The Impact of Prebiotics and Probiotics to Intensify Barrier Function for the Prevention of Disease

Bibi Saima[1,*], Tanzeela Iram[1], Maira Ashraf[1], Javaria Iftikhar[2], Khansa Adeel[3], Warda Arshad[1], Humna Rasheed[4], Arfa Saeed[5], Maha Hamid[2] and Malaika Hameed[2]

[1]Institute of Microbiology, University of Agriculture Faisalabad, Pakistan
[2]Department of Epidemiology and Public Health, University of Agriculture Faisalabad, Pakistan
[3]Institute of Microbiology, Government College University Faisalabad, Pakistan
[4]Institute of Microbiology and Molecular Genetics, Punjab University Lahore, Pakistan
[5]Department of Parasitology, University of Agriculture Faisalabad, Pakistan
*Corresponding author: bibisaima2001@gmail.com

Abstract

The human gut microbiota plays a crucial role in sustaining barrier function integrity. The intestinal barrier, which primarily consists of surface mucus, the epithelium, and the defense mechanism, maintains gut microbiota homeostasis. This chapter focuses on the impact of probiotics and prebiotics on the health of gut barrier function. Probiotics, live, helpful microorganisms, regulate the immune system, prevent pathogen entry, and facilitate digestion. Prebiotics, dietary substances, are taken up by the probiotics, promote their growth, and assist in the metabolism and health of the gut microbiome. A combination of both probiotics and prebiotics, synbiotics facilitate the growth and survival of beneficial microorganisms. They are referred to as potential therapeutic agents for improving the viability of gut microbiota. The chapter includes the mechanisms that aid probiotics and prebiotics in defending the host against many diseases, such as gastrointestinal, cardiovascular, neurological, dermal, respiratory, and urinary tract infections, either by preventing the entry of pathogens or by establishing a microbial balance.

Keywords: Gut microbiota, Barrier function, Microbiome, Probiotics, Prebiotics, Synbiotics

Cite this Article as: Saima B, Iram T, Ashraf M, Iftikhar J, Adeel K, Arshad W, Rasheed H, Saeed A, Hamid M, and Hameed M, 2025. The impact of prebiotics and probiotics to intensify barrier function for the prevention of disease. In: Aadil RM, Salman M, Mehmood K and Saeed Z (eds), Gut Microbiota and Holistic Health: The Role of Prebiotics and Probiotics. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 74-80. https://doi.org/10.47278/book.HH/2025.56

A Publication of Unique Scientific Publishers

Chapter No: 25-010

Received: 25-Jan-2025
Revised: 18-Feb-2025
Accepted: 08-March-2025

Introduction

The gut microbiome has become evident as the basis for health in the human body. Microbial ecology also impacts disease resistance, immunity, metabolism, and digestion (Naeem & Bourassa, 2025). The human body is encapsulated by the trillions of microorganisms that reside in the gastrointestinal tract. Supplemental bacterial products known as probiotics and dietary supplements like prebiotics can change the formation of the intestinal microbiome (Saedi et al., 2025). The intestinal mucosal surface constitutes probiotic bacteria, which form the bacterial film barrier known as the biological barrier. This barrier competitively forbids the bonding of harmful bacteria to the intestinal mucosa creating an isolated zone among pathogenic bacteria and mucosal surface (Wang et al., 2025). Probiotics are living organisms that may positively affect human health when given in adequate numbers. These advantageous microbes can inhibit pathogens, improve digestion, strengthen the intestinal barrier, preserve the intestinal barrier, and modify immune responses (Maione et al., 2025). The elaborated correlation between probiotics and gut microbiota contributes to the assumption that intestinal health is interlinked with systemic inflammation and metabolic stability (Njolke et al., 2025). Prebiotics, indigestible food ingredients, have become a crucial modulator of this intricate microbial community by selectively encouraging the development and function of beneficial microbiota (Yoo et al., 2024). Prebiotics with antioxidant effects, such as inulin and pectin, can prevent cancer, reduce the period of diarrhea, lower inflammation, and reduce the probability of intestinal bowel issues. Furthermore, they supplement the bioavailability and absorption of minerals, thereby decreasing the risk of diseases (Manzoor et al., 2022). Synbiotics merge a particular probiotic strain with specific prebiotics, support its growth, and exhibit more advantages than using probiotics and prebiotics alone. Numerous beneficial impacts of synbiotics have been indicated, including regulation of the immune system and boosted gut barrier function (Zhang et al., 2025).

Overview of the Immune System

The intestinal barrier is a dynamic system that interacts with and reacts to various stimuli. It comprises surface mucus, the epithelial layer, and immune defense (Zheng et al., 2023). Gut microbial metabolites are likely to influence immune responses and gut barrier function because they are produced near the gut epithelium (Ghosh et al., 2021).

A Broad Summary of Probiotics

The living, non-pathogenic microorganisms known as probiotics should help the human host by boosting the equilibrium of the gut microbiota and promoting ingestion when given in suitable amounts (a minimum count of 10^6 CFU/g microorganisms) (Stavropoulou & Bezirtzoglou, 2020). Improving the internal microbial balance means probiotics are ingested through food or water, promoting good health (El-Saadony et al., 2021). Numerous products on the market may contain probiotics, and their potential applications are expanding daily. This is primarily because certain probiotic strains support the health of the gut microbiota, particularly Firmicutes and Bacteroidetes, and may prevent specific gastrointestinal tract issues (Ranjha et al., 2021). In recent years, probiotics have been used to alter the microbiome positively, preventing infections that endanger the health of both humans and animals (Stavropoulou & Bezirtzoglou, 2020). Probiotics are being developed as live bio therapeutics and are utilized as ingredients in foods and nutritional supplements (Roe et al., 2022). Additionally, probiotics have been regarded as a cost-effective and secure substitute for managing numerous chronic illnesses and enhancing human well-being (Yadav et al., 2022). Synbiotics merge a particular probiotic strain with a specific prebiotic and contribute to its growth. Their collaboration shows a wide range of advantages over using probiotics or prebiotics alone. Synbiotics display various functions, including intensification of gut barrier function and regulation of immune response (Zhang et al., 2025).

An Overview of Prebiotics

Prebiotics are substances that the host cannot digest but that probiotics can use and ferment to support intestinal probiotic metabolism and reproduction for the body's well-being (You et al., 2022). Studies indicate that prebiotics can impact the production of SCFAs, change the immune system, enhance the gut barrier function, decrease the concentration of unfavorable bacteria, influence brain function and mineral bioavailability, lower blood lipid levels, or affect insulin resistance (Yoo et al., 2024). By enhancing nutrition and regulating the defense mechanism and gut microbiota, undigested nutrient elements that support and contribute to the growth of probiotics and human health are regarded as prebiotics (Yadav et al., 2022).

Mechanisms of Gut Barrier Integrity

The gut is a vital organ that continuously supports the microbiome ecosystem. The gut microbiota cooperates with the host and controls how the immune, metabolic, and neurological systems grow and operate (Gwak & Chang, 2021). Gut endocrine hormone production and secretion are disrupted by changes in the homeostasis of gut barrier function and gut microbiota composition, leading to metabolic diseases (Régnier et al., 2023). Translating endotoxins derived from the microbiota, like lipopolysaccharide, into the systemic circulation may be facilitated by increased intestinal permeability brought on by impaired barrier function (Ma et al., 2020).

Barrier Function

The intestinal barrier is actively regulated by the gut microbiota, reducing inflammation and blocking the entry of potentially dangerous substances. Gut health and immunological function depend heavily on a healthy intestinal barrier, as shown in Figure 1 (Zhou et al., 2024). The gut barrier is a dynamic and intricate environment that prevents pathobionts, antigens, and other invasive bacteria from entering the host by acting as a physical and chemical barrier (Genua et al., 2021). Due to the proximity of gut microbes to intestinal epithelial cells, the gut barrier must function extremely well to keep enteric microbiota and strong immune-stimulatory chemicals out of the bloodstream (Régnier et al., 2021).

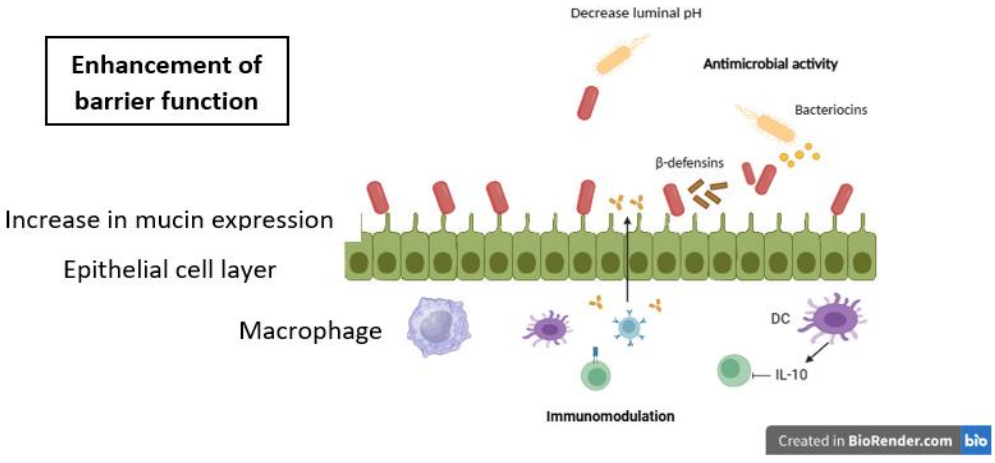

Fig. 1: A schematic illustration of the possible functions that probiotic bacteria may have in the intestine. These mechanisms include mucosal and epithelial antimicrobial activity (competition for adherence), enlarged production of mucus and improved barrier function (intensified barrier integrity), incompatibility of various microbes, and immunomodulation, which alters the human immune system (Retrieved from Bio Render).

Probiotics and Microbial Balance

A better understanding of gut-microbial interactions is necessary to choose the best probiotic because the functioning of beneficial microorganisms is closely related to the host's gastrointestinal tract (GIT) compatibility and diversity of enteric microorganisms (Van Zyl et al., 2020). The microbial diversity has been directly linked to the gut microbiota's ability to sustain equilibrium resulting from different stimuli such as physiological (pH, variations in intestinal passage value), enzymatic (nourishment), or microbial (live microorganisms, intestinal microbiota transplant) (Sehrawat et al., 2021).

Prebiotics and Microbial Balance

Prebiotics positively influence the human host by promoting the development and function of several colonic bacterial species (Ji et al., 2023). The solubility of dietary fiber determines its classification; soluble fiber improves serum lipids, while insoluble fiber has laxative effects (Peredo-Lovillo et al., 2020). The gut microbiota can metabolize plant-origin polysaccharides as prebiotics, producing metabolites like neurotransmitters and SCFAs (Liu et al., 2024).

Synbiotics

Synbiotics are a dietary mixture of prebiotics and probiotics that contribute to beneficial microorganisms' development and survival, improving general immunity and gastrointestinal health (Al-Habsi et al., 2024). Additionally, complementary and synergistic were identified as two subsets of Synbiotics. A complementary synbiotic consists of a probiotic and a prebiotic selected to function separately for health. A synergistic synbiotic is one in which the prebiotics in the gut specifically enhance a probiotic supplement (Kim & Mills, 2024). Synbiotics facilitate the growth and better integration of probiotics in the large intestine. In the digestive tract, they aid in the survival of beneficial microbes that are added to nourish and promote the growth of normal flora. Therefore, selecting microbial compounds and substrates is crucial for synbiotic products (Saedi et al., 2025).

Impact of probiotics and prebiotics in the prevention of Diseases

Prebiotics and probiotics have become safe and effective choices for many treatment approaches. In clinical trials, bacteria have shown encouraging outcomes for various illnesses and ailments (Manzoor et al., 2022a). This chapter compiles and identifies the mechanisms by which the microbiota can modify the intestinal barrier and stop the progression of diseases. Below are a few of the diseases that can be treated by the use of probiotics and prebiotics.

Gastrointestinal Diseases

Lactic acid bacteria live in the human small and large intestines and have various probiotic qualities, including the production of microbicidal compounds, receptor attachment, and keeping infectious microbes out, fortifying the intestinal barrier, or impacting the defense mechanism (Van Zyl et al., 2020). An environmental factor of great importance in human homeostasis, the gut microbiota sustains the homeostasis of the human intestine. It has numerous effects, including defense against pathogens, digestion of carbohydrates, control of fat storage, production of vital vitamins, and modulation of the immune response (Olvera-Rosales et al., 2021). Commensal microbiota has been shown to diminish intestinal permeability and boost epithelial defense mechanisms, thereby shielding mucosa from inflammation (Guarino et al., 2020). Probiotics may defend against antibiotic-associated diarrhea, IBS, and intestinal diseases and lower the severity of colds and flu (Pavlidou et al., 2022). Probiotics and prebiotics can help treat some of the diseases listed below:

Irritable Bowel Disease

The potential therapeutic applications of selected commensal microorganisms may benefit patients with irritable bowel disease due to the defensive mechanism of these microorganisms on the intestinal mucosa and contribute to altering the immune responses (Akutko & Stawarski, 2021). A concentration ranging from 10^{10} to 10^{12} CFU/day is considered a standard range for the intake of probiotics to get rid of irritable bowel disease, and probiotic supplements based on Lactobacillus and Bifidobacterium or multiple strains are supposed to be helpful for the subsidence of irritable bowel disease (Zhang et al., 2021). The most common Synbiotic formulae consist of Bifidobacteria and/or Lactobacillus GG combined with fructooligosaccharides and/or inulin (Martyniak & Medy, 2021).

Antibiotics-induced Diarrhea

Probiotics have been demonstrated to enhance gut health through many hypothesized mechanisms, including immune system activation and nutritional competition, preventing pathogen attachment to mucosal and epithelial surfaces, preventing epithelial invasion, and the production of antimicrobial compounds (Naeem et al., 2024).

Cardiovascular Diseases

Probiotics and prebiotics have been shown to protect against CVD by boosting and enhancing immune responses, lowering cholesterol, reducing oxidative stress, and balancing structural and functional changes in the gut microbiota (Pavlidou et al., 2022). Furthermore, probiotic research has demonstrated encouraging outcomes in treating obesity, insulin resistance, dyslipidemia, and hypertension, with potential precautionary and therapeutic benefits against myocardial infarction and heart failure (Dixon et al., 2020). The intestinal microbiome composition is associated with atherogenesis, thrombosis, chronic heart conditions, and arterial hypertension; a recent meta-analysis also discovered that dietary changes alter the intestines' microbial and metabolic makeup, which is known to be characteristic of a variety of physiological and pathological states, including CVD (Olas, 2020). Probiotics and prebiotics can treat the following diseases:

Obesity

Research on humans and animals has shown that the diversity of the intestinal microbiome plays a role in obesity progression by controlling metabolism processes (Cerdó et al., 2019). It has been reported that the formation of short-chain fatty acids, bile acid consumption, and the protection from endotoxins found in blood are the three primary ways that gut microbiota balance may affect body weight (Daniali et al., 2020). SCFAs support defense mechanisms and nutrient absorption, provide energy to colonocytes, and impact the process of fat accumulation by influencing adipocytes' sensitivity to insulin (Włodarczyk & Śliżewska, 2021).

Myocardial Infarction

Dietary metabolic products produced by gut bacteria can affect the host's cardiac situation; for instance, the circulation of histidine, tryptophan, and essential amino acids have been associated with circulatory disease and reduced insulin sensitivity (Oniszczuk et al., 2021). Studies have shown that probiotics reduce inflammation and ischemia/reperfusion injury, control lipid metabolism, and shrink the myocardial infarction site (Moludi et al., 2021). Propionate, one of the major SCFAs, has recently been identified as a crucial mediator of cardioprotection due to its capacity to inhibit the enlargement of an angiotensin-II mediated fart size via G-protein coupled receptor 41 (Borshchev et al., 2022).

Neurological Diseases

Human intestinal strains of *B. dentium* and *L. brevis DPC6108* have been shown to generate a significant amount of γ-aminobutyric acid, a neurotransmitter that also helps people suppress their anxiety and depression (Manzoor et al., 2022b). The brain axis and gut microbiota interact; they are connected to the development of brain cancer and contribute to the emergence of mental and neurodegenerative diseases (Olvera-Rosales et al., 2021). The following are some diseases that are cured by the probiotics and prebiotics supplements:

Brain Cancer

Probiotics, such as *Bifidobacterium* and *Lactobacillus acidophilus*, can inhibit the production of β-glucuronidase and nitroreductase, which is a highly effective way to stop procarcinogens from turning into carcinogens (Balta et al., 2021). The gut microbiota produces molecules like vitamins, tryptophan metabolites, and SCFAs that control G-protein-coupled receptors to mediate the release of neurotransmitters (serotonin, dopamine, noradrenaline, acetylcholine, and histamine) and support the function of neurons and glial cells (Fijan & Šmigoc, 2024).

Anxiety and Depression

According to several studies, probiotics may help treat depression and improve the host's physical and mental health as a treatment for depression (Alli et al., 2022). Preclinical and clinical evidence suggest that certain prebiotics have beneficial effects on the central nervous system by reducing neuroinflammation; as a result, they may play a significant role in reducing depression, anxiety, and cognitive impairment (Paiva et al., 2020).

Alzheimer's Disease

An innovative treatment for Alzheimer's disease may involve altering the gut microbiota through dietary modification or beneficial microflora interventions such as probiotics or prebiotics, altering microbiological partners, and modifying their byproducts, such as amyloid protein (Pluta et al., 2020). As indicated by the statistical analysis of randomized control experiments done for assessing the efficacy of probiotics, it is believed that probiotics enhance cognitive function in AD patients, possibly by decreasing levels of oxidative and inflammatory biomarkers (Thakkar et al., 2023).

Dermal Diseases

The microbiota of the skin, which includes microorganisms (e.g., *Staphylococcus epidermidis* and *Propionibacterium acnes*), fungi (like *Pityrosporum sabour*), and some viruses, is pivotal in healthy skin maintenance (Kreouzi et al., 2025). The microbiome on our skin and gut plays two primary roles: first, they protect us from many infections; second, they play an important role in maintaining the intricate balance between damaging inflammation and efficient defense (Lee et al., 2021). The skin microbiota must interact beneficially with the skin's immune system for survival. A predominant cutaneous bacterium, *Staphylococcus epidermidis*, processes several microbicidal substances and proteolytic enzymes that can block pathogenic species from forming biofilms (Patra et al., 2020). The microbiota's immune-regulating properties are essential for preserving the skin's balanced immune tone and lowering the risk of autoimmune and inflammatory diseases (Kreouzi et al., 2025). The WAO guideline concluded that probiotics taken by pregnant women benefit high-risk infants, mainly in preventing eczema. Nevertheless, it was a "conditional recommendation" founded on "very low-quality evidence" (Sestito et al., 2020).

Respiratory Diseases

Probiotics can prevent various respiratory conditions because they have anti-inflammatory and antimicrobial activities. Common probiotics that treat respiratory conditions include *Bifidobacterium longum*, *L. casei*, and *Actobacillus fermentum* (Sarita & Kovaleva, 2025). According to the research, Streptococcus oralis89a and Streptococcus salivaris 24SMB are good probiotics for treating and avoiding upper respiratory tract infections (Naeem et al., 2024). When both the mother (during pregnancy) and the child (from 6 months of age) took the probiotics, the correlation between rhino conjunctivitis and probiotics seemed to be stronger than when either parent took them alone (Sestito et al., 2020).

Urinary Tract Infections

Lactic acid-producing bacteria lower the pH of the vagina. This reduction in vaginal pH has been shown to have a protective effect against UTI recurrence by inhibiting the microbial propagation (Abdullatif et al., 2021). UTI Lactobacillus species, including *Lactobacillus brevis*, *L. rhamnosus,* and *L. vaginalis*, are the basis for more than 50 probiotics effective in treating urinary tract infections (Sarita & Kovaleva, 2025). The urobiome stabilizes, and the urinary tract colonizes during childhood and changes as the child matures. Oral probiotics and cranberry products may help nearly all kids who frequently suffer from UTIs (Kawalec & Zwolińska, 2022).

Conclusion and Future Perspectives

The availability of probiotics and prebiotics defends the human body against several diseases that may disturb the functioning and activity of the intestinal gut microbiota balance. Various intestinal infections are cured by the synergism of probiotics and prebiotics. The gut

microbiome exists in an equilibrium, and when this balance is disrupted, the human host develops infections or diseases. Thus, the balance between gut microbiota composition and function is crucial, along with the activity of probiotics and prebiotics. This chapter focuses on the correlation between gut microbiome and the treatment of diseases. Many therapeutic methods are discussed for different diseases, but the mechanisms are not fully explained. Future research should focus on explaining the mechanisms for a better understanding of the probiotics and prebiotics' role in preventing diseases.

References

Abdullatif, V. A., Sur, R. L., Eshaghian, E., Gaura, K. A., Goldman, B., Panchatsharam, P. K., Williams, N. J., & Abbott, J. E. (2021). Efficacy of Probiotics as Prophylaxis for Urinary Tract Infections in Premenopausal Women: A Systematic Review and Meta-Analysis. *Cureus*, *13*(10). https://doi.org/10.7759/cureus.18843.

Akutko, K., & Stawarski, A. (2021). Probiotics, prebiotics and synbiotics in inflammatory bowel diseases. *Journal of Clinical Medicine*, *10*(11), 2466.

Al-Habsi, N., Al-Khalili, M., Haque, S. A., Elias, M., Olqi, N. Al, & Al Uraimi, T. (2024). Health Benefits of Prebiotics, Probiotics, Synbiotics, and Postbiotics. *Nutrients*, *16*(22), 1–23.

Alli, S. R., Gorbovskaya, I., Liu, J. C. W., Kolla, N. J., Brown, L., & Müller, D. J. (2022). The Gut Microbiome in Depression and Potential Benefit of Prebiotics, Probiotics and Synbiotics: A Systematic Review of Clinical Trials and Observational Studies. *International Journal of Molecular Sciences*, *23*(9), 4494.

Balta, I., Butucel, E., Mohylyuk, V., Criste, A., Dezmirean, D. S., Stef, L., Pet, I., & Corcionivoschi, N. (2021). Novel Insights into the Role of Probiotics in Respiratory Infections, Allergies, Cancer, and Neurological Abnormalities. *Diseases*, *9*(3), 1–25.

Borshchev, Y. Y., Burovenko, I. Y., Karaseva, A. B., Minasian, S. M., Protsak, E. S., Borshchev, V. Y., Semenova, N. Y., Borshcheva, O. V., Suvorov, A. N., & Galagudza, M. M. (2022). Probiotic Therapy with Lactobacillus acidophilus and Bifidobacterium animalis subsp. lactis Results in Infarct Size Limitation in Rats with Obesity and Chemically Induced Colitis. *Microorganisms*, *10*(11), 2293.

Cerdó, T., García-Santos, J. A., Bermúdez, M. G., & Campoy, C. (2019). The role of probiotics and prebiotics in the prevention and treatment of obesity. In *Nutrients* (Vol. 11, Issue 3), 635.

Daniali, M., Nikfar, S., & Abdollahi, M. (2020). A brief overview on the use of probiotics to treat overweight and obese patients. *Expert Review of Endocrinology and Metabolism*, *15*(1), 1–4.

Dixon, A., Robertson, K., Yung, A., Que, M., Randall, H., Wellalagodage, D., Cox, T., Robertson, D., Chi, C., & Sun, J. (2020). Efficacy of Probiotics in Patients of Cardiovascular Disease Risk: a Systematic Review and Meta-analysis. *Current Hypertension Reports*, *22*, 1-27.

El-Saadony, M. T., Alagawany, M., Patra, A. K., Kar, I., Tiwari, R., Dawood, M. A. O., Dhama, K., & Abdel-Latif, H. M. R. (2021). The functionality of probiotics in aquaculture: An overview. *Fish and Shellfish Immunology*, *117*(October), 36–52.

Fijan, S., & Šmigoc, T. (2024). Overview of the Efficacy of Using Probiotics for Neurosurgical and Potential Neurosurgical Patients. *Microorganisms*, *12*(7), 1–14.

Genua, F., Raghunathan, V., Jenab, M., Gallagher, W. M., & Hughes, D. J. (2021). The Role of Gut Barrier Dysfunction and Microbiome Dysbiosis in Colorectal Cancer Development. *Frontiers in Oncology*, *11*, 626349.

Ghosh, S., Whitley, C. S., Haribabu, B., & Jala, V. R. (2021). Regulation of Intestinal Barrier Function by Microbial Metabolites. *Cmgh*, *11*(5), 1463–1482.

Guarino, M. P. L., Altomare, A., Emerenziani, S., Di Rosa, C., Ribolsi, M., Balestrieri, P., Iovino, P., Rocchi, G., & Cicala, M. (2020). Mechanisms of action of prebiotics and their effects on gastro-intestinal disorders in adults. *Nutrients*, *12*(4), 1–24.

Gwak, M. G., & Chang, S. Y. (2021). Gut-brain connection: Microbiome, gut barrier, and environmental sensors. *Immune Network*, *21*(3), e20.

Ji, J., Jin, W., Liu, S. J., Jiao, Z., & Li, X. (2023). Probiotics, prebiotics, and postbiotics in health and disease. *MedComm*, *4*(6), 1–23.

Kawalec, A., & Zwolińska, D. (2022). Emerging Role of Microbiome in the Prevention of Urinary Tract Infections in Children. *International Journal of Molecular Sciences*, *23*(2), 870.

Kim, Y. T., & Mills, D. A. (2024). Exploring the gut microbiome: probiotics, prebiotics, synbiotics, and postbiotics as key players in human health and disease improvement. *Food Science and Biotechnology*, *33*(9), 2065–2080.

Kreouzi, M., Theodorakis, N., Nikolaou, M., Feretzakis, G., Anastasiou, A., Kalodanis, K., & Sakagianni, A. (2025). *Skin Microbiota : Mediator of Interactions Between Metabolic Disorders and Cutaneous Health and Disease*. 1–32.

Lee, Y. H., Verma, N. K., & Thanabalu, T. (2021). Prebiotics in atopic dermatitis prevention and management. *Journal of Functional Foods*, *78*, 104352.

Liu, X., Su, S., Yao, J., Zhang, X., Wu, Z., Jia, L., Liu, L., Hou, R., Farag, M. A., & Liu, L. (2024). Research advance about plant polysaccharide prebiotics, benefit for probiotics on gut homeostasis modulation. *Food Bioscience*, *59*(December 2023), 103831.

Ma, L., Ni, Y., Wang, Z., Tu, W., Ni, L., Zhuge, F., Zheng, A., Hu, L., Zhao, Y., Zheng, L., & Fu, Z. (2020). Spermidine improves gut barrier integrity and gut microbiota function in diet-induced obese mice. *Gut Microbes*, *12*(1), 1–19.

Maione, A., Imparato, M., Buonanno, A., Galdiero, M., de Alteriis, E., Guida, M., & Galdiero, E. (2025). Protective and immunomodulatory effects of the novel probiotic yeast Pichia kudriavzevii isolated from a home-made kefir during infection in human colon epithelial cells: An exploratory study. *Journal of Functional Foods*, *125*(January), 106666.

Manzoor, S., Wani, S. M., Ahmad Mir, S., & Rizwan, D. (2022a). Role of probiotics and prebiotics in mitigation of different diseases. *Nutrition*, *96*(April), 111602.

Manzoor, S., Wani, S. M., Ahmad Mir, S., & Rizwan, D. (2022b). Role of probiotics and prebiotics in mitigation of different diseases. *Nutrition*, *96*, 111602.

Martyniak, A., & Medy, A. (2021). Compounds in IBD. *Biomolecules*, *11*(1903), 1–24.

Moludi, J., Kafil, H. S., Qaisar, S. A., Gholizadeh, P., Alizadeh, M., & Vayghyan, H. J. (2021). Effect of probiotic supplementation along with calorie restriction on metabolic endotoxemia, and inflammation markers in coronary artery disease patients: a double blind placebo controlled randomized clinical trial. *Nutrition Journal*, *20*(1), 1–10.

Naeem, H., Hassan, H. U., Shahbaz, M., Imran, M., Memon, A. G., Hasnain, A., Murtaza, S., Alsagaby, S. A., Al Abdulmonem, W., Hussain, M., Abdelgawad, M. A., Ghoneim, M. M., & Al Jbawi, E. (2024). Role of Probiotics against Human Cancers, Inflammatory Diseases, and Other Complex Malignancies. *Journal of Food Biochemistry*, *2024*(1), 6632209.

Naeem, M., & Bourassa, D. (2025). *Probiotics in Poultry : Unlocking Productivity Through Microbiome Modulation and Gut Health*. 1–21.

Mafe, A. N., Iruoghene Edo, G., Akpoghelie, P. O., Gaaz, T. S., Yousif, E., Zainulabdeen, K., ... & Umar, H. (2025). Probiotics and Food Bioactives: Unraveling Their Impact on Gut Microbiome, Inflammation, and Metabolic Health. *Probiotics and Antimicrobial Proteins*, 1-42.

Olas, B. (2020). Probiotics, prebiotics and synbiotics-a promising strategy in prevention and treatment of cardiovascular diseases? *International Journal of Molecular Sciences*, *21*(24), 1–15.

Olvera-Rosales, L. B., Cruz-Guerrero, A. E., Ramírez-Moreno, E., Quintero-Lira, A., Contreras-López, E., Jaimez-Ordaz, J., Castañeda-Ovando, A., Añorve-Morga, J., Calderón-Ramos, Z. G., Arias-Rico, J., & González-Olivares, L. G. (2021). Impact of the gut microbiota balance on the health-disease relationship: The importance of consuming probiotics and prebiotics. *Foods*, *10*(6), 1–28.

Oniszczuk, A., Oniszczuk, T., Gancarz, M., & Szymańska, J. (2021). Role of gut microbiota, probiotics and prebiotics in the cardiovascular diseases. *Molecules*, *26*(4), 1–15.

Paiva, I. H. R., Duarte-Silva, E., & Peixoto, C. A. (2020). The role of prebiotics in cognition, anxiety, and depression. *European Neuropsychopharmacology*, *34*(May), 1–18.

Patra, V., Sérézal, I. G., & Wolf, P. (2020). Potential of skin microbiome, pro-and/or pre-biotics to affect local cutaneous responses to UV exposure. *Nutrients*, *12*(6), 1–14.

Pavlidou, E., Fasoulas, A., Mantzorou, M., & Giaginis, C. (2022). Clinical Evidence on the Potential Beneficial Effects of Probiotics and Prebiotics in Cardiovascular Disease. *International Journal of Molecular Sciences*, *23*(24), 15898.

Peredo-Lovillo, A., Romero-Luna, H. E., & Jiménez-Fernández, M. (2020). Health promoting microbial metabolites produced by gut microbiota after prebiotics metabolism. *Food Research International*, *136*(June), 109473.

Pluta, R., Ulamek-Koziol, M., Januszewski, S., & Czuczwar, S. J. (2020). Gut microbiota and pro/prebiotics in Alzheimer's disease. *Aging*, *12*(6), 5539–5550.

Ranjha, M. M. A. N., Shafique, B., Batool, M., Kowalczewski, P. Ł., Shehzad, Q., Usman, M., Manzoor, M. F., Zahra, S. M., Yaqub, S., & Aadil, R. M. (2021). Nutritional and health potential of probiotics: A review. *Applied Sciences (Switzerland)*, *11*(23), 11204.

Régnier, M., Van Hul, M., Roumain, M., Paquot, A., de Wouters d'Oplinter, A., Suriano, F., & Cani, P. D. (2023). Inulin increases the beneficial effects of rhubarb supplementation on high-fat high-sugar diet-induced metabolic disorders in mice: impact on energy expenditure, brown adipose tissue activity, and microbiota. *Gut Microbes*, *15*(1), 2178796.

Régnier, M., Van Hul, M., Knauf, C., & Cani, P. D. (2021). Erratum: Gut microbiome, endocrine control of gut barrier function and metabolic diseases. *Journal of Endocrinology*, *248(2)*, R67–R82.

Roe, A. L., Boyte, M. E., Elkins, C. A., Goldman, V. S., Heimbach, J., Madden, E., Oketch-Rabah, H., Sanders, M. E., Sirois, J., & Smith, A. (2022). Considerations for determining safety of probiotics: A USP perspective. *Regulatory Toxicology and Pharmacology*, *136*(December), 1–69.

Saedi, S., Derakhshan, S., Hasani, A., Khoshbaten, M., Poortahmasebi, V., Milani, P. G., & Sadeghi, J. (2025). Recent Advances in Gut Microbiome Modulation: Effect of Probiotics, Prebiotics, Synbiotics, and Postbiotics in Inflammatory Bowel Disease Prevention and Treatment. *Current Microbiology*, *82*(1), 1–13.

Sarita, B., & Kovaleva, E. G. (2025). *A comprehensive review of probiotics and human health-current prospective and applications*. *January*, 1–14.

Sehrawat, N., Yadav, M., Singh, M., Kumar, V., Sharma, V. R., & Sharma, A. K. (2021). Probiotics in microbiome ecological balance providing a therapeutic window against cancer. *Seminars in Cancer Biology*, *70*(June 2020), 24–36.

Sestito, S., D'Auria, E., Baldassarre, M. E., Salvatore, S., Tallarico, V., Stefanelli, E., Tarsitano, F., Concolino, D., & Pensabene, L. (2020). The Role of Prebiotics and Probiotics in Prevention of Allergic Diseases in Infants. *Frontiers in Pediatrics*, *8*(December), 583946.

Stavropoulou, E., & Bezirtzoglou, E. (2020). Probiotics in Medicine: A Long Debate. *Frontiers in Immunology*, *11*(September), 1–20.

Thakkar, A., Vora, A., Kaur, G., & Akhtar, J. (2023). Dysbiosis and Alzheimer's disease: role of probiotics, prebiotics and synbiotics. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *396*(11), 2911–2923.

Van Zyl, W. F., Deane, S. M., & Dicks, L. M. T. (2020). Molecular insights into probiotic mechanisms of action employed against intestinal pathogenic bacteria. *Gut Microbes*, *12*(1), 1831339.

Wang, X., Huang, Y., Yang, Z., Yang, Y., Wei, F., Yan, M., Li, F., & Wang, C. (2025). Effect of probiotics combined with immune checkpoint suppressors and chemotherapeutic agents on digestive system function , intestinal immunity and prognosis in patients with metastatic colorectal carcinoma : a quasi - experimental study. *BMC Gastroenterology, 25*(1), 38.

Włodarczyk, M., & Śliżewska, K. (2021). Obesity as the 21st Century's major disease: The role of probiotics and prebiotics in prevention and treatment. *Food Bioscience*, *42*(January), 101115.

Yadav, M. K., Kumari, I., Singh, B., Sharma, K. K., & Tiwari, S. K. (2022). Probiotics, prebiotics and synbiotics: Safe options for next-generation therapeutics. *Applied Microbiology and Biotechnology*, *106*(2), 505–521.

Yoo, S., Jung, S. C., Kwak, K., & Kim, J. S. (2024). The Role of Prebiotics in Modulating Gut Microbiota: Implications for Human Health. *International Journal of Molecular Sciences*, *25*(9), 4834.

You, S., Ma, Y., Yan, B., Pei, W., Wu, Q., Ding, C., & Huang, C. (2022). The promotion mechanism of prebiotics for probiotics: A review. *Frontiers in Nutrition*, *9*, 1000517.

Zhang, C., Zhang, Q., Zhang, X., Du, S., Zhang, Y., Wang, X., Liu, Y., Fang, B., Chen, J., Liu, R., Hao, Y., Li, Y., Wang, P., Zhao, L., Feng, H., Zhu, L., Chen, L., Chen, S., Wang, F., … He, J. (2025). Effects of synbiotics surpass probiotics alone in improving type 2 diabetes mellitus: A randomized, double-blind, placebo-controlled trial. *Clinical Nutrition*, *44*(10), 248–258.

Zhang, X. F., Guan, X. X., Tang, Y. J., Sun, J. F., Wang, X. K., Wang, W. D., & Fan, J. M. (2021). Clinical effects and gut microbiota changes of using probiotics, prebiotics or synbiotics in inflammatory bowel disease: a systematic review and meta-analysis. *European Journal of Nutrition*, *60*(5), 2855–2875.

Zheng, Y., Zhang, Z., Tang, P., Wu, Y., Zhang, A., Li, D., Wang, C. Z., Wan, J. Y., Yao, H., & Yuan, C. S. (2023). Probiotics fortify intestinal barrier function: a systematic review and meta-analysis of randomized trials. *Frontiers in Immunology*, *14*(April), 1143548.

Zhou, P., Chen, C., Patil, S., & Dong, S. (2024). Unveiling the therapeutic symphony of probiotics, prebiotics, and postbiotics in gut-immune harmony. *Frontiers in Nutrition*, *11*(February), 1–12.