Prebiotics and Probiotics in Functional Nutrition: A Holistic Approach

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Abstract

The use of probiotics and prebiotics as functional nutrition have gained significant attention in recent year which offer a promising strategy for promoting optimal health. Prebiotics are non-digestible fibers that beneficially influence the host. Prebiotics consumption improves the advantageous microbial growth and activity resulting in better absorption and utilization of nutrients, necessary for dietary transitions of animals. These prebiotics regulate gut microbiota leading to enhanced pathogen resistance, lowered gastrointestinal infections, and better immunity. Probiotics are live micro-organisms that exert health benefits to the host when given in an adequate amount. Probiotics reside in their host and compete with pathogenic bacteria and do not allow them to grow, which provides protection against infections. Both prebiotics and probiotics have synbiotic effects in gut health and digestive functions, the immune system, enhancing growth and feed efficiency, weight management and many other applications in the field of poultry, aquaculture and livestock. Developing probiotics and probiotics products by new methods will help in optimum absorption and utilization of nutrients. Microencapsulation technique is used to make probiotic and prebiotic more stable and viable. In summary, inclusion of probiotic and prebiotics in animal's feed results in various beneficial effects ranging from efficient gut health, nutrient absorption and body growth rate to overall strong immunity.

Keywords: Functional nutrition, Probiotics, Prebiotics, Synbiotics, Microencapsulation

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Introduction

(i) Functional Nutrition

The way to use nutrient or functional-dense foods with nurturing properties in body in a reflective and evidenced-based manner is called functional nutrition. The investigation of the several layers that may interfere with one's health and the best possible efficiency of the body's systems is part of a functional nutrition approach to health. It involves getting the body back into balance, which promotes health. Poor metabolic health can be caused by weakened underlying physiological processes, which functional nutrition might help to support (Works et al., 2023).

(ii) Prebiotics

These are fermentable, indigestible food elements that change the chemical composition and behavior of gut bacteria in the favor of the host. Although not all dietary fibers contain prebiotic features, almost all prebiotics are dietary fibers. The main groups of prebiotics are glucose-derived oligosaccharides (pectin oligosaccharides and polydextrose) and fructans, which include galacto-oligosaccharides (GOSs), lactulose, resistant starch, fructo-oligosaccharides (FOSs) and inulin. Various nutritious foods naturally contain these substances, such as barley, garlic, chicory, onion, rye, asparagus, tomatoes, Jerusalem artichoke and wheat (Rau et al. 2024). Prebiotics work to reduce obesity and metabolic syndrome, positive impact on useful microflora, reduce risk of colon cancer, support immune system and pathogen inhibition etc.

The following criteria are used to classify a compound as prebiotics:

a. It should not be absorbed in the gastrointestinal tract, be resistant to the stomach's acidic pH, and be resistant to being hydrolyzed by mammalian enzymes.

b. The gut microbiota can ferment it.

c. The compound should possess the ability to selectively boost gut bacterial growth and activity, which enhances host health (Davani et al., 2019).

(iii) Probiotics

These are live, non-pathogenic microorganisms that can change the gut microbiota for the benefit of the host. One or more microbial strains may be involved in probiotics products, commonly belonging to the following genera: Lactococcus, Lactobacillus, Enterococcus, Bifidobacterium, Bacillus or Streptococcus. Strains of yeast are also commonly used which belong to the Saccharomyces genus (Rau et al., 2024). Traditionally, it has been proposed that a useful probiotic must fulfil the following selection criteria demonstrated in Figure 1.1: (Kiprono et al., 2024)

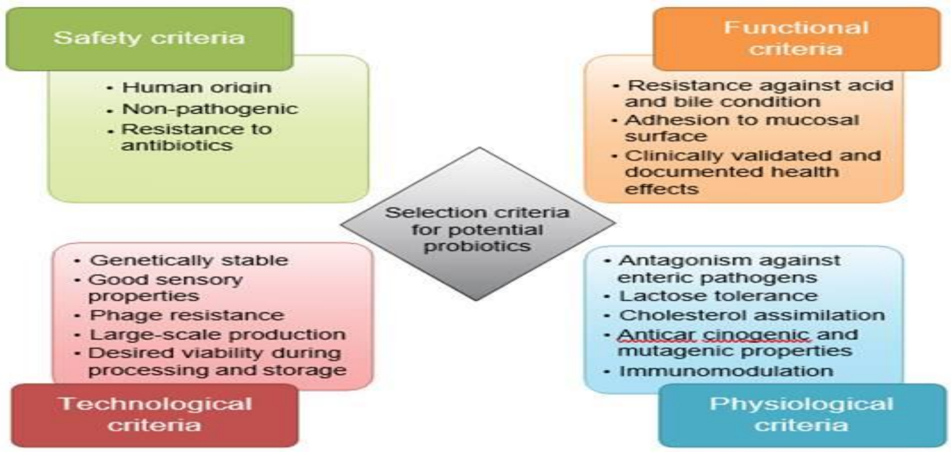

Fig. 1.1: Selection criteria for probiotics (Anandharaj et al., 2017)

(iv) Synbiotic

The products that are a mixture of probiotics and prebiotics may have a synergistic effect. The viability of the probiotic component is thought to be improved by prebiotics compound, as resistance to bile salts, acids, and proteases in the upper gastrointestinal tract is an essential feature of prebiotics. The mixture of Lactobacillus or Bifidobacterium with fructo-oligosaccharides is frequently used in synbiotic composition (Rau et al., 2024).

(v) The Combined Benefits of Probiotics and Prebiotics

In Table 1.1 the combined effect of different prebiotics and probiotics are discussed **(**Obayomi et al., 2024**)**

Table 1.1: Combined Benefits of Prebiotics and Probiotics

Prebiotic	Probiotics	Short chain fatty acid produced	Benefits	References
Inulin	*Lactobacillus acidophilus*, *Catenibacteria*, *Bifidobacteria*, *Bifidobacterium longum*	Increased production butyrate and acetate	Improved mineral absorption, immune support, digestion	(Yang et al., 2013)
Fructo-oligosaccharides (FOS)	*Lactobacillus rhamnosus*, *Bifidobacterium lactis*	Increased production butyrate and acetate	Improved gut health, increased satiety, reduced blood glucose levels	(Li et al., 2015), (Chen et al., 2017)
Lactulose	Lactobacillus, Bifidobacteria	Increased butyrate acetate, propionate, lactate,	improved gut health and treatment of the constipation,	(Wang et al., 2023), (Karakan et al., 2021),
Galacto-oligosaccharides (GOS)	Lactobacillus, Bifidobacterium	Increased production butyrate and propionate	Improved calcium absorption, gut health and immune function,	(Li et al., 2015)

1. Mechanisms of Action: How Prebiotics and Probiotics Work

(i) Understanding the Gut Microbiome

The trillions of bacteria, fungi, viruses and many other microbes residing in GI tract are known as gut microbiome. This microbial colonization plays an important role in regulating overall health significantly assisting in nutrition absorption, immunity, human development and digestion. Synbiotics, prebiotics and probiotics are emerging as potentially effective strategies for regulating the gut microbiome and enhancing human health in general (Kim & Mills, 2024).

(ii) Gut Health and Immune System Enhancement by Prebiotics

Fermentation of prebiotics produces Short Chain Faty Acids (SCFAs) that create an acidic environment which lowers the pH from 6.5 to 5.5 in gut. This acidic environment is unfavorable for pathogenic bacteria to grow and promotes the beneficial bacteria to growth, which flourish under these acidic conditions, thus maintaining the health of gut. Gut-associated lymphoid tissue (GALT) is the vital part in regulation of immune system. Prebiotics boost up the growth of bacteria that interfere with the Gut-associated lymphoid tissue, which is useful to regulate the activities of immune system. By regulating the immunological responses in the gut, this interaction lowers inflammation and promotes a balanced immune system. In GI tract, immunological responses are also controlled by short chain fatty acids. The enhancement in immune tolerance and function of immune cells like Thymus(T) cells are also controlled by prebiotics (Ashaolu, 2020).

(iii) How Probiotics works in Digestive system

Species of probiotics like Bifidobacterium and Lactobacillus are important because they help in maintaining a balanced colony of beneficial bacteria in the digestive system. The maintenance of intestinal barrier against pathogens is essential for nutrient absorption, immunological response and healthy digestion that are served by probiotics. Probiotics strengthen the intestinal lining that restricts the consumption of toxins and pathogens into the blood. This improves the digestive system and enhances good health in general. Probiotics ferment the food fibers that are indigestible by the body. SCFAs, during this fermentation process, like butyrate, acetate and propionate are produced and nurture the cells of colon lining, control inflammation and support gut health. The probiotics efficiency to treat digestive disorders such as constipation, irritable bowel syndrome (IBS), diarrhea and inflammatory bowel disease (IBD) has been comprehensively investigated (Ashaolu, 2020).

2. Health Benefits of Probiotics and Prebiotics

(i) Gut Health and Digestive Function

Probiotics modulate several mechanisms like influencing the gut microbiome and contributing to the host health. Firstly, they balance the habitat, variety and composition of the gut microbiota, by outcompeting harmful microbes actively regulating a healthy microbial balance for nutritional resources. Secondly, boosting the immune system is an important role played by probiotics. Thirdly, by reducing permeability probiotics contribute to gut health, enhancing the barrier's resistance to harmful infections and chemicals. Fourthly, the formation of compounds particularly short-chain fatty acids (SCFAs) that are bioactive. Probiotic synthesized SCFAs offer a variety of health advantages and have anti-inflammatory properties. Finally, probiotics demonstrate their capacity to inhibit disease by directly inhibiting pathogenic viruses and bacteria from boosting and operating in the digestive system (Zhou et al., 2024).

Prebiotics are considered as indigestible fiber that are difficult to digest for the upper gastrointestinal tract. For fermentation by beneficial bacteria like Bifidobacteria and Lactobacilli they serve as substrates and enter the colon undigested. Short-chain fatty acids (SCFAs) like butyrate, acetate and propionate are produced by this fermentation. For the energy requirements of colonocytes SCFAs are essential, which are necessary for intestinal integrity and line the colon. Frequent consumption of prebiotics maintains the variety and stability of gut microbiome. Lactobacilli and Bifidobacterial are advantageous bacteria with several health-promoting properties whose growth boosted by prebiotics especially fructo-oligosaccharides (FOS) and inulin. The significance that how important prebiotics are in regulating a robust and well-balanced environment of gut is highlighted by this complex interaction (Zhou et al., 2024).

(ii) Immune System Enhancement by Probiotics and Prebiotics

Table 1.2: Immune system enhancement by probiotics (Ashaolu, 2020)

Probiotic	Immune boosting functions	Mechanisms	References
Lactobacillus plantarum MON03	Detoxification of toxins	Binding via surface structures	(Jebali et al. 2015)
Lactobacillus kefiri KFLM3, *Saccharomyces cerevisiae* KFGY7	Detoxification of toxins	Biotransformation and adsorption	(Taheur et al. 2017)
Bacillus licheniformis CFR1	Detoxification of toxins	Degradation of enzyme	(Rao et al. 2017)
Saccharomyces cerevisiae HR 125a	Detoxification of toxins	Binding via surface structures	(Ismail et al. 2017)
Several other Bifidobacterium strains	Protect from enteropathogenic infection	Produce acetate and improve intestinal defense with epithelial cells	(Fukuda et al. 2011)
	Inhibit allergy	Suppress Th2 chemokines	(Miyauchi et al. 2013)

Table 1.3: Immune system enhancement by prebiotics (Ashaolu, 2020)

Prebiotics	Bacteria	Influences	References
Orange juice enriched with hesperidin and naringin	Acetate, butyrate, lactobacilli and bifidobacteria	Up-regulation of insulin, glucose, triglycerides and total cholesterol.	(Lima et al. 2019)
Galacto-oligosaccharides (GOS) and sialyllactose	Lactate, propionate, butyrate, bifidobacteria and Bacteroides	Regulation and modulation of genes associated with cell cycle stages and cyclin-dependent kinases.	(Perdijk et al. 2019)
Insulin	Acetate, propionate, butyrate, bifidobacteria, actinobacteria and members of Bacteroides and Lentisphaerae.	Improved gut barrier and immune function	(Van Den Abbeele et al. 2018)

(iii) Prebiotics and Obesity Weight Management

Coffee oligosaccharides, Fructo-oligosaccharides and Galacto-oligosaccharides determined an improvement in the dysbiosis of the gut microbiota with a noticeable anti-inflammatory effect, most likely due to the generation of SCFA. A common effect of decaffeinated green, black tea polyphenols and flavanols, aqueous extracts of cinnamon, tea, inulin, marc, lignans and vanillin is the decline in the ratio of Bacteroidetes/Firmicutes. This ratio, which is high in obese individuals and tends to drop after weight loss, is thought to be a potential indicator of obesity (Bevilacqua et al., 2024).

Compounds like pomegranate extract, soy isoflavones, arctic berries, genistein and pollen extract positively influence microbiota of gut composition and help in loss of weight. Prebiotics also have a positive impact on obese people by lowering cortisol levels, which directly influence sleep quality, remarkably lowering plasma triglycerides, and lowering waist and hip circumferences (Bevilacqua et al., 2024).

(iv) Mental Health and the Gut-Brain Axis

The gut-brain axis, a network of two-way communication between the gut and the brain, may be impacted by probiotics. The relationship between microflora of gut and host health is widely acknowledged. Neurotransmitters related to regulation of mood, such as gamma-aminobutyric acid (GABA), dopamine and serotonin are formed both in the brain and gut. Moreover, Results relating to the gut microbiota and the parasympathetic nervous system's vagus nerve provide evidence to the gut-brain axis idea. The vagus nerve plays a pivotal role in conveying signals between the intestinal epithelium and brain to manage the body's response to stress. Moreover, probiotics have been linked with regulating homeostasis of gut, so alleviating stress levels and lowering anxiety in people. Like human research, studies on farm animals have revealed that gut microbiota may affect the stress levels of dairy animals. According to another study, when probiotics were supplemented to and growing and weaned calves, stress-related behaviors were reduced. Although more research is required to completely understand the pathways via which probiotics may boost stress responses, this suggests that probiotics could be used to help dairy animals manage stress (Shukla et al., 2024).

3. Probiotics and Prebiotics in Animal Nutrition

Role in Enhancing Growth and Feed Efficiency

Probiotic bacteria from the genus Vibrio, Bacillus, Enterococcus, Lactobacillus, Arthrobacter and Alteromonas have been narrated to increase growth and boost health in species of farmed shrimp. The mode of action of bacteria includes quorum quenching effects, antagonistic activities against pathogen bacteria, gut colonization, synthesizing profitable metabolites (e.g., SCFAs) and provision of essential nutrients. In addition to supplying the host with vital nutrients (such as vitamins, short-chain fatty acids and polyamines), lactic acid bacteria, such as those belonging to the genera Lactobacillus and Bacillus, can also enhance digestion and nutrient absorption by boosting the activity of digestive enzymes (such as cellulases, amylases, lipases and proteases) in the gut. These enzymes may stimulate growth hormones and enhance feed consumption with faster rates of absorption by decomposing nutrients into simpler components (Khanjani et al., 2024).

Furthermore, after using a variety of prebiotics there are reports of enhanced shrimp growth. Among other useful nutrients and compounds, synthesizing SCFAs and lactate prebiotics may metabolize beneficial bacteria. These bioactive compounds have carboxylic acids in their chemical structure with fewer than six carbons that can cause bacterial fermentation. By altering the digestive system and metabolism, they can have beneficial physiological effects like immunostimulatory and anti-inflammatory impacts. They also can provide energy for enterocytes to retain and rehabilitate gastrointestinal homeostasis (Khanjani et al., 2024).

Application of Prebiotics and Probiotics

(i) Poultry

The goal of adding probiotics to poultry feed is to replace the microorganisms that are lacking from the gastrointestinal system while simultaneously providing the chicken with the advantages of beneficial bacteria. Prebiotics amplify probiotic activity and growth in poultry GIT. Prebiotics give native bacteria, which are already present in the colon, the carbon and energy they require to thrive in the digestive system. Prebiotics enhance the intestinal absorptive surface and reduce the colonization and migration of infections into internal organs. One of the health benefits of prebiotics is improved intestinal morphological makeup; many prebiotics have been shown to change the microscopic (density, size and microvilli size including crypt depth) and macroscopic (including intestinal length) structures of different intestine sections in chicken species. To prevent pathogenic organisms from adhering to the intestinal mucosa, probiotics either colonize adult animals or mimic the natural colonization process in newborn. Some strains of Bifidobacterium and Lactobacillus have proteins on the surface layer that are hydrophobic, and aid bacteria stick to the surface of animal cells without any pattern. Probiotics stop Salmonella, *E. coli*, and other potentially dangerous bacteria from sticking to the intestinal epithelium bacterium's adhesion, which blocks the receptor binding sites (Nugusa et al., 2024).

(ii) Aquaculture

In aquaculture probiotics have an advantageous effect on the environment by increasing feed utilization and growth, decreasing emissions and waste, lowering the requirements of antibiotics, and improving water quality. They play a remarkable role, particularly *Bacillus* species, in enhancing quality of water by influencing several parameters such as pH, transparency, conductivity, total dissolved solids, dissolved oxygen, oxygen demand, nitrogen and phosphates species. Heavy metals and other contaminants can also be bioremediated using Bacillus. Despite their role in the breakdown of organic materials, probiotics assist in recycling nutrients. Furthermore, according to a life cycle assessment (LCA) study, because probiotics are consumed at lower rates and produce less waste and emissions, their environmental effects are typically compensated for. However, more research is needed to fully understand the impacts of probiotics on the environment and to address knowledge gaps, such as the optimization and selection of probiotics for aquaculture species, the efficient delivery methods development, and the evaluation ecological risks (Calcagnile et al., 2024).

4. Probiotics and Prebiotics in Human Health

(i) In Human Studies

Although the makeup, duration, and kind of human participants vary widely throughout studies, the psychotropic effects of probiotics and, to a lower level, prebiotics have been evaluated in humans. After three weeks of treatment, a GOS prebiotic has been demonstrated to dramatically lower the waking cortisol response in healthy participants. Fecal Bifidobacteria levels rose, and anxiety decreased in people with irritable bowel syndrome (IBS), a condition where anxiety is highly associated. Probiotics have also been tested in individuals with subclinical levels of depression and anxiety. A four-week course of treatment with a multispecies probiotic had substantial effects on people with mild to moderate depression, indicating an antidepressant effect. After eight weeks of treatment, in individuals with moderate to severe depression, a mixture of *Bifidobacterium longum* R0175 and *Lactobacillus helveticus* R0052 probiotic did not enhance psychological outcomes including anxiety or depression (Radford-Smith et al., 2023).

(ii) Inflammatory Bowel Diseases (IBD)

IBD patients are very interested in the potential benefits of probiotic therapy. Since 1997, studies have been done on the use of probiotics to treat IBD. Even a 50% rise in probiotic use has been documented among IBD patients. This is because probiotics are thought to be safe and effective when used as a supplemental treatment for IBD patients. In patients with mild or moderate ulcerative colitis (UC), it has been demonstrated that using the non-pathogenic strain of *E. coli* Nissle 1917 in ongoing treatment has a similar safety profile and efficacy to using salicylates. According to a similar study, patients with UC who received *Lactobacillus rhamnosus* GG either alone or in combination with mesalazine saw a significantly longer duration of clinical recovery at the one-year mark as compared to the group that received anti-inflammatory mesalazine separately. Patients with UC also had a marked improvement in the treatment of their condition and the maintenance of clinical remission when Bifidobacteria and different lactic acid bacteria were used as adjuvant therapy. One of the best-studied is probiotic complex VSL#3 consisting of four *Lactobacillus* strains (*L. casei*, *L. delbrueckii, L. plantarum* and *L. acidophilus*), three *Bifidobacterium* (*B. breve, B. longum* and *B. infantis*) and one *Streptococcus* (*S. salivarius*) that are helpful in IBD treatment.

Many prebiotics utilized in IBD patient studies belong to the oligosaccharide and inulin groups. In animal experiments, it was demonstrated that giving prebiotic fructans and resveratrol to rat and mice with IBD enhanced the colon's levels of Lactobacillus and Bifidobacterium. Additionally, giving rats with induced chronic enteritis inulin orally reduced the severity of colon lesions and improved the intestinal bacterial profile by reducing the pH in the large intestine and increased Lactobacillus production. Psyllium husk treatment reduced gastrointestinal symptoms in patients with UC in remission, according to studies conducted on people with IBD (Akutko & Stawarski, 2021).

(iii) Probiotics Managing Asthma and Food Allergy

As a treatment for allergic diseases like asthma, probiotics are becoming more and more well-known. By strengthening the type 1 T helper cells immune response, they reduce the synthesis of Immunoglobulin E, reduce inflammation in the airways, and strengthen the body's defenses against respiratory-related infections. Immune mediators, cytokines, and chemokines are produced when probiotics interact with intestinal epithelial cells and immunocompetent cells via Toll-like receptors. The *Lactobacillus gasseri* strain, which controls expiratory flow rate and pulmonary function, significantly improved when supplemented. Research have shown clinical evidence reporting that strain of *Ligilactobacillus salivarius* LS01 (DSM-22775) and *Bifidobacterium breve* B632 (DSM-24706) may prevent asthma in children (Vijayan et al., 2024).

By altering gut flora and binding it to intestinal epithelial cells, probiotics can also aid people with food allergies. Their ability to protect human health indicates their capacity as restorative agents. Probiotics that are mostly used to treat food allergies include Lactobacillus and Bifidobacterium. Both *Lactobacillus murinus* and *Lactobacillus rhamnosus* are commonly utilized strains of Lactobacillus. *Lactobacillus murinus* has proven to be successful in treating newborns with allergies to cow's milk. Food allergies can also be avoided with the help of other helpful bacteria, such as *Bifidobacterium lactis* and *Bifidobacterium longum* (Vijayan et al., 2024).

5. Incorporating Probiotics and Prebiotics into Diets

(i) Natural Sources of Probiotics: Fermented Foods and Supplements

Sources of probiotic microbes including fruit juices, cereals, honeycomb, and soil, can be screened. Numerous fruit juice varieties contain *Lactobacillus plantarum*, the primary LAB. Additionally, probiotics from sources like tomato juice and pineapple wastes can be selected using the same alternative growth medium that is used to culture lactic acid bacteria. Several vegetables and fresh fruits, including ginger, dragon, papaya, durian, guava and star fruits, can be screened to isolated beneficial lactic acid bacteria that produce antimicrobial substances. To introduce probiotic strains as starter cultures for fermentation in items like yoghurt, cheese and butter, they can be extracted directly from milk or naturally fermented milk products. In human feces, a few research have showed probiotic *Enterococcus faecalis* are found. It has been discovered that human milk and the faeces of infants in a mother-child pair contain *Ligilactobacillus salivarius* (Sornplang, & Piyadeatsoontorn, 2016).

Isolated from human breast milk, *Lactobacillus rhamnosus* and *Lactobacillus casei* demonstrated antibacterial efficacy against *Staphylococcus aureus*, *Bacillus cereus*, and *Escherichia coli*, and as well as tolerance to a 0.3% bile composition and resistance to low pH (pH 3) (Sornplang, & Piyadeatsoontorn, 2016).

(ii) Prebiotic Rich Cultivated Plants

There are several examples of food plants that are abundant in prebiotics.

- **Bananas:** FOS is a form of prebiotic found in bananas that is fermented by beneficial microbes in the digestive tract. FOS has been demonstrated to strengthen the immune system, reduce inflammation, and promote intestinal health (Jadhav et al., 2023).
- **Garlic:** Inulin, a prebiotic fiber found in garlic, supports beneficial bacteria in the gut. Its antibacterial qualities are another well-known characteristic (Davani-Davari et al., 2019).
- **Oats:** Beta-glucans are abundant in oats that is a type of soluble fiber synthesized by beneficial gut bacteria. Beta-glucans have demonstrated lowered cholesterol, promoted intestinal health and aid in weight management (Jadhav et al., 2023).
- **Legumes:** The beneficial bacteria in the gut digest resistant starch, a form of prebiotic, which is abundant in legumes like peas, lentils and beans. It has been demonstrated that resistant starch improves weight control, lowers the risk of chronic diseases, and improves gut health (Mirmiran et al., 2014).
- **Whole grains:** Resistant starch and prebiotics can be found in whole grains in large amounts including brown rice, quinoa and barley (Jadhav et al., 2023).
- **Onion:** Onions, like garlic, can encourage the establishment of beneficial intestinal microbes and are high in insulin (Davani-Davari et al., 2019).
- **Asparagus:** Inulin is found in abundance in asparagus that is fermented by healthy bacteria in the gut and a type of soluble fiber. It has been studied that inulin promotes intestinal health, increases immunity and reduces the risk of chronic illnesses (Jadhav et al., 2023).

6. Challenges and Limitations of Probiotics

Although probiotics have become well-known and quite popular due to their reported health advantages, there are still several restrictions that industry and the researchers must overcome to fully realize their potential. Below is the list of a few of the most important restrictions and obstacles.

a) Strain Specificity

Probiotic bacterial strains can affect the human body in many ways. It's important to determine which strains are best for a given medical issue and to understand how they work. Understanding strain-specific effects and creating individualized probiotic therapies should be the main goals of future research. It may therefore be inaccurate to extrapolate the effects of probiotics on all strains within a species. The effectiveness of probiotics can also differ from person to person and depend on specific factors like age, nutrition, gut microbiota composition, and health state. For probiotic supplementation it can be difficult to predict the precise reaction and the probiotic supplement that works for one individual might not work for another individual (Campaniello et al., 2023).

b) Quality Control and Standardization

It can be hard to expect the stability, quality and viability of probiotic products. It is important to preserve probiotic viability during manufacturing, storage, and ingestion because they are live bacteria. It is essential to establish specific guidelines and strong quality control procedures for probiotic manufacture to ensure efficient and consistent products (Skoufou et al., 2024).

c) Survival in the Gastrointestinal Tract

Probiotics need to withstand the sever environment of the GI tract to have their positive benefits. Improving probiotics' ability to colonize and survive the gut is a continuous task. Modifying genes, protective coatings, and microencapsulation are the techniques that may enhance survival rate of the probiotic strain. Probiotics are temporary in the gut, and their effects could lessen after dosing is discontinued. They might not colonize permanently in the gut flora in every person and beneficial effects may stop when the probiotics are stopped. This emphasizes how probiotics must be taken consistently to sustain their potential advantages. Their survival and viability, however, may be impacted by constraints like exposure to bile salts, stomach acid, and competition from other gut microorganisms. For probiotics to be effective, enough live cells must enter the intestines (Han et al., 2021).

d) Understanding Mechanisms of Action

Even though probiotics have shown several health advantages, further investigation is needed to determine the precise mechanisms and interactions that probiotics and the host have. The development of specific probiotic interventions will be made easier with this knowledge (Skoufou et al., 2024).

d) Personalized Approaches

Every person's gut microbiota composition and health state are different. To maximize results, customized probiotic therapies must be created based on each person's unique microbial profile, genetic composition, and medical problems. Customizing probiotic therapies for individual patients can be achieved by combining metagenomic and meta/transcriptomic data with other individualized health information (Salazar et al., 2014).

e) Regulatory Framework

Different countries regulate probiotics differently, so it's important to set clear rules and regulations to ensure that commercial and medical practices are consistent. Stronger regulations can guarantee the efficacy, safety, and correct labeling of probiotic goods while simultaneously encouraging advancements in the industry (Skoufou et al., 2024).

7. Microencapsulation of Probiotics

Probiotic microencapsulation has been regarded as an effective and innovative method for enhancing the viability of probiotics in food products and the digestive tract since probiotic microorganisms that are intended to colonize the host gut to provide health benefits must survive. One popular low-cost method of microencapsulating probiotics is spray drying. Despite being cost-effective and efficient, this technique reduces cell viability due to the high mortality rate from probiotic dehydration and thermal inactivation. However, these restrictions can be lessened by adding protective substances to the media prior to spray drying, such as trehalose, maltodextrin, adonitols, acacia, granular starch, milk solids not fat (MSNF), prebiotics, soluble fiber, gum Arabica, etc. (Vivek et al., 2023).

In spray chilling, also known as spray cooling, a solid particle is left behind after a microcapsule containing the molecule of interest and lipids are atomized in a cold chamber. It can best maintain encapsulated cells' viability in both intestinal and stomach environments. It is appropriate for heat-sensitive activities and lowers operating costs. In addition to this, cyclodextrin microencapsulation, complicated coacervation, freeze drying, and extrusion are employed (Kiprono et al., 2024)

8. Future Directions in Prebiotic and Probiotic Research

Probiotics for Specific Health Conditions

(i) Cancer

The induction of colon cancers is known to be prolonged by *Lactobacillus acidophilus*. Tumor proliferation was shown to be reduced by 16–41% when milk and colostrum fermented with *Lactobacillus acidophilus* were fed. Solid Ehrlich ascites tumors and sarcoma-180 have both been shown to exhibit anticancer action when treated with the other probiotic, *Lactobacillus bulgaricus*. Probiotics have been shown to have anti-tumor effects through the following mechanisms:

- Modification of immunological responses associated with immune functioning.
- Antiproliferative effects through controlling cell differentiation and cell death.
- Enzymes such as urease, choloylglycine hydrolase, azedoreductase, nitro-reductase, and β glucuronidase are suppressed by harmful bacteria, particularly entero-pathogens like *Clostridium perfringens* and *E. coli*. Pro-carcinogens are changed into proximate carcinogens by beta-glucosidase and urease (Pandey et al., 2015).

By secreting SCFAs into culture media, *Propionibacterium freudenreichii* has been demonstrated to cause the cell death of human colon and stomach cancer cell lines. When taken with FOS, Bifidobacteria probiotics prevented liver and mammary cancers in rats and decreased colon carcinogenesis in mice induced by 1, 2-dimethylhydrazine. Human GOS consumption decreased nitro reductase activity, which is implicated in the production of genotoxic compounds, suggesting that prebiotics and probiotics may be able to slow or stop the development of cancer (Pandey et al., 2015).

(ii) Cardiovascular Diseases and lipid Metabolism

Some probiotic strains that have been shown to have hypocholesterolemia effects include *Lactobacillus bulgaricus, Lactobacillus reuteri*, and *Bifidobacterium coagulans*. Human studies using milk containing *Lactobacillus acidophilus* showed a notable decrease in blood cholesterol. In a study with 32 hypercholesterolemic patients, consuming low-fat yogurt with *Bifidobacterium longum* BL1 resulted in a significant decrease in low-density lipoprotein cholesterol, total blood cholesterol, and triglycerides. Moreover, high-density lipoprotein cholesterol increased by 14.5% (Homayouni et al., 2012).

Studies have shown that prebiotics also appear to increase hypercholesterolemic activity. Inulin was shown to reduce both triglycerides and total cholesterol by 63% and 29%, respectively, in hamsters. In a different study, Xylo-oligosaccharides was used as a prebiotic to reduce triglycerides by 27% in 40 male Sprague-Dawley rats. Men with hypercholesterolemia showed a reduction in serum triglycerides after receiving a three-week course of chronic chicory inulin (20 g/day) (Pandey et al., 2015).

Future Research Directions

- **Long Term Effects:** The long-term sustainable advantages of probiotic and prebiotic use on immunity, GIT health and production performance should be studied.
- **Multi-Omics Approaches:** Advanced omics technologies like meta transcriptomics, metagenomics, host transcriptomics and metabolomics are essential for gaining a thorough understanding of how probiotic and prebiotic supplementation relate to microbial dynamics, functional pathways, and host-microbe interactions of the gastrointestinal tract.
- **Gut-Brain Axis:** Examining how the use of prebiotics and probiotics affects the gut-brain axis and neuroimmune interactions in animals can provide possible signs like stress relief, behavioral improvement, and improved recovery from post-environmental stressors.
- **Environmental Sustainability:** It covers how using probiotics and prebiotics supports the objectives of sustainable animal production as well as the environmental impacts they have, including on greenhouse gas emissions, the composition of manure, and the recycling of nutrients in agricultural systems.
- **Precision Nutrition Strategies:** It is essential to create Precise Nutrition Strategies (PNS) that concentrate on the unique traits and characteristics of each animal, biomarkers, GIT health, and microbial profiles to maximize the effectiveness and cost-effectiveness of prebiotic and probiotic treatment.

The complete potential of probiotics and prebiotics in nutritional science may be unlocked if the above given challenges are effectively overcome. This would enhance animal health and productivity and result in a sustainable livestock sector (Akram et al., 2024).

Conclusion

A healthy digestive tract and a robust immune system are just two of the numerous positive outcomes of regularly incorporating prebiotics and probiotics into an animal's diet. Prebiotic consumption improves the growth and activity of good bacteria, which facilitates more effective nutrient absorption. Additionally, it strengthens immunity, lowers the risk of GIT-related diseases, and aids the animal in overcoming environmental stress. Whereas probiotics lead to decreased gut diseases by preventing the proliferation of harmful bacteria. Additionally, probiotics increase the digestibility, availability, and efficiency of nutrient absorption. The animal's body growth rate, food absorption, reproductive function, and gastrointestinal health are all enhanced when probiotics and prebiotics are fed together. Several obstacles must be overcome for probiotic and prebiotic manufacturing and use to be successful, including formulation durability, dose synthesis and delivery techniques, and handling species-specific reactions. Numerous microbiologists, dietitians, and animal scientists are concentrating on investigating new areas of these compounds.

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