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PROBIOTICS: INTEGRAL AGENTS IN HUMAN HEALTH AND DISEASE PREVENTION

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ABSTRACT

Probiotics are healthy microorganisms that support gut health. They have drawn a lot of interest because of their potential to improve immunity, prevent disease, and improve digestion. In this review, the synergistic interaction between probiotics and prebiotics is examined, with a focus on their mechanisms of action, health advantages, and food business uses. Probiotics produce bioactive substance such as short chain fatty acid which balance microbiota, and fortify the gut barrier, all of which improve gastrointestinal health. Their medicinal potential includes improving immunological function, treating digestive issues, and potentially lowering the risk of inflammatory and metabolic diseases. Probiotics use prebiotics which are indigestible food fibers and act as fuel for probiotics to increase their activity, survival in the gut. Synbiotics, a combination of prebiotics and probiotics, have demonstrated encouraging results in optimizing the advantages of both ingredients. Food technology advancements have made probiotics more widely available and useful by incorporating them into various items such as dairy, beverages, baked goods, and edible films. However, a number of variables affect their efficacy including strain specificity, stomach environment, and storage condition. Probiotics increasing significance for human health, as well as their developing involvement in functional diets and medicinal therapies.
***Keywords*:** Microbiota, Probiotics, Gastrointestinal tract, short chain fatty acid, Pathogens

Introduction

Human beings are exposed to numerous pathogens daily, predominantly bacteria. Probiotic microbes have been used in many diets for years because of their beneficial effects on human health (Bodke & Jogdand, 2022). In 1953, German scientist Werner Kollath introduced the term "Probiotic," which are derived from the Latin word *pro* and the Greek word *bios*, meaning "for life." He defined probiotics as active substances that have imporatnt roles in supporting several health characteristics (Giovanni *et al*., 2016). Additionally, fermented foods gained more popularity after Kollath introduced the term Probiotic.

Numerous bacterial genera have shown potential as probiotics, including Lactococcus, Enterococcus, Streptococcus, Pediococcus, Propionibacterium, and Bacillus. However, the *Bifidobacterium* and *Lactobacillus* categories include the most commonly used probiotic starins. It is generally known that these bacteria may produce organic acids like acetate and lactate (Hamad *et al*., 2022).

The intestinal tract and other parts may benefit from a variety of these organic acids that are created by microbes in the colon. They serve an essential function in building a better gut environment by suppressing unwanted microorganisms and cross-feeding other helpful gut microbes, resulting in the synthesis of butyrate, which fuels intestinal epithelial cells (Sander *et al*., 2018). Since these microbes naturally exist in the microbiota of the gut, the majority of research focuses on their impacts on the gut's normal function and as agents that can prevent or treat the development of disease. Probiotics can be taken as supplements in the form of beverages, ice cream, yogurt, and bread, or they can be added to foods and beverages as dairy or non-dairy foods such as miso, sauerkraut, kefir, tempeh, etc (Fenster *et al*., 2019). Consuming probiotics can promote intestinal health by regulating microbiota, stimulating and developing the immune system, and improving nutrient synthesis and bioavailability, to name a few positive impacts (Nagpal *et al*., 2012).

For Probiotics to work effectively, prebiotics are needed because prebiotics act as "food" for the Probiotic bacteria, allowing them to thrive and multiply in the gut, thus maximizing their beneficial effects on health. They are defined as the substrate that is selectively used by host micro-organisms offering a health benefit (Gibson *et al*., 2017). Generally recognized prebiotics are fermentable carbohydrates or any dietary fiber that can be utilized by gut flora. These include inulin and other fructo-oligosaccharides (FOS), which are important carbohydrate energy sources for resident microorganisms of the gut. Usually, they are not further metabolized or absorbed within the earlier segments of the intestines, but probiotic bacteria can hydrolyze them in the large intestine and convert them into metabolizable, health-promoting substances for the host. Prebiotics can be prepared by either extracting them from plant sources such as chicory inulin or hydrolyzing plant polysaccharides enzymatically to yield products such as xylooligosaccharides (XOS), produced by hydrolysis of xylans derived from cereal grains, or galactooligosaccharides (GOS), produced through enzymatic transgalactosylation reactions where either mono or disaccharides serve as substrate and lactose with β-galactosidase acts as a biocatalyst (Charalampopoulous & Rastall 2012). Prebiotics have been associated with multiple health advantages, including improved mineral bioavailability, especially calcium; immune system modulation, inflammatory state modification, control of metabolic issues connected to obesity, and decreased cancer risk.

Even the synergistic effects of probiotics and prebiotics are frequently applied to food products. Consequently, these combinations are referred to as synbiotics. Prebiotics such as RaftilosesP95 when used in conjunction with *Lactobacillus rhamnosus*, *Bifidobacterium* species, *Lactobacillus acidophilus*, and *Lactobacillus casei*, increase their viabilities at 4°C for four weeks of storage (Al-Sheraji *et al*., 2013). The principal purpose of this type of combination is to increase the ability of probiotic microorganism to survive in the gastrointestinal system. Therefore, when both ingredients are used in a single product, the result should be better than if the probiotic or prebiotic were used alone.

Current research continues to explore the potential of probiotics and prebiotics in disease prevention and overall health improvement, emphasizing strain-specific functions and appropriate dosages for therapeutic effects (Markowiak & Slizewska 2017). This review provides an in-depth discussion of the mechanisms of probiotic action, their health benefits, and the latest advancements in probiotic research.

Archival Advancements in Prebiotics and Probiotics

Elie Metchnikoff, a Russian scientist at the Pasteur Institute in Paris, made significant contributions to the development of the probiotic in the early 20th century (Alok *et al*., 2017). He examined, despite the hard climate and extreme poverty, Bulgarians living in rural areas survived to very old ages; their average life spans were longer than those of wealthier European nations. Metchnikoff pointed out that yogurt and other fermented milk products were a major part of their diets. In 1907, he proposed that the bacteria involved in yoghurt fermentation such as Lactobacillus *bulgaricus* and *Streptococcus thermophilus,* block the putrefactive type fermentations of the intestinal flora (Soccol *et al*., 2010). He also asserted that “the dependence of the intestinal microbes on the food makes it possible to adopt measures to modify the flora in our bodies and to replace the harmful microbes by useful microbes” (Gasbarrini *et al*., 2016).

In the 1930s, Japanese microbiologist Minoru Shirota directed his research to select the strains of intestinal bacteria which are capable of surviving transit through the intestines. He intended to use such strains to develop fermented milk products for delivery in his clinic. The first product containing *L. acidophilus* Shirota (later named *L. casei* Shirota) became the basis for founding Yakult Honsha Company. Then from 1950s researchers started focusing on probiotic strains and screening for potential strains derived from natural isolates or from human host (McFarland 2015). Later research enhanced our understanding of how resident microbiota interact with and resist colonization by harmful bacteria.

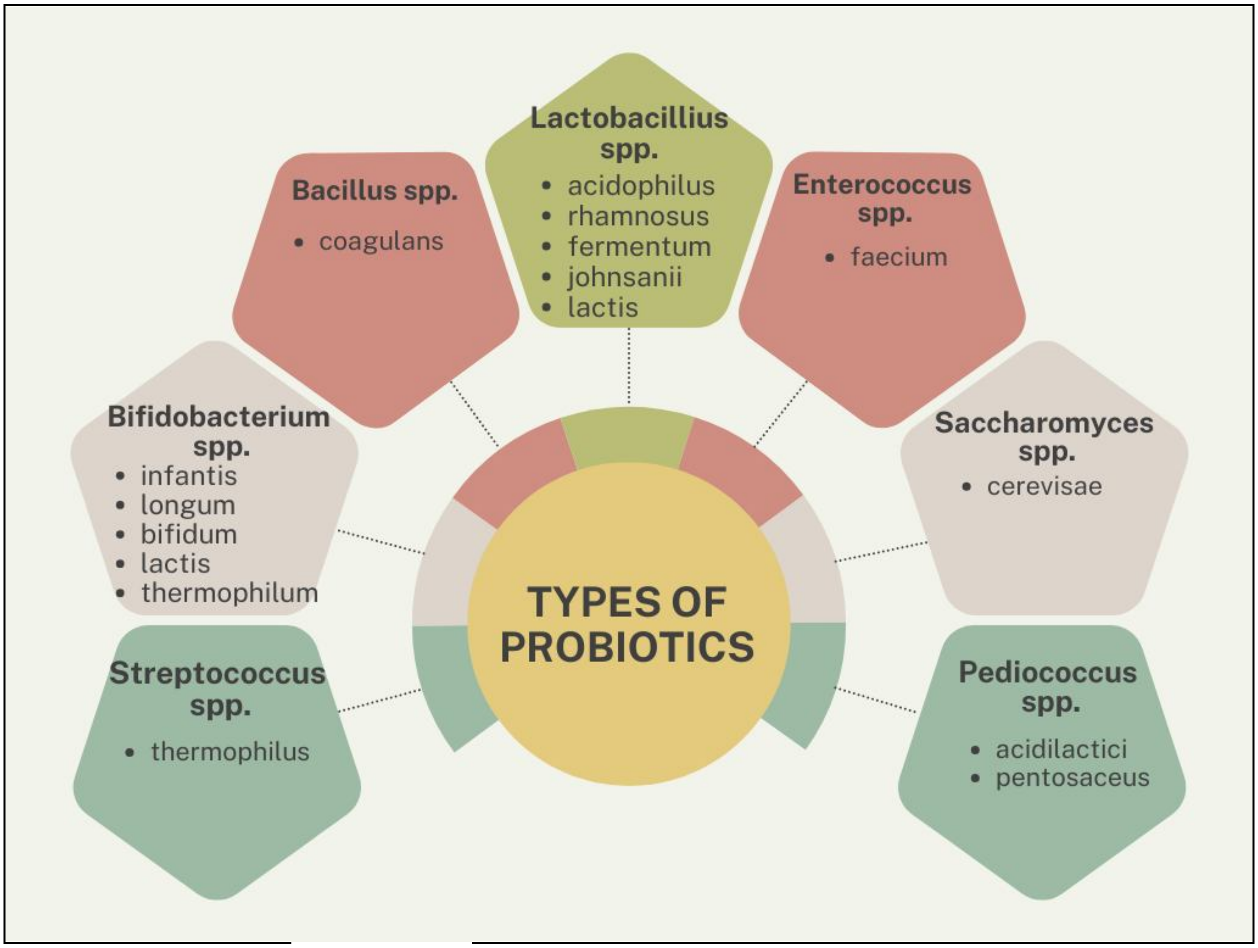

Fig. 1 : various microorganism species used as probiotics

Characteristics of Probiotics

1. **Tolerance to Upper GI Environment:** Gastrointestinal (GI) conditions have a critical effect on the survival and adhesion potential of probiotic bacteria, including the pH variations, bile salts, and exposure to digestive enzymes. Various bacterial strains have different levels of resistance to these environmental conditions. For example, research has shown that the adhesion capacity of *Lactobacillus rhamnosus* to mucus is greatly diminished by about 90% after exposure to digestive enzymes like amylase, pepsin, bile, and pancreatin. Lactobacillus johnsonii La1, on the other hand, has a smaller decrease in adhesion, which is estimated at about 67%. With these strain-specific differences, it is essential to determine the GI tolerance of all potential probiotics to ensure their effectiveness in enhancing gut health.
2. **Adhesion:** Probiotic adhesion to intestinal mucosa is pivotal in prolonging their residence time, particularly in the small intestine with its short transit time. As an example, *Lacticaseibacillus rhamnosus* GG proved to adhere to and colonize the small intestine, successfully lessening the duration of rotavirus-induced infant diarrhea. On the contrary, strains such as *Lactobacillus delbrueckii* subsp. bulgaricus are unable to adhere. Thus, testing the adhesion capacity of every probiotic strain is necessary to confirm their effectiveness in maintaining gut health (Monteagudo-Mera *et al*., 2019).
3. **Specificity to target sites:** Probiotics reach and survive at targeted sites along the gastrointestinal tract successfully to provide the health benefits. For example, *Lactobacillus* and *Bifidobacterium* strains exhibit site-specific adhesion that improves their probiotic activity. They adhere to intestinal mucosa, enabling transient colonization and the provision of immunomodulatory functions and gut barrier integrity. This specificity allows even lower doses of probiotics to be effective and minimize the requirements for high levels of supplementation. By binding to specific sites, probiotics can compete with pathogens for binding

sites, thus enhancing their protective functions in the GI tract**.**

4. **Immunomodulation by Probiotics:** Probiotics are also important in the modulation of the immune system, which aids in enhancing host defenses against infection and inflammation. Some strains, including Lactobacillus acidophilus and casei, have been reported to induce the secretion of anti-inflammatory cytokines, which assist in regulating immune responses and ensuring homeostasis. By modulating immune cells, probiotics are capable of regulating pro- and anti-inflammatory signals, dampening overactive immune responses that underlie conditions such as inflammatory bowel diseases (IBD) and allergies. Their immunomodulatory actions make probiotics a hopeful therapeutic option for the management of inflammatory conditions (Azad *et al*., 2018).

5. **Growth and Metabolic Activity:** The ability of probiotics to multiply within the gastrointestinal tract is the important characteristic feature of a probiotics. Through the multiplication of their numbers, probiotics increase the production of bioactive compounds that promote gut health. Short chain fatty acids (SCFAs) including acetate, propionate, and butyrate, are one of the most important metabolic products of probiotic activity (Koh *et al*., 2016). These SCFAs regulate intestinal pH, suppress pathogenic bacteria, and maintain immune function. Lactobacillus and Bifidobacterium strains are critical in fermenting dietary fiber to produce SCFAs, which further feed colonocytes and enhance gut barrier integrity. SCFAs also affect the balance of the gut microbiota, promoting the growth of beneficial bacteria while inhibiting pathogens. Therefore, the growth and metabolic activity of probiotics are essential for sustaining a healthy gut environment and promoting overall well being.

Table 1 : List of probiotic products, raw material, strain with their health benefits

Sr. No.	Probiotic Products	Raw Material	Probiotic Strains	Benefits	References
1	Yogurt	Milk	*Lactobacillus casei Shirota*	Reducing the risk of high blood pressure, preventing osteoporosis	Weerathilake *et al*. (2014)
2	Natto	Soybeans	*Bacillus natto*	Protection against bacteria and toxins. Also help in constipation, antibiotic-associated diarrhea, bloating, as well as reducing other symptoms of inflammatory bowel disease.	Pradhananga (2019)
3	Kefir	Milk drink	*Lactobacillus, Lactobacillus acidophilus*	protects against cancer, may help lower cholesterol, and has great skin benefits, also helpful to diabetic patients because it reduces the fasting of blood glucose	Rosa *et al.* (2017)
4	Sauerkraut	Cabbage	*Lactobacillus brevis*	Promoting cardiovascular health, supporting a healthy gut microbiome, and Enhancing digestive health.	Fijan *et al.* (2024)
5	Miso	Soybeans with salt and koji	*Tetragenococcus halophilus and Lactobacillus acidophilus*	Prevent cell damage, atopic dermatitis, and bowel diseases.	Ito (2020).
6	Kvass	Wheat, rye, barley	*Lactobacillus delbrueckii, Lactiplantibacillus plantarum, Lacticaseibacillus casei, Lacticaseibacillus paracasei,*	Great for detoxing, Improving the immunity system, and supporting good health, beneficial effects on gastrointestinal disorders	(Baschali *et al.*, 2017)
7	Tempeh	Soybeans	*Rhizopus oligosporus*	Reduced pain and swelling, Improved insulin resistance, and Improved bone health	Ahnan *et al*. (2021).
8	Koumiss	Mare's milk and yeasts	*Lactobacillus delbrueckii*	Improve the absorption of nutrients, and regulate the gastrointestinal environment.	Afzaal, *et al.* (2021)
9	Kombucha	Yeast, sugar, and black tea	*Gluconacetobacter xylinu*	Lowers the cholesterol and blood pressure levels, decrease the progression of cancer, and the enhancement of liver, immune and gastrointestinal function.	Kapp & Sumner, (2019).

10	Bors	wheat bran	*Lactobacillus amylolyticus*	Reduced Inflammation, Good for liver health, and reduces the chances of cancer disease.	Bădăluță *et al.* (2022)
11	Brem	Rice	*Saccharomyces cerevisiae*	good for appetite and skin health	Setiarto *et al.* (2024).
12	Boza	cereal	*Lactobacillus acidophilus, Lactobacillus fermentum, Lactobacillus plantarum, Lactobacillus rhamnosus, Lactobacillus casei, Bifidobacterium longum*	Good for digestion, also beneficial for heart diseases.	Bayat & Yildiz, (2019).

How Probiotics and Prebiotics Work: Their Mechanisms of Action

The mechanisms of action of both probiotics and prebiotics relate to their influence on gut microbiota, which refers to the diverse community of microorganisms residing in the gastrointestinal (GI) tract. In contrast, the gut microbiome includes all the microorganisms, their genetic material, and the environmental factors that influence them. The GI tract consists of approximately 100 trillion microorganisms (bacteria, viruses, fungi, protozoa) of at least 1000 different species. In the stomach and duodenum (small intestine), only a limited number of microbes, primarily Lactobacilli and Streptococci can survive due to the presence of gastric acid, bile, and pancreatic secretions, which create a highly restrictive environment for most microorganisms whereas colon is the most heavily populated region of the GI tract where mostly anaerobic microbes are found (Jenkin & Mason, 2022).

There are several mechanisms in which probiotics exert their effects on diseases**.** They colonize themselves in the gut environment of the human and their colonization pattern can vary among individuals depending on the individual’s microbiota, the probiotic strain/strains, and the region of the GI tract (Zmora *et al.*, 2018). They primarily influence gut microbiota composition, intestinal barrier function, immune modulation, and metabolic processes.

Manipulating gut Microbiota: Probiotics directly engage with the GI system to restrict the development of pathogenic microbes. They achieve this inhibition through the improvement of gastrointestinal passage which prevents the pathogenic bacteria from adhering or colonizing on the epithelial lining of the gut. In addition, they contest with the pathogens for essential nutrients and receptor binding sites, thereby limiting the survival of harmful organisms in the gut environment. They also improve nutritional value of microbiota by generating a number of enzymes which help in the fermentation of endogenously generated mucus and non digestible food residue, as well as in replenishing lost energy (Nagpal *et al.*, 2012).

Improvement of Gut Barrier Function: Probiotics communicate with the cells inside and outside the gastrointestinal tract through biochemical signals, resulting in a strengthened gut barrier by stimulating the synthesis of mucin proteins, controlling the expression of some tight junction proteins such as occludin and claudin-1, also suppress pro inflammatory cytokines, and better immune response. There are some specialized barrier cells which are found in the mucus layer and the intestinal epithelium. They serve as a physical barrier against the harsh luminal environment, assisting in food passage, and blocking the harmful pathogens from binding. The intestinal mucosa is a major shield and protects the body from highly toxic materials lying in the intestinal cavity (Maftei *et al.*, 2024).

Bioactive Compound Production: Probiotics enhance the host's immune response by increasing the time that antigenic response is exposed to the host, meanwhile the development of antimicrobial compounds is then stimulated, with the restriction of the pathogens from binding to the host cells. They also help in producing bioactive metabolites such as short chain fatty acids (SCFAs) that help create an environment that is unfriendly towards pathogenic bacteria by decreasing the pH of the colon. Other notable roles include vitamin synthesis in the gastrointestinal tract, bile salt metabolism, enzyme-related neurotoxicity and various physiological processes (Jenkin & Mason, 2022).

Modulating the Immune System : The probiotics establish contacts with the gut-associated lymphoid tissue (GALT) and regulate some aspects of immunity. They enhance the activity of immune cells mainly macrophages, dendritic cells, and T lymphocytes, involved in the reduction of inflammation and boosting of the body's overall defences against infection (You *et al.*, 2022). Probiotics also influence immune signalling pathways through reduced production of pro-inflammatory cytokines and enhanced levels of anti-inflammatory cytokines, thus facilitating balance in the immune system (Plaza *et al*., 2019).

Digestion and Nutrient Absorption: Some probiotic strains support digestion by producing lactase, amylase, and proteases, which in turn result in breakdown of food substances, thus enhancing the digestive process through degradation of complex food items. The enzymatic activity increases the bioavailability of nutrients, mostly in certain individuals suffering from specific digestive disorders, including lactose intolerance. They also help recycle bile acids and supply vitamins and enhance overall digestion (Nicolae *et al*., 2010).

So the mechanism includes restoring intestinal permeability, supporting mucosal healing, enhancing mucus secretion, and preserving the integrity of the mucosal barrier and normal intestinal mechanical function. These processes enable probiotics to play a significant role in promoting overall health and managing various diseases in both children and adults.

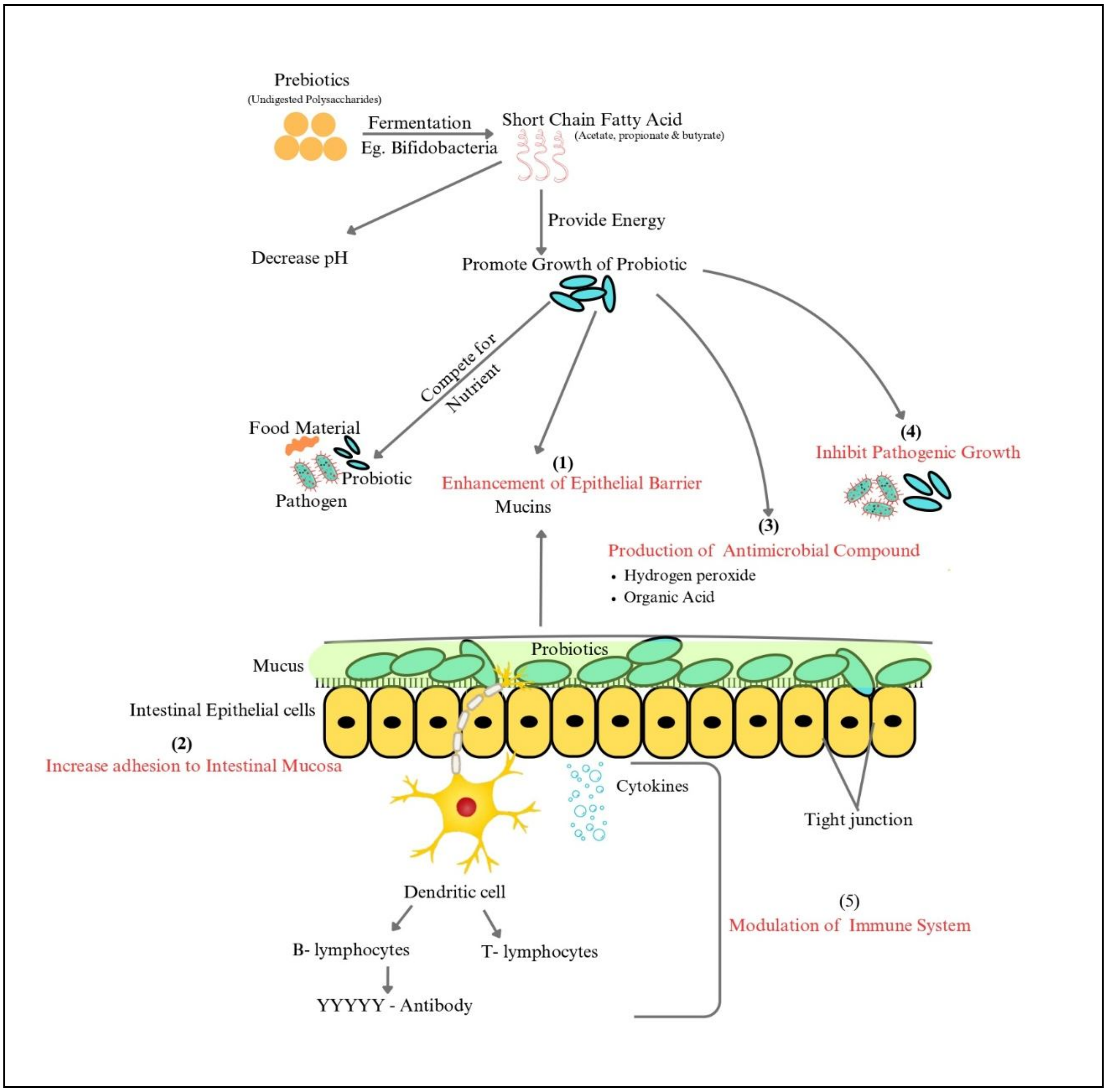

Fig. 2 : Mechanism of action of prebiotics and probiotics

Factors Influencing Probiotic Efficacy

Probiotics are live microorganisms that provide health benefits when consumed in adequate amounts. However, their effectiveness and survival are influenced by various intrinsic and extrinsic factors. Several other factors control the functions of probiotics as they relate to their viability, stability, and functional performance.

1. **Temperature and Storage Conditions:** The viability of probiotics is highly dependent on both temperature and storage conditions. Environmental stresses such as high

temperatures, moisture, and oxygen can lead to instability, and thus its viability may be reduced. Probiotics are highly sensitive to high temperatures, which lead to cell destruction, thereby reducing their effectiveness. High heat exposure during processing and storage can reduce bacterial viability. Preferably between 4-5ºC, found that storage at 2°C gave the highest viability of *Lactobacillus acidophilus*, while for B. lactis the maximum viability was obtained when yogurt was kept at 8°C (Lamba & Goomer 2018).

2. **pH and Gastric Conditions:** Probiotics must pass through the adverse conditions of the gastrointestinal tract prior to reaching the intestines, where they exert their beneficial effects.

a) **Gastric Acid:** Stomach which secretes highly acidic gastric juice with a pH ranging from 1.5 to 3.5 so probiotics must withstand this acidic environment to reach the intestines alive. Sometimes this acidic pH damage probiotic cell membranes and DNA but probiotic strains, such as *Lactobacillus* and *Bifidobacterium*, have higher acid resistance, allowing them to survive in the stomach.

b) **Bile Salts:** it is a digestive fluid produced by the liver and gallbladder. As food enters the small intestine, bile is released to breakdown fats. However, bile salts also affect probiotics. They have the ability to chelate iron and calcium, denature cellular proteins, rupture bacterial membranes, and cause oxidative DNA damage (Ayyash *et al*., 2021).

c) **Digestive Enzymes:** The GI tract produces a variety of enzymes that help digest food into absorbable nutrients: for example, pepsin, trypsin, amylase. Breaks down proteins, including bacterial cell proteins, which leads to probiotic degradation (Govaert *et al*., 2024).

3. **Host-Related Factors:** Numerous host-related factors such as age, immunological condition, and antibiotic use, affect the probiotics.

a. **Age**: Throughout the human life, gut microbiota composition changes. Gut microbiota composition differs in infants and the elderly compared to other age groups. For instance, an infant's gut microbiome is less diverse than with maturity, and reduced microbial diversity is observed in the elderly. Such variations indicate a more effective use of specific probiotic strains when the body needs it during certain life stages, hence supporting gut health.

b. **Antibiotic Use**: Antibiotics can disrupt the normal balance of gut microbiota, which leads to a decrease in diversity and potential overgrowth of pathogenic bacteria. Such disruption may reduce the colonization and action of probiotics (Elias *et al*., 2023).

4. **Carrier /Medium of Probiotic:** The efficacy of probiotics depends not only on the strain selected used but also depends on how it's delivered. Various forms of probiotics such as fermented dairy products, capsules, and combinations with prebiotics are able to influence probiotic viability and functionality.

a. **Fermented Dairy Products:** Dairy fermented products such as yogurt, kefir, and cheese provide an excellent carrier for probiotics due to their buffering ability and protective atmosphere, which enhances the viability and stability of probiotics during storage and transit through the GI tract (Ranadheera *et al*., 2010). The presence of lactose, proteins, and lipids in dairy products provides nutrition and stability to probiotic bacteria. Further, the acidic nature of fermented dairy products facilitates the viability of acid-tolerant probiotic strains.

b. **Capsules and Powder:** Usual forms of non-dairy probiotic delivery, such as capsules and powders, are bound to some kind of protective measure that ensures the survival of bacteria in the acidic environment of the stomach. These formulations often use microencapsulation technologies such as alginate, chitosan, and lipid-based coating, to provide stability, and slow-release in the intestine. Also, these encapsulated probiotics are highly resistant to gastric and bile stress, and thus enhance their functional efficacy (Tripathi & Giri, 2014).

c. **Prebiotics Combination for Enhanced Efficacy**: The combination of probiotics with prebiotics (such as inulin, fructooligosaccharides (FOS), and galactooligosaccharides (GOS)) enhances probiotic function. Prebiotics provide the source of nourishment for probiotics, improving their ability to adhere and metabolic activities. This means that synbiotics increase the survival, adherence, and therapeutic potential of probiotics in the human gut (Gibson *et al*., 2017).

5. **Strain Specificity**: Strain specificity has a profound influence on the efficacy and functionality of probiotics because various strains of probiotics have different biological properties, including their survival capacity in different environmental conditions, their interaction with

host cells, and their beneficial effects on health. Different strains of a probiotic species can differ regarding their tolerance to gastric acidity, bile salts, temperature, and exposure to oxygen. Also, certain strains will produce special metabolites, for example, lactic acid or short-chain fatty acids, which are beneficial to gut health and others, might possess immune-modulating effects (Nicolae *et al*., 2010).

Table 2 : Various prebiotics from their natural source

S. No.	Prebiotics	Natural Sources	Benefits	References
1	Inulin	Chicory Root, Asparagus, Banana	Improved digestion, enhanced mineral absorption, immune support	Shoaib *et al*. (2016)
2	Fructooligosaccharides	Garlic, Onion, Wheat	Increased satiety, reduced blood glucose levels, improved gut health	Li, *et al.* (2015)
3	Galactooligosaccharides	Legumes, Soybean, Milk	Enhanced immune function, improved calcium absorption, gut health	Li, *et al.* (2015)
4	Resistant starch (RS)	Raw Potato, Green banana	Improved insulin sensitivity, reduced appetite, enhanced gut health	Plongbunjong *et al.* (2017)
5	Beta glucans	Oats, Barley, Mushroom	Reduced cholesterol levels, enhanced immune function	Yang *et al.* (2013).
6	Arabinoxylan	Wheat, Rye, Barley, and Oats	Immune Modulation, Antioxidant effects, Anticancer,	Mendez-Encinas *et al*. (2018).
7	Lactosucrose	Milk sugar	Enhanced Mineral Absorption, Anti-inflammatory Properties, Reduction of putrefactive products	Silvério *et al*. (2015).
8	Lactulose	Skim milk	Treatment of constipation, improved gut health	Karakan *et al*. (2021).
9	Pectin	Guava, Citrus fruits, Apple	Lowered cholesterol levels, and improved gut barrier function	Blanco-Pérez *et al.* (2021)
10	Xylooligosaccharides	Bamboo shoot, Fruits, Vegetables, Milk, Honey	"enhanced fecal weight and mineral uptake, immune stimulation,	Samanta *et al*. (2015).

Health Benefits of Probiotics

Probiotics are suggested as they may translocate across the gut wall, modulate epithelial and immune function, and produce chemicals that affect pain receptors within the gut. The modern diet needs to be change with the incorporation of probiotics and these beneficial microorganisms must be supplemented from outsources, usually either as parts of a typical diet or as additives because pre-historic humans consumed diets rich in fibers (prebiotics), which support the generation of probiotic-type bacteria. Numerous illnesses are associated with gut microbial dysbiosis. So they affect the intestinal microbiota, by increasing the production of short-chain fatty acids (SCFA), and decrease the likelihood of developing disease. Their intake is related to a reduction in many diseases, such as constipation, colon cancer, type 2 diabetes mellitus, obesity, and treatment of a variety of intestinal disorders such as inflammatory bowel disease.

1. **Probiotics for treatment of GI tract issues:** The gut plays a vital role in the digestion and absorption of nutrients as well as preservation of the mucosal barrier integrity. The gut harbors a diverse community of bacteria that have profound effects on human physiology. Disruptions in the microbial balance, known as dysbiosis, can result in acute and persistent disorders including antibiotic-associated diarrhea (AAD), ulcers, inflammatory bowel disease (IBD), irritable bowel syndrome (IBS), and even cancers of the gastrointestinal tract. To restore a healthy gut, treatments such as probiotics, prebiotics, antibiotics, or fecal transplants are the encouraging

way of treating these disorders (Onyenweaku *et al.*, 2016).

Probiotic promote microbial diversity, enhance enzyme activity (e.g., lactase), improve immune microenvironment, and promote intestinal permeability. These actions can be used to reduce intestinal diseases, and regulate the gut health of the whole body. Probiotics are not new to human health, newborns are given helpful bacteria such as Bacteroides, Bifidobacterium, Lactobacillus, and through the mother's birth canal. Probiotics have two main ways of protecting health. In the digestive tract, they first keep the balance between beneficial and harmful bacteria in a healthy state. Poor nutrition, stress, sleep deprivation, abuse of antibiotics, and environmental pollutants can all upset this equilibrium and encourage pathogenic microorganisms. In addition to controlling gastrointestinal motility and barrier function, a healthy gut removes toxins, pollutants, and infections. Probiotics have been found to help treat a number of illnesses, including necrotizing enterocolitis, Helicobacter pylori infections, ulcerative colitis, AAD, IBS, and infectious diarrhea. Second, probiotics help the immune system, which is essential for preventing autoimmune diseases including rheumatoid arthritis, ulcerative colitis, and Crohn's disease as well as for protecting against infections. Probiotics can lessen infections, allergic responses, and other immune-related disorders by reestablishing microbial equilibrium (Onyenweaku *et al.*, 2016).

2. **Cancer prevention:** Antigenotoxicity, antimutagenicity, and anticarcinogenicity are the most likely functional properties of probiotics. The properties of cancer prevention are attributed to the probiotic bacteria in fermented milk products. Some of the suggested mechanisms behind their effects, which are explored both in vitro and in animal studies, include inhibition of tumor-growth and proliferation of tumor cells via glycopeptides and cytotoxic metabolites of lactobacilli, alteration of the gut microbiota, inhibition of pro carcinogenic, mutagenic, and genotoxic agents in the colon, and inhibition of cancer-promoting enzymes.

   It has to be noted that, due to the difference in intestinal microbiota, the beneficial effects of probiotics regarding the intestinal tract might vary from individual to individual. This is because, in most cases, probiotics must compete with indigenous organisms for nutrients and habitat in the intestine; however, in certain cases, they can produce relationships of synergism with indigenous organisms. So, the difference in indigenous intestinal microbiota leads to considerable variability in the degree to which particular probiotics can exert their effects. Given this, it is therefore likely that probiotic strains that are effective in one particular animal species would not necessarily be beneficial to members of another host species.

3. **Lactose intolerance:** Lactose intolerance (LI) is a condition affecting over 60% of the global population, characterized by the inability to digest lactose due to insufficient production of the enzyme lactase (Venkatesh *et al.*, 2024). Lactase is responsible for breaking down lactose, a disaccharide found in dairy products, into glucose and galactose for absorption in the intestine. When lactase is deficient, undigested lactose reaches the colon, where it undergoes microbial fermentation and results in the production of short-chain fatty acids (SCFAs), therefore leading to lactose intolerance. This process produces gases like carbon dioxide and methane, leading to symptoms such as bloating, abdominal cramps, nausea, diarrhea, and flatulence. The causes of beta galactosidase deficiency are pelvic radiotherapy that destroys the mucosa, infection with rotavirus that infects lactase producing cells (Kechagia *et al.*, 2013).

   Probiotics have emerged as a potential solution to alleviate lactose intolerance. They provide an external source of lactase, promoting lactose fermentation and improving lactose digestion. Probiotics also enhance the gut microbiota by increasing the population of beneficial bacteria in the intestine. Certain strains of probiotics, such as *Lactobacillus acidophilus*, *Lactobacillus delbrueckii* spp., *Lactobacillus bulgaricus*, *Bifidobacterium bifidum*, and Streptococcus thermophilus, exhibit β-galactosidase activity. This enzyme plays a crucial role in breaking down lactose and facilitating its absorption (Das *et al.*, 2022).This implies that there should have been a positive effect that occurred in the digestive tract following the consumption of milk with probiotics.

Application of probiotics in food industry

With the growing public awareness of issues related to diet, as well as a broader base of scientific evidence supporting the health benefits of probiotics, consumer demand for probiotic foods has been increased. These comprise yogurt, powdered milk, fermented dairy-based frozen desserts, cheese and its derivatives, ice cream, infant foods, cereals, and fruit juices, etc. but in the application of probiotics into food products, there could be some problems like they are sensitive to heat during processing, and they are susceptible to gastrointestinal tract conditions in the human body. Despite these problems, commonly used in dairy, beverage, baking, and edible film industries. (Reque and Brandelli, 2021).

1. **Use of probiotics in food industry:** Probiotics are increasingly being incorporated into dairy-based products due to their health benefits and high consumer demand, primarily strains of Lactobacillus and Bifidobacterium, are incorporated to enhance the nutritional and functional properties. For example, in yogurt, *Lactobacillus bulgaricus* and *Streptococcus thermophilus* are commonly used as starter cultures, with addition of probiotic strains like *Lactobacillus acidophilus* and *Bifidobacterium* bifidum to increase health benefits. These probiotics produce lactic acid during fermentation, which produces a tangy flavor and also inhibits the growth of pathogenic and spoilage microorganisms, thereby extending the product's shelf life (Hadjimbei *et al*., 2022). Likewise probiotic enriched cheese has gained popularity due to its ability to protect probiotics during digestion, ensuring their survival in the gastrointestinal tract.

   Moreover probiotic ice creams and infant formulas are rising in the functional food category, adapting to various consumer needs. The continuous innovation of probiotic dairy products demonstrates their significance in improving health also fulfills the consumer demand.

2. **Use of probiotics in beverage industry:** With the consumers becoming more aware of the side effects associated with medicines, the importance and demand for the non-dairy probiotic food products are on the rise. Probiotic fortified fruit juices are preferred for their nutrient value, and functional capacities. However, it is very hard to keep the probiotic viable in non-dairy beverages due to harsh conditions such as lowered pH, increased acidity, and the presence of anthocyanins. To alleviate those issues, microencapsulation techniques have been employed, allowing a protective coat around probiotics, increasing their viability during any kind of processing and later storage.

   The various methods to optimize probiotic incorporation have been explored in many studies. (Miranda *et al*., 2019) found that the direct addition of activated and microencapsulated probiotics resulted in better retention of essential volatile compounds and sensory attributes than their counterparts in orange juice. Secondary packaging approaches such as compartmentalizing probiotics in the bottle cap or straws have also been developed to release prior to consumption into beverages with better shelf life. For example, in coconut water, *Lactobacillus plantarum* is used for its fermentation to enhance its vitamin, mineral, and bioactive properties to make it a functional anti-hypertensive and antimicrobial beverage. These advancements highlight the growing potential of non-dairy probiotic beverages as functional foods, offering enhanced health benefits and improved consumer appeal (Latif *et al*., 2023).

3. **Use of probiotics in Meat products:** Probiotics are increasingly used in fermented meat products, for example, sausages, to enhance safety, taste, and shelf life. In these applications, probiotic strains such as *Lactobacillus plantarum* and *Lactobacillus rhamnosus* are introduced as starter cultures during fermentation. These bacteria produce lactic acid and other antimicrobial compounds, including bacteriocins, which lower the pH of the product and create an unfavorable environment for pathogenic microorganisms like Salmonella, Listeria and E. coli. Also, probiotics contribute to desirable flavors and texture in fermented meats by hydrolyzing proteins and fats during fermentation. For example *Lactobacillus plantarum* has been shown to enhance the sensory properties of fermented sausages while ensuring microbial safety (Rubio *et al*. 2014).

   Since probiotics use in meat products might be an encouraging way for food safety, quality, and consumer appeal, meticulous consideration must be taken about further studies and support from meat industry-based supporting actions.

4. **Use of probiotics in Bakery:** Bakery products such as breads, biscuits, doughnuts, and cookies, more generally, are fully nutritious providing certain amounts of carbohydrate, protein, fat, dietary fiber, vitamins, and minerals. With increasing awareness about functional foods, scientists are turning their attention toward ways of incorporating probiotics to baked foods products. The biggest challenge in this is maintaining the viability of probiotic bacteria through the high-temperature baking process. Cost-effective

methods that deliver heat-stable active agents that protect probiotics from heat-induced degradation have been developed. Amongst these approaches, which are promising in protecting probiotics, one method is microencapsulation, where probiotic cells are surrounded by protective coatings that improve their heat resistance. The method of sourdough fermentation was also investigated as an alternative method to enhance probiotic viability in baked products. To illustrate, (Zhang *et al*., 2018) encapsulated *Lactobacillus rhamnosus* in sodium alginate, which significantly enhanced its resistance during pan bread baking and under simulated gastrointestinal conditions. Another study examined *Lactobacillus plantarum* when encapsulated in various matrices including reconstituted milk, gum arabic, maltodextrin, and inulin. The results indicated that bacterial survival was better in gum arabic and reconstituted skim milk compared to other carriers.

Further research discussed survival of *L. plantarum* after baking it specifically at 175°, 205°, and 235°C. Survival of the bacteria dropped from levels of 10^9 CFU/g during baking to levels as low as 10^4–10^5 CFU/g (Latif *et al*., 2023). During storage, however, there was growth of probiotic viability that reached from 2 to 3 logarithmic cycles, reaching up until 10^8 CFU/g, which had been connected to a fall in pH of the bread over time. This provides new means where innovative methods such as microencapsulation and sourdough fermentation could provide vast progress toward realizing a bakery good with probiotic enrichment.

5. **Use of probiotics inedible food coatings:** Encapsulating probiotics into edible films protects probiotics from premature degradation and increases their viability within the human body. It boosts the stability and safety of food products by inhibiting the growth of spoilage microorganisms. This method helps combat both stability and gastrointestinal tract stresses faced by probiotics.

Many researchers investigated film-forming materials, such as biopolymers including cellulose, zein, seaweed extracts, pectins, alginates, and chitosan for entrapping probiotics to enhance their nutritional values. These films exhibit good antimicrobial properties and protect the probiotics against various gastrointestinal stresses. Therefore, bacterial microorganisms are introduced to films and coatings to confer the ability of probiotics and/or to act as an antimicrobial agent to food. For example, cellulose-based edible films along with *L. rhamnosus* were fabricated using sodium carboxymethyl cellulose (CMC) and hydroxymethyl cellulose (HEC) with citric acid acting as a cross linker to control the consistency of the film loaded with *L. rhamnosus* (Ebrahimi *et al*., 2018).

According to (Bambace *et al*., 2019), *L. rhamnosus* is incorporated into an alginate prebiotics fiber solution to maintain the shelf life of minimally processed and ready-to-eat blueberries for up to fourteen days. Alginate effectively demonstrated antimicrobial activity with *L. rhamnosus*, in addition to showing sensory acceptability as a coating for food.

Future prospect

Currently, some probiotics (*Lactobacillus, Bifidobacterium*) and prebiotics (inulin, oligofructose) do not require FDA approval and are found in our everyday diet. Several legal authorities worldwide have validated the safety of probiotics and prebiotics for food applications, but few research have been undertaken investigating instances of bloating, flatulence, and excessive osmotic pressure, which can lead to gastrointestinal discomfort (Yoo & Kim., 2016).The only way to overcome the obstacle is to subject it to sublethal stress, encapsulates it, and uses it in food matrixes or carriers. Encapsulation is a procedure that protects delicate materials from external conditions using mechanical or chemical means (Abatenh *et al*., 2018).

Based on the findings provided in this review, it is theoretically possible to use different strain combinations to examine the reducing effects of probiotics Lactic acid bacteria (LABs) and *Bifidobacterium* spp on the intestinal microbiota with the aim of lowering obesity and T2D. Research on the impact of different strains on gut microbiota can lead to the development of anti-obesity foods and dairy products. Such research may reveal fresh and creative pipelines for pharmaceuticals and food products with broad industrial uses. Recent results provide a theoretical foundation for additional study on gut microbiota modification, including assessing the effects of probiotic LAB strain doses (Evivie *et al*., 2017)

Conclusion

Probiotics have become an essential part of human health, helping to prevent many diseases, improve immune function, and maintain the balance of the gut microbiota. Numerous studies have examined the synergistic interaction between probiotics and prebiotics, showing that they can work together to maximize gastrointestinal health and general well-being. The advantages of probiotics in aiding digestion, avoiding infections, lowering inflammation, and even treating long-term illnesses including lactose intolerance, metabolic disorders, and irritable bowel syndrome have been repeatedly demonstrated by research over the years.

The development of probiotics from their historical discovery to their present uses in medications, nutritional supplements, and functional foods demonstrates their versatility and potency. Probiotic viability and effectiveness have been significantly improved by developments in biotechnology, specifically in strain selection, microencapsulation, and genetic engineering. These advancements have opened the door for the development of probiotic formulations that are more robust and able to endure severe gastrointestinal conditions, guaranteeing their positive effects when taken.

The efficiency of probiotics is influenced by a number of parameters, including host-related characteristics, dosage, strain specificity, and storage conditions, despite its unquestionable benefits. The fact that different probiotic strains have different effects highlights the necessity of strain-specific research and customized probiotic treatments. Furthermore, new uses of probiotics in baked goods, drinks, meat products, and edible films are increasing their accessibility and functional diversity, even though probiotic rich foods like yogurt, kefir, and fermented vegetables are still common dietary sources. Even though probiotics have shown encouraging effects in dietary and clinical settings, further research is necessary to fully understand their potential in order to establish the best dosages, long-term safety, and strain-specific roles. To optimize therapeutic results, future developments should concentrate on customized probiotic therapy based on each patient's unique microbiome composition. The necessity for strict scientific validation and regulatory frameworks to guarantee probiotics' efficacy and safety is highlighted by the growing recognition of these natural and powerful health-promoting agents.

Conclusively, probiotics are an essential part of today's nutritional and therapeutic strategies, providing a natural way to improve gut health and general wellbeing. They represent a move toward preventative healthcare and open the door to a better and more sustainable future through their incorporation into food, medicine, and everyday eating practices. Future developments in nutrition, medicine, and human health will be significantly influenced by probiotics as research advances.

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