



## Review Article

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### Eiman Zahid

Department of Biochemistry and Biotechnology,  
University of Gujrat, Hafiz Hayat Campus,  
Gujrat, Pakistan

### Zahid Anwar

Department of Biochemistry and Biotechnology,  
University of Gujrat, Hafiz Hayat Campus,  
Gujrat, Pakistan

### Umer Rashid

Department of Biochemistry and Biotechnology,  
University of Gujrat, Hafiz Hayat Campus,  
Gujrat, Pakistan

### Muddassar Zafar

Department of Biochemistry and Biotechnology,  
University of Gujrat, Hafiz Hayat Campus,  
Gujrat, Pakistan

## Correspondence:

### Dr. Zahid Anwar

Department of Biochemistry and  
Biotechnology, University of  
Gujrat, Hafiz Hayat Campus,  
Gujrat, Pakistan  
Email: [eimanzahid161@gmail.com](mailto:eimanzahid161@gmail.com)

# Revealing the Significance of Probiotics on Gut Health and Beyond: A Comprehensive Review

Eiman Zahid, Zahid Anwar, Umer Rashid, Muddassar Zafar

## Abstract

Probiotics described as good bacteria that, when ingested in suitable amounts, give health benefits and have drawn a lot of attention due to their wide range of uses in several sectors. This review explores the mechanics, uses and historical evolution of probiotics. Probiotics were first identified in the early 20th century and are now found in a variety of dietary, pharmaceutical and personal care items in addition to their dairy-based roots. They are useful in the treatment of gastrointestinal disorders such as inflammatory bowel disease, irritable bowel syndrome and antibiotic-associated diarrhea because of their advantageous mechanisms, which include strengthening the intestinal barrier, competing with pathogens, modulating the immune system as well as influencing the production of neurotransmitters. Recent study also emphasizes their potential for treating *Helicobacter pylori* infections and problems of the gut-brain axis. Because of their numerous health advantages and useful qualities, probiotics are being utilized more and more in a variety of areas of life due to their adaptability and wide range of benefits. This review also highlights the guarantee about safety and adherence to regulations regarding probiotics, especially for susceptible groups, which calls for the implementation of stringent clinical research and standards.

**Keywords:** Gastrointestinal disorders, Gut-brain axis, Intestinal barrier, Neurotransmitters, Pathogens.

## INTRODUCTION

Worldwide, gastrointestinal (GI) disorders are a leading source of disease and death, especially those brought on by bacterial infections. The number of species developing antibiotic resistance is growing, making treatment more challenging. Probiotic lactic acid bacteria (LAB) exhibit significant promise as substitutes for antibiotics in preventive and therapeutic contexts. Probiotic bacteria can prevent or reduce gastrointestinal diseases, but selecting the right probiotics requires understanding gut-microbial interactions due to their connection to the host's GI tract [1]. Healthcare researchers are increasingly recommending probiotics as beneficial therapeutic interventions as a mean to manage immunological as well as digestive health [2].

The word "Probiotic" comes from the Greek word "pro bios," that means "for life." Probiotics have an extensive history dating back to human history. Romans and Greeks were habitual with cheese and fermented milk, but prevented consumption, particularly for young people and those recovering from illness. "Probiotics" refer to the living microorganisms that are given in enough quantity to remain viable in the intestinal environment. Lilly and Stillwell developed the term "probiotic" in 1965 to refer to "substances secreted by one microorganism that stimulate the growth of another" [3].

A complete and cooperative definition of probiotics was presented in 2001 by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), with definition i.e. "Live microorganisms, which when introduced in sufficient quantities; exhibit a beneficial influence on the host's wellness" [4]. The most often utilized probiotics in fermented foods and other nutritious foods include *Lactobacilli*, *Leuconostoc*, *Enterococci*, *Bifidobacteria* species. In addition to this category of lactic acid bacteria, probiotics are also made from yeasts such as *Saccharomyces* spp. [5].

Probiotic have been used in current years to modify the microbiome in a favorable way and resist illnesses that present a health risk to humans as well as animals. Since antibiotics are sometimes overused or misused to cure illnesses, Probiotics use may frequently be a substitute to antibiotics, allowing for the reduction of antimicrobial resistance [6]. These days, probiotics are a significant class of advantageous

bacteria that can be found in food, supplements and the intestines and are consumed or added as supplements. Probiotics have the ability to interact with various immune cells and positively affect composition of intestinal microbiota, which can enhance immune activities when taken. Probiotics are consequently generally recognized to have immunomodulatory as well as health-promoting qualities [7].

Probiotics, which were formerly only present in fermented dairy products, are now also present in dry food matrices and dietary supplements. They can remain stable for up to 24 months at room temperature and humidity. Sufficient strains, product composition and production methodology can effectively integrate premium probiotics into diverse delivery systems [8]. One potential avenue for future research in maintaining health could involve developing next-generation beneficial bacteria or probiotics to modify the microbiota. This could lead to the creation of pharmaceutical or dietary interventions [9].

### Historical Perspective on Probiotics:

The first beneficial bacteria were identified in 1905 by Elie Metchnikoff, who postulated that the lactobacilli used to make a yogurt that was popular in that area were the cause of the longer lifespans observed in the Bulgarian population, rather than the yogurt itself as was previously thought [10]. Shirota first reported on the intestinal bacteria's capability to survive the gut passageway in the early 1930s. He created fermented milk that included Yakult, a product of *Lactobacillus acidophilus* Shirota, is still well-known today. Then the word "probiotic" was first used by Lilly and Stillwell in 1965 to refer to a material that encourages the growth of other microorganisms [11].

Parker in 1974 defined probiotics as the "organisms and materials that support gastrointestinal microflora". Probiotics were redefined in an effort to clarify the term by Fuller in 1989 i.e. "A living microbial feed supplement which beneficially impacts the host by enhancing its intestinal microbial balance" [12]. According to Havenaar and Huis in 1992, probiotics improved the characteristics of the host's natural microflora when given to humans or animals in a suitable manner. Probiotic is "a preparation of or a product containing live, specified microorganisms in sufficient quantities, which affect the microflora via

implantation or colonization, in a compartment of the host and through that, exhibit beneficial effects on host health," according to Schrezenmeir and de Vrese [13].

Probiotics, according to Guarner and Schaafsma's 1998 assumption, are live microorganisms that give health advantages to their host when ingested in sufficient quantities [14]. Because aquatic species are in constant communication with the aqueous environment around them, Moriarty in 1998 expanded the definition of probiotics, which similarly views them as "water additives" made of microorganisms [15]. In 1999, Gatesoupe described as "microbial cells introduced in a particular manner, which enters the gastrointestinal tract and stay alive with the goal to promote health" [16].

In 2001, probiotics were defined as "all live microorganisms that, when given in sufficient quantities conferred a beneficial effect to the host" by the International Scientific Association for Probiotics and Prebiotics (ISAPP), in accordance with the framework established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) [17]. In 2014, according to Lazado and Caipang, probiotics-beneficial microbes are thought to be a safe, effective, and ecologically friendly substitute for antibiotics because of their enormous benefits for host's health and their capacity to fight against infections [18].

Live biotherapeutic products (LBPs) are biological products that have live organisms for the purpose of curing, treating, or preventing disease, as defined by the FDA. The European Pharmacopeia of 2019 classified LBPs as pharmaceuticals for human use that contain live microorganisms [19].

### Sources of Probiotics:

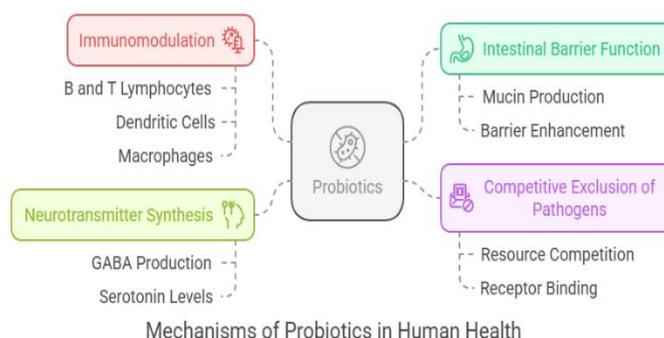
Humans have been consuming fermented foods and drinks such as yogurt, cheese and beverages for centuries, which contain probiotics. Probiotics like *Lactobacillus acidophilus* and *Bifidobacterium bifidum* are found in yogurt. Other sources of probiotic-rich foods include kefir, sauerkraut, kombucha, fermented veggies, tempeh, human breast milk and supplements [20]. (Table 1)

**Table 1:** Microorganisms and their example strains from different sources

SOURCE	MICROORGANISMS	EXAMPLES OF STRAINS
Dairy Products	Lactobacillus, Bifidobacterium, Streptococcus	<i>Lactobacillus delbrueckii</i> subsp. <i>bulgaricus</i> , <i>Bifidobacterium lactis</i>
Fermented Foods	Lactobacillus, Leuconostoc, Pediococcus, Bifidobacterium	<i>Lactobacillus plantarum</i> , <i>Leuconostoc mesenteroides</i> , <i>Pediococcus pentosaceus</i>
Human and Animal GI Tracts	Lactobacillus, Bifidobacterium, Enterococcus, Escherichia	<i>Lactobacillus rhamnosus</i> , <i>Bifidobacterium bifidum</i> , <i>Enterococcus faecium</i>
Soil and Plant Rhizospheres	Bacillus, Pseudomonas, Azotobacter	<i>Bacillus subtilis</i> , <i>Pseudomonas fluorescens</i> , <i>Azotobacter chroococcum</i>
Traditional Fermented Beverages	Saccharomyces, Lactobacillus, Acetobacter	<i>Saccharomyces cerevisiae</i> , <i>Lactobacillus kefir</i> , <i>Acetobacter aceti</i>

### Mechanism of Action of Probiotics:

Probiotic research has progressed greatly, nonetheless, a noteworthy advancement in our knowledge of how they function has not yet been recorded. Probiotics could be advantageous to human health through the following key mechanisms: increased intestinal barrier function, competitive exclusion of pathogens, host-body immunomodulation and neurotransmitter synthesis. Probiotics make it harder for infections to survive in gut by competing with them for resources as well as receptor-binding sites [21]. By producing compounds including short chain fatty acids (SCFA), organic acids, hydrogen peroxide and bacteriocins, probiotics also have anti-microbial properties that reduce harmful bacteria in digestive tract [22]. (Figure 1)



**Figure 1:** Mechanism of Probiotics in Human Health

Moreover, probiotics enhance the function of intestinal barrier by promoting the synthesis of mucin [23]. Furthermore, probiotics control innate as well as adaptive immune response by influencing B and T lymphocytes, dendritic cells (DC) and macrophages. Along with their ability to interact with intestinal epithelial cells and draw in macrophages and mononuclear cells, probiotics boost the production of anti-inflammatory cytokines too [24].

In addition, through the gut-brain axis, probiotics can cause the production of neurotransmitters in gut. Certain probiotic strains can alter gamma-aminobutyric acid (GABA) and also serotonin levels, that can have an impact on gut motility, behavior, mood and stress-related pathways [25]. (Figure 1)

### Probiotics in Gut Health- Clinical Evidence:

Probiotics are live bacteria that, when given in enough amount, offer health advantages to host. Because of their potential to improve gut health, interest in probiotics has increased recently. The effectiveness of different probiotic strains in treating gastrointestinal illnesses and preserving general gut health has been thoroughly studied in clinical investigations. (Figure 2)

- **Irritable Bowel Syndrome:**

The majority of medication approaches for the treatment of irritable bowel syndrome (IBS), a prevalent chronic functional bowel condition, appear to be ineffective, according to the available data. Probiotics are frequently used to help irritable bowel syndrome symptoms as well as suggested a beneficial effect on the illness. Moreover, probiotics are potentially crucial in the management of irritable bowel syndrome [26].

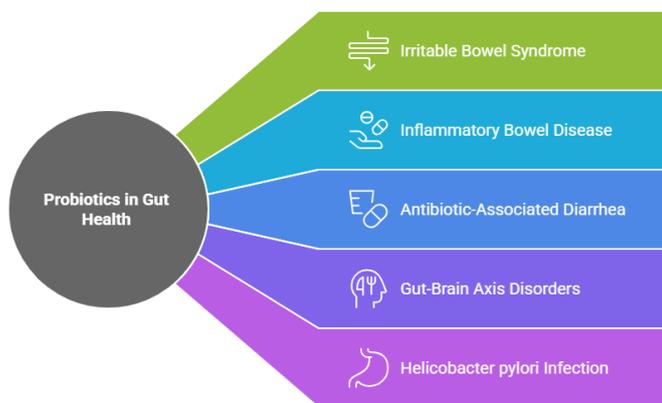
multiple clinical trials to prevent this disease. Probiotics affect the immune system, enhance intestinal barrier function, induce epithelial solute transporter activity, change bile acid and modulate gut microbiota to lower the risk of antibiotic-associated diarrhea [28].

- **Gut-Brain Axis Disorders:**

Globally, nervous system problems are common and probiotic use especially psychobiotic use has attracted a lot of attention. Psychobiotics have been demonstrated to be useful in treating neurological diseases by influencing the gut-brain axis. Taking these nutrients enhances microbiota and reduces symptoms associated with illnesses of the central nervous system. These are useful in reducing symptoms of a number of central nervous system disorders such as anorexia nervosa, Parkinson's disease, depression and diabetic neuropathy. This implies that mental health may be enhanced by functional foods that include psychoactive strains [29].

- **Helicobacter pylori Infection:**

Since *Helicobacter pylori* (*H. pylori*) is the cause of stomach disorders such duodenal ulcers and gastric cancer, it is becoming increasingly important to completely eradicate this bacterium. Probiotics by a variety of methods including co-aggregation ability, competitive inhibition, enhanced mucus production, bacteriocin synthesis and immune response modulation, boost the cure rate of *H. pylori* infections. They can be applied therapeutically for things like adjuvant therapy, medication delivery and strengthening the immune system to fight *H. pylori* infection [30]. (Figure 3)



Probiotics: Multifaceted Gut Health Solutions

Figure 2: Probiotics in Gut Health

- **Inflammatory Bowel Disease:**

Millions of people worldwide suffer with inflammatory bowel disease (IBD). It encompasses ulcerative colitis and Crohn's disease, two distinct diseases. It is increasingly evident that inflammatory bowel disease is linked to a multitude of factors, including genetic background, host immune response and the reduced diversity status of microbes. Probiotics can regulate the gut, which is one possible method of preventing inflammatory bowel disease. Numerous researches conducted over the past twenty years have concentrated on the impact of probiotics, particularly Bifidobacterium spp., in all variables that may be connected to the epidemiology of inflammatory bowel disease [27].

- **Antibiotic-Associated Diarrhea:**

An unintentional side effect of antibiotic treatment that occurs frequently is antibiotic-associated diarrhea. It is typified by abnormal water absorption, buildup of luminal carbohydrates and colonic bile acids, alteration of the gut microbiota, decreased intestinal short-chain fatty acid concentrations and diarrhea. Probiotics have been demonstrated in

### MECHANISM OF ACTION OF PROBIOTICS

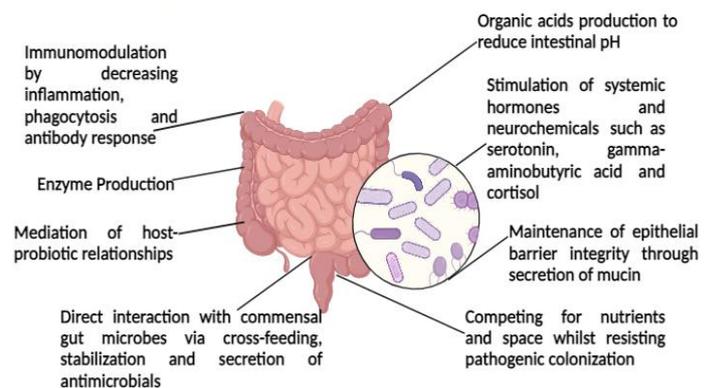


Figure 3: Mechanism of Action of Probiotics

### Applications of Probiotics:

Probiotics, which have historically been linked to health and wellbeing, are currently being investigated for possible uses in a wide range of industries. Novel applications in many industries are being fueled by advancements in probiotic research and technology. Here are a few novel applications for probiotics across a range of industries:

- **Food and Beverages:**

The increased popularity of foods that promote health among consumers has prompted the creation of probiotic-containing functional products. Due to their ability to prevent spoilage bacteria and increase shelf life, probiotics are becoming more and more popular in the food preservation industry. Lactic acid bacteria and bifidobacteria are examples of probiotic cultures that support balance of the intestinal microbiota, have anticarcinogenic and antimutagenic properties, lower cholesterol and lessen lactose intolerance symptoms. Probiotics are typically found in the dairy products, but because of lactose sensitivity and veganism, the probiotic beverages may also be made from other food matrices, such as cereals, legumes, fruits and vegetables [31].

- **Agriculture:**

In order to meet the demands of the world's population, modern agriculture focuses on producing food-based crops responsibly. However, contamination, pest resistance and a decline in soil fertility are caused by intensive practices, the use of agrochemicals and environmental conditions. In order to lessen the negative impacts of agrochemicals, experts are now concentrating on environmentally benign fertilizing techniques, such as using plant probiotics as biofertilizers. By colonizing soil or plant tissues, plant probiotics encourage plant development while minimizing the need of agrochemicals. Better crop-modulating effects, increased crop productivity, reduced environmental stress, restored soil fertility and strengthened the bioeconomy have all been demonstrated by plant probiotics combinations [32].

- **Aquaculture:**

Probiotics are found in many aquatic creatures and are crucial for maintaining the health of digestive system. They are mostly represented by Lactobacilli, which are essential for reducing disease and enhancing the GIT functions of aquatic animals by excreting beneficial substances and the secondary metabolites like lactic acid. They may also be taken out of probiotics found in marine and terrestrial plants to strengthen the immune system, improve feed quality as well as improve resistance to illness. Probiotics are used in aquaculture to enhance the health of aquatic creatures and the quality of water. They increase feed efficiency, aid in control of harmful microorganisms and promote the development and survival rates of fish and shellfish [33].

- **Pharmaceuticals:**

Probiotics-based pharmaceuticals, referred to as pharmabiotics have proven to have a great potential for treating and preventing a wide range of illnesses such as cancer, cardiovascular disease, inflammatory diseases and neurological disorders. Probiotics also support the upkeep of a balanced gut microbiota ecology and are effective against pathogens that are resistant to many drugs. As a result, the probiotic business is expanding quickly on the global scale and the efforts to turn probiotics into medicinal adjuvants are intensifying through research [34].

- **Cosmetics and Personal Care:**

Probiotic-based cosmetics have a natural foundation and a therapeutic impact, making its application in cosmetology a new approach to everyday skin care. Probiotic-based cosmetic products made from living cells and their lysates, according to experts, not only improve skin health but also shield it from the effects of aging. Probiotic-containing cosmetics are appropriate for both mature and sensitive skin, as well as skin that has been overexposed to the sun. Many studies have demonstrated that the use of probiotic culture lysates in cosmetics improves the skin's capacity for regeneration and repair, balances pH and microbiota as well as supports the restoration of skin immunity [35].

- **Animal Health:**

Animal health, growth and productivity have all greatly improved as a result of biotechnological advances in nutrition and health. Probiotics have reduced difficulties associated with raising cattle, resulting in healthier animals and animal products. Probiotic products can help animals develop more quickly and be healthier overall by enhancing intestinal health, boosting immunity and improving nutrient absorption. Probiotics and other safer alternatives have become more popular due to worries about food safety and the rising need for productivity, especially in consideration of the overuse of antibiotics [36].

- **Personalized Nutrition:**

Trillions of microorganisms i.e. bacteria, fungus, viruses and protozoa, live in the human gastrointestinal system. Diet and eating habits have an impact on variety of the gut microbiota, every person has a different gut microbial composition, health and illness may be influenced by interactions between host, gut microbiota as well as nutrition. Disease is

linked to dysbiosis of the gut microbiota. Probiotics are thought to be a preventative and therapeutic approach; personalized eating recommendations are offered via personalized nutrition techniques. Analyzing each person's gut microbiota makeup allows for the creation of customized probiotic formulations that address various health issues and enhance immunological response, metabolic disease management and digestive health [37].

- **Enhancing Vaccine Efficacy:**

Vaccination introduces certain antigens that activate adaptive immune system. The effectiveness of vaccines differs throughout civilizations because of biological, social and economic reasons. The gut microbiota is essential for controlling how the body reacts to vaccinations. Unbalances in the makeup of gut microbiota or dysbiosis, can lead to immunological problems and reduce the effectiveness of vaccinations. Probiotics, which are frequently found in the gut microbiota, influence both the innate and acquired immune systems and are beneficial to host's health. Probiotics such as *Lactobacillus casei* and *Bifidobacterium lactis* have been proven in studies to enhance immune response to oral as well as systemic vaccinations such as those for rotavirus, cholera and influenza [38]. (Figure 4)

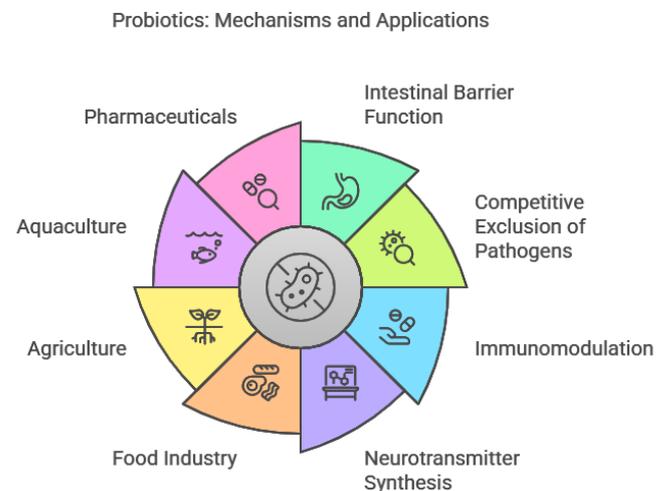


Figure 4: Applications of Probiotics

**Probiotics Safety and Regulation:**

Probiotics are classified by the FDA as Generally Recognized as Safe (GRAS) and may be used to treat symptoms associated with radiation exposure, Alzheimer's disease, celiac disease, cystic fibrosis and caries. Premature infants, those with immunodeficiency, patients receiving immunosuppressive, anticancer and acute pancreatitis therapies, as well as those with severe illnesses, are encouraged to exercise caution [39].

To guarantee safety, quality, identity, purity and potency; dietary supplements like probiotics must be manufactured in facilities that adhere to Good Manufacturing Practices (GMP). Throughout the process, a risk management system has to be in place to keep an eye on any chemical, allergic, physical, biological or microbiological contamination. To keep an eye on, manage and deal with the presence of pollutants, an effective surveillance strategy has to be in place. To guarantee product safety, raw materials must go through assessment and quality control analysis. To verify if overages are adequate for the planned storage duration, real-time stability studies on the completed product are required. To guarantee the safety of the consumer, the existence of significant food allergies must be disclosed on the product label. The most common allergies in probiotics are gluten, soy and milk [40].

**CONCLUSION**

In this study probiotics and their significance is discussed i.e. they give their host health advantages when consumed in sufficient concentrations.

Probiotics have attracted attention as an alternative to antibiotics since gastrointestinal (GI) diseases are a significant source of sickness and death globally, particularly those caused by bacterial infections. This is especially true given the growing problem of antibiotic resistance. Understanding the intricate relationships that exist between the host's GI tract and gut bacteria is essential to choose probiotics wisely.

Probiotics are a safe, all-natural way to help with immune system function, digestive health and the occurrence of digestive diseases including diarrhea brought on by antibiotics and irritable bowel syndrome. Also, they are essential to the gut-brain axis, which may help to improve mental and neurological conditions. Probiotics are vital for individualized nutrition and vaccination effectiveness, and they have uses in food, drink, medicines, aquaculture, cosmetics and animal health. They should, however, be used carefully, particularly by those whose immune systems are weakened. Customer safety is guaranteed by the FDA's generally recognized as safe designation. Probiotics are anticipated to be used in more novel treatment approaches and customized medicine in the future.

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### Conflict of interest

There is no conflict of interest.

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### REFERENCES

1. van Zyl WF, Deane SM, Dicks LMT. Molecular insights into probiotic mechanisms of action employed against intestinal pathogenic bacteria. *Gut Microbes*. 2020;12(1):1–25.
2. Sanders ME, Merenstein D, Merrifield CA, Hutkins R. Probiotics for human use. *Nutr Bull*. 2018;43(3):212–25.
3. Socol CR, Vandenberghe LP de S, Spier MR, et al. The potential of probiotics: A review. *Food Technol Biotechnol*. 2010;48(4):413–34.
4. Aponte M, Murru N, Shoukat M. Therapeutic, prophylactic, and functional use of probiotics: A current perspective. *Front Microbiol*. 2020;11:1–16.
5. Ashaolu TJ. Immune boosting functional foods and their mechanisms: A critical evaluation of probiotics and prebiotics. *Biomed Pharmacother*. 2020;130:110625.
6. Stavropoulou E, Bezirtzoglou E. Probiotics in medicine: A long debate. *Front Immunol*. 2020;11:1–20.
7. Mazziotta C, Tognon M, Martini F, Torreggiani E, Rotondo JC. *Cells*. 2023;12(1):184.
8. Fenster K, Freeburg B, Hollard C, Wong C, Laursen RR, Ouwehand AC. The production and delivery of probiotics: A review of a practical approach. *Microorganisms*. 2019;7(3):1–17.
9. Wicęrs G, Belkhir L, Enaud R, et al. How probiotics affect the microbiota. *Front Cell Infect Microbiol*. 2020;9:1–12.
10. Puebla-Barragan S, Reid G. Forty-five-year evolution of probiotic therapy. *Microb Cell*. 2019;6(4):184–96.
11. Mishra S, Acharya S. A brief overview on probiotics: The health friendly microbes. *Biomed Pharmacol J*. 2021;14(4):1869–80.
12. Adama H. The challenges of decentralized management of the Ngoyla-Mintom Forest Massif (South-East Cameroon). *Int J For Anim Fish Res*. 2020;4(4):46–51.
13. Muhsin SN, Abass AA, Al-shareefi ALM. Review about probiotics, what are they, mode of action and health benefits. 2022;62(10):6029–38.
14. Manish N. Role of probiotics in aquaculture with special reference to water quality, disease control and feed digestibility. 2017;8(1):78–87.
15. Simón R, Docando F, Nuñez-Ortiz N, Tafalla C, Díaz-Rosales P. Mechanisms used by probiotics to confer pathogen resistance to teleost fish. *Front Immunol*. 2021;12:1–19.
16. Mathan Muthu CM, Vickram AS, Bhavani Sowndharya B, Saravanan A, Kamalesh R, Dinakarkumar Y. A comprehensive review on the utilization of probiotics in aquaculture towards sustainable shrimp farming. *Fish Shellfish Immunol*. 2024;147(3):168–73.
17. Ibrahim SA, Yeboah PJ, Ayivi RD, et al. A review and comparative perspective on health benefits of probiotic and fermented foods. *Int J Food Sci Technol*. 2023;58(10):4948–63.
18. Amoah K, Tan B, Zhang S, et al. Host gut-derived *Bacillus* probiotics supplementation improves growth performance, serum and liver immunity, gut health, and resistive capacity against *Vibrio harveyi* infection in hybrid grouper. *Anim Nutr*. 2023;14:163–84.
19. Wortelboer K, Koopen AM, Herrema H, de Vos WM, Nieuwdorp M, Kemper EM. From fecal microbiota transplantation toward next-generation beneficial microbes: The case of *Anaerobutyricum soehngeni*. *Front Med*. 2022;9:1–14.
20. Kaur S, Kaur R, Rani N, Sharma S, Joshi M. Sources and selection criteria of probiotics. 2021:27–43.
21. Latif A, Shehzad A, Niazi S, et al. Probiotics: mechanism of action, health benefits and their application in food industries. *Front Microbiol*. 2023;14:1–16.
22. Ahire JJ, Jakkamsetty C, Kashikar MS, Lakshmi SG, Madempudi RS. In vitro evaluation of probiotic properties of *Lactobacillus plantarum* UBLP40 isolated from traditional indigenous fermented food. *Probiotics Antimicrob Proteins*. 2021;13(5):1413–24.
23. Chang YH, Jeong CH, Cheng WN, et al. Quality characteristics of yogurts fermented with short-chain fatty acid-producing probiotics and their effects on mucin production and probiotic adhesion onto human colon epithelial cells. *J Dairy Sci*. 2021;104(7):7415–25.
24. Petruzzello C, Saviano A, Ojetti V. Probiotics, the immune response and acute appendicitis: A review. *Vaccines*. 2023;11(7):1–10.
25. Gangaraju D, Raghu AV, Siddalingaiya Gurudutt P. Green synthesis of  $\gamma$ -aminobutyric acid using permeabilized probiotic *Enterococcus faecium* for biocatalytic application. *Nano Sel*. 2022;3(10):1436–44.
26. Yang R, Jiang J, Ouyang J, Zhao Y, Xi B. Efficacy and safety of probiotics in irritable bowel syndrome: A systematic review and meta-analysis. *Clin Nutr ESPEN*. 2024;60:362–72.
27. Bowel I, Ibd D. The effectiveness of probiotics in the treatment of. *J Nutr Biol*. 2020;12:1–8.
28. Mekonnen SA, Merenstein D, Fraser CM, Marco ML. Molecular mechanisms of probiotic prevention of antibiotic-associated diarrhea. *Curr Opin Biotechnol*. 2020;61:226–34.
29. Oroojzadeh P, Bostanabad SY, Lotfi H. Psychobiotics: the influence of gut microbiota on the gut-brain axis in neurological disorders. *J Mol Neurosci*. 2022;72(9):1952–63.
30. Keikha M, Karbalaei M. Probiotics as the live microscopic fighters against *Helicobacter pylori* gastric infections. *BMC Gastroenterol*. 2021;21(1):1–18.
31. Gomes IA, Venâncio A, Lima JP, Freitas-Silva O. Fruit-based non-dairy beverage: A new approach for probiotics. *Adv Biol Chem*. 2021;11(6):302–30.
32. Upadhayay VK, Chitara MK, Mishra D, et al. Synergistic impact of nanomaterials and plant probiotics in agriculture: A tale of two-way strategy for long-term sustainability. *Front Microbiol*. 2023;14:1–22.
33. Austin B, Sharifuzzaman SM. Probiotics in aquaculture. *Probiotics Aquac*. 2022:1–313.
34. Baral KC, Bajracharya R, Lee SH, Han HK. Advancements in the pharmaceutical applications of probiotics: Dosage forms

- and formulation technology. *Int J Nanomedicine*. 2021;16:7535–55.
35. Voloshyna IM, Shkotova LV. The use of probiotic microorganisms in cosmeceuticals. *Biopolym Cell*. 2022;38(1):3–8.
  36. Bhogaju S, Nahashon S. Recent advances in probiotic application in animal health and nutrition: A review. *Agric*. 2022;12(2):1–15.
  37. Ubhayawardana DLNL, Fernando SSN, Gunasekara TDCP, Weerasekara DD. Prebiotics, probiotics and personalized nutrition in modification of gut microbiota. 2021:49–53.
  38. Kazemifard N, Dehkohneh A, Baradaran Ghavami S. Probiotics and probiotic-based vaccines: A novel approach for improving vaccine efficacy. *Front Med*. 2022;9:1–10.
  39. Dudek-Wicher R, Junka A, Paleczny J, Bartoszewicz M. Clinical trials of probiotic strains in selected disease entities. *Int J Microbiol*. 2020;2020:1–10.
  40. Roe AL, Boyte ME, Elkins CA, et al. Considerations for determining safety of probiotics: A USP perspective. *Regul Toxicol Pharmacol*. 2022;136:105266.