The Role of Probiotics and Prebiotics in Modulating Human Gut Health and Immunity

Muhammad Anees Ur Rehman[1,*], Muhammad Azeem[1], Kanza Saeed[1], Khuram Ashfaq[2], Abdul Ahad Qureshi[3], Muhammad Abu Zar Ghaffari[2], Kashif Ameer[4], Faiza Iqbal[5], Muhammad Abdullah Jamil[4] and Sidra Javed[1]

[1]Faculty of Food Technology & Nutrition Sciences, Lahore University of Biological and Applied Sciences, Lahore
[2]Faculty of Pharmaceutical Sciences, Lahore University of Biological and Applied Sciences, Lahore
[3]Department of Horticulture, PMAS Arid Agriculture University Rawalpindi, Pakistan
[4]Institute of Food Science and Nutrition, University of Sargodha, 40100 Sargodha, Pakistan
[5]Doctors Institute of Health Sciences Sargodha, Sargodha 40100, Pakistan
*Corresponding author: anees.rehman@ubas.edu.pk

Abstract

Using prebiotics together with probiotics enhances the right gut flora, increases the absorption of nutrients, reduces inflammation, and enhances immunity to pathogens. The human gut microbiota is a complex ecosystem comprising trillions of micro-diverse populations in the gastrointestinal tract and it is very crucial for the maintenance of human health. In recent years, there has been a lot of research on the complex network of bacteria, fungi, viruses, and other microbes highlighting their significance and functions. It has been revealed that this multi-layered physiological symbiont is involved in metabolic processes, it is involved in vitamin synthesis; is also involved in the growth and regulation of the immune system, which makes gut microbiome very essential in human bodies. Knowledge of these factors and their combinations is significant for designing suitable approaches to improve gut microbiota and health.

Keywords: Probiotics, Prebiotics, Gut health, Immunity, Functional Foods, Microbiota

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Introduction

The gut microbiome in humans is very important in terms of health and immune systems. Gut Health can be preserved by using probiotics and prebiotics as they have immune boosting and gut health promoting characteristics. Probiotics are the live microorganisms which when administered at a right dose confers benefits to the host (Hao et al., 2023). These beneficial bacteria are useful for the regeneration of healthy microbiota, and is very useful for the restoration of the damaged intestinal microbiota, digestion and support for the intestinal barrier. While, prebiotics are food substances that are not digestible and used to selectively enhance and advance the development of specific beneficial bacteria in Gastrointestinal Tract (GIT) (Kadam et al., 2021).

Dietary interventions, which have recently attracted much scientific and consumer attention, can modulate composition and function of gut microbiota (Kassem et al., 2017). The beneficial bacteria which are usually of Lactobacillus, Bifidobacterium and Saccharomyces genera support gut microbiota homeostasis, digestion and increase the intestinal barrier tone (Spiljar et al., 2017). Plethora of effects attributed to probiotics are; competitive inhibition of pathogenic bacteria, secretion of antibiotics and immunomodulation. They have shown success in managing and preventing conditions including antibiotic related diarrhoea, inflammatory bowel illnesses and irritable bowel syndrome (Giromini et al., 2019).

While on the other hand prebiotics are the food ingredients that are not subjected to digestion in the human body yet help in the promotion of the activity of these friendly bacteria in the gut. These are dietary fibers and oligosaccharides that act as prebiotics to the good bacteria in the gut (Rezende et al., 2021). Prebiotics are not a direct stimulant to the gut and immune systems themselves but they favour the growth of helpful microbes. Some foods that are well known to contain prebiotics include fruits, vegetables, whole grain and pulses. Prebiotic substances which are being investigated include inulin, fructo-oligosaccharides (FOS) as well as galacto-oligosaccharides (GOS) (Guarino et al., 2020).

Complementarily, probiotics and prebiotics help to make conditions within the gut hospitable, improve digestion and assimilation of nutrients, temper or eliminate inflammation, and contribute to the immune system's capacity to subjugate pathogens and other threats. This synergistic interaction is known as synbiotics. It is proven that the utilization of prebiotics and probiotics has a major impact collectively than either component alone. Since prebiotic fibers are the food for probiotic bacteria, they can help probiotics perform to their fullest (Al-Habsi et al., 2024).

In the last few years, scientists have found out that taking probiotics and prebiotics can impact more than just the gut; it has an impact

also on mental, metabolic, and skin health. The gut-brain barrier also known as the microbiota-brain axis is the interaction between the gastrointestinal system and the brain and has been proposed to explain the interaction between the gut and the brain (Liu et al., 2016). Research has also indicated that the interaction between gut microbial and probiotics and prebiotics that act on the gut microbiome may play a role on mood, anxiety, and cognition (Plaza-Díaz et al., 2017).

With regard to metabolic health, it can be mentioned that the gut microbiome is responsible for energy acquisition, utilization, and conservation. The literature exists on how probiotics and prebiotics are capable of modulating metabolic activities; thus, may be beneficial in obesity, enhancing insulin sensitivity, and preventing other metabolic-related diseases such as type 2 diabetes and obesity (Pannerchelvan et al., 2024).

Additionally, the link between the intestine and skin has been discussed recently, and the study shows that the state of gut health might affect skin health and skin diseases including acne or eczema, or psoriasis (Widhiati et al., 2021). Gut-skin axis idea claims that using probiotics and prebiotics to control the gut microbiome may be useful to the skin and its appearance (Stavrakidis, 2024).

The Human Gut Microbiome

The human gut microbiome refers to a population of trillions of microorganisms that inhabit the gastrointestinal tract in our bodies, which include bacteria; fungi; viruses, among other microorganisms. The composition and architecture of the gut microbiota are distinct and change with age and are determined by factors including diet, environment, genetic, and lifestyle (Strasser et al., 2021). The main functions of gut microbiota are; digestion of nutrients, absorption of nutrients, synthesis of necessary vitamins, metabolism of xenobiotics, and immune system control. The microbiota supports the function of the intestinal barrier, inhibits the settlement of pathogens and regulates systemic inflammation (Asgar & Chauhan, 2019).

New findings have been revealed regarding the intricate GI microbiota and CNS bidirectional signalling network known as the Gut-Brain Axis that is connected by tryptophan metabolic pathways (Bosi et al., 2020). This has been established to greatly affect not only the organ system responsible for digestion, but many other aspects of human health; including mood, behaviour and cognition. This communication system comprises millions of different microorganisms living in the gastrointestinal tract and directly contributes to it through several processes – synthesis of neurotransmitters, changing of the immunological response, and the regulation of the activity of the hypothalamic-pituitary-adrenal axis (Karoń et al., 2024).

In addition, evidence also suggest that the gut-brain axis communicates in both ways and using neural, hormonal, and immune mechanisms, the brain can also affect the composition of the gut microbiota. Such cross-sectional interaction also exemplifies the possibilities of selective modulation of the gut microbiota as a new strategy for treating neurological and psychiatric diseases (Li et al., 2020). Prebiotics, probiotics, and dietary management has first-in-class evidence of effectiveness in preclinical studies and initial clinical trials, despite further investigations are required to demonstrate their proper mode of action and to discover safe and efficient interventions (Hao et al., 2023).

With new developments in research, it is forthcoming that the balance of intestinal bacteria or gut microbiota play an important role in the proper functioning of our brains and overall mental health throughout life. Thus, this newly arising knowledge proposes the possibility of developing newer preventive as well as therapeutic strategies through the effective modulation of gut-brain axis, which may completely transform neurological and psychiatric care model (Bhalla et al., 2024). Other external factors which impact the microbiome include stress, pollution and hygiene. Moreover, the host's genetics influence microbial signature by determining specific genetic alleles that possess inherent microbial characteristics (Kumari et al., 2024).

Recent studies have established that the gut microbiota synchronizes with the CNS through what is now referred to as the gut-brain axis. They play a complex role that affects mood, behaviour and cognitive functions of any human being. Recent findings indicate that any disruption of the microbiome in the gut is correlated with neurological and psychiatric disorders including depression, anxiety and neurodegenerative diseases (Mitrea et al., 2022).

Mechanisms of Probiotics in Gut Health

It is important to note that the human gastrointestinal microbiome plays a critical role in modulating and enhancing general health and immune competence. This micro world comprising trillions of microbial communities such as bacteria, fungi, viruses, and archaea has gained much interest in the last couple of years. The effect of the microbiome is not limited to the gastrointestinal tract; it plays significant roles in modulating several physiological functions and organs of the body (Greenwood-Van Meerveld et al., 2017). Dietary practices have received much attention because of their impact on the composition and function of gut microbiota (Pan et al., 2022).

Probiotics are microorganisms that have to be consumed in sufficient quantity to have a positive healthy impact. They can help in the healing and maintenance of the microbiota or the balance of gut bacteria, improve digestion, fortify the lining in the intestines, inhibit the growth of pathogenic bacteria by outcompeting them, produce substances toxic to pathogenic bacteria, and influence immune process. While prebiotics are food ingredients that the human body cannot digest, they preferentially promote beneficial gut bacteria. Its role entails that they act as prebiotic substances for the probiotic bacteria, support the growth of bacterial colonies, facilitate digestion, and reduce inflammation (Maftei et al., 2024).

In parallel, probiotics and prebiotics act generally in the prevention of GI diseases, improving nutrient assimilation, decreasing inflammation, and strengthening the immune repertoire against pathogens (Table 1). In further studies, probiotics and prebiotics seem to affect the brain-gut interaction, as well as mental and cognitive functions, metabolism, and skin conditions via multiple physiological pathways (Karoń et al., 2024).

The human gastrointestinal microbiome is a primary determinant of health and immune status of the host. The human gut microbiome is home to trillions of microbes, such as bacteria, fungi, viruses, and archaea, and has gained more attention over the last few years. Several physiological processes and various systems of the body are modulated by the diverse host microbiome including extra-gut microbiome (Jiang

et al., 2022). Gut microbiota has been associated with various health status including gastrointestinal disorders, metabolic disorders, auto-immune disorders, and neurological disorders (Barbosa & Barbosa, 2020).

Table 1: Comparison of Probiotics and Prebiotics

Parameter	Probiotics	Prebiotics
Definition	Live microorganisms providing health benefits when consumed in adequate amounts	Non-digestible food components that stimulate the growth/activity of beneficial gut bacteria
Sources	Yogurt, kefir, sauerkraut, kimchi	Garlic, onions, bananas, asparagus, whole grains
Mechanism of Action	Directly colonize the gut and compete with pathogens	Act as substrates to nourish beneficial gut bacteria
Health Benefits	Improve digestion, enhance immunity, reduce gut inflammation	Support gut microbiota balance, boost immune function, enhance mineral absorption
Stability	Sensitive to heat, pH, and storage conditions	Stable under heat and various processing conditions

As, per recent research studies probiotics and prebiotics positively impact cognitive and mental development, and treat dermatological ailments. This bidirectional communication between the gut-brain axis indicates the possible effectiveness of this combination in treating issues like anxiety, cognitive development, and mood disorders. Similarly, gut-skin axis relationship opens new avenues for treating dermatological disorders by modulating gut microbiome (Kerry et al., 2018). Age, stress levels, environmental factors, level of physical activity, use of antibiotics, and other medications greatly impact natural gut microflora.

Various dietary patterns including high-fibre plant-based diets stimulate the growth of probiotics and gut microbiome (You et al., 2022). When antibiotics are used for the treatment of bacterial infections, it facilitates bacterial pathogen overgrowth and reduction in gut microbiome diversity (Bamigbade et al., 2022). In case of stress, gut microbiome composition and functionality are altered due to changes in permeability, secretion, and mobility (Yadav et al., 2022). Physical exercise improves the diversity of health-promoting microbes, thus, improving immune function, gut motility, and immune function (Guamán et al., 2024). In older age, the gut microbiome becomes less diverse, resulting in increased occurrence of health conditions developed by pathogenic bacteria (Lee et al., 2024). Exposure of the gut microbiome to the antibiotic agent reduces gut microflora viability. Environmental toxins and pollutants and geographic locations greatly impact the composition and viability of gut microflora. Increased industrialization and urbanization is imparting deteriorative effects on the gut microbiome, which in turn increase the incidence of chronic health-related disorders, particularly in developed countries (Şanlier et al., 2019). To develop targeted intervention for overall health improvement, it is crucial to understand the interplay between gut microflora and above discussed factors (Dos Santos et al., 2020).

Recent advances in bioinformatics and gene sequencing technologies have provided a detailed analysis of intricate interactions and complex relationships of the gut microbiome with human health implications in the host. Novel therapeutic strategies like faecal microbiota transplant and personalized prebiotic and probiotic interventions, have provided a better insight and paved a path for the provision of better treatment of numerous health-related disorders (Pan et al., 2022). In addition to it, gut microbiome research is achieving new myriads in the domain of environment, agriculture, and space exploration. More sustainable agricultural practices can be developed by establishing the link of microbiome with animal and human health. Whereas, ecosystem conservation and restoration can be achieved through better insight of the environmental microbiome (Liu et al., 2016).

It can be concluded, that human gut microflora represents a biomedical research frontier that opens the way to unprecedented opportunities for disease prevention and health improvement. This complex ecosystem is a great subject of interest for researchers, it could lead to a revolution in the field of medicine, health care, nutrition, and lifestyle interventions (Carnicelli et al., 2021).

Role of Prebiotics in Modulating Gut Microbiota

There are trillions of microbes that makeup the human gut microbiome, among them 3000 bacterial species play a distinguished role. The primary source of microbiome development during birth is through amniotic fluid, placenta, vaginal exposure and meconium. However, prebiotic components act as the nutrition and growth substrate for local bacteria (You et al., 2022). Prebiotics are nutrients that have been explicitly fermented to cause specific changes in the makeup and/or activity of the gut microbiome, which benefits the well-being of the host. It preserves the integrity of the intestinal barrier, influences immunological responses, and promotes the growth of immune cells by promoting beneficial bacteria and suppressing harmful bacteria (Bergamaschi & Bittante, 2018). Gut bacteria have been shown to affect brain function and behaviour through a two-way communication system known as the gut-brain–microbiota axis (Pessione & Cirrincione, 2016).

Diseases, infections, age, stress, diet, and antibiotic use can potentially alter a patient's gut flora. Alterations in gut microflora play a vital role in causing disease. Beneficial bacteria such as *Bifidobacterium*, *Faecalibacterium,* and *Roseburium spp.* are much more abundant in the gut microbiome of healthy people than in COVID-19 patients. In contrast, disease-causing bacteria, such as *Bacteroides, Enterococcus, Rothia, and Lactobacillus spp.*, are more prevalent in COVID-19 patients (Yilmaz-Akyuz et al., 2019). Regular physical activity has been shown to improve the gut barrier, lower the likelihood of a leaky gut, and reduce inflammation in conditions such as IBD, IBS, and even mental health problems. To improve health status and modify gut microbiota composition, most intervention studies have been carried out in conjunction with an existing diet, such as probiotic species or dietary practices (Yadav et al., 2022).

The microbiome plays a vital role in human health and disease prevention by regulating the immune system, brain health, and overall quality of life. The microbiome plays an essential role in modulating human immune responses. This research provides a critical relationship between microbiome effects and the human immune system, and how immune function is regulated by the microbiome's effect. Microbiome-specific treatments such as faecal transplantation and probiotic interventions have medicinal effects (Murtaza et al., 2017). The main factor

involved in this activity is the metabolites produced by microbes. Immune cell function is regulated by metabolites such as short-chain fatty acids (SCFAs). An imbalance in the natural microbiome leads to disorders of immune functions, such as autoimmune diseases, and gut health diseases, such as inflammatory bowel disease (IBD) (Azad et al., 2018).

General health depends on the interactions between gut microorganisms and the immune system. Probiotics, prebiotics, and postbiotics have become popular treatment strategies that positively affect this axis. Probiotics encourage the growth of immune cells and the integrity of the intestinal barrier, repress harmful bacteria while fostering beneficial ones, and work with the immune system to boost the activity and generation of cytokines that reduce inflammation (Dos Santos et al., 2020). Prebiotics promote the development of healthy bacteria and increase the diversity and activity of gut microbes to improve health, strengthen immune responses, and reduce inflammation (Aryana & Olson, 2017).

Probiotic fermentation produces antibacterial peptides and short-chain fatty acids that improve gut health and regulate immunological responses. Standardization and quality control are necessary for its successful clinical use (Hao et al., 2023). Improving immunological and digestive health may be possible by utilizing the relationship between the immune system and the gut microbes. The essential advantages of beneficial bacteria include improved immunity, reduced inflammation, better gut health, and improved general health. Through comprehension and utilization of the relationship between the immune system and gut microbes, these treatments may prevent and treat several illnesses (Table 2) (Balthazar et al., 2022).

Table 2: Effects of Probiotics and Prebiotics on Human Gut Health

Effect	Probiotics	Prebiotics
Gut Microbiota Composition	Increase in beneficial bacteria such as Lactobacilli and Bifidobacteria	Promotes the growth of beneficial bacteria such as Bifidobacteria
Pathogen Inhibition	Compete with and inhibit harmful pathogens	Indirectly suppress pathogenic bacteria by enhancing beneficial bacteria
Barrier Function	Strengthen intestinal epithelial barrier	Support epithelial integrity and mucus production
Metabolite Production	Produce short-chain fatty acids (SCFAs), vitamins	Increase SCFA production by nourishing gut bacteria
Anti-inflammatory Effects	Reduce pro-inflammatory cytokines	Modulate immune responses and reduce inflammation

Interaction between Probiotics and Prebiotics: Synbiotic

In May 2019, the International Scientific Association for Probiotics and Prebiotics (ISAPP) called for a panel of expert academic scientists in gastrointestinal physiology, microbiology, and nutrition, which panel updated the definition of Synbiotics to a new updated definition as “A mixture comprising of live microorganisms and substrate that are selectively utilized by host microorganisms to provide health benefits to the host.”(Kumari et al., 2024). In this definition, host microorganisms refer to organisms that reside in or colonize the host. Synbiotics must contain a live microorganism and selectively utilized substrate. The formulation of a synbiotic product must include components that promote the co-dependent functions of components to provide health benefits (Karoń et al., 2024).

To provide desired health benefits in the host body, synbiotics must comprise compatible probiotic and prebiotic combinations. The prebiotics and probiotics must be capable of imparting desired health effects (Hardy et al., 2013). A symbiotic product must have the potential to improve survival rate of microbial dietary supplements, microbial activity and selective stimulation of microbial growth. The most accepted combinations include. *L. rhamnose* and inulin and *B. bifid* with frucrtooligosacchrides combinations (Eslami et al., 2019). Complimentary synbiotics is a type of synbiotics in which probiotics and prebiotics does not require a co-dependent function to generate desired clinical health benefits (Azad et al., 2018). Whereas, the synergistic synbiotics are based on specific prebiotics substrate to escalate growth and stability of particular probiotic strains (Giromini et al., 2019).

Understanding the effects of nutrient absorption and assimilation on metabolism and energy balance is therefore essential. As synbiotics are a combination of prebiotics and probiotics, probiotics help regain the microflora after antibiotic therapy, and prebiotics are fed to the microflora. Many metabolic diseases are associated with gut microbiota dysbiosis, characterized by a smaller number of bifidobacteria, lactobacilli, and many pathogenic bacteria, resulting in gut microflora imbalance. This triggers several metabolic diseases (Ahmad et al., 2019).

Studies suggest that some recently discovered probiotics, Akarnania and Prevotella plentifulness, are associated with improved glucose and lipid metabolism by enhancing receptor sensitivity. Inulin has been reported to improve glycaemic dysregulation. Synbiotics (probiotic strains and prebiotic foods) are directly related to modulation of microbial composition, regulation of metabolites, and improvement of the intestinal barrier (Ferreira et al., 2023). Modulation of gut microbiota homeostasis has been reported to improve metabolic diseases. The abundance of strains such as Bifidobacterium, Akkermansia, Enterobacteria, and Prevotella is associated with the upregulation of GLUT-4 and expression of IL-10, which reduces the expression of TNF-α and circulating endotoxins. The action of probiotic-produced metabolites and cell components is linked to an improved barrier function and immunity (Karoń et al., 2024). In a mouse model study, Lactobacillus positively affected the increase in regulatory T-cells in Pseudomonas pneumonia. Synbiotics protect the immune system against pathogenic attacks (Roy et al., 2024).

Gut-Immune System Axis and Immunomodulatory Effects

The Human body is a super-complexed ecosystem, a social network with gut microbiota that had a symbiotic relationship with parasitism. The gastrointestinal (GI) microbiota interacts symbiotically with enteric cells, contributing to the fundamental physiological processes of digestion, absorption, and repair (Franke et al., 2009). Gut microbiota plays a vital role in maintaining host health and can provide various health benefits. Probiotics are "live microorganisms that confer a health benefit on the host when administered in adequate amounts." The human GI epithelium serves as the initial point of contact between the host and microorganisms; the pathogenic bacterial infection will interact

with the mucosa of the intestinal tract and activate the immune response (Ningtyas et al., 2019).

Many studies have shown that probiotics can regulate and restore the gut microbiota balance by promoting significant bacterial growth and inhibiting the growth of harmful bacteria. The mechanism by which probiotics modulate is not yet fully understood, and they may inhibit pathogen growth by producing SCFA (short-chain FA), creating toxins, and competing for colonization sites (Li et al., 2020). Moreover, the strain-specific effective doses of the newly identified probiotics require more precise investigation. Prebiotics are non-digestible compounds that resist degradation by secretions and enzymes in the gastrointestinal tract and traverse the intestine to reach the colon in an intact form (Abadía-García et al., 2013). Prebiotics in the colon are metabolized by the gut microbiome or consumed by probiotic microorganisms to produce beneficial compounds. The breakdown of prebiotics produces therapeutic compounds and enhances colon-based probiotics by serving as a food source (Liu et al., 2016). The key prebiotics are carbohydrates, specifically galactooligosaccharides (GOS), fructooligosaccharides (FOS), and xylooligosaccharides. The combined use of prebiotics and probiotics is known as a symbiotic that helps control and reduce the risk of certain diseases, such as mental health disorders. Prebiotics serve as a food resource for probiotics. Prebiotics minimize the impact on host health and disease management if probiotics are absent or present in lower numbers (Li et al., 2020). Probiotics have been shown to enhance immune functions in the context of the immune system. This observation was noted in a probiotic clinical trial involving 187 pregnant women, in which colostrum enhanced with probiotics demonstrated potential benefits in improving maternal and infant immune responses (Singh et al., 2018).

Probiotic supplements may enhance sleep quality by stabilizing gut microbiota. It improves the production of free tryptophan in the central nervous system, facilitates melatonin synthesis of serotonin, and regulates melatonin levels, which maintains the circadian rhythm. Prebiotics positively influence mental health and improve cognitive function and the sleep-wake cycle. Clinical trials have shown the effect of *Lactobacillus casei* strain Shirota on sleep quality. A psychological stress report indicated improved sleep quality with LCS supplementation (Nami et al., 2025). Immunomodulatory Roles of probiotics and prebiotics has been elaborated in Table 3.

Table 3: Immunomodulatory Roles of Probiotics and Prebiotics

Immunological Aspect	Probiotics	Prebiotics
Innate Immunity	Enhance phagocytic activity, stimulate natural killer (NK) cells	Modulate macrophage activity via SCFA production
Adaptive Immunity	Regulate T-cell differentiation, enhance IgA secretion	Influence T-cell balance, enhance IgA secretion
Cytokine Production	Increase anti-inflammatory cytokines, reduce pro-inflammatory cytokines	Promote anti-inflammatory cytokine production
Gut-Associated Lymphoid Tissue (GALT)	Stimulate immune cells in GALT	Support GALT development through microbial fermentation products
Allergy Modulation	Reduce allergic responses by modulating immune tolerance	Decrease allergic inflammation through gut microbiota modulation

Future Perspectives and Challenges

The microbiome comprises millions of tiny living organisms within and outside the human body, which significantly affect human health. It has been shown that changes in the composition of the microbiome, or 'dysbiosis' as referred to, is linked to some illnesses, e.g., Inflammatory Bowel Disease (IBD), obesity, and diabetes, and even more significantly, mental health-related diseases such as anxiety and depression (You et al., 2022). A complete (healthy) term given to the colonized surface of the human body, including the skin, gut, and so-called sterile places such as the blood in constant circulation, possesses a varying microbial compositional index. A few studies have reported that more than 10000 microbial species have been found in different locations in the human body (Shehata et al., 2022).

Emerging Research Trends

Personalized Microbiome Therapeutics

An emerging branch of microbiome studies is personalized medicine, which focuses on the development of treatments for persons. Personalized microbiome therapeutics determine an individual's microbiome profile and correct it to promote a wide range of health. Studies have indicated that individual microbiomes differ widely based on several factors, such as genetic composition, diet, environment, and lifestyle (Tuohy et al., 2024). Consequently, adopting a standard protocol for microbiome-based interventions is likely ineffective. Traditional and novel interventions could include specific foods or supplements containing targeted strains of bacteria, probiotic therapy, or even fecal transplants (FT) to regenerate more normal microflora or enhance health (Hao et al., 2023).

Next-Generation Probiotics

Next-generation probiotics (NGPs) are more advanced than standard probiotics because they emphasize specific strains with distinct health benefits instead of the conventional approach dominated by a few bacterial strains, in which NGP development is more sophisticated in terms of knowledge of germs and their relationships. For example, some NGPs are already in development to inhibit specific diseases, such as inflammatory bowel disease (IBD), obesity, and metabolic syndrome. Therefore, these developments have enabled the development of more complex therapies that are available in a broad spectrum and focus on the microbial populations present within the client (Yadav et al., 2022).

Conclusion

Probiotics and prebiotics have emerged as effective tools for modulating gut microbiota, offering a wide range of health benefits. Probiotics, as live beneficial microorganisms, restore microbial balance, strengthen the intestinal barrier, and inhibit pathogens, while prebiotics, as non-digestible food components, selectively nourish beneficial bacteria, promoting their growth and activity. Together, they function synergistically

as synbiotics, enhancing gut health and systemic well-being. Research highlights the potential of probiotics and prebiotics in managing gastrointestinal disorders (e.g., IBS, IBD), metabolic diseases (e.g., obesity, diabetes), mental health conditions (e.g., anxiety, depression), and skin ailments (e.g., acne, eczema). The gut-brain and gut-skin axes illustrate the extensive influence of gut microbiota on overall health, emphasizing the importance of maintaining microbial balance. Additionally, their immunomodulatory effects enhance immune function, reduce inflammation, and mitigate infections and allergies. However, challenges such as individual microbiome variability, lack of standardized protocols, and the need for personalized interventions hinder the translation of research into clinical practice. Future advancements in personalized microbiome therapeutics and next-generation probiotics hold promise for addressing these challenges, paving the way for innovative, targeted treatments that harness the full potential of the gut microbiome for improved health outcomes.

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