantarum</i> , <i>Lactobacillus paracasei</i> , <i>Bacillus coagulans</i> GBI-30 6086	Various fruit mixture (Strawberry, and coconut, lime, mint and coconut, pineapple and coconut)
Malee Probiotics	Malee Enterprise Company, Thailand	<i>Lactobacillus paracasei</i>	Prune, grape and orange juice
Probiotic Machine Tropical Mango	Pepsi Company (PepsiCo)	<i>Bifidobacterium</i> spp.	Mixture of apple, orange and pineapple juice, mango puree, banana puree, FOS and natural flavors
Tropicana Probiotics	Tropicana, USA	<i>Bifidobacterium lactis</i>	Fruit juice mixture such as strawberry, banana, pineapple, mango and peach passion fruit
ProViva	EMEA Probi AB, Sweden	<i>Lactobacillus plantarum</i> 299v	Fruit juice (orange, strawberry, or blackcurrant)
PERKii Probiotic Water	PERKii, Australia	<i>Lactobacillus casei</i> Lc431	Fruit juice mixture (such as mango, strawberry, lime, coconut, watermelon, raspberry, pomegranate, passion fruit)
Bio-Live Gold	Bio-Live/Micobz Ltd., UK	Mixture of 13 strains, including <i>Lactobacillus acidophilus</i> , <i>Lactobacillus bulgaricus</i> , <i>Lactobacillus casei</i> , <i>Lactobacillus fermentum</i> , <i>Lactobacillus plantarum</i> , <i>Lactococcus lactis</i> , <i>Bacillus subtilis</i> , <i>Bifidobacterium bifidum</i> , <i>Bifidobacterium infantis</i> , <i>Bifidobacterium longum</i> , <i>Streptococcus thermophilus</i> , <i>Saccharomyces cerevisiae</i>	Mixture of fruit juices such as acai, berry, cherry, goji, noni, lemon, and various herbs.
Malee Probiotics	Malee Enterprise Company Ltd., Thailand	<i>Lactobacillus paracasei</i>	Fruit juices such as prune, grape, and orange
Cereal-based			
Bushera	Basilia Foods, centurion, Gauteng, South Africa	<i>Lactobacillus brevis</i> , <i>Lactobacillus delbrueckii</i> , <i>Lactobacillus paracasei</i> , <i>Lactobacillus plantarum</i>	Sorghum, millet flour
Mahewu	Basilia Foods, centurion, Gauteng, South Africa	<i>Lactococcus lactis</i> subsp. <i>lactic</i>	Maize, sorghum, millet malt, wheat
Avenly velle	Avenly Oy Ltd., Finland	<i>Lactobacillus</i> and <i>Bifidobacterium</i>	Oat based drink
Grainfields wholegrain liquid	AGM Foods Pvt. Ltd., Australia	<i>Lactobacillus acidophilus</i> , <i>Lactobacillus delbrueckii</i> , <i>Saccharomyces boulardii</i> , <i>Saccharomyces cerevisiae</i>	Grains, beans and seeds

Kefir Soy	Life way, Greek	<i>Kluyveromyces marxianus</i> , <i>Lactobacillus kefir</i> , <i>Kluyveromyces lactis</i> , <i>Lactobacillus brevis</i> , <i>Leuconostoc mesenteroides</i> , <i>Lactobacillus helveticus</i>	Soya beans
Ogi	West Africa	<i>Lactobacillus acidophilus</i> , <i>Lactobacillus agilis</i> , <i>Lactobacillus cellobiosus</i> , <i>Lactobacillus confusus</i> , <i>Lactobacillus murinus</i> , <i>Lactobacillus plantarum</i>	Gruel
Mucilon	Nestle	Bifidus BL	Oat and Rice
Boza	Vefa, Turkey	<i>Lactobacillus plantarum</i> , <i>Lactobacillus acidophilus</i> , <i>Leuconostoc raffinolactis</i> , <i>Lactobacillus brevis</i> , <i>Lactobacillus fermentum</i> , <i>Leuconostoc mesenteroides</i>	Rye, millet, wheat, cereal, corn
Vegetable-based			
Vegetable Juices and pickle	Healthy life Probiotics, Golden Circle, Australia, Bioprofit, Gefilus, Valio Ltd, Finland	<i>Lactobacillus paracasei</i> 8700:2, <i>Lactobacillus plantarum</i> Hea9, <i>Lactobacillus rhamnosus</i> GG, <i>Propionibacterium freudenreichii</i> ssp. <i>shermanii</i> JS, <i>Lactobacillus acidophilus</i> , <i>Lactobacillus plantarum</i> , <i>Lactobacillus casei</i> , <i>Bifidobacterium longum</i> , <i>Lactobacillus delbrueckii</i>	Carrots, beets, ginger, tomatoes, cabbage, onions, peanuts
Kimchi	Korea Ginseng Corporation, Korea	<i>Streptococcus</i> , <i>Pediococcus</i> , <i>Leuconostoc</i> spp., <i>Enterococcus</i> , <i>Lactococcus</i>	Cabbage, garlic, red pepper, onion, ginger, radish
KeVita	H-E-B, USA	<i>Bacillus coagulans</i> GBI-306086, <i>Lactobacillus paracasei</i> 8700:2, <i>Lactobacillus plantarum</i> HEAL 9	Sparkling lemon and ginger drink

* Adapted from Aspri et al., 2020; Chaudhary, 2019; Ranadheera et al., 2017.

quinoa, and amaranth are pseudo-cereals connected to the diet (Fernandes *et al.*, 2018).

Nowadays, several nondairy cereal-based probiotic products exist. These products have the potential to harbor probiotic cultures, such as boza, bushera, mahewu, pozol, kvass, ben-saalga, degue, kenkey, koko, kanun-zaki, mawe, munkoyo, thobwa, ting, uji, and togwa (Dahiya and Singh-Nee Nigam, 2022; Misra *et al.*, 2019). However, this chapter is restricted to cereal-based probiotic products sold in different parts of the world.

Boza is popular in Turkey, Kazakhstan, Kyrgyzstan, Albania, Bulgaria, Macedonia, Montenegro, Bosnia and Herzegovina, and parts of Romania and Serbia. Boza, the Turkish name, comes from the Persian word, *buze*, which means millet. Boza is made from various cereals such as wheat, rye, millet, maize, but the variety with the best quality and taste is made of millet flour. Boza production steps are as follows: (1) preparation of the raw materials, (2) boiling, (3) cooling, (4) sugar addition, and (5) fermentation (Aladeboyeje and Sanli, 2021). Boza is a viscous, low-alcohol beverage that ranges from creamy white and beige to light brownish colors, with a pleasant sweet taste and slightly acidic taste. Two types of fermentation co-occur during Boza fermentation. Alcohol fermentation produces carbon dioxide bubbles and increases the volume, while lactic acid fermentation produces lactic acid and provides its acidic character. The microbiota responsible for its fermentation shows a diversity of both homo- or hetero-fermentative LAB and yeasts. LAB strains are *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Pediococcus*, *Enterococcus*, *Oenococcus*, and *Weissella*. These include *Lactobacillus paracasei* subsp. *paracasei*, *Lactobacillus pentosus*, *Lactobacillus plantarum*, *Lactobacillus brevis*, *Lactobacillus rhamnosus*, *Lactobacillus fermentum*, *Lactobacillus acidophilus*, *Lactobacillus coprophilus*, *Lactobacillus coryniformis*, *Lactobacillus sanfranciscensis*, *Leuconostoc lactis*, *Leuconostoc mesenteroides*, *Leuconostoc mesenteroides* subsp. *dextranicum*, *Leuconostoc raffinolactis*, *Weissella kimchi*, and *Weissella paramesenteroides*. However, LAB cocci, including *Enterococcus faecium*, *Oenococcus oeni*, *Lactococcus lactis* subsp. *lactis* and *Pediococcus pentosaceus* are rare. Yeast isolates in Boza are *Candida diversa*, *Candida inconspicua*, *Candida pararugosa*, *Issatchenkia orientalis*, *Pichia fermentans*, *Pichia guilliermondii*, *Pichia norvegensis*, *Rhodotorula mucilaginosa*, and *Torulasporea delbrueckii* (Petrova and Petrov, 2017).

Bushera is an other traditional beverage most commonly consumed by children and adults in Uganda's urban and rural areas. It is produced by mixing sorghum or millet flour with boiling water and then fermenting at room temperature. The dominant flora consists of five LAB genera (*Lactobacillus* spp., mainly *Lactobacillus brevis*,

Lactococcus spp., *Leuconostoc* spp., *Enterococcus* spp., and *Streptococcus* spp.). Although studies on the probiotic potential of Bushera are still limited, there is evidence of its antidiarrheal effects (Panghal *et al.*, 2018).

A fermented corn product, ogi is a popular breakfast cereal in sub-Saharan African communities, primarily Nigeria. Traditional production begins with the fermentation of corn grains by soaking them in the water for 2–4 days at room temperature, then resting the milled and sieved slurry for 2–3 days at room temperature (Enujiugha and Badejo, 2017). The main microorganisms isolated were LAB, mainly *Lactobacillus* (*Lactobacillus acidophilus*, *Lactobacillus plantarum*, *Lactobacillus brevis*, and *Lactobacillus fermentum*) and yeast (*Saccharomyces cerevisiae*, *Rhodotorula graminis*, *Candida krusei*, *Candida tropicalis*, *Geotrichum candidum*, and *Geotrichum fermentum*) (Omemu, 2011). In many parts of Nigeria, it is a tradition for mothers to give their babies ogi liqueur (water prepared with fermented grain paste) to treat diseases such as diarrhea and abdominal pain (Adebolu *et al.*, 2007). Ogi is commonly consumed as semisolid oatmeal called “akamu” or steamed pudding called “agidi.” Therefore, heat treatment applied in both forms of ogi eliminates the existing LAB and, thereby, the ogi probiotic effect (Enujiugha and Badejo, 2017).

Mahewu is also a nondairy cereal-based probiotic product preferred by consumers of all age groups in South Africa. Mahewu is an alcohol-free beverage made by a multigrain mix, including maize, sorghum, millet, malt, and wheat flour. In the traditional production process, a multigrain mix is kept at room temperature for approximately 24 h for spontaneous fermentation. After fermentation, various fruit flavors may be added to the mixture to enhance the flavor. The major microorganisms responsible for Mahewu fermentation is *Lactococcus lactis* subsp. *lactis* (Bansal *et al.*, 2016; Enujiugha and Badejo, 2017).

Moreover, togwa, a traditional fermented beverage in Tanzania, is produced by fermenting multigrains such as maize, sorghum, finger millet, rice, cassava, and corn-flour. Due to the unhygienic preparation and variable end product characteristics, togwa is consumed by low-income people (Panghal *et al.*, 2018). Many *Lactobacillus* species, predominantly *Lactobacillus plantarum*, *Weissella confuse*, and *Pediococcus pentosaceus* and yeast (*Issatchenkia orientalis*, *Saccharomyces cerevisiae*, *Candida tropicalis*, and *Candida pelliculosa*), are the main microflora of Togwa (Aspri *et al.*, 2020; Mugula *et al.*, 2003).

In addition, Pozol, a nonalcoholic beverage, is mostly consumed in Southeast Mexico. Pozol is produced by cooking

corn in about 1% (w/v) lime solution, washing with water, grinding to make the dough known as nixtamal. They form into balls, wrapped in banana leaves, and fermented for half a day to 4 days at ambient temperature. Prior to consumption, the fermented dough is suspended in water. Pozol dominant microflora is amylolytic LAB strains, *Cladosporium guilliermondii* var. *guillier-mondii*, *Cladosporium cladosporioides*, and *Geotrichum candidum* (Bansal *et al.*, 2016; Panghal *et al.*, 2018).

Finally, soybean is the most important cereal because of its high nutritional value (Soccol *et al.*, 2010). Functional soybean products are fermented commonly by the LAB such as *Lactobacillus paracasei*, *Lactobacillus casei*, *Lactobacillus mali*, and *Bifidobacterium breve*. Traditionally in the past, soy products were made from China. Today, they are known in other parts of Asia and Europe. Soy products can be classified into two forms, including fermented soy products such as tempeh, natto, shoyu, miso, and sufu, and unfermented soy products include soy milk and tofu. Soy cheese is often called Tofu, a high-protein unfermented product (Zielińska *et al.*, 2015). Zielińska *et al.* (2015) aimed to produce tofu with probiotic bacteria such as *Bifidobacterium animalis* ssp. *lactis* BB-12 and *Lactobacillus casei* LOCK 0900. It was concluded that the viable count of *Lactobacillus casei* LOCK 0900 was 10^9 – 10^{10} CFU/g, but *Bifidobacterium animalis* ssp. *lactis* BB-12 did not exceed 10^3 CFU/g after 15 days of storage of tofu at 4°C. Tempeh is a fermented soybean product that originated from Indonesia. Tempeh is rich in soy protein and genistein, with beneficial effects on high blood sugar regulation and prevents diabetes. Tempeh is fermented with *Rhizopus microsporus* var. *oligosporus*. Moreover, *Acetobacter indonesiensis*, *Klebsiella pneumoniae*, *Bacillus subtilis*, *Flavobacterium* spp., *Brevundimonas* spp., *Pseudomonas putida* also play an important role in producing Indonesian tempeh. *Lactobacillus* families, such as *Lactobacillus agilis*, *Lactobacillus fermentum*, and *Enterobacteria cecorum* are commonly isolated from tempeh (Subandi *et al.*, 2019). Miso is a traditional Japanese fermented soy paste. There are three main types, including bean miso, rice miso, and barley miso, based on the malt material. Miso is commonly produced by fermentation of soybeans with *Aspergillus oryzae* together with some strains of LAB, including *Tetragenococcus halophilus* and yeast such as *Saccharomyces cerevisiae* (Kumazawa *et al.*, 2018). Natto is a Japanese cheese-like product made from soybeans by fermentation with *Bacillus subtilis* var. *natto* (former name, *Bacillus natto*). *Bacillus natto*, as a probiotic strain, could be used as a functional ingredient in natto production (Fujiwara *et al.*, 2008). Soymilk is a lactose-free product and contains GOS considered prebiotics as a source of energy due to the β -galactosidases in soybean. Soymilk can be obtained from the water extract of soybean and supports probiotic bacteria growth in probiotic foods.

Soymilk with probiotic cultures has some advantages, for example, decreasing the problems of beany flavor and flatulence connected to the oligosaccharide constituents (Hassanzadeh-Rostami *et al.*, 2015). Božanić *et al.* (2011) studied soy milk fermentation by the probiotic culture ABT5 (a mixture of *Lactobacillus acidophilus*, *Bifidobacterium* spp., and *Streptococcus thermophilus*) at two different temperatures (37°C and 42°C). Soymilk fermentation time was 7 h at 42°C and 8 h at 37°C. However, *Lactobacillus acidophilus* grew poorly in both fermentation procedures. The viable cell count of *Bifidobacteria* spp. was approximately 10^7 CFU/mL during 28 days of cold storage, better than *Lactobacillus acidophilus*. The authors emphasized that soymilk is a good substrate for *Bifidobacterium* spp.

Fruit- and vegetable-based probiotic products

Fruits and vegetables are rich in several nutrients such as phytochemicals, minerals, vitamins, soluble dietary fibers, and antioxidants. Moreover, they do not contain allergens and cholesterol. Thus, several food industries have produced healthy fruit- and vegetable-based probiotic products. Vegetable-based drinks, fermented or nonfermented fruit-based drinks, fermented banana pulp, beets-based and tomato-based drinks, peanut milk, dried fruits, green coconut water, and ginger juice are examples of some fruit- and vegetable-based probiotic products (Kumar *et al.*, 2022; Misra *et al.*, 2019; Song *et al.*, 2012). These fruit and vegetable juices are a novel and an appropriate probiotic vehicle that are investigated lately (Coşkun, 2017a, 2017b; Fazali *et al.*, 2007; Fu *et al.*, 2014; Garcia *et al.* 2020; Khatoon and Gupta, 2015; Lu *et al.*, 2018; Nguyen *et al.*, 2019; Pakbin *et al.*, 2014; Panghal *et al.*, 2018; Pereira *et al.*, 2013; Swain *et al.*, 2014; Thakur and Joshi, 2017; Yoon *et al.*, 2006).

Several factors limit the viability and survival of probiotic cultures in fruit and vegetable juices. The major parameters are (1) food matrix such as titratable acidity, water activity, pH, molecular oxygen, presence of sugar, artificial flavoring and coloring agents, (2) processing parameters such as heat treatment, cooling rate, packaging materials, and storage techniques, and (3) microbiological factors including probiotic strains, inoculum proportion, and rate of culture growth (Kumar *et al.*, 2022; Patel, 2017). There are two applications in obtaining probiotic fruits and vegetables: fermented and nonfermented probiotic products (Chaudhary, 2019). Many strains of *Lactobacillus plantarum*, *Lactobacillus acidophilus*, *Lactobacillus bifidus*, and *Lactobacillus casei* can grow on fruit and vegetable matrices due to their tolerance to acidic environments (Perricone *et al.*, 2015). Lactic fermentation occurs in fruits and vegetables in three ways: (1) spontaneous fermentation by natural microflora,

(2) fermentation by starter cultures added to raw material, and (3) fermentation by heat treatment materials by starter cultures (Chaudhary, 2019). The stability and viability of probiotic culture can be improved in juices by adding some prebiotics (dietary fiber, cellulose) or some ingredients that protect their effect (Perricone *et al.*, 2015). Microencapsulation techniques have also been investigated to preserve probiotic viability in these juices (White and Hekmat, 2018).

Probiotic fruit juices such as pineapple, orange, apple, mango, grapes, sweet lime, watermelon juice, cashew apple juice, blackcurrant juice, and cranberry are the most popular products in this category (Panghal *et al.*, 2018). Watermelon juice was produced using four *Lactobacillus* strains (*Lactobacillus casei*, *Lactobacillus acidophilus*, *Lactobacillus fermentum*, and *Lactobacillus plantarum*) by Fazali *et al.* (2007). Watermelon juice was first pasteurized at 63°C for 30 min and then inoculated with a 24 h-old culture of individual probiotic cells. After incubation at 37°C, the *Lactobacillus* strains grew in watermelon juice and reached a viable cell count of 10⁸ CFU/mL after 48 h. The antibacterial activity of probiotic watermelon juice against *Salmonella typhimurium* was also studied. All the *Lactobacillus* strains could completely inhibit the growth of *Salmonella typhimurium* after 2–6 h. Moreover, Pereira *et al.* (2013) optimized cashew apple juice fermentation by *Lactobacillus casei* NRRL B-442. The viable probiotic cell counts were observed to be higher than 8.0 log CFU/mL at 4°C for 42 days. Pakbin *et al.* (2014) also reported that *Lactobacillus delbrueckii* grew well in peach juice, and viable cell count reached nearly 10 × 10⁹ CFU/mL after 48 h of fermentation at 30°C. After 4 weeks of cold storage at 4°C, the viable cell count of *Lactobacillus delbrueckii* was 1.72 × 10⁷ CFU/mL. Thus, this juice can be consumed as a healthy probiotic beverage by vegetarians and lactose-allergic consumers. Khaton and Gupta (2015) found that the viable cell count of *Lactobacillus acidophilus* cultures in sugarcane juice and sweet lime juices reached 10⁸ CFU/mL after 24 h of fermentation at 37°C. After three weeks of storage at 4°C, the viable cell count of *Lactobacillus acidophilus* in the sugarcane juice was 4.0 × 10⁸ CFU/mL, while culture viability was lost in sweet lime juices after the second week of storage due to higher acidic conditions. The authors implied that fermented sweet lime and sugarcane juice could be further developed as a functional probiotic beverage. Grape juice, also called hardaliye, is a traditional fermented nonalcoholic beverage produced in Thrace, the European part of Turkey. *Lactobacillus sanfranciscensis*, *Lactobacillus acetotolerans*, *Lactobacillus pontis*, *Lactobacillus paracasei* ssp. *paracasei*, *Lactobacillus brevis*, and *Lactobacillus vacci-nostercus* are used as the probiotic bacteria in the fermentation of hardaliye. The health benefits of hardaliye

are: (1) high antioxidant effect, (2) prevents oxidative stress to inhibit cancer cells formation, and (3) decreases plasma lipid peroxidation parameters and serum homocysteine concentration (Coşkun, 2017a). Apple juice was fermented for 72 h by *Lactobacillus plantarum* by Thakur and Joshi (2017). After storage for four weeks at 4°C, the initial probiotic cell count decreased from 10⁷ CFU/mL to 4.76–6.00 × 10⁶ CFU/mL. The authors concluded that *Lactobacillus plantarum* is suitable for apple juices as a probiotic culture. Tempoyak produced from durian fruit widely grown in Southeast Asian countries such as Malaysia, Thailand, and the Philippines is a traditional fermented beverage. Durian pulp is fermented by spontaneous lactic acid fermentation. *Lactobacillus* species like *Lactobacillus mali*, *Lactobacillus brevis*, *Lactobacillus durianis*, *Lactobacillus fermentum*, and *Leuconostoc mesenteroides* are used to ferment tempoyak (Lu *et al.*, 2018; Swain *et al.*, 2014). In a similar study by Nguyen *et al.* (2019), pineapple juice fermented with *Bifidobacterium lactis* Bb-12, *Lactobacillus plantarum* 299V, and *Lactobacillus acidophilus* La5 was investigated. The viable cell counts of *Lactobacillus* strains were approximately 10⁹ and 10¹⁰ CFU/mL, while the *Bifidobacterium* strain was in the range of 10⁸ and 10⁹ CFU/mL in the first month of storage at 4°C. The authors suggested that probiotic *Lactobacillus plantarum* 299V was more suitable for developing probiotic pineapple juice drinks.

Cabbage, sauerkraut, fermented cucumbers, carrot root, potato, tomato, beet, onion, ginger, peanuts, and kimchi are the most studied vegetable-based probiotic products (Garcia *et al.*, 2020). Some examples of these products are summarized below. Firstly, shalgam is a red and sour soft traditional Turkish beverage made from black or purple carrot or their mixture. Shalgam, also called turnip juice, shalgam juice, or shalgam water, is produced by two methods with different formulations. Its microbiota mainly include yeasts such as *Saccharomyces cerevisiae* and *Lactobacillus* spp. (*Lactobacillus plantarum*, *Lactobacillus arabinosus*, *Lactobacillus fermentum*, *Lactobacillus buchneri*, *Lactobacillus pentosus*, *Lactobacillus brevis*, and *Lactobacillus paracasei* subsp. *paracasei*) (89.63%), *Leuconostoc* spp. (*Leuconostoc mesenteroides* subsp. *mesenteroides*) (9.63%) and *Pediococcus* spp. (*Pediococcus pentosaceus*) (0.74%). Generally, shalgam fermentation occurs in about 7 days at 25°C with a 3–4 months shelf life stored at 4 °C in a closed container. Its shelf life increases to about 6 months at 4–20°C if sterile filtration is used (Coşkun, 2017b; Garcia *et al.*, 2020). The other product is cabbage juice. Yoon *et al.* (2006) determined cabbage availability for probiotic cabbage juice production using *Lactobacillus L. plantarum* C3, *Lactobacillus casei* A4, and *Lactobacillus delbrueckii* D7 as probiotic cultures. During the fermentation at 30°C, *Lactobacillus casei*, *Lactobacillus delbrueckii*, and *Lactobacillus plantarum*

reached nearly 10×10^8 CFU/mL. After 4 weeks at 4°C, the viable cell counts of *Lactobacillus plantarum* and *Lactobacillus delbrueckii* was 4.1×10^7 CFU/mL and 4.5×10^5 CFU/mL, respectively, but *Lactobacillus casei* did not survive after 2 weeks because of low acidity. The authors concluded that *Lactobacillus plantarum* and *Lactobacillus delbrueckii* could be used as probiotic cultures to produce cabbage beverage. Do and Fan (2019) studied the suitability of a mixture of juices from jicama, winter melon, and carrot to produce a probiotic juice using *Lactobacillus plantarum* CICC22696 and *Lactobacillus acidophilus* CICC20710 strains. Both strains grew well in the vegetable juice mixtures after 24 h of fermentation at 37°C and reached nearly 9 and 8 log CFU/mL when inoculated with *Lactobacillus plantarum* and *Lactobacillus acidophilus*, respectively. At the end of the storage, the viability of *Lactobacillus plantarum* was approximately 8 log CFU/mL, whereas *Lactobacillus acidophilus* was 4.57 log CFU/mL. Kombucha is another vegetable-based probiotic drink consumed worldwide as a medicinal health-promoting drink (Kozyrovska *et al.*, 2012). Kombucha beverage is produced by fermenting sugared tea with a symbiosis of yeast spp., fungi, and acetic acid bacteria at ambient temperature for about 7–14 days. Besides, this beverage is composed of some probiotic lactic acid bacteria. Acetic acid bacteria species such as *Acetobacter xylinoides*, *Acetobacter pasteurianus*, *Acetobacter xylinum*, *Acetobacter aceti*, and *Bacterium gluconicum* are the main microflora in kombucha. Moreover, yeasts species, including *Brettanomyces bruxellensis*, *Brettanomyces lambicus*, *Brettanomyces custersii*, *Kloeckera imchite*, *Saccharomyces ludwigii*, *Schizosaccharomyces pombe*, *Saccharomyces cerevisiae*, *Zygosaccharomyces bailii*, *Candida*, and *Pichia* were also isolated from kombucha (Fu *et al.*, 2014). Tomato juice is also another product based on vegetable probiotic juice. Yoon *et al.* (2004) determined the suitability of tomato juice as a raw material for probiotic juice production using *Lactobacillus acidophilus* LA39, *Lactobacillus plantarum* C3, *Lactobacillus casei* A4, and *Lactobacillus delbrueckii* D7. Tomato juice was inoculated with 24 h-old probiotic cultures and incubated at 30°C. The viable cell count reached nearly from 1.0 to 9.0×10^9 CFU/mL after 72 h. Moreover, the four LAB strains' viable cell count ranged from 10^6 to 10^8 CFU/mL after 4 weeks at 4°C.

Traditionally, vegetable-based fermented pickles have a long history in different cultures worldwide (Fan *et al.*, 2017). It can be produced by lactic fermentation (vegetables and fruits), alcoholic fermentation (cassava and rice), high salt fermentation (fish and soy sauce), and mold fermentation (peanut press cake and soybeans) (Behera *et al.*, 2020). There are several pickles produced under different names in the world. Kimchi is a traditional pickled vegetable from Korean culture. Cabbages, radish,

garlic, green onion, ginger, red pepper, mustard, parsley, jeotgal (fermented seafood), carrot, and salt are used for producing kimchi. The main microflora of kimchi were various LAB strains, with *Lactobacillus kimchii* being the typical fermenting species, and also fermented kimchi contained high levels of LAB (about 10^7 – 10^9 CFU/g). In addition, many *Leuconostoc* spp. and *Lactobacillus* spp., including *Leuconostoc citreum*, *Leuconostoc gasicomitatum*, *Leuconostoc gelidum*, *Lactobacillus sakei*, and *Lactobacillus brevis* are the predominant species. Many active compounds in kimchi showed anticancer, antiobesity, and antiatherosclerotic functions (Park *et al.*, 2014). Gundruk is another pickled product from Nepal. Gundruk is a nonsalted, fermented, acidic vegetable product obtained by fermenting leafy vegetables (rayo-sag, mustard leaves, cauliflower leaves, and cabbages). Its fermentation is usually dominated by *Pediococcus* spp. (*Pediococcus pentosaceus*) and *Lactobacillus* spp., (*Lactobacillus fermentum*, *Lactobacillus casei*, *Lactobacillus casei* subsp. *pseudopantarum*, *Lactobacillus cellobiosus*, and *Lactobacillus plantarum*) the initiators of fermentation. Fermentation time is reported to be about 15–22 days (Swain *et al.*, 2014). Khalpi, also called cucumber, is a pickled cucumber from Nepal. *Lactobacillus plantarum*, *Lactobacillus brevis*, and *Leuconostoc fallax* are commonly involved in khalpi fermentation. Moreover, the cucumber can be fermented using a pure or mixed culture of *Lactobacillus plantarum* and *Saccharomyces cerevisiae*. Khalpi fermentation occurs in 4–7 days at room temperature (Behera *et al.*, 2020). Turşu, a traditional fermented Turkish pickle, is made of different vegetables such as cabbage, cucumber, carrot, beet, pepper, turnip, eggplant, and beans. *Lactobacillus plantarum*, *Lactobacillus brevis*, *Leuconostoc mesenteroides*, and *Pediococcus pentosaceus* are the dominant microorganisms during fermentation (Irkin and Songun, 2012). Al-Shawi *et al.* (2019) investigated the effect of adding probiotic bacteria (*Lactobacillus acidophilus*) and synbiotic (*Lactobacillus acidophilus* + inulin) in tursu. The cell count of *Lactobacillus acidophilus* was higher in the synbiotic (log 9.68 CFU/mL) than the probiotic (log 9.54 CFU/mL) and control (log 3.97 CFU/mL) at the end of the storage period. After 30 days, the total cell count was higher in the control sample (log 6.99 CFU/mL) than probiotic (log 6.90 CFU/mL) and synbiotic samples (log 6.52 CFU/mL), respectively. The authors implied that synbiotic pickle had more desirable characteristics compared with probiotic and control pickle. Sunki is a traditional Japanese nonsalted pickle made from the fermentation of the leaves of red turnips. *Lactobacillus kisonensis*, *Lactobacillus otakiensis*, *Lactobacillus rapi*, and *Lactobacillus sunkii* are the predominant species in sunki. However, *Lactobacillus delbrueckii* identified as the subdominant LAB strain (Kudo *et al.*, 2012).

Meat-based probiotic products

Meat and meat products are essential components of human nutrition. Raw-cured and ripened meat products are traditionally produced by fermentation worldwide. Moreover, drying is the oldest food preserving methods in the world. Meat-based probiotic products are relatively new and recently adopted by the meat industry (Kołożyn-Krajewska and Dolatowski, 2012; Kumar *et al.*, 2022).

LAB (*Lactobacillus casei*, *Lactobacillus curvatus*, *Lactobacillus pentosus*, *Lactobacillus plantarum*, *Lactobacillus sakei*, *Pediococcus acidilactici*, and *Pediococcus pentosaceus*), Staphylococci (*Staphylococcus xylosus*, *Staphylococcus saprophyticus* or *Staphylococcus carnosus*), and Micrococci (*Micrococcus varians*) are frequently used as a starter culture in the meat fermentation process (Song *et al.*, 2012). In general, a single LAB species or together with other bacteria are used as a starter culture. Due to its high moisture content (70–80%), raw meat is easily contaminated with pathogenic microorganisms transmitted from animal skin to raw meat during slaughter (Holck *et al.*, 2017; Kumar *et al.*, 2022). LAB strains used in meat fermentation strongly inhibit pathogens. Therefore, LAB is widely used to preserve meat products for consumer quality purposes (Fraqueza *et al.*, 2020). Various factors influence the viability of probiotic cultures in fermented meat products. These are low pH, low water activity, acidity, organic acid concentration, microorganisms (native microflora of meat), processing and storage temperature, oxygen content, salt, low content of natural sugars, and additives (nitrite and nitrate) (Aspri *et al.*, 2020).

Dry-fermented sausages are the only example of a probiotic application in fermented meats (Song *et al.*, 2012). Dry-fermented meat products are popular in the world. Depending on the geographic region, there are many types of dry-fermented sausages. For example, in Portugal, chouriço, paio, catalão, salsichao, linguiça, palαιο, salpicão, butelo, cacholeira, alheira, farinheira, and morcela are produced as a dry-fermented sausage (Rocha and Elias, 2016). Salami in Italy, sucuk in Turkey, and salchichon and chorizo-like Mediterranean-type sausages in Spain are the other examples of dry-fermented sausage types (Holck *et al.*, 2017). However, producing these food products has a high contamination risk, especially during drying, slicing, and packaging steps (Song *et al.*, 2012). Thermal processes during the production of dry-fermented meat are usually not used or only heated mildly. This temperature is not harmful to probiotic strains, so the transfer of probiotic microorganisms into the human gastrointestinal tract is provided easily (Rocha and Elias, 2016). Some probiotic microorganisms such as *Lactobacillus acidophilus*, *Lactobacillus casei*, *Lactobacillus paracasei*, *Lactobacillus rhamnosus*,

Lactococcus lactis subsp. *lactis*, *Lactobacillus plantarum*, *Lactobacillus reuteri*, *Lactobacillus fermentum*, *Bifidobacterium animalis*, *Bifidobacterium lactis*, and *Pediococcus pentosaceus* have also been used in fermentation and ripening of these meat products as bioprotectors against pathogenic strains (Cavalheiro *et al.*, 2015). Thus the selection of suitable probiotic starter culture is vital in the production of dry-fermented sausage products.

The most important probiotic selection criteria are that probiotic strains can compete with the bacteria in meat, survive the production processes such as fermentation and drying, refrigeration, and storage. Moreover, they should have sufficient numbers in the final products for expected health effects (Khan *et al.*, 2011; Kumar *et al.*, 2022). LAB plays the central role in sausage production by producing organic acids (mainly lactic acid) that inhibit undesirable microorganism growth. At the beginning of the sausage fermentation, the LAB count ranged between 3.2 and 5.3 log CFU/g. However, LAB count reached 7–9 log CFU/g in the first days and remained at this level during ripening (Maksimović *et al.*, 2015).

Jofré *et al.* (2015) tested the efficiency of *Lactobacillus casei/paracasei* CTC1677, *Lactobacillus casei/paracasei* CTC1678, *Lactobacillus rhamnosus* CTC1679, *Lactobacillus gasseri* CTC1700, *Lactobacillus gasseri* CTC1704, and *Lactobacillus fermentum* CTC1693 as potential probiotic strains in model sausage systems. Only CTC1677, CTC1678, and CTC1679 were able to grow and dominate at 15°C after 9 days (10^8 CFU/g) during ripening. Probiotic strain *Lactobacillus casei* CRL431 was added in traditional Turkish dry-fermented sausage, namely sucuk (Bağdatlı and Kundakci, 2016). At the end of the fermentation and ripening period, the number of *Lactobacillus casei* CRL-431 reached a sufficient microbial count (approximately 10^6 CFU/g). Thus, the authors implied that *Lactobacillus casei* CRL 431 could be used as a probiotic strain in Turkish sausage production. Nedelcheva *et al.* (2014) prepared the raw-dried meat sausages using a probiotic strain *Lactobacillus plantarum* NBIMCC 2415. The viable cell count of *Lactobacillus plantarum* NBIMCC 2415 was approximately 10^{12} CFU/cm³ on day 6 at 15–18°C. This probiotic strain completely inhibited the growth of pathogenic bacteria such as *Escherichia coli* ATCC 25922, *Proteus vulgaris* G, *Salmonella abony* NTCC 6017, *Staphylococcus aureus* ATCC 25093, and *Listeria monocytogenes* I at 15–18°C during the meat production.

Conclusion

Probiotic foods comprise 60–70% of the total functional food market. Dairy-based probiotic products are the primary vehicle of probiotic cultures to humans and

animals. However, lactose intolerance, nutrition habits, protein allergies, and vegetarianism restrict dairy-based probiotics consumption. Nondairy-based food products are utilized by probiotic cultures to overcome this situation. Hence, currently, the interest in the development of these probiotic products is increasing in the world. Consequently, depending on the increase in the research on nondairy-based probiotic foods, different products are expected to reach the market shelves.

Conflict of Interest

The author declares no conflict of interest associated with this work.

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