Boosting Immunity by Prebiotics; A Natural Approach

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Abstract

Prebiotics are food particles that are non-digestible. They can either directly or indirectly increase immunity. Prebiotics promote the development of good bacteria in guts, such as *Bifidobacteria* and *Lactobacilli* which are important for gut health. The gut microbiota can digest prebiotics resulting in production of short-chain fatty acids (SCFAs) that help in immune response modulation. Certain prebiotics have the ability to directly interact with immune cells by affecting cellular signaling pathways after they are absorbed in the walls of intestine. These methods boost resistance to infections, enhance intestinal barrier functioning and improve immunological responses. Prebiotics show many benefits in different health conditions, like colorectal cancer, inflammatory bowel disease, etc. This chapter presents the significance of prebiotics in boosting immune functions and overall health conditions.

Keywords: Immunity, Prebiotics, Sources, Fermentation, Supplementation

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Introduction

The ability of an organism to withstand and fight off illness, particularly those brought on by some infectious agents, agents, is known as immunity. The body is protected from injury by the immune system that is a complex network of cells, tissues and chemicals (Abbas et al., 2015). Innate and adaptive immunity are two main branches of immune system. The adaptive system uses T and B cells to give targeted and durable protection, while the innate system uses cells like neutrophils and macrophages to provide quick and initial defense. T cells play a key role in coordinating immune responses. CD8+ T cells directly attack and destroy infected cells, while CD4+ helper T cells carry out a variety of immune functions. B cells produce antibodies that neutralize pathogens. Memory cells generated by both T and B cells enable rapid responses to re-encountered threats. Eliminating pathogens and reducing tissue damage must be balanced for the immune system to work effectively. Modern lifestyles, however, may be a contributing factor to persistent low grade inflammation and have an effect on overall health (Childs et al., 2019).

Over 1000 different species of bacteria makeup the varied community known as the gut microbiota that lives in human gut. These four major phyla *Proteobacteria, Bacteroidetes, Actinobacteria* and *Firmicutes* make up the majority of this complex community (Yoo et al., 2024). The gut flora is important for development and maintenance of immunity from childhood to old age. The immune system co-evolves with beneficial bacteria that live inside our bodies in this intricate relationship that involves mutualistic interactions. As immune system successfully fights off invasive pathogens, it also keeps a balanced relationship with these beneficial microbial communities (Bosco & Noti, 2021). The gut microbiota changes dynamically over time by adapting and reacting to environmental signals just like host biological systems do (Dejong et al., 2020). The gut microbiome is now widely recognized as an important factor for various host functions, including digestion, pathogen defense, immune system development and regulation (Kaplan et al., 2011).

Prebiotics are indigestible food elements that promote the growth of good bacteria in the large intestine and improve overall health (Davani-Davari et al., 2019). In order to improve health, prebiotics that are fermented, dietary particles nourish good gut bacteria, encourage their growth and activity. The word prebiotics was initially limited to specific oligosaccharides, such as galactooligosaccharides (GOS) and fructooligosaccharides (FOS). Other substances, such as resistant starch, pectin and milk oligosaccharides have been the focus of more research. However, the primary focus of initial research was on promoting the growth of bacteria that increase health benefits, such as *Bifidobacterium* and *Lactobacillus*. Advanced sequencing techniques used in more recent studies have produced a more compex picture showing a range of microbial reactions to prebiotics. This has led to a discussion regarding the suitability and constraints of current prebiotic definitions. More general terms pharmabiotics include all substances that increase the growth of gut microbiota (Hutkins et al., 2016).

Human health depends on the many and diverse microorganisms known as gut microbiome that live in human gut. Along with other aspects of human health, it regulates immune responses, susceptibility to disease and food absorption. One of the most important roles of prebiotics is to support and nurture beneficial bacterial in the gut microbiota. As they pass through the digestive tract and arrive to the colon these fermented dietary components do not undergo digestion. These undigested food particles are fermented by some specific bacteria. The short-chain fatty acids (SCFAs) produced by this fermentation are vital for gut health and overall well-being (Bock et al., 2024).

1. Types and Dietary Sources of Prebiotic

1.1. Fructooligosaccharides (FOS)

Fructooligosaccharides (FOS) are the most researched prebiotics. These low-calorie substances have many other health advantages like they can help to lower cholesterol, boost the absorption of minerals in gut and inhibit the growth of dangerous bacteria in addition to their prebiotic function. FOS is made up of a chain of two to sixty fructose molecules joined to a glucose molecule and fructose units are connected by glycosidic linkages β-(2-1) or β-(2-6). For example, fructofuranosyl nystose (one glucose and four fructose units), nystose (one glucose and three fructose units) and 1-kestose (one glucose and two fructose units) (Singh et al., 2017). Because of incomplete digestion in small intestine, fructooligosaccharides (FOS) are transported to cecum where they undergo fermentation by gut microflora and produce lactate, short-chain fatty acids (SCFAs) and other health promoting bioactive substances (Hutkins et al., 2016). Table: 1 shows different types of prebiotics and its sources.

1.2. Galactooligosaccharides (GOS)

Galactooligosacchrides (GOS) are prebiotic composed of galactose units connected by β-(1→4) and β-(1→3) glycoside linkages. It stimulates the growth of beneficial *Bifidobacterium* species in the gut and provides a bifidogenic effect. GOS can be used as food additive in different food because of its ability to bear high temperature and pressure (Vera et al., 2016). GOS is also added in formulae milk powder of newborn as a functional element that can increase positive effects as human milk's oligosaccharides do (Bhatia et al., 2015).

1.3. Inulin

Inulin is a naturally occurring polysaccharide that is primarily composed of fructose units with one glucose molecule at one end (Apolinario et al., 2014). The glucose unit in inulin is joined by α-(1↔2) linkage and the fructose units are joined by β-(2→1) glycoside linkages (Teferra, 2021). Diabetic patients have been given inulin as a sweetener (Saeed et al., 2015).

1.4. Resistant Starch (RS)

Starch is a complex carbohydrate that consists mainly of amylose and amylopectin. Amylose makes up about 15-20% of starch. It is a linear chain of glucose molecules connected by α-(1→4) glycosidic bonds. Amylopectin is a larger, branched molecule containing both α-(1→4) and α-(1→6) glycosidic bonds. Starches are categorized by their digestibility: rapidly digestible starch (RDS), which is broken down within 20 minutes of eating; slowly digestible starch (SDS), digested between 20-120 minutes and resistant starch (RS) (Tekin & Dincer, 2023). Resistant starch (RS) is a fermentable prebiotic essential for a healthy colon. Because it resists digestion in the small intestine, RS reaches the colon intact, where it's fermented by gut bacteria. This fermentation produces beneficial compounds that contribute to overall gut health (Thompson et al., 2022).

Table 1: Sources of Prebiotics

Prebiotics	Bonding	Benefits	Sources	References
Fructooligosaccharides	β (2–1) or β (2–6)	Increase gut microbe growth, reduce risk of gut diseases, enhances absorption of minerals	Onion, Aspargus, Barley, Wheat, Oat	(Kherade et al., 2021)
Galactooligosaccharides	β-(1→3) and β-(1→4)	Promotes growth of beneficial gut bacteria, Alleviating symptoms of IBS, Repairing gastrointestinal microbiota after alcohol abuse, Relieving constipation, Anti-colitis	Cow milk, Human milk	(Olivares-Tenorio et al., 2022)
Inulin	β-(2→1), α-(1↔2)	Antioxidant Activity, Anti-inflammatory Effects, , Improved Gut Health, Reduced Inflammation, Improved Cardiovascular Health, Protection against Pathogens	Chicory, Jersualem artichoke Garlic, Dahlia	(Teferra, 2021).
Resistant Starch	α-(1→4) and α-(1→6)	Promotes the growth of beneficial gut bacteria, Improves bowel regularity, beneficial for those with celiac disease	Legumes, potato, green banana, raw fruits	(Bojarczuk et al., 2022)
Maltooligosaccharides	α-(1→4)	Prevent constipation, increase gut microbe growth, enhace intestinal peristalsis	Beverages and Fermented food	(Bláhová et al., 2023)
Xylooligosaccharides	β-(1→4)	XOS with a degree of polymerization (DP) of less than four, such as xylobiose and Xylotriose, among other xylooligosaccharides, stands out as a particularly effective prebiotic, fostering the growth of beneficial gut microbes.	Vegetables, Fruits, Honey, Milk, Bamboo shoots,	(Palaniappan et al., 2021)

2. The Science behind Prebiotics and Immunity

2.1. How Prebiotics Work

Different prebiotics work according to the bacteria present in the intestine. Some prebiotics bind to specific bacteria, preventing them from attaching to the intestinal wall. This reduces the colonization of harmful bacteria, such as Mannan oligosaccharides. It has potential to reduce the risk of infections caused by harmful bacteria. Some prebiotics are also fermented by beneficial bacteria, particularly *Bifidobacteria,*

in the large intestine like inulin. They promote the growth of beneficial bacteria, lower the intestinal pH (creating an environment that hinders harmful bacteria) and produce short-chain fatty acids (SCFAs) that nourish intestinal cells and improve gut health (Khare et al., 2018).

2.2. Short-Chain Fatty Acids (SCFAs) and Their Benefits

Gut bacteria ferment dietary fiber in the colon, producing short-chain fatty acids (SCFAs) such as acetate, propionate and butyrate. The specific SCFAs produced in gut and their quantities are influenced by like type and amount of fiber used, the composition of gut bacteria, pH of the colon, digestion rate, the location of fermentation within the colon and physiological factors of the host like stress and intestinal environment. So, SCFA production is a complex process that impacts both gut health and overall systemic well-being (Xiong et al., 2022).

Benefits

Short-chain fatty acids present in human milk can prevent excess weight gain in infants (Prentice et al., 2019). People with greater SCFAs might have less severe cirrhosis (Bloom et al., 2021). A high SCFAs content results in less severe constipation (Shi et al., 2016). Women who consume insufficient amounts of SCFAs, especially acetate and propionate, may develop depression (Skonieczna-Zydecka et al., 2018). Butyrate and other SCFAs can increase the antimicrobial ability of the immune system without causing harmful inflammation (Schulthess et al., 2019). SCFAs like acetate and propionate prevent the colorectal cancer by preventing the growth and division of malignant cells (Casanova et al., 2018). Figure 1 shows different benefits of prebiotics on human organs.

2.3. Prebiotics and Gut Barrier Function

Microflora of gut can significantly be increased by increasing the intake of prebiotics that ultimately enhance the gut health. Prebiotics directly induce an effect on the gut microflora that results in altered distribution and expression of tight junction proteins (TJP). This changed distribution helps in strengthening the barrier of intestine. Prebiotics can also start AMP-activated protein kinase (AMPK) that can help to improve gut barrier function (Rose et al., 2021). Some specific prebiotics such as oligosaccharides and polysaccharides have been shown to strengthen the Intestinal Barrier by upregulating TJP like ZO-1, claudin-3 and occludin, prebiotics fortify the lining of intestine, preventing harmful substances from entering the bloodstream (Uerling et al., 2020). FOS can transport tight junction proteins such as Occludin and ZO-1 toapical region of cell that can increase gut barrier function (Wongkrasat et al., 2020). As TJP can boost the gut barrier function, GOS also helps in production of TJP as Occludin, Claudin-1 and ZO-1 (Wang et al., 2021).

2.4. Prebiotics and Immune System

Prebiotics show different effects on the immune system by using indirect and direct methods. Indirectly, they increase the growth of beneficial bacteria of gut and inhibit the growth of harmful bacteria. Increased populations of microflora also increase the production of short-chain fatty acids like butyrate that have high immunomodulatory properties. Some prebiotics have a direct effect on immune responses, such as those prebiotics which low molecular weight are absorbed in intestinal cells and increase efficacy of cellular signaling pathways. Prebiotics can also directly affect the immune system, alter their activity and production of cytokines. Both direct and indirect methods combined to enhance gut barrier function, improved resistance against infections and balanced immune responses (Shokryazdan et al., 2017). Naturally occurring prebiotics such as vegetables, fruits, legumes etc has many beneficial phytochemicals like saponins, flavonoids and phenolic compounds that help in reduction of parasitic burden like Eimeriosis in cattle and can treat many other parasites of animals (Sarfaraz et al., 2025).

2.5. Prebiotics and Digestive Health

2.5.1. Inflammatory Bowel Disease (IBD)

Inflammatory Bowel Disease (IBD) is a set of inflammatory conditions that disturbs the gut. Hyperactivity of immune system results in inflammation in gut by damaging the lining of digestive tract. Addition of dietary fibers in diet play a vital role in managing the IBD. A high-fiber diet can help maintain regular bowel function, reduce gastrointestinal discomfort and support a healthy gut during remission. But since many individuals don't get enough dietary fibre, there is research being done on supplementing with prebiotics, which are indigestible food ingredients that promote the growth of good bacteria. Prebiotics have the potential to target specific beneficial bacteria within the gut, but identifying the most effective prebiotics for IBD remains challenging due to the complex and still-evolving understanding of the gut microbiome and how it contributes to the disease (Rasmussen & Hamaker, 2017).

2.5.2. Colorectal cancer

Colorectal cancer is a cancer of colon which develops through a multi-stage process. Initial stage is genetic variations that result in the formation of cysts or polyps, which may become cancerous and spread. Research suggests that prebiotics, that encourage the growth of beneficial gut bacteria, may play a protective role. Prebiotic fermentation produces butyrate, a short-chain fatty acid that can inhibit cancer cell growth and induce their death. A clinical trial provided further evidence suggesting that a combined approach using probiotics and the prebiotic inulin may offer a protective effect against colorectal cancer, potentially reducing the risk of developing the disease by inhibiting cell growth, inducing the death of colon cells, and strengthening the intestinal lining (Candela et al., 2011).

2.6. Prebiotics and Nervous System

Research on prebiotics suggests that these food particles help in nourishing the microflora of gut may also have some positive effects on nervous system. Some prebiotics like B-Galactoligosacchrides can reduce the production of cortisol, which is a stress hormone. Further, it may also reduce the depression and anxiety (Ironside et al., 2016). In children, some prebiotics have shown to improve appetite regulation by reducing energy intake (Hume et al., 2017). However, research on the effects of prebiotics on developmental disorders of the nervous system

like attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorder (ASD) is limited and has yielded mixed results. More investigation is needed to fully understand the mechanism by which prebiotics establish their efficacy and safety on a nervous system for different populations (Theije et al., 2014).

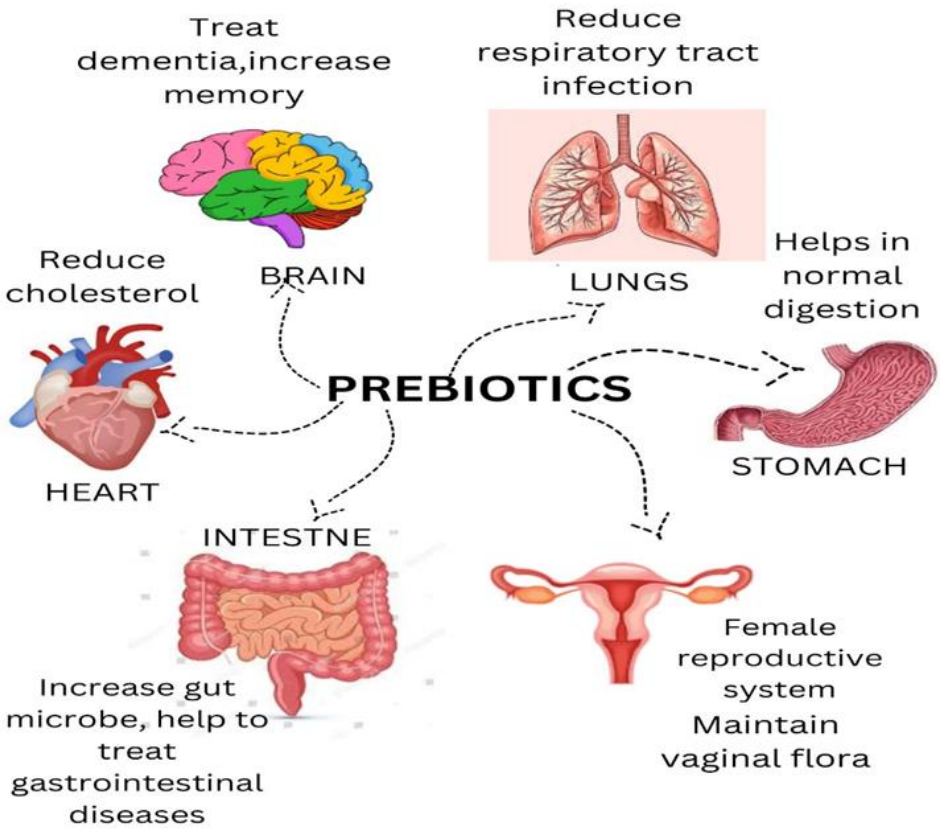

Fig. 1: Effects of prebiotics on different organs

3. Boosting Immunity with Prebiotics: Practical Tips

3.1. Benefits of Prebiotics

Prebiotics are dietary fibers that help in the growth and nourishment of beneficial gut microbiota. These positive effects of prebiotics ultimately lead to potential health benefits. Prebiotics help to develop healthy gut, better digestion, decrease irritable bowel syndrome symptoms and also aid in repairing the gut lining which has been distorted due to excessive use of antibiotics and alcohols (Al-Habsi et al., 2024). Prebiotics enhances the ability of gut barrier and shapes the immune system by increasing the immunity of body (Pujari& Banerjee, 2021). They can also aid in weight management by altering the appetite and metabolism (Bedu-Ferrari et al., 2022). Moreover, prebiotics can also improve the absorption of essential minerals like calcium, magnesium and iron etc., (Husmann et al., 2022).

3.2. Choosing a Prebiotic Supplement

Prebiotic intake can be increased in the body by eating food that is rich in nutrients and by avoiding processed food. Excellent sources include fruits like apples, bananas (unripe), berries and citrus fruits; vegetables such as onions, garlic, leeks, asparagus, and Jerusalem artichokes, legumes like chickpeas, lentils, beans and grains like brown rice, quinoa, oats, and barley. In addition to whole foods, some yogurts contain added prebiotics, like inulin or fructooligosaccharides (FOS). To minimize digestive discomfort when increasing fiber intake, it's essential to do so gradually. Adequate water intake is crucial to support fiber digestion. Combining prebiotics with probiotics can synergistically enhance gut health, as probiotics are live microorganisms that further support a healthy gut microbiome. Prebiotic supplements are also available in various forms, but consulting with a healthcare professional is crucial before starting any supplement regimen (Cunningham et al., 2021).

Conclusion

Prebiotics nourish the beneficial bacteria in your gut, leading to a healthier and more diverse gut microbiome. This, in turn, boosts the production of short-chain fatty acids (SCFAs), which have powerful effects on your immune system. Furthermore, some prebiotics can be directly absorbed by intestinal cells, influencing cellular signaling pathways and interacting with immune cells. These combined effects contribute to a balanced immune response, strengthened gut barrier function, and increased resistance against infections. Prebiotics illustrate many benefits to various health conditions, including colorectal cancer and inflammatory bowel disease (IBD). Prebiotics can directly be obtained from vegetables, fruits, pulses, beans, grains and legumes. Besides natural sources, supplements of prebiotics can be used but only with the consultation of doctors. Further studies are needed to investigate the potential mechanisms of prebiotics working and their uses in different clinical settings. By doing this, we can fully understand the working of prebiotics and can utilize it in supporting immune health and overall well-being.

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