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The new age of prebiotics: Traditional mechanisms, emerging benefits and future potential

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Abstract
Prebiotics are indigestible food elements that specifically increase the activity and rate of development of beneficial bacteria, hence having a positive effect on the host. In the past, well-known substances like galactooligosaccharides (GOS), inulin, fructooligosaccharides (FOS) and which have been well researched for their potential health advantages, were included in prebiotics. The primary mechanism of action for these conventional prebiotics is that they enter the colon undamaged, where the gut flora ferments them to create short-chain fatty acids (SCFAs) like butyrate, propionate and acetate. These SCFAs improve gut barrier integrity, lower inflammation and provide colonocytes with energy. Thus, taking conventional prebiotics has been associated with better immune system performance, better digestion and a lower chance of developing conditions including inflammatory bowel disease and colorectal cancer. The study of prebiotics has recently broadened to encompass a variety of novel substances with distinct modes of action and supplementary health advantages. Human milk oligosaccharides (HMOs) are unique among them since they are found naturally in human breast milk and are known to encourage the growth of good bacteria in newborns, including Bifidobacteria. The goal of research on artificial HMOs is to duplicate these advantages in nutrition for both adults and infants. With the development of biotechnology, prebiotic production has changed to include enzymatic, chemical synthesis and extraction methods for both established and novel prebiotics. These developments make prebiotics more widely available to the public by enabling their large-scale production and integration into a variety of food products, nutritional supplements, and functional foods. Newly developed prebiotics have great promise for a variety of uses, such as baby formula, functional meals and drinks and nutritional supplements. They are appealing for both therapeutic and wellness purposes because of their capacity to improve gut health, strengthen immunity and support general well-being. Furthermore, new prebiotics may have a wider range of applications by helping to treat metabolic disorders, heart ailments and neurodegenerative problems.

Keywords: Prebiotics, metabolic health, prebiotic mechanism, application, emerging prebiotic benefits, future prebiotic research

Introduction
According to the most recent definition provided by (ISAPP) the International Scientific Association for Probiotics and Prebiotics, “Substrates known as prebiotics are those that host bacteria specifically use to provide health benefits” (Bevilacqua *et al*., 2024) [19]. Prebiotics are known as “a nondigestible dietary element that acts as a selective growth and/or activity stimulant for one or a small number of beneficial bacteria in the colon, improving the health of the host” by Gibson and Roberfroid in 1995 [42]. For twenty years, despite multiple revisions, the essential components remained constant (Bevilacqua *et al*., 2024; Gibson & Roberfroid, 1995) [19, 42]. Prebiotics are a family of plant-derived oligosaccharides that were discovered by Gibson and Roberfroid in 1995 [42]. These oligosaccharides show preferential activity towards beneficial targets in the gut flora, such as Lactobacillus and Bifidobacterium (Yang *et al*., 2020; Lam & Cheung, 2013) [67, 133].
Prebiotics often show resistance to heat and acid and they also lessen the proportion of bacteria in the population that cause disease and those that break down choline (Markowiak & Slizewska., 2017) [83]. Prebiotics can be categorized into multiple groups based on their regulatory status and stage of development.

Well-known prebiotics include lactulose, fructooligosaccharides, galactooligosaccharides and inulin. Prebiotics categorized as “emerging” include xylooligosaccharides, isomaltooligosaccharides, chitooligosaccharides, and lactosucrose; neoagaro-oligosaccharides, raffinose and epilactose are considered “under development.” Some materials are regarded as "new candidates, " including peptides, proteins, hydrolysates of proteins, polyphenols, polyunsaturated fatty acids and oligosaccharides found in human milk (Cardoso *et al*., 2021; Yang *et al*., 2020; Lam & Cheung, 22013) [24, 67, 133]

Prebiotics are indigestible materials that stimulate the growth and function of useful gut bacteria; these are usually dietary fibers (Ji *et al*., 2023) [54]. Prebiotic degradation was not observed when new technologies were applied to prebiotic products. Nevertheless, it enhanced the amounts of health-promoting substances (antioxidant activity and inhibition of α-amylase, α-glucosidase, and ACE) and bioactive compounds (polyphenols, flavonoids, anthocyanins and ascorbic and citric acids) (Balthazar *et al*., 2022) [13]. According to Cresci *et al*. (2019) [29], the gut microbiota is the collective habitat of microorganisms that are present in the gastrointestinal tract (GIT), including bacteria, fungi, viruses and protozoans. These bacteria regulate the host's metabolism (Jana *et al*., 2021; Lepage *et al*., 2013) [52, 71].

A nutritious diet is one of the main external variables that impact the formation of up to 98% of the human microbiota, according to genetic studies conducted by Israeli scientists. A collection of microbes that reside in the human body is known as the microbiome. Microbial communities that are viable are part of the structure of the microbiome. There is diversity in the gut microbiota and ever-changing population of microorganisms found in the colon. It is the densest microbial ecology found in the human body. Due to the important role these commensal gut microorganisms play in human health and illness, regulating the gut microbiota has a significant Possibility of enhancing health (Bedu-Ferrari *et al*., 2022) [17].

Products that are essential to the microbiome's existence establish what foods humans require to survive. An individual's susceptibility to certain diseases is also determined by their microbiome. Human health development is determined by the interaction between the human host and his microbiota (Bazarnova *et al*., 2020) [15].

Prebiotics are frequently utilized in the manufacturing of meats, dairy products, baked goods and beverages because of their technological advantages as well as their health benefits. They are also added to symbiotic meals in conjunction with probiotics to increase the viability, proliferation and development of probiotic bacteria during digestion and processing. Benefits such as better lipid metabolism, alleviation of constipation, decreased risk of gastrointestinal disorders, enhanced vitamin and mineral absorption, prevention of type II diabetes, aid in blood glucose control and weight loss (Ferreira *et al*., 2023) [36].

Fructans are utilized in food formulations for their techno-functional qualities, such as substituting sugar in low-calorie foods, in addition to their intriguing nutritional and health advantages (Hamdi *et al*., 2022) [47]. They are easily employed as a fat replacement in culinary preparations because of their gelling ability. According to Alaei *et al*. (2018) [4], the product that uses fructans in place of fat has a mouthfeel that is comparable and a suitable creamy, consistent texture. According to Román *et al*. (2017) [102], natural food is strongly preferred by modern consumers over processed food, and humans are particularly concerned in regulating and limiting the danger to their own health. Reducing the risk of developing illnesses such as dietary fibers and oligosaccharides can help prevent conditions including colorectal cancer (CRC), cardiovascular disorders, obesity, diabetes and other conditions.

Prebiotics that have been studied the most (Davani-Davari *et al*., 2019) [31] and marketed (Hexa Research, 2018) globally are probably inulin, fructooligosaccharides (FOSs) and galactooligosaccharides (GOSs). Worldwide markets are interested in commercializing them due to their shown ability to alter the gut flora and offer preventative health effects against chronic illnesses. Furthermore, the industry has been using these prebiotics to enhance food processes and physical-chemical and nutritional qualities to make foods more appealing to the senses and healthier for overall consumers (Farias *et al*., 2019; Mohammadi and Mortazavian, 2011) [32, 87].

Thus, the prebiotics listed below will be referred to as "emerging" for the purposes of this section: resistant starch (RS), xylooligosaccharides (XOSs), pectin and pectic oligosaccharides (POSs), algal carbohydrates, bacterial exopolysaccharides (EPSs), isomaltooligosaccharides (IMOSs), polyphenols and others (glucomannan, soybean oligosaccharides, etc.). Prebiotics have been shown to be essential for enhancing the viability and functionality of conventional probiotics. Prebiotics are also crucial for NGPs; they are defined as substrates that the host microbes specifically use to provide a health benefit.

Over 90% of the variety of gut bacteria in healthy people is found in two phyla: Gram-negative Bacteroidetes and Gram-positive Firmicutes. The term "dysbiosis" refers to the fundamental patterns of compositional alterations in the gut microbiota that underline an increasing variety of chronic illnesses with different clinical manifestations. Therefore, disorders such as cardiovascular disease (Karlsson *et al*., 2012; Koren *et al*., 2011) [59, 65], obesity (Le Chatelier *et al*., 2013), inflammatory bowel disease (Franzosa *et al*., 2019; Becker *et al*., 2015) [16, 39], diabetes (Karlsson *et al*., 2013) [60], and non-alcoholic fatty liver disease (NAFLD) are linked to changes in microbial patterns when compared to healthy individuals (Aron-Wisnewsky *et al*., 2020) [6].

1. The role of prebiotics in human health

A significant amount of data now suggests that human physiology and metabolism are significantly influenced by gut bacteria. The gut microbiota does, in fact, assist the host immune system in its training and functioning (Bedu-Ferrari *et al*., 2022; Zheng *et al*., 2020; Round & Mazmanian, 2009) [17, 103, 139], support host metabolic homeostasis (Bedu-Ferrari *et al*., 2022; Aron-Wisnewsky *et al*., 2021; Cani *et al*., 2019) [7, 17, 22], have an impact on neurocognitive function and supply colonization resistance to invasive pathogenic infections (Bedu-Ferrari *et al*., 2022; Rieder *et al*., 2017; Leshem *et al*., 2020) [17, 72, 96].

The word "microbiome" refers to the vast array of microorganisms that inhabit the human body, including the skin, gut and other mucosal habitats (Zheng *et al*., 2020; Sender *et al*., 2016) [109, 139].

According to recent developments in the field of microbiome research, the gut microbiota actively influences several host processes, including as metabolism, immunity, circadian rhythmicity, and nutritional responses (Zheng *et al*., 2020; Lynch & Hsiao, 2019; Hacquard *et al*., 2015) [46, 80, 139].

Prebiotic compounds can engage in competition for resources, antagonistic interactions, cross-feeding and stabilizing the gut microbiota. "Prebiotic substances are characterized as "a substrate that is selectively used by host microorganisms that confer a health benefit." Food ingredients have a significant effect on the gut microbiota, affecting its makeup in terms of richness and diversity. Dietary practices have a significant effect on the gut microbiota's makeup. Maintaining overall health requires healthy gut microbiota and one of the key factors influencing this fascinating world of bacteria is nutrition. This should provide us with even more motivation to lead a healthy lifestyle.

Normal gut microbial interactions with their human hosts are symbiotic and advantageous to both parties: the microbiota supplies essential components for the host's health, while the host offers a nutrient-rich environment (Capurso, 2016) [23]. Among the many essential functions that the intestinal microbiota performs in maintaining health are the development of the immune system, proper intestinal function during digestion, maintenance of the integrity of the intestinal barrier, metabolic homeostasis, vitamin synthesis, synthesis of amino acids and neurotransmitters, bile acid metabolism and protective roles (Sanders *et al*., 2019) [106].

It is estimated that the gastrointestinal system is home to more than 100 trillion microorganisms per gram, or over 2, 000 different kinds (Chong *et al*., 2019) [26]. Because of the vast number of bacterial cells in the body, the host and the microbes that reside there are frequently referred to as “superorganism." (Thursby & Juge, 2017) [118]. The whole population of microorganisms in a certain area is referred to as the "microbiota." The biggest population of microorganisms is found in the gut's microbiota, which is composed of about 2000 distinct bacterial species. Because nutrition regulates microbial activity and gene expression, it is significantly impacted by both intrinsic (such as genetics and age) and extrinsic (such as physical activity, smoking, body mass index and food) variables (Jumpertz *et al*. (2011) [57].

Some groups of metabolites specifically, the polyunsaturated and short-chain fatty acids generated by probiotics and prebiotics, or prebiotic-like substances such flavonoids, polyphenols and vitamins are the main contributors. Functional foods also include prebiotic-like components. These dietary components with functional properties affect the gut microbiota by promoting the development of advantageous bacteria and the synthesis of advantageous metabolites, which directly benefit the host and offer defense against infections and the maintenance of a healthy gut ecology (Truong *et al*., 2020) [94]. There are many benefits associated with intake of prebiotics like it lowers diabetes, hypertension, reduce the obesity, lower hypertension as well as less anxiety, depression, high bone mineralization and immune response.

The term "human gut microbiome" describes all the bacteria and other microorganisms that make up the microbial population of the human gastrointestinal tract (GIT). About 500-1000 different species of gut bacteria inhabit the human body and their genomes encode 100 times more distinct genes than the human genome. The host gains several advantages from the microbiota through different kinds of physiological processes, including harvesting energy (Den Besten *et al*., 2013) [34], increasing gut health or forming the intestinal lining (Natividad & Verdu, 2013) [90], controlling the immune system of the host (Gensollen *et al*., 2016) and defending against infections (Bäumler & Sperandio, 2016) [14]

Table 1: A summary of prebiotics' impact on human health that considers both established and newly discovered prebiotics

Prebiotic type	Examples	Mechanism of action	Health benefits	References
Traditional Prebiotics				
Inulin	Chicory root, garlic, onions	Produced SCFAs through fermentation by intestinal microbes	boosts immunity, lessens inflammation and improves digestion	Gibson &Roberfroid, 1995 [42]
Fructooligosaccharides (FOS)	Onions, garlic, and bananas	Encourages the growth of lactobacilli and bifidobacteria	Decreases gastrointestinal illnesses and improves the absorption of minerals	Roberfroid, 2007 [97]
Galactooligosaccharides (GOS)	Beans and Dairy products	Encourages the development of good gut flora	Strengthens the intestines and boosts immunity	Gibson *et al*., 2004 [142]
Emerging Prebiotics				
Human Milk Oligosaccharides (HMOs)	Milk from human beings	Encourages the development of Bifidobacteria in babies	Lowers infection risk and promotes intestinal health in babies	Bode, 2012 [143]
Xylooligosaccharides (XOS)	bamboo with corn cobs	Fermented specifically by good bacteria	Improves intestinal health and could lower cholesterol	Carvalho *et al*., 2013 [144]
Arabinoxylans	Rye and wheat bran	Oxidized to generate SCFAs	Enhances intestinal health and reduces inflammation	Broekaert *et al*., 2011 [145]
Beta-Glucans	Barley, mushrooms, and oats	Oxidized to generate SCFAs	Boosts the immune system and lowers cholesterol	Vetvicka & Vetvickova, 2011 [146]
Resistant Starch	Raw bananas and cooked but cooled potatoes	Resists digestion and is broken down by gut flora	Increases intestinal health and insulin sensitivity	Sajilata *et al*., 2006 [147]
Polyphenols	Wine, tea, vegetables, and fruits	Alters the gut microbiota's makeup	Benefits of antioxidants, reduce inflammation, and promote cardiovascular health	Cardona *et al*., 2013 [148]
Pectins	Apples and citrus fruits	Oxidized to generate SCFAs	lowers cholesterol and promotes intestinal health	Voragen *et al*., 2009

2. Traditional prebiotics

In large intestine oligofructose and inulin are prebiotic oligosaccharides formed by fermentation (Flickinger *et al*., 2003) [37]. As a reserve carbohydrate, particularly in ASTERACEAE inulin is widespread in plants (Rubel *et al*., 2018) [104]. It is not absorbed or digested in small intestine due to its structure and thus carry out a prebiotic action by stimulating development of useful bacteria (Lu X *et al*., 2019) [79]. Due to the ability to substitute sugar and fat ingredients inulin is widely used in food industries (Zhu Z *et*

al., 2016) [140]. In numerous plants like onion, garlic, asparagus leeks, wheat, artichokes, chicory and banana, inulin is present (Azorin-Ortuno *et al*., 2009) [10] (Liu & R.H., 2007) [76].

A mixture of oligosaccharides, fructose units, polysaccharides and eventually fructan structure linked with terminal glucose unit composes inulin (Lopez-Molina *et al*., 2005). As recommended by health practitioners when fructooligosaccharides are consumed in sufficient amounts so they show bifidogenic nature and health promoting properties due to which they are classified as prebiotics (Huebner *et al*., 2007) [50] (Nguyen *et al*., 2011) [92] (Roberfroid *et al*., 1998) [98] (Van Laere *et al*., 2000) [123].

In human nutrition some health benefits associated with Fructooligosaccharides are enhanced calcium absorption in gastrointestinal tract, activation of immune system, synthesis of B-complex vitamins and resistance to infections (Tanriseven & Aslan., 2005) [115] (Yun & J.W., 1996) [136]. Galactooligosaccharides are carbohydrates-based food ingredients which are non-digestible that provide protection from infection, decrease the number of potentially pathogenic bacteria, facilitate the normal functions of gut, stimulates absorption of few minerals, less blood lipid content and enhance health related physiological activities (Van den Broek *et al*., 2008) [121].

Now a days Galactooligosaccharides are said to belong to prebiotics which are substances that stimulate the beneficial bacteria's growth in lower part of human intestine (Schaafsma., 2008) [107]. Without being digested by humans and other animals GOS leads to health benefits by selectively increasing beneficial microflora of intestine (Macfarlane *et al*., 2008) [82].

Table 2: Effect of different substrates on humans

Substrate	Subjects	Effects
GOS	Humans	GOS induces a small but statistically significant increase in bifidobacteria as compared to the controlled therapy (Davis *et al*., 2010) [32].
GOS	Mice	A rise in total protein content and sucrase activity was discovered, along with an increase in O-Linked glycoproteins linked to the intestinal mucosa but on intestine villus height no detectable effect was found (Leforestier *et al*., 2009) [69].

3. Emerging prebiotics

Before the term "prebiotic" was coined in 1995, Glenn Gibson and Marcel Roberfroid defined it as "a non-digestible food ingredient which benefits host by selectively vivifying activity or growth of a specific number of bacteria in colon.", in this way improves health.' (G.R. Gibson *et al*., 2010) [43]. After that many researchers proposed revised definition. Like prebiotics are undigested dietary carbohydrates which produce short chain fatty acids (SCFA) as end products on fermentation by colonic bacteria (Bird *et al*., 2010) [20]. Currently recognized definition of prebiotics provided by The International Scientific Association for Probiotics and Prebiotics is Prebiotics are substances that grant health benefits by being selectively utilized by host microorganism (ISAPP *et al*., 2017) [41].

To classify a compound as a prebiotic these criteria should be followed:

Substances should not be absorbed in gastrointestinal tract, can resist acidic pH of stomach, mammalian enzymes cannot hydrolyze it, should not be fermented by intestinal microbiota, selectively stimulate growth or activity of intestinal bacteria, helps to improve host health (Gibson *et al*., 2010) [43]. There are many sources of prebiotics, which mainlycome from plant-based foods. A potential source of prebiotics is mushrooms that contain carbohydrates like hemicellulose, chitin, mannas, Xylans and galactans (Aida *et al*., 2009) [3]. Prebiotics naturally occur in seaweed and marine microalgae (Zaporozhets *et al*., 2014) [137]. Prebioticsnaturally occur as Jerusalem artichoke, rye, chicory, milk, honey, onion, salsify etc. (R. Yadav & P. Shukla, 2017) [135].

Prebiotics are classified into 3 main groups:

- Galacto-oligosaccharides (GOS)
- Trans-galacto-oligosaccharides (TOS)
- Fructo-oligosaccharides (FOS)

FOS are naturally occurring prebiotics and are indigestible compounds, they travel through small to large intestine here in gastrointestinal tract they effect the activity and growth of probiotics and through fermentation influence bowel functioning. GOS are stable carbohydrates and are present in different kinds of foods, they act as bulking agents, have pleasant taste and can increase the texture of food. That's the reason GOS are being employed in wide variety of commercial commodities like dairy goods, sauces, soups, drinks etc. (Yang *et al*., 1995) [134].

4. Mechanism of action of prebiotics

The health benefits of prebiotics have been underlined during recent decades, which include effect on gastrointestinal tract (*i.e*. short chain fatty acids creation, immune system regulation, improvement of gut barrier function) carbohydrates that are non-digestible such as prebiotics regardless the potential effects on GI tract can modulate activity and composition of intestinal microbiota (Roberfroid, 2007; kleessen *et al*., 2001; Van Der Beek *et al*., 2017) [62, 122].

In human intestines, enzymes that dissolve polymer bonds of these prebiotics are generally lacking, so by resisting small-intestinal digestion they entirely reach in colon whereby beneficial bacteria (Lactobacilli and bifidobacteria) undergo fermentation (Van Der Beek *et al*., 2017) [122]. There is expanding interest in dietary strategies to regulate microbiota, so on use of prebiotics for this reason research has obliged, intestinal microbiota metabolizes many of these poly saccharides and induced to creation of short chain fatty acids SCFAs (Holscher, 2017) [49].

These intact prebiotics are then transferred to large intestine by human body where they are carefully fermented to bring about certain secondary metabolites and are degraded by the intestinal flora, these metabolites are either socked up by intestinal epithelium or transferred by portal vein to liver and can have advantageous effects on physiological actions of host such as managing immunity, boosting mineral absorption and lessen blood lipid level (Slavin, 2013; Cockburn & Koropatkin, 2016; Guarino *et al*., 2020) [27, 44, 113]. For means of human studies a little substrates like GOS and FOS are proved among many potential prebiotics accessed, GOS and lactulose are seemed to be determined the development of Lactobacilli and Bifidobacteria, fructans are known as main substrate of healthy microbes (Watson *et al*., 2012) [126]. The lipid-oxidation and of other food

substances are able to promoted by gastric acid secretion (Kanner *et al*., 2001) [58]. The beneficial bacteria metabolize most abundant SCFAs in the intestine which include propionate, butyrate, acetate these are beneficial in maintenance intestinal and systemic health. An advantage of prebiotics is referred as they promote growth of aimed microbes, after the utilization of some particular prebiotics to competing with other species they encourage growth of beneficial flora and to increase production of fermented products (Ashaolu, 2020) [8] Figure 1

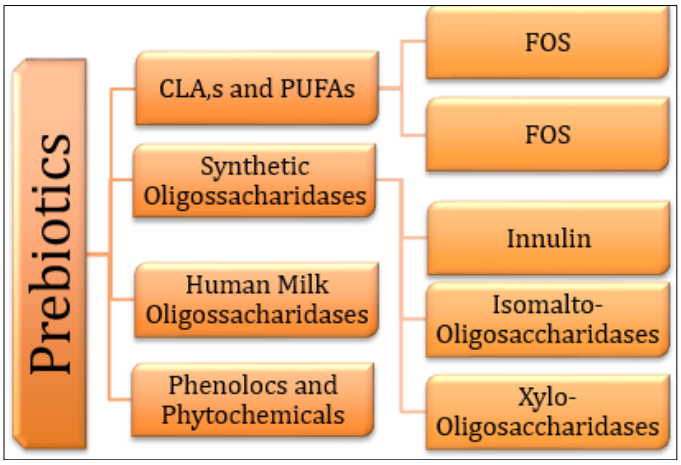

Fig 1: Prebiotics enhance beneficial gut bacteria and short-chain fatty acid production.

5. Production of prebiotics

Prebiotics can be produced by various methods like in industries, by microbes, by enzymes, and by agro-industrial waste. One method for production of prebiotics is by transgalactosylation of carbohydrates from raw materials like starch, lactose, Xylan with the help of chemical and enzymatic methods (WU Y *et al*., 2013) [131]. Agro industrial sector produces large amounts of wastes, the waste which is left after agricultural activities include straw, stem, stalk, husk, shell, leaves and many others (Sadh *et al*., 2018) [105]. A huge portion of this waste is made up of materials called "lignocellulosic materials" this material is used in production of prebiotics (Mussatto *et al*., 2013) [89]. Fungi are used to produce enzyme fructosyl transferase which is further used to produce prebiotics. Potential sources of prebiotics include fungal chitin and their complexes (Sridhar *et al*., 2022) [114]. Many prebiotics are non-digestible oligosaccharides which are either gained by natural resources or synthesized by using enzymes (Vera *et al*., 2021) [125]. Well-known prebiotics also include polysaccharides which are derived from mushrooms (Thatoi *et al*., 2018) [117].

6. Health benefits of emerging prebiotics

Prebiotics optimize stool consistency and increase fecal bulk by increasing fecal microbial mass, this increase shortens transit time and stimulates passage through colon, stool becomes soft and heavy as colonic water resorption is reduced through this constipation is alleviated Sharma *et al*., 2012) [110]. According to a recent study on elderly constipated adults it is proved that laxative effect of 20 grams inulin type fructans is better than that of lactose (Kleessen *et al*., 1997) [63].

In pregnant women xylooligosaccharides have been shown to reduce severe constipation (Tateyama *et al*., 2005) [116]. (GALT) Gut associated lymphoid tissue are network of highly complex aggregated and non-aggregated immunity cells and represents the greatest immune organ (Watzl *et al*., 2005) [127]. Prebiotics by increasing villous height enhance the integrity of intestinal mucosa and enhance healthy mucosal biofilm composition (Kleessen and blaut, 2005) [61]. It is indicated by research that both systematic and intestinal immunity are modulated by prebiotics due to association with gut microflora. Human studies involving elderly residents of a nursing facility that examined prebiotic effects on systemic immunity showed a significant increased percentage of peripheral T lymphocytes, CD8 and CD4 lymphocytes by taking 8 grams/day supplementation for 3 weeks (Guigoz *et al*., 2023) [45]. Another open trail examination on the influence of prebiotics on a little group of Crohn's disease patients showed a significant reduction in disease activity by supplementation of fructooligosaccharides for 3 weeks with a significant increase in mucosal bifidobacteria and an immunoregulatory activity (Lindsay *et al*., 2006) [74].

A study of baby food formula containing combination offructooligosaccharides and galactooligosaccharides was shown to lessen extent of atopic dermatitis as compared to similar formula without these prebiotics (Moro *et al*., 2006) [88]. Prebiotics produce biomolecules which influence immune response and help in suppression and lessen the intestinal inflammatory diseases.

Table 3: Health Benefits of Prebiotics in our Body

Health benefit	References
Enhanced composition of the gut microbiome	(Gibson, G. R., & Roberfroid, M. B. 1995) [42]
Improved function of intestinal barrier	(Cani, P. D *et al*., 2019) [22]
Elevated short-chain fatty acid (SCFA) synthesis	Slavin, J. (2013) [113].
Enhanced Immune Response	(Lomax, A. R., & Calder, P. C., 2009) [149].
Decreased likelihood of inflammatory bowel disorders	(Flint, H. J *et al*., 2012) [150]
Increased socking of minerals (such as calcium and magnesium)	(Scholz-Ahrens, K. E *et al*., 2007) [108]
Possibility of lower colorectal cancer risk	(Roberfroid, M *et al*., 2000) [99]
Improved sensitivity to insulin and blood glucose control	(Weickert, M. O., & Pfeiffer, A. F., 2008) [151]
Decreased irritable bowel syndrome (IBS) symptoms	(Hungin, A. P. S *et al*., 2013) [152]
Potential advantages for managing weight	(Parnell, J. A., & Reimer, R. A., 2012) [153]

7. Applications for emerging prebiotics

Some prebiotics mostly non-digestible carbohydrates due to their technological characteristics by incomplete substitution of sugars and fats can cause enhancement in the standard of final products such as texture, sensorial properties and physiochemical. (Rodrigues *et al*., 2012) [101] by special focus on fused linoleic acid investigated the influence of inulin and FOS of cheese free fatty acid profile, during ripening time increase of fused linoleic acid content suggests incorporation of prebiotics in probiotic manufacturing of cheese with lower atherogenicity index and better-quality product. The influence of addition of specific prebiotic oligosaccharides mixture to protein alternate diet was investigated using a unilateral study in PKU identified in 9 infants (MacDonald *et al*., 2011) [81].

The major determining factor during food purchasing is the health effect of food, mainly investment in formulation of ingredients and additives, transgenic food, functional food and packaging are being made by food industry. In treatment of hepatic encephalopathy, for preventing and decreasing the concentration of ammonia in blood lactulose is being widely used. When prebiotics incorporated into food the growth of microflora in gastrointestinal tract is enhanced and thus food quality is improved, prebiotics also keep food moist and provide freshness to it. For the manufacturing of confectionery, wheat bread, infant formulas, meat products, dairy products, cereal bar and others prebiotics can be employed (Ashwini *et al*., 2019) [9]. Enhancing the mouthfeel by providing better tongue lubrication and an innovative way to replace sugar and fats in wide range of products in food industry offered by prebiotics incorporation (Singla & Chakkaravarthi., 2017) [112]. Reaching the colon in fermentation of non-digestible carbohydrates gutmicrobiota has been involved and these process leads to great health benefits with creation of short chain fatty acids (Den Besten *et al*., 2013) [34]. Figure 2.

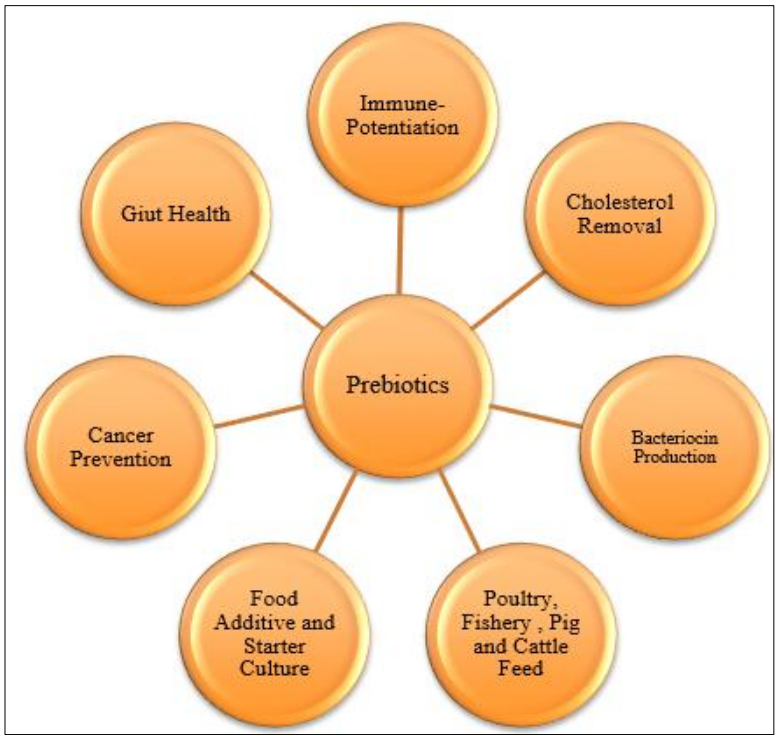

Fig 2: Prebiotics improve mouthfeel and promote SCFA production through gut fermentation.

8. Challenges and considerations

For thorough understanding of function and structure of microbiome with respect to prebiotics, modern techniques based on genetic engineering, system biology, molecular biology, nanotechnology and immunology must be utilized. Due to varying classification of probiotics, prebiotics as dietary supplements regulatory concerns arise in countries which leads to different approval processes and regulatory standards (Williams LM *et al*., 2022) [130]. Challenges in terms of product development, market access, registration might be created due to conflicts with some cultural or religious beliefs by the consumption of live bacteria in certain prebiotics (Freedman SB *et al*., 2020) [40].

In clinical practice interactions between probiotics and prebiotics can impact treatment outcomes that's why it is essential to identify and manage potential interactions (Merenstein D *et al*., 2023) [85] (Kothari D *et al*., 2019) [66] (Gwee K-A *et al*., 2018). In addition to these vast studies on animal models about prebiotic impact on health through gut-brain axis have been conducted, but gaps are still there in understanding interaction of mechanism of treating diseases and human body (NG QX *et al*., 2023) [91]. The vast adoption of prebiotic therapies leads to reduced reliance on antibiotics, improved patient's outcomes and lowered health care costs (Veiga P *et al*., 2020) [124].

For acceptable use of prebiotic health Canada is developing guidelines, on this topic a guidance document was published (May 2009). During the last decade in Japan countless prebiotics have been commercialized by Japanese ministry of health, labor and welfare on the basis of their grading as food for particular health use, this status is allowed to the food that contains ingredient which is approved officially to claims physiological impacts on human body and work for health (Japanese Ministry of Health, Labor and welfare., 2010). To initiate work on the assessment of functional and health effects of prebiotics a scientific meeting was convened by FAO (Pinero M *et al*., 2008) [95].

9. Future perspective and directions

For the proliferation of beneficial bacteria and to stimulate metabolism the derived prebiotics from non-digestive carbohydrates exhibit a selective capacity and thus improve the composition of gut microbiota (Davani-Daivari *et al*., 2019) [31] (Gibson & Roberfroid., 1995) [42]. A significant success of 91% is shown by prebiotic products in human trial studies and proved that Propionibacterium acne can be decreased efficiently and acne can be treated (Bockmuhl *et al*., 2007) [21].

To indicate the favorable effects on health of synbiotics and prebiotics further clinical trials are needed, by recognizing appliance of purpose and by the usage of microscopic tools for characterizing modification in microbial profile of colonic microbes the studies would be strengthened (Conway & P.L., 2001) [28]. There is not any requirement of approval from FDA for prebiotics (inulin, oligofructose) available in our daily intake, though the well-being of prebiotics for food utilization have been validated by worldwide various legal authorities. Gastrointestinal discomfort caused by bloating, high osmotic pressure and flatulence is being studied (William & C.M., 1999) [129].

There is an urgent need of food industrial application of emerging prebiotics perused by new studies to acknowledge the complexity of food and to put a wider perspective and to shed light on specific effect and mechanism of cereal prebiotics further research is required (Abdi *et al*., 2021) [1]. If prebiotics are not well brewed constantly an osmotic reaction in host GIT is exerted, but if effectively fermented by GIT microflora they exert prebiotic effect and shows higher metabolic gas production (Robefoid M & Savin J., 2000). Metabolic retort to certain foods determined by gut microbiota arrangement is individual and thus microbiota possession also plays a significant role within obesity control this is found by advances in personalized nutrition (Zmora *et al*., 2016) [141] (Korem T *et al*., 2017) [64].

Previously unknown health prospects of prebiotics have been shown by recent research findings. Prebiotic feeding lessens firmicutes outbreak in obese mice that stimulates advances in glucose liberty, reduce oxidative stress, inflammation and fat build up. prebiotic may be a key approach in diabetes cure by improving glucose homeostasis and by inducing gut microbiota modulation (Ahmdifar E *et al*., 2011) [2].

10. Conclusion

Prebiotic research has come a long way, from conventional molecules like inulin, FOS and GOS to a wide range of novel compounds with distinct health advantages. Conventional prebiotics have demonstrated their capacity to generate advantageous short-chain fatty acids, which in turn can improve immunological function, lower the risk of disease and improve gut health. This fundamental knowledge has brought attention to the critical role that gut bacteria plays in general health. Newer prebiotics with immune-modulating, antioxidant, and anti-inflammatory properties include alginate oligosaccharides, beta-glucans, resistant starches, polyphenols, arabinoxylans and pectin. These novel substances have potential applications in treatment and prevention of a broad range of illnesses, including neurodegenerative illness and metabolic disorders. Technological developments in biotechnology have enhanced the manufacturing of prebiotics, increasing their availability in food items, functional foods and nutritional supplements. Comprehensive clinical trials are yet required to guarantee safety and validate health claims. Regulatory frameworks need to change in tandem with scientific discoveries. Prebiotics' future is in discovering new substances, creating individualized dietary plans and combining prebiotics with other medicinal modalities. Prebiotics hold great promises for improving human health and well-being using both new and traditional knowledge.

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