Probiotics database: a potential source of fermented foods

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ABSTRACT
Probiotics have been widely explored in production, research, environmental protection, and disease prevention. Recent efforts have been devoted to the separation of new probiotics from microbes that have never been discovered and the research of their mechanism of action. PBDB, it is a database that collects probiotics from different fermented foods. It has been established and collected 1730 known probiotics (768 production, 264 research, 22 environmental protection, 17 disease control, 659 others) providing the biological information for use in humans, animals, and plants. The database will be updated and expanded periodically. The database can provide empirical data for better comprehension and application in bioinformatic studies. The potential function of the database has been confirmed by the included database, which allows for the analysis of biological information and the mechanisms of probiotics to predict new probiotics from unknown microbial resources. PBDB can be accessed at http://www.lzubiodrugs.com/.

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Introduction
Fermented foods containing beneficial bacteria have existed for thousands of years. These bacteria are called probiotics and when administered in adequate amounts, confer a health benefit to the host. In recent years, probiotics has been confirmed to be clinically effective for the treatment of various diseases \textit{in vitro} and \textit{in vivo}. Probiotics have been widely explored for production, including the production of poultry products\textsuperscript{[1]}. The new feed additives, such as probiotics, are used to regulate the intestinal microbial population of poultry to incur a protective effect on animal health and the fermentation of functional foods. Another example is kimchi, a traditional and popular Korean fermented food of which there are approximately 200 types. Serofluid dish, a traditional food in the Chinese culture for thousands of years, is another example. Serofluid dish forms complex and distinct bacterial communities\textsuperscript{[2]}, resulting in the production of probiotic cultures, bacteriocins, and enzymes. A number of probiotics have been used in research. The PDBD includes classification research, research and analysis, research and teaching, protease production research, and biological control research. Some probiotics are used in environmental intelligence and protection, specifically in the degradation of organic pollutants\textsuperscript{[3]} and the treatment of phenol wastewater. Probiotics can also be used for the control of animals, plants, and human diseases. This includes the control of peanut nematode disease, inhibition of cotton \textit{Fusarium oxysporum}, biological insecticide, and killing Lepidoptera pests.

Probiotic products have become rapidly growing fields both in China and globally, giving them broad market prospects and social values. However, probiotic resources have not yet fully developed. The formation of the industrialization of probiotics and the existence of small-scale production such
as small workshops and environmental hygiene generally does not meet the requirements of product development. There is a need to realize the industrialization of probiotics. Therefore, a better-standardized way was developed for the probiotic products. Most of the bacterial diversity studies in the last two decades have shown that less than 1% of the microbes of a community can be cultured in vitro with known cultivation approaches, but 99% still remain unexplored.\[4] The role of probiotics in human health, as well as the safety of their application, should be further investigated as the current knowledge of their functionality in the gut is not complete. People do not fully understand the nutritional functions of probiotics present in fermented products because there is no scientific knowledge and classification analysis of these probiotics. A database of probiotics from fermented foods can help us solve the above problems. Fermentation may improve the digestibility and nutritional quality of food through the enrichment of food substrates with vitamins, proteins, essential amino acids, and essential fatty acids. More precisely, fermentation may link the diversity of the community of fermenting microbes and their properties to the energetics of the process and to product quality. In recent years, there has been an increasing interest in probiotic fermented foods, which has stimulated innovation and fueled the development of new products around the world. Probiotic bacteria have increasingly been incorporated into foods in order to improve gut health by maintaining the microbial gastrointestinal balance. Some important bacteria are the acetic acid producing species *Acetobacter*, associated with the fermentation of fruits and vegetables, and *Bacillus*, associated with the fermentation of legumes. In addition, we also provide some information about the bacteriocins produced by bacteria in fermented foods (Table 1). Yeast plays an important role in the food industry because of the production of enzymes that result in desirable biochemical reactions. This is seen in the production of ethanol in wine and beer and the leavening of bread. Therefore, it is beneficial to the industrial development of probiotics products. Through researching the biological information of probiotics in different fermented foods, we have a better understanding of probiotics and the active substances. Moreover, the functions and characteristics of various microorganisms in different fermented foods can be understood by PBDB. Although no report has fully showed the probiotics in fermented foods using integrated database, this work will very important to develop in health field.

This paper aimed to research the biological information platform of probiotics in different fermented foods by summarizing different probiotics and predicting the new microbial strains with comparative analysis. It can be said that the status quo of probiotics, we also created a database of probiotic media. Typical patterns of probiotic media usage and composition can reveal fundamental trends in microbial nutrition, as well as help us find new probiotic microorganisms through the knowledge of existing microbes. And then we developed a phylogenetic-based new microbial-medium pairing predictor that enabled the successful prediction of new microbes in cultured organisms. We can provide this resource in an online searchable database and provide a tool to predict new probiotics based on biological information such as 16S rDNA sequences. The PBDB database have collected 1730 known probiotics (768 production, 264 research, 22 environmental protection, 17 disease control, 659 others) and their biological information in humans, animals, and plants. The database will be updated and expanded periodically, which can provide biological information of reported-probiotics and predict new probiotics from unknown microbial resources.

**Nutritional characteristics of different fermented foods**

**Fermented dairy products or food**

The probiotics were obtained from Genbank, Pubmed, BeNa Culture Collection (BNCC) database by searching a variety of probiotic strains. The four classified probiotics come from the following sources. The probiotics from fermented dairy products or food has benefits for humans. There are also therapeutic and preventive effects of probiotics in yogurt on diseases such as cancer, infection,
| Bacteriocin       | Origin/source of fermented food | Producer Strain | Proffits/activity against                                                                                                                                     | Reference |
|------------------|---------------------------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| LiN333           | Chinese fermented vegetable     | *Lactobacillus casei* | LiN333 displayed antimicrobial ability against Gram positive and Gram negative pathogenic and antibiotic resistant bacteria                                      | [5]       |
|                  | (Jiangshui Cai)                 |                 | Lactobacillus casei, Lactobacillus sakei, Pseudomonas aeruginosa, *Escherichia coli* and *Enterococcus faecalis*.                                                 |           |
| Bacteriocins     | South African barley beer       | *Lactobacillus paracasei subsp. paracasei*, *Lactobacillus plantarum*, *Lactobacillus pentosus*, *Lactococcus lactis subsp. lactis* |                                                                                                           | [6]       |
|                  |                                 |                 | Lactobacillus casei, Lactobacillus sakei, Pseudomonas aeruginosa, *Escherichia coli* and *Enterococcus faecalis*.                                                 |           |
| ST11BR, ST13BR,  |                                 |                 |                                                                                                           | [7]       |
| ST151BR and ST34BR |                                |                 |                                                                                                           |           |
| Bacteriocins     | Honeybee beebread               | *Enterococcus avium* | Listeria monocytogenes, Listeria spp.                                                                                                                         |           |
|                  |                                 |                 |                                                                                                           | [8]       |
| HA-6111–2 and HA-5692–3 |                      |                 |                                                                                                           |           |
| Bacteriocin      | Kefir                            | *Lactobacillus plantarum* | Lactobacillus casei, *L. salivarius*, *L. curvatus* and *Listeria innocua*.                                                                               | [9]       |
| ST8KF            |                                 |                 |                                                                                                           |           |
| Bacteriocina     | Lukanka, dry Bulgarian sausage  | *Lactobacillus pentosus*, *Lactobacillus brevis* |                                                                                                           | [10]      |
| Lactococcin 972  | Starter-free cheese made from raw milk | *Lactococcus lactis subsp. lactis Q1-2* | Lactobacillus sakei and same strains of *L. lactis* subsp. lactis and *cremoris*.                                                                            | [11]      |
| Lactococcin G    | Starter-free cheese made from raw milk | *Lactococcus lactis subsp. Cremoris 2A27* | Lactobacillus sakei and same strains of *L. lactis* subsp. lactis and *cremoris*.                                                                            | [11]      |
| Nisin A          | Starter-free cheese made from raw milk | *Lactococcus lactis subsp. lactis* | Staphylococcus aureus, *Listeria innocua*, Lactobacillus casei, Lactobacillus plantarum, same strains of *L. lactis* subsp. lactis. | [11]      |
| Nisin Z          | Starter-free cheese made from raw milk | *Lactococcus lactis subsp. lactis* | Staphylococcus aureus, *Listeria innocua*, Lactobacillus casei, Lactobacillus plantarum, same strains of *L. lactis* subsp. lactis. | [11]      |
| Plantaricin MG   | Jiaoke, a traditional, naturally fermented cream from China | *Lactobacillus plantarum* | Listeria monocytogenes, *Staphylococcus aureus*, *Salmonella typhimurium* and *Escherichia coli*.                                                           | [12]      |
| Bacteriocin      | Norwegian smoked salmon         | *Enterococcus faecium* | Enterococcus faecalis, Lactobacillus curvatus, *L. sakei*, *Listeria innocua*, *L. monocytogenes*.                                                            | [13]      |
| ST5Ha            |                                 |                 |                                                                                                           |           |
| Bacteriocin      | Boza, a fermented cereal-based  | *Lactococcus lactis subsp. lactis MA23* | Many gram-positive bacteria, also lactococcal strains that are producing nisin, lactocin or lactococcin.                                                        | [14]      |
| MA23             | beverage (from Turkey)          |                 |                                                                                                           |           |
| Lactococcin BZ   | Boza, a fermented cereal-based  | *Lactococcus lactis subsp. lactis BZ* | Lactobacillus, *Enterococcus*, *Leuconostoc*, *Listeria*, *Bacillus*, *Enterobacter*, *Escherichia*, *Rhodococcus*, *Salmonella* | [15]      |
|                  | beverage (from Turkey)          |                 |                                                                                                           |           |
| Garvieacin Q     | Nham, Thai fermented pork sausages | *Lactococcus garvieae* | Strains of the closely related bacteria *L. garvieae*, as well as the potentially pathogenic *Enterococcus faecium*, and *Listeria monocytogenes*. | [16]      |

(Continued)
gastrointestinal disorders, and asthma. Intestinal disorders, including chronic constipation, diarrhea, colitis, dyspepsia, dysentery, sprue, can be improved by probiotics. Furthermore, they can have antibacterial effects in gut, antitumor properties, increase the nutritional quality of food, and act as a treatment of pulmonary tuberculosis.

**Fermented soy products or grain-based foods**

The probiotics from fermented soy products or grain-based foods have a benefit to humans. Soybeans have many compounds with a variety of biological properties that potentially benefit human health. Soy products can increase nutritional quality and stimulate the immune system. Over the generations, utilizing microorganisms and their enzymes, cereal grains have been transformed into value-added products. Fermented cereals also can improve digestion and lower blood lipid levels.

**Fermented vegetable or fruit foods**

The probiotics from traditional fermented vegetable or fruit foods also have a benefit for humans. Several fermented vegetables products have a long history in human nutrition. Fermented vegetables benefits include anticancer, anti-obesity, anti-constipation, antimicrobial, and antitumor
Kimchi can be considered a vegetable probiotic food that contributes health benefits in a similar manner as yogurt as a dairy probiotic food. Serofluid dish (or Jiang shui, in Chinese), a traditional food in the Chinese culture for thousands of years. Serofluid dish formation complex and distinct fungal communities structure. Kimchi, probably Korea’s most famous traditional fermented food, about 200 types of kimchi in Korea. Kimchi types vary according to vegetables, spices, and other ingredients used, and methods of preparation. Kimchi possesses anti-inflammatory, antibacterial, probiotic properties, cholesterol reduction, and anti-aging properties.\[^{28}\]

**Application of probiotics from fermented foods**

Other probiotics from traditional fermented foods can be used in production. They are mainly used to produce pectinase, alkaline protease, esterase, high-temperature protease, lipase, cellulase, lignin plum, and amylase. Microorganisms have been recognized as potential sources of novel enzymes because they produce enzymes that are relatively more stable than the corresponding enzymes derived from plants and animals.\[^{29}\] It can also be used as a feed additive to improve poultry health. The beneficial effects of probiotics include greater growth, increased feed efficiency, prevention of intestinal disorders, and the pre-digestion of anti-nutritional factors present in the ingredients. Some studies have attributed probiotics to the enhancement of animal growth due to the bacterial production of vitamins, amino acids, minerals, trace elements, and digestive enzymes.\[^{30}\] A meta-analysis of the effects of probiotics on pig growth was conducted by a study from 1980 to 2015. Among them, 67 studies were conducted on the effects of probiotics on average daily gain of pigs, and 60 studies on feed efficiency. The results showed that pigs supplemented with probiotics The average daily gain is increased and the feed efficiency is improved.\[^{31}\]

In addition, studies have shown that probiotics can increase the flavor of chicken and increase the diversity of intestinal flora. The probiotic powder was prepared from P. pentrea and five Bacillus spores for 76 days. The abundance of Bacteroides in the probiotic group increased, Bacillus was beneficial to increase the body weight of the cock, and the average short-chain fatty acid level in the Pediococcus pentosus group was higher. The chicken breast of the Pediococcus pentosus group has more characteristic flavor substances, especially (E)-2-heptanal, (E, E)-2, 4-nonadienal and some C6-C9 unsaturated fatty acids. Strong chicken fat or fat aroma directly improves chicken flavor.\[^{32}\] In this way, probiotics will be more widely used in fermented foods.

The correspond information for each probiotic, including species, storage conditions, growth conditions, growth characteristics, strain patterns, application areas, passage methods, description, were obtained from the BNCC database. The probiotic function of each was extracted from the descriptions in the literature. The literature describes the function of some probiotics for use in humans, animals, plants. There is increasing empirical evidence that the gut microbiota is an indispensable component of human physiology system. Disruption of the gut microbiota can bring about a range of inflammatory, immune, and metabolic disorders. This has also contributed to research on the impact of some probiotics on human health through the mediation of the human gut microbiota. Internationally, the World Gastroenterology Organization (WGO) have presented the evidence and proposed recommendations for the use of probiotics for the prevention and treatment of disease. The probiotics also have been widely explored for therapeutic and health benefits in humans and the growth, protection eth and health maintenance\[^{33,34}\] of animals in diverse medicine. The application of probiotics on plants can also enhance growth and yield.

**Importance and potential application of PBDB**

**PBDB database structure and access**

PBDB currently contains 1730 known probiotics (768 production, 264 research, 22 environmental protection, 17 disease control, 659 others) and provides corresponding biological information.
Probiotics from traditional fermented foods (Figure 1) are mainly used to produce a probiotic food drink, nutrition supplements, and feed additive to improve health in humans, animals, or plants. The currently understood information about these probiotics have been collected (Table 2). The database can provide empirical data for comparative and bioinformatic studies. The potential application of the database has been confirmed by the included database, which allows for the analysis of biological information and the mechanisms of probiotics to predict new probiotics from unknown microbial resources. PBDB can be accessed at http://lzubiodrugs.com

Applications of the PBDB database

The direct applications of the PBDB database can be illustrated by the development of a probiotic product. Using the PBDB keyword search, 768 probiotics are used to produce probiotic products. Of these, 679 probiotics were used to produce probiotic food drink, 13 were used to produce nutritional supplements, and 76 were used to produce animal feed. There are 264 kinds of probiotics used in the research field. Twenty-two are studied for probiotic food drinks, five for nutritional supplements, and six for animal forage. In addition, there are 22, 17 species for environmental protection and disease control (Table 3). In particular, many probiotics are marketed for human, animals and plants use, and their probiotic effects can be found in the respective probiotics entry page and further details of the relevant investigation can be obtained from the references provided in PBDB database.

In PBDB database, the probiotics entries are cross-linked to the respective complete information from references. The information of microorganisms and health or nutrition benefits on the probiotic fermented foods is highly useful for the investigations of the functions, mechanisms, and

Figure 1. Overall probiotics in PDBD.
| Food                        | Country          | Ingredients          | Microorganisms                                                                 | Health/Nutrition Benefits                                                                 | References |
|-----------------------------|------------------|----------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|------------|
| Acidophilus milk            | Various countries| cow milk             | *Lactobacillus acidophilus, Lactobacillus, deLactobacillus rueckii subsp. bulgaricus, Lactobacillus. helveticus, Lactobacillus. paracasei subsp. paracasei, Lactobacillus. paracasei subsp. pseudoplantarum* | intestinal disorders including chronic constipation, diarrhea, colitis, sprue              | [35–37]   |
| Amasi or mukaka wakora or zifa | Zimbabwe      | milk                 | *Lactococcus. lactis subsp. laci, Lactococcus. lactis subsp. lactic, Lactobacillus. bulgaricus, Lactobacillus. paracasei subsp. paracasei, Lactobacillus. plantarum, Lactobacillus acidophilus, Leuconostoc. Mesenteroides subsp. mesenteroides, Enterococcus. faecium Enterococcus. faecalis* | inhibition of pathogens                                                                   | [38]      |
| Ayib                        | Ethiopia        | goat milk            | *Lactobacillus. bulgaricus, Lactococcus. lactis subsp. lactis, Lactococcus. lactis subsp. cremoris, Lactococcus. lactis subsp. lactis biovar diacetylactis, Leuconostoc. mesenteroides s subsp. cremoris* | easy to absorb nutrients                                                                  | [39]      |
| Butter milk (various local names) | Various countries | cow milk             | *Lactobacillus. bulgaricus, Lactococcus. lactis subsp. lactis, Lactococcus. lactis subsp. cremoris, Lactococcus. lactis subsp. lactis biovar diacetylactis, Leuconostoc. mesenteroides s subsp. cremoris* | stimulates the power of digestion, treating hemorrhoids, IBS and other abdominal disorders. | [35]      |
| Caplis                      | Japan           | cow milk             | *Lactobacillus. helveticus, Saccharomyces cerevisiae Lactococcus. lactis subsp. lactis, Lactococcus. lactis subsp. cremoris, Streptococcus Thermophilus, Lactobacillus. helveticus, Lactobacillus. deLactobacillus rueckii subsp. bulgaricus, yeasts, molds* | the source of proteins, fat, vitamins and minerals. it creates a buffer against the high acidic environment | [40]      |
| Cheese (various local names) | Various countries | cow milk, or goat milk, or sheep milk | *Lactobacillus. helveticus, Saccharomyces cerevisiae Lactococcus. lactis subsp. lactis, Lactococcus. lactis subsp. cremoris, Streptococcus Thermophilus, Lactobacillus. helveticus, Lactobacillus. deLactobacillus rueckii subsp. bulgaricus, yeasts, molds* | the source of proteins, fat, vitamins and minerals. it creates a buffer against the high acidic environment | [37]      |

(Continued)
| Food                  | Country            | Ingredients                          | Microorganisms                                                                 | Health/Nutrition Benefits                                                                 | References |
|----------------------|--------------------|--------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|------------|
| Dahi (Indian yogurt) | India              | cow milk or buffalo milk             | *Lactococcus. lactis* subsp. *cremoris*, *Lactococcus. lactis* subsp. *lactis*,  | intestinal disorders (dyspepsia, dysentery, diarrhoea, etc); improved digestion, antibacterial effects in gut | [35]       |
|                      |                    |                                      | *Streptococcus Thermophilus*, *Lactobacillus. delactobacillus rueckii subsp. bulgaricus*, *Lactobacillus acidophilus*, *Lactobacillus. helveticus*, *Lactobacillus. fermentum*, *Lactobacillus. casei*, *Lactobacillus. plantarum* |                                                |            |
|                      |                    |                                      |                                                                                |                                                |            |
| Ergo or irgo         | Ethiopia           | cow milk                            | *Lactobacillus sp.* *Streptococcus sp.*                                      | increased nutritional value                                                                  | [40]       |
|                      |                    |                                      |                                                                                |                                                |            |
| Jben                 | Morocco            | sheep milk                          | *Streptococcus Thermophilus*                                                   | accelerated discharge of toxic and hazardous substances                                     | [39]       |
|                      |                    |                                      |                                                                                |                                                |            |
| Katyk                | Kazakhstan         | cow milk                            | *Streptococcus Thermophilus*, *Lactococcus. lactis* subsp. *lactis* *biovar diacetylactis*, *Lactobacillus. helveticus*, *Lactobacillus. casei*, *Lactobacillus. plantarum* | increased nutritional value, easy to absorb nutrients                                      | [40]       |
|                      |                    |                                      |                                                                                |                                                |            |
| Kefir                | Russia             | cow milk or goat milk or sheep milk  | *Lactobacillus sp.*, *Leuconostoc sp.*, *Lactococcus sp.* *yeasts*              | antitumour properties; digestive system disorders                                           | [41]       |
|                      |                    |                                      |                                                                                |                                                |            |
| Kehran or karan or heran or lapte-akru | Siberia, Rumania | cow milk                            | *Streptococcus Thermophilus*                                                   | increased nutritional value                                                                  | [40]       |
|                      |                    |                                      |                                                                                |                                                |            |
| Kishk or kisk, or kushuk (various local names) | Egypt, Syria, Lebanon, (many other countries) | milk (yogurt) and wheat | *Lactobacillus. casei*, *Lactobacillus. plantarum*, *Lactobacillus. brevis*, *Bacillus subtilis*, *Bacillus. lichenformis*, *Bacillus. megatherium*, *yeasts* | increased nutritional quality                                                                | [35,42]   |
|                      |                    |                                      |                                                                                |                                                |            |
| Koumiss or kumys or coomys | Russia | mare milk, or cow milk              | *Lactobacillus. deLactobacillus rueckii subsp. bulgaricus*, *Lactobacillus acidophilus Torula yeast* | hypolipidemic and immunomodulatory effects                                                    | [35,40]   |
|                      |                    |                                      |                                                                                |                                                |            |
| Liban                | Lebanon            | cow, sheep, goat, or camel milk      | *Streptococcus Thermophilus*, *Leuconostoc. lactis*, *Lactobacillus acidophilus*, *Kluyveromyces fragilis*, *Saccharomyces cerevisiae* | potential ability to help with allergies and autism                                             | [43]       |
|                      |                    |                                      |                                                                                |                                                |            |
| Laban rayeb or leban rayeb, or raib | Egypt | cow or sheep milk                  | *Lactococcus. lactis* subsp. *lactis*, *Staphylococcus. kefir*, *Lactobacillus. casei*, *Staphylococcus. faecalis* | help probiotics colonize                                                                       | [35,39]   |

(Continued)
| Food                  | Country          | Ingredients         | Microorganisms                                                                 | Health/Nutrition Benefits                                                                 | References |
|----------------------|------------------|---------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|------------|
| Leban zeer           | Egypt            | cow milk            | *Lactobacillus. casei*, *Lactobacillus. plantarum*, *Lactobacillus. brevis*      | promote digestion                                                                          | [35]       |
| Leben (or Lactobacillus en) | Zimbabwe, Morocco | cow milk            | *Lactic acid bacteria*, *Lactococcus. lactic subsp. lactis*, *Lactococcus. lactis subsp. lactis* biovar diacetylactis, *Leuconostoc. lactis*, *Leuconostoc. mesenteroides subsp. cremoris* *Leuconostoc. mesenteroides subsp. dextranum*, *Lactobacillus sp.*, yeasts, molds | reduce blood fat, fight cancer                                                               | [35,39,43] |
| Liban Lyubitelskii   | Iraq, USSR       | cow milk            | *Sterptococcus Thermophilus*, *Lactococcus. lactic subsp. lactis* biovar diacetylactis, *Lactococcus. lactis subsp. cremoris* *Lactococcus. lactis subsp. lactis biovar diacetylactis*, *Leuconostoc. mesenteroides subsp. cremoris* | reduce cholesterol preventing cardiovascular disease in the elderly                           | [35], [40] |
| Miziwa lala or mala  | Kenya            | cow milk            | *Lactococcus. lactis subsp. cremoris*, *Lactococcus. lactis subsp. lactis* biovar diacetylactis, *Leuconostoc. mesenteroides subsp. cremoris* | improve human immune function                                                              | [40]       |
| Nono                 | West Africa      | cow, sheep milk     | *Lactobacillus acidophilus*, *Lactococcus. lactis subsp. cremoris*, *Lactobacillus. deLactobacillus rueckii subsp. bulgaricus*, *Lactobacillus. helveticus*, *Lactobacillus. plantarum* *Lactobacillus. lactis subsp. cremoris* | overcoming lactose intolerance                                                            | [39,40]    |
| Nordic or Scandinavian sour milk (various local names) | Norway, Sweden | cow milk            | *Lactic acid bacteria*, *Lactococcus. lactis subsp. lactis*, *Lactococcus. lactis subsp. cremoris*, *Lactococcus. lactis subsp. lactis biovar diacetylactis*, *Leuconostoc. mesenteroides subsp. cremoris* | enhance flavor, prevention and treatment of diabetes and liver disease also have a certain effect | [40]       |
| Skyr                 | Iceland          | cow milk            | *Sterptococcus Thermophilus*, *Lactobacillus. De Lactobacillus rueckii subsp. bulgaricus*, *Lactobacillus. helveticus* | skyr is high in protein and calcium, and low in sugar and fat                           | [40]       |
| Food            | Country       | Ingredients                           | Microorganisms                                                                                           | Health/Nutrition Benefits                                      | References |
|-----------------|---------------|---------------------------------------|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|------------|
| Sour milk       | Egypt         | cow milk                              | Lactococcus. lactis subsp. lactis, Staphylococcus. kefir, Staphylococcus. citrovorus, Lactobacillus. casei, Lactobacillus. plantarum, Lactobacillus. brevis, micrococi, coliforms                                   | Promote gastrointestinal digestion                               | [35]       |
|                   |               |                                      |                                                                                                          |                                                                  |            |
| Susa            | Kenya         | camel milk                            | Lactobacillus acidophilus, Kluveromyces fragilis, Saccharomyces cerevisiae                                    | benefits for heart and immune health                              | [40]       |
| Suusaac         | Somalia       | camel milk                            | Lactobacillus acidophilus, Kluveromyces fragilis, Streptococcus, Thermophilus                                | Mitigate autoimmune disease and diabetes                         | [40]       |
| Tairu           | Malaysia      | cow milk or soybean milk              | Lactic acid bacteria                                                                                     | organic acids promote gastrointestinal motility and gastric secretion preventive and therapeutic effects on constipation and bacterial diarrhea | [40]       |
| Trahanas or tarhanas | Greece, Turkey | wheat, sheep milk                     |                                                                                                          |                                                                  |            |
| Viili           | Finland       | cow milk                              | Lactobacillus. lactis subsp. lactis, Lactobacillus. lactis subsp. cremoris, Lactobacillus. lactis subsp. lactis biovar diacetylactis, Leuconostoc. mesenteroides subsp. cremoris, Geotrichum candidum | health improving potential                                       | [40]       |
| Ymer            | Denmark       | cow milk                              | Lactobacillus. paracasei subsp. paracasei                                                               | inhibit the growth and reproduction of spoilage bacteria in the intestine | [40]       |
| Yakult          | Japan         | cow milk                              | Lactobacillus. bulgaricus, Lactobacillus. acidophilus, Lactobacillus. casei, Streptococcus, Thermophilus, Lactococcus. lactis subsp. lactis | increase beneficial bacteria and reduce harmful bacteria          | [40]       |
| Yogurt (also known as dahi, leben, goidu, dahi) | Various countries | cow milk primarily, sheep milk, goat milk, buffalo milk | Lactobacillus. bulgaricus, Lactobacillus. acidophilus, Lactobacillus. casei, Streptococcus, Thermophilus, Lactococcus. lactis subsp. lactis | relieve lactose intolerance, constipation, diarrhea, inflammatory bowel disease, etc. | [40]       |
| Zabadi (yogurt) | East, North Africa | goat, cow or sheep milk               | Lactobacillus. bulgaricus, Lactobacillus. acidophilus, Lactobacillus. casei, Streptococcus, Thermophilus, Lactococcus. lactis subsp. lactis | regulate intestinal flora and improve gastrointestinal function | [40,44]    |
| Žinčica         | Žinčica (in Slovakia), Žínčice (in the Czech Republic), Zentycza (in Poland) | sheep milk | Lactobacillus casei, Lactobacillus plantarum, Lactococcus. lactis and Leuconostoc mesenteroides. | benefit for the digestive system and cardiovascular system | [39]       |
Table 2. (Continued).

| Food          | Country          | Ingredients                              | Microorganisms                              | Health/Nutrition Benefits                                                                 | References |
|---------------|------------------|------------------------------------------|---------------------------------------------|------------------------------------------------------------------------------------------|------------|
| (b) Based on different regions of legume and cereals fermented foods |                 |                                          |                                             |                                                                                          |            |
| Bhallae       | India            | black gram                               | Lactic acid bacteria, yeasts                | high protein, easy to absorb                                                              | [45]       |
| Dawadawa      | Nigeria          | locust beans (Parkia biglobosa) seeds    | Bacillus sp.                                | antioxidants                                                                               | [46,47]    |
| Doenjang      | Korea            | soybeans                                 | Aeromonas. oryzae                           | prevention of chronic diseases                                                             | [48]       |
| Hama-natto    | Japan            | soybeans                                 | Aeromonas. oryzae, Streptococcus sp., Pediococcus sp., Bacillus sp. | strong cytotoxic activity against cancer cells                                            | [47]       |
| Iru           | West Africa      | locust bean (Parkia biglobosa) seed      |                                             | rich in B vitamins                                                                         | [47]       |
| Kecap         | Indonesia        | soybeans                                 | Aeromonas. oryzae                           | antiobesity potential helps cholesterol reesterification and protects fat-soluble vitamin E from damage | [47]       |
| Kenima        | India, Nepal     | soybeans                                 |                                             | increased nutritional quality                                                               | [47,49]    |
| Kinema        | India, Nepal     | soybeans                                 | Bacillus subtilis, Escherichia. faecium, Candida parapsilosis, Geotrichum candidum Actinomucor elegans | reduce blood cholesterol, anti-mutagenic antiobesity potential                            | [45]       |
| Meitauza      | China, Taiwan    | soybeans                                 |                                             | increased nutritional quality                                                               | [47,49]    |
| Miso          | Japan            | soybeans                                 | Aeromonas. oryzae, Rhizopus sp.             | enhances the lingering aftertaste of cooked dishes                                        | [42]       |
| Natto         | Japan            | soybeans                                 | Bacillus (subtilis) natto                   | possible stimulation of immune system, increased digestibility                            | [35,50]    |
| Ogiri-igbo    | Nigeria          | castor beans (Ricinus communis)          | Aeromonas. oryzae, Rhizopus sp.             |                                             | [47]       |
| Ogiri-nwan    | Nigeria          | fluted pumkin beans (Telfaria occidentale) | Actinomucor elegans                        | increased nutrients                                                                         | [47]       |
| Ontjom        | Indonesia        | peanut cake                              | Neurospora intermedia, Rhus. oligosporus    | lower cholesterol levels and contains substances that resist dietary free radicals         | [45]       |
| Papadam       | India            | black gram                               | Saccharomyces sp, Lactic acid bacteria, yeasts | antibiostatic potential                                                                   | [42]       |
| Puda or pudla | India            | Bengal gram, mung beans, wheat locust beans, Parkia biglobosa seed soybeans |                                             | increased nutrients                                                                         | [47]       |
| Soumbara      | Ivory Coast      |                                        | Bacillus sp.                                | antiobiotic reduction                                                                       | [47]       |
| Sufu or furu  | China, Japan, Vietnam, Thailand, Philippines | soybeans                                 | Actinomucor elegans, Aeromonas. taiwanensis, Mucor sufu, Mucor burj, Mucor tenebrosus, Rhizopus sp. | increased nutritional quality                                                               | [35,51]    |
| Tempeh        | Indonesia        | soybeans                                 | Rhizopus mold                               | prevention of atherosclerosis, cancer, osteoporosis and menopausal disorder                | [35]       |

(Continued)
| Food  | Country       | Ingredients                          | Microorganisms                           | Health/Nutrition Benefits                      | References |
|-------|---------------|--------------------------------------|------------------------------------------|------------------------------------------------|------------|
| Tempe kecipir | Indonesia     | winged beans (Psophocarpus Tetragonolobus) | Rhizopus mold                            | increased nutrients                            | [35]       |
| Thua-nao | Thailand      | soybeans                             | Bacillus subtilis                        | reduce blood cholesterol, anti-mutagenic       | [47,49]    |
| Vada or vadai | India        | black gram (Phaseolus mungo), rice    | Pediococcus sp., Leuconostoc sp., Streptococcus sp. | improve human immunity                         | [42,52]    |
| Waries | India         | black gram flour                      | Candida sp., Saccharomyces sp., Rhizopus oryzae, Rhus chinensis, Chlamydomucor, Aeromonas oryzae, Saccharomyces mucroceous molds, yeasts | has anti-oxidant effect, helps prevent aging inhibition effect on α-glucosidase | [45]       |
| Lao-zao | China, Indonesia | rice                                |                                          |                                                 | [42]       |
| Chinese yeast | China  | maize                                |                                          |                                                 | [42]       |
| Mantou | China         | wheat flour                          | Saccharomyces sp., Paecilomyces sp., Asperillus sp, Cladosporium sp, Fusarium sp. | antioxidant, anti-aging                         | [45]       |
| Minchin | China         | wheat gluten                         |                                          |                                                 | [45]       |

(c) Based on different regions of vegetable fermented foods

| Food  | Country       | Ingredients                          | Microorganisms                           | Health/Nutrition Benefits                      | References |
|-------|---------------|--------------------------------------|------------------------------------------|------------------------------------------------|------------|
| Dhamuoi | Vietnam      | cabbage, various vegetables           | Ln. mesenteroides, Lactobacillus. plantarum | removal of antinutrient compounds              | [53]       |
| Kawal  | North Africa  | vegetables                           | Lactobacillus. plantarum                | enhancing food quality and safety              | [39]       |
| Kimchi | Korea         | Korean cabbage, radish, various vegetables cabbage | Ln. mesenteroides, Lactobacillus. brevis, Lactobacillus. plantarum | antimicrobial properties, antitumour activity, prevent constipation source of vitamins and fibre | [48,53]    |
| Sauerkraut | Germany     | cabbage                              | Ln. mesenteroides, Lactobacillus. brevis, Lactobacillus. plantarum, P. cerevisiae | improve the digestive functions, enhance the immune system, reduce the risk of colorectal cancer, control the serum cholesterol levels | [54]       |
| Tsukemono | Japan        | Vegetables, rice flour               | Lactic acid bacteria                      |                                                 | [55]       |
| Iru    | West Africa   | locust bean (Parkia biglobosa) seed | Bacillus sp.                              |                                                 | [47]       |

(d) Based on different regions of fish and meat fermented foods

| Food  | Country       | Ingredients                          | Microorganisms                           | Health/Nutrition Benefits                      | References |
|-------|---------------|--------------------------------------|------------------------------------------|------------------------------------------------|------------|
| Anchovy | Mediterranean countries, Argentina Philippines | anchovy                             | Lactic acid bacteria, yeasts             | improve liver function and immunity           | [55]       |
| Burong dalag | Philippines | fish (dalag), rice                   | Ln. mesenteroides, P. cerevisiae, Lactobacillus. plantarum, S. faecalis, Micrococcus sp. | inhibit the proliferation of harmful bacteria | [35,56]    |
| Burong hipon | Philippines | shrimp                              |                                          | inhibit the proliferation of harmful bacteria | [56]       |
| Burong isda | Philippines | fish, rice                          | Lactobacillus. brevis, Streptococcus sp. P. cerevisiae |                                                 | [39]       |
| Kungchao | Thailand      | shrimp, rice                         |                                          | provide vitamins                                | [39]       |
clinical effects of the fermented probiotics. Selected examples of other potentially interesting microbrial strains are summarized in Tables 4 and 5. Table 4 provides information on the relevant probiotics in the listed human products from the top 10 probiotic brands, which will help us to further study human microorganisms. To illustrate the usefulness of the PBDB database and cross-linking data for facilitating such studies, we discuss below the potential applications based on some of the literature-described genomic, functional, and mechanism studies of the probiotics. This information allows for the analysis of biological information and the mechanisms of probiotics to predict new probiotics from unknown microbial resources.

### Bioinformatics research of probiotics

In recent years, the roles of probiotics as functional ingredients in food has been highly adopted by consumers and are under constant investigation by the scientific community. As a result, several probiotic-containing foods have been introduced in the market with an annual share of several billion dollars. The profiling of the microbes involving both in vitro and in vivo approaches is of particular interest in the probiotics research. One potential application of profiling is the comparative genomic analysis of the specific phylogenetic sub-branches of the gut microbiota and the analysis of nucleic acids for the identification of new probiotic candidates. Meta-genomic analysis of bacterial strains evolved from a specific species in a dairy fermentation environment, with information from the complete genome sequence information in the GenBank database, has been confirmed as having the tendency to undergo genome reduction when exposed to a less complex environment. The same approach may be used for identifying the bacterial strains that produce specific probiotic molecules in fermented foods.

There are variety of proposed beneficial health effects of probiotics. Clinical symptoms that have been reportedly treated or have the potential to be treated with probiotics include diarrhea, gastroenteritis, irritable bowel syndrome, and inflammatory bowel disease (IBD; Crohn’s disease), cancer, depressed immune function, inadequate lactase digestion, infant allergies, failure-to-thrive,
hyperlipidaemia, hepatic diseases, and *Helicobacter pylori* infections. The use of probiotics should be further investigated for its possible benefits and its side-effects, if any. The direct applications of the PBPD data can be illustrated by the use of fermented milk with beneficiary effects for various diseases. Using the PBPD keyword search, corresponding probiotics or probiotic products were identified with beneficiary effects against the disease. The use of probiotics may help treat certain types of diarrhea, including antibiotic-associated diarrhea, diarrhea during travel, and diarrhea associated with *C. difficile* infection.\textsuperscript{71} Aflatoxin B1 induces liver cancer in rats. After induction of hepatic cancer in rats, fermented milk containing probiotics and chlorophyllic acid significantly reduces thiobarbituric acid-reactive substrate (TBARS). Fermented milk containing probiotics or fermented milk containing probiotics as well as chlorophyllin play a protective role in liver cancer by reducing TBARS and increasing antioxidant enzyme activity.\textsuperscript{72} Probiotics represented by lactic acid-producing bacteria in yogurt have potential anti-cancer effects. In BALACTOBACILLUS/c mice, probiotics in yogurt have an inhibitory effect on rectal cancer tumor growth. Yogurt consumption increased mouse IgA-secreting cells and CD4\(^+\) T cell count in the large intestine, while IgG\(^+\) and CD8\(^+\) T cell count decreased. Certain biologically active peptides produced by probiotics contained in fermented milk inhibit the growth of fibrosarcomas in mouse models. *Propionibacterium* can produce important metabolites such as propionic acid, vitamins, bacteriocins, and enzymes. *Propionibacterium* also stimulates the immune system and lowers blood cholesterol levels. *Propionibacterium* has a broad-spectrum antibacterial activity and inhibits Gram-positive bacteria. Some Gram-negative bacteria, as well as some yeasts and molds have grown. *Propionibacterium* have been used in the industry to make cheese. Now, *Propionibacterium* is being used as a probiotic in fermented milk.\textsuperscript{73} The anti-cancer effects of probiotics may not be through a single mechanism, but a combination of multiple mechanisms. Some of the possible mechanisms are that the probiotics are changing the composition and metabolites of the intestinal

| Table 4. The example of marketed probiotics products and constituent probiotics species. |
|-----------------------------------------------|-----------------------------------------------|
| **Probiotic species** | **Products name** | **Brand/Manufacturer** | **Constituent Probiotics Species** |
|-------------------------|-------------------|------------------------|-----------------------------------|
| Human probiotics | Compound probiotic health drinks | Yijia/mei/Weilan Biological Co., Ltd. | *Lactobacillus paracasei IMC-4* (patent strain), *Lactobacillus acidophilus*, *Lactobacillus plantarum*, *Lactobacillus casei* |
| Hengxin Brand Probiotics | | Hengxin/Harbin Meihua Biotechnology Co., Ltd. | *Lactobacillus acidophilus*, *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, *Lactobacillus bifidum*, yeast |
| Ang Li Super Probiotic Powder | | University Anoli Co., Ltd. | *Bifidobacterium longum* BL88-ONLLY, *Lactobacillus plantarum* LP-ONLLY, *Lactobacillus acidophilus* LA11-ONLLY, *Bifidobacterium lactis*, *Lactobacillus rhamnosus*, *Lactobacillus paracasei*, *Lactobacillus casei*, *Bifidobacterium breve* |
| Minsheng Puribiao Probiotics Granules | Puribiao/Hangzhou Minsheng Pharmaceutical Co., Ltd. | *Lactobacillus acidophilus*, *Bifidobacterium longum* |
| Beiyoudun Probiotic Lyophilized Powder | Revised pregnant baby / Jilin modified medicine pregnant baby division | *Bifidobacterium lactis* HN019, *Lactobacillus rhamnosus* HN001, *Lactobacillus fermentum* CECT5716 |
| High Change probiotic powder | Culture/ Shenzhen Jinhuo Pharmaceutical Co., Ltd. | *Lactobacillus rhamnosus*, *Bifidobacterium lactis*, *Lactobacillus reuteri*, *Bifidobacterium animalis* |
| Bacillus subtilis live particles | Mommy love / Beijing Hanmei Pharmaceutical Co., Ltd. | *Lactobacillus rhamnosus* GG |
| Newmans Probiotic Adult Powder | Nemans/Jin Neumanns (Shanghai) Food Co., Ltd. | *Enterococcus faecium*R-026, *Bacillus subtilis*R-179 |
| Synbiotics brand probiotics granules for children | Biostime BIOSTIME / Biostime International Holdings Limited | *Bifidobacterium BB-12*, *Lactobacillus acidophilus* LA5 |
| Synbiotics brand probiotics granules for children | | *Bifidobacterium bifidum*, *Bifidobacterium infantis*, *Lactobacillus helveticus* |
flora, reduce the number of harmful bacteria, anti-genotoxic activity of probiotics, anti-gene mutation function of probiotic metabolites, and inhibition of enzymes in the colon. Along with activity and interaction with colon cells, probiotics also can regulate the immune system. Probiotics may prevent neoplastic transformation by protecting mucosal and gastrointestinal tract barrier stability, competing with pathogenic bacteria, reducing anti-inflammatory reactions, degrading potential carcinogens, affecting cell proliferation, and affecting polyamine metabolism at gastric mucosa.\[74\]

| Probiotics                                      | Object   | Characteristic and functional properties         | Mechanisms                                                                 | References |
|-------------------------------------------------|----------|-------------------------------------------------|-----------------------------------------------------------------------------|------------|
| Lactobacillus plantarum LS/07                   | Rats     | Relieve symptoms of acute colitis               | Decreased 0205-glucuronidase activity, levels of IL-6 and IL-8.              | [59]       |
| Lactobacillus Bifidobacteria                    | Rats     | nonaLactococcusoholic fatty liver disease obesity | Increased levels of Bacteroidetes, Lactobacillus, and Bifidobacterium. decreases in the level of Firmicutes | [60]       |
| Lactobacillus. acidophilus LA1                  | Rats     |                                                                           |                                                                            | [61]       |
| Lactobacillus. rhamnosus LR5                    | Rats     |                                                                           |                                                                            | [62]       |
| Bacillus. lactis BL3                            | Rats     |                                                                           |                                                                            | [63]       |
| Bacillus. longum BG7                            | Rats     |                                                                           |                                                                            | [64]       |
| Streptococcus thermophilus ST3                  | Rats     |                                                                           |                                                                            | [65]       |
| Lactobacillus rhamnosus Saccharomyces boulardii | Infants;  | Antibiotic-Associated Diarrhea                  | May prevent antibiotic-associated diarrhea via normalization of disrupted microbiota and competitive inhibition of pathogens. | [66]       |
| Lactobacillus plantarum CCFM8610 multiple probiotic strains | Cell; Mouses | Inhibits heavy metal absorption | Probiotics can inhibit Cd absorption by protecting the intestinal barrier, and the protection is related to the alleviation of Cd-induced oxidative stress. Improved bowel habits in patients with PD who had constipation. | [67]       |
| Lactobacillus plantarum CCFM8610                | humans   | Constipation associated with Parkinson disease |                                                                            | [68]       |
| Lactobacillus plantarum CCFM8610                | humans   | Probiotics in preventing or treating small intestinal bacterial overgrowth (SIBO). | Increased intestinal permeability, inhibited the colonization by disease-related bacteria through nutrients competition, immune system enhancement, and the production of antitoxins. Increased intestinal permeabilty and inhibited the colonization | [69]       |
| Lactobacillus paracasei STII01                  | Rats     | Attenuated cardiac dysfunction by improving cardiac | Increased production of IL-10 that favoured the balance of Th1/Th2 pathways increased the production of IFN-c via Th1 using in vitro stimulation methods | [70]       |
| Bifidobacterium bifidum                         | infants  | As an adjunct for the treatment of recurrent wheezing |                                                                            | [71]       |
| Lactobacillus casei                             | children | therapy for eradication of Helicobacter pylori reduce the incidence of diarrhea | significantly increased H. pylori eradication rates | [72]       |
| Bifidobacterium infantis                        | children |                                                                           |                                                                            | [73]       |
Mechanisms research of typical probiotics

The combined knowledge of the probiotic molecules and typical modes of probiotic actions (Table 5) is useful for facilitating the study of their molecular mechanisms. For instance, the correlation between intestinal flora and obesity has been confirmed by many studies. The intestinal flora can be changed. The balance of a variety of metabolic pathways centered on energy metabolism affect the occurrence and development of obesity. More than three kinds of probiotics and prebiotics can play a role in fighting obesity by reducing intestinal bacterial lipopolysaccharides, altering bacterial composition, and reducing fat storage. Adding specific probiotics or Garcinia cambogia extract to the diet can reduce weight gain and adipocyte size in rats caused by a high-fat diet. Network analysis based on diet, flora, and host correlation from 48 in bacteria was conducted, looking for bacteria that caused obesity. Clostridium aminophilum, an ammonia-producing bacterium, was highly associated with the obesity phenotype. The combination of specific probiotics and Garcinia cambogia extracts inhibited the bacteria. Clinical trials have confirmed that probiotics can effectively reduce fasting blood glucose and insulin levels in patients with diabetes. They can also improve Hb1Ac and insulin resistance. Furthermore, probiotics have significant effects on oxidative stress, inflammatory factors, and lipids with no adverse events reported. Mechanisms for these obesity related effects include regulation of immune differentiation and insulin sensitivity, inhibition of pathogenic bacteria adhesion to the intestine and translocation to adipose tissue, and improvement of intestinal barrier function. Commonly used probiotics include Lacobacillus, Bifidobacterium, Bacillus, Saccharomyces, Streptococcus, Clostridium.

Conclusion

Probiotics are active bacteria or yeast that are good for human health, especially the health of the digestive system. Most probiotics are from the genus Lactobacillus and Bifidobacterium, and they are two probiotics that are commonly found in fermented products and dairy products. The function, genealogy, and genomics of probiotics are useful for the discovery of new probiotics and other microbial species and strains, as well as understanding their function and mechanism. Microbial groups, microbial populations, and microbial dark matter research and new techniques for screening microbial sources and probiotic research have made rapid progress. The data obtained from these research advancements will further advance our understanding of the function and mechanism of probiotics to better suit human health, animal care, environmental protection, and agricultural development.

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