Prebiotics Types Sources and Their Impact on Gut Ecology

Muhammad Haris Naeem[1], Muhammad Uzair[1], Abdul Ahad Qureshi[2], Kashif Sarfraz Abbasi[3], Kashif Ameer[1,*], Muhammad Abid[1], Mian Anjum Murtaza[1], Ehsan-ul-Haque[4], Nouman Rashid Siddiqui[5] and Anum Noureen[6]

[1]Institute of Food Science and Nutrition, University of Sargodha, 40100 Sargodha, Pakistan
[2]Department of Horticulture, PMAS Arid Agriculture University, 46000 Rawalpindi, Pakistan
[3]Institute of Food & Nutritional Sciences, PMAS Arid Agriculture University, 46000 Rawalpindi, Pakistan
[4]Citrus Research Institute, Sargodha 40100, Pakistan
[5]Food Science Research Institute, National Agricultural Research Centre, Islamabad 45000, Pakistan
[6]Punjab Agriculture Department, Punjab, Pakistan
*Corresponding author: kashifameer89@gmail.com

Abstract

Prebiotics are undigestible food for the human body that acts positively on the host's gut by encouraging the growth on helpful bacteria responsible for the positive health of the gut. Various components include fibers, oligosaccharides, and some polyphenols that stimulate the population of Bifidobacteria and Lactobacilli. Prebiotics can be found in the form of dietary fiber, which originates from fruits, vegetables, whole grain, and legumes and can also be manufactured as functional ingredients such as inulin and fructo-oligosaccharides. These data show that prebiotics have a profound impact on gut microbiota by increasing the overall richness of microbiota, the SCFAs producing capabilities, and the overall beneficial gut conditions. Their consumption is believed to have many health benefits ranging from improved digestion, increase in the immune system ability, and fight inflammation. Selected prebiotics might add positive impact on the microbes in GIT and make it effective against different disease. More investigations are needed to identify their chronic effects on people's health and their potential as treatment agents for some GIT disorders.

Keywords: Prebiotics, Bifidobacteria, Lactobacilli, Gut microbiota, Digestion, Inflammation

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Introduction

Prebiotics is the term used to describe food that are un digested by humans, yet they enhance the proliferation and or activity of the so-called 'friendly' bacteria in the large bowel thereby promoting health. Some of these are FOS and inulin that belong to the short and long-chain β-fructans, lactulose, and GOS. In the 6th ISAPP meeting held in 2008, a more detailed description of dietary prebiotics was given as "a selectively fermented substance that advantage of using lactic acid produced added during fermentation and worked as a prebiotic substance brought out in the 6th meeting of ISAPP held in 2008 (Gibson et al., 2010). Prebiotic classification includes: There are four mechanisms through which prebiotics can impact on the intestinal microbiota and thereby the health of the host: (i) protection from the acidic environment in the stomach, (ii) undergoing fermentation by the bacterial populations in the intestines, (iii) selectively encouraging performance ability of intestinal microbes and (iv) changes the health of consumer (Gibson et al., 2010).

All the prebiotics are not carbohydrates. Carbohydrate-derived prebiotics are differentiated from the fibers on the following basis. Fibers are: (i) Carbohydrate polymers with DP greater than 3, and (ii) resistant to the action of endogenous enzymes of the small intestine. What consumers should know is that the solubility or fermentability of fiber does not play an important role. (Howlett et al., 2010; Slavin and Joanne 2013). Carbohydrate-derived prebiotics are differentiated from the fibers on the following basis.

Types of Prebiotics

Several classifications of prebiotics of which belong to one of the carbohydrate groups known as oligosaccharide carbohydrates (OSCs) (Table 1). Despite the perception that most prebiotics are carbohydrates, there are a number of studies relating to OSCs present also (Fig. 1).

Prebiotics of natural origin include fibers such a s inulin, FOS and GOS that are contained in products like chicory, onions and garlic that promote good bacteria living in the gut (Table 2). In contrast, synthetic prebiotics are obtained by enzymatic reactions or chemical synthesis, generate oligosaccharides that have similar impact to natural prebiotics. Natural and synthetic prebiotics are used to balance gut microbiota in order to improve digestion and immune response.

Techno functional Properties of Prebiotics

Water-Holding Capacity and Texture Improvement

Techno-functional feature of prebiotic is the action on the textural properties and water holding capacity of the food matrix. The most

used prebiotic called inulin forms a gel matrix that can imitate fat in texture when used in low calorie applications (Franck, 2002). In conjunction with domoic acid it was reported to provide the yogurt like characteristics due to its function in texture and stability of the product (Aryana & McGrew, 2007). Similarly, fructo-oligosaccharides (FOS) increases the softness of baked products to reduce staling and increase shelf-life (Roberfroid, 2007).

Table 1: Carbohydrate group of Prebiotics.

Sr. No	Prebiotic	Composition	Stimulant Bacteria	Reference
01	Fructans	Inulin and fructo-oligosaccharides (FOS), or oligofructose, are both fructan type that is built up from fructose molecules linked primarily by β(2→1)-glycosidic bonds. The majority of these compounds have terminal glucose units and are linked through β (2 → 1) bonds. Inulin and olive aglycone in particular are found to have a DP up to 60 while DP of FOS has less than 10.	*Bifidobacterium, Lactobacillus* & *Faecalibacterium prausntizii*	Louis et al., 2016; Hugheset al., 2022
02	Galacto-Oligosaccharides	GOS is produced by trans-glycosylation of lactose through enzyme catalyzed reaction. We know that a reaction favorably produces tri- to pentasaccharides containing β(1→6), β(1→3), and β(1→4) linkage. It is also referred to as trans-galacto-oligosaccharides, and in short, it is abbreviated by TOS.	*Bifidobacteria* and *Lactobacilli*. *Bifidobacteria* in infant; *S. Enterobacteria, Bacteroidetes* and *Firmicutes* are also positively influenced by GOS, though with less efficiency than *Bifidobacteria*.	Davari et al., 2019
03	Starch and Glucose-Derived Oligosaccharides	A glucan with numerous branches and glycosidic linkages.	In the in vitro study, similar authors established that RS could also be declined by *Ruminococcus bromii, Bifidobacterium adolescentis, Eubacterium rectale* and in a lesser measure by an organism *Bacteroides thetaiotaomicron*. However, although RS is degraded in the mixed bacterial and fecal incubations, degradation is impossible if *R. bromii* is unavailable.	Costabile et al., 2012; Ze et al., 2012
04	pectic oligosaccharide (POS)	Rapid turnover, substitution with either galacturonic acid (homogalacturonan) or rhamnose (rhamnogalacturonan I). The carboxyl groups could be methyl esterified and the structure can be configured with an acetyl group at any of C2 or C3 positions. Side chains are connected with numerous sugars; for example, arabinose, galactose, and xylose or ferulic acid		Yoo et al., 2012

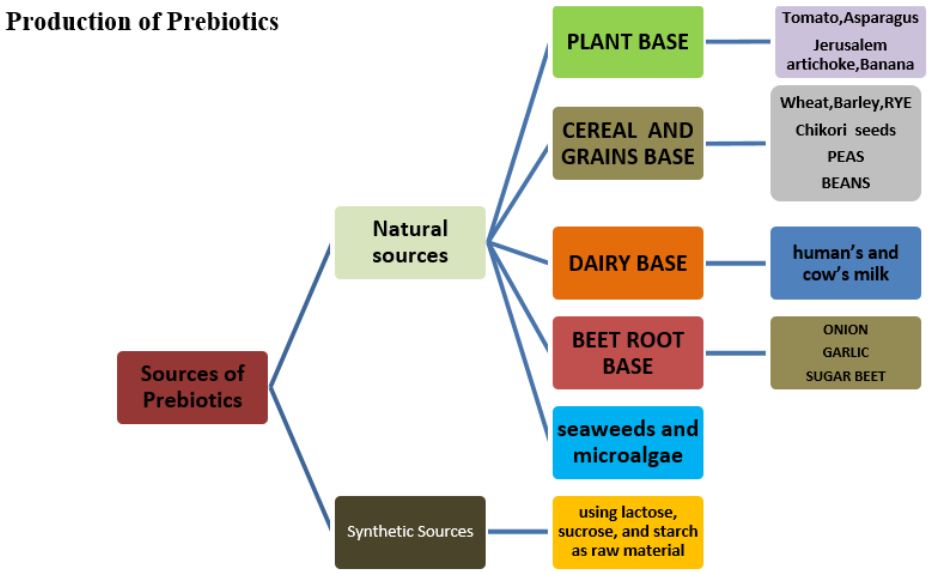

Fig. 1: Production of Prebiotics (Al-Sheraji et al., 2013; Panesar et al., 2013; Varzakas et al., 2018)

Solubility and Sweetness Modulation

FOS and galacto-oligosaccharides (GOS) are middle-sweet non-cariogenic prebiotics, which are highly soluble and could be used as sugar

replacements. It employed in beverages and confectionerie products makes it possible to lower calorific content without significant impacts on taste sensations and product texture (Slavin, 2013).

Table 2: Source of Natural Prebiotics Inulin & Fructooligosaccharide (Thammarutwasik et al., 2009)

Sr. No	Sources	Inulin (% fresh weight)	Fructooligosaccharide (% fresh weight)
01	Onion	2-6	2-6
02	Jerusalem artichoke	16-20	10-15
03	Chicory	15-20	5-10
04	Leek	3-10	2-5
05	Garlic	9-16	3-6
06	Artichoke	3-10	<1
07	Banana	0.3-0.7	0.3-0.7
08	Rye	0.5-1	0.5-1
09	Barley	0.5-1.5	0.5-1.5
10	Yakon	3-19	3-19
11	Salsify	4-11	4-11
12	Wheat	1-4	1-4
13	Asparagus	1-30	5-10

Emulsification and Stabilization

Inulin and its derivatives are known to function as stabilizers and emulsifiers in different food systems. Their amphiphilic nature helps create stable emulsions, making them especially useful in products like dressings, sauces, and creams (Rao et al., 2016). These properties not only improve the stability of the product but also aid in the effective delivery of bioactive compounds, including vitamins and antioxidants, in functional foods.

Prevention of Crystallization

Prebiotics help control crystallization in frozen and confectionery products. For example, inulin reduces the formation of large ice crystals in ice cream, leading to a smoother texture (Franck, 2002). Similarly, In candies and syrup sucrose crystallization can be inhibited to retain the its textural and the qualitative attributes (Roberfroid, 2007).

Fermentability and Flavor Development

Soluble fiber products act as prebiotics to enhance the several recognized aspects of the foods under consideration. This process produces SCFAs, as well as other metabolites that boost the flavor intensity of food such as; sourdough bread, fermented vegetables and dairy (Bindels et al., 2015).

Fiber Enrichment and Nutritional Labeling

While incorporating prebiotics into the foods increases the fiber content thus satisfying consumer needs for fiber products. This also improves the nutritive value so that the relevant benefits can be imprinted on product labels. (Slavin, 2013).

Thermal Stability and Processing Compatibility

Some of the prebiotics are highly thermostable while others are less soluble in heat which affects how they will be used in food processing. For instance, inulin stands heat stable at moderate temperatures, and therefore it finds application in baked food and extruded products (Patel & Prajapati, 2015). Nevertheless, it has poor high-temperature stability and requires careful formulation changes to overcome this problem. Resistant starch another prebiotic has better thermal stability and can be incorporated where high temperature cooking and frying is required (Makki et al., 2018)**.**

Applications in Encapsulation and Delivery Systems

Prebiotics are increasingly used in encapsulation technologies to enhance the stability and bioavailability of probiotics and other sensitive ingredients. Inulin and FOS act as protective carriers, shielding probiotics from adverse environmental conditions during processing and gastrointestinal transit (Patel & Prajapati, 2015).

Use of Prebiotics in Functional Foods and Product Development

Prebiotics are non-digestible food ingredients that confer health benefits to the host by selectively stimulating the growth and/or activity of beneficial gut bacteria, particularly Bifidobacterium and Lactobacillus species (Gibson et al., 2004). The most commonly studied prebiotics include fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS), inulin, and resistant starch. Prebiotics are fermented by gut microbiota, resulting in the production of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate (Roberfroid et al., 2010).

Health Benefits of Prebiotics in Functional Foods

Functional foods are foods that have desirable nutritional and physiological effects on top of the normal culinary properties. These precursors are incorporated into these products for several reasons such as: Gut health, immune support and metabolism.

Gut Health

Prebiotics improve gut microbiota composition by enhancing the growth of beneficial bacteria, which helps prevent the overgrowth of pathogenic organisms. This modulation can alleviate conditions such as GIT issues (Gibson & Roberfroid, 1995). The SCFAs produced during prebiotic fermentation also maintain colonic health by lowering pH, suppressing harmful bacteria, and providing energy for colonic epithelial cells (Bindels et al., 2015).

Immune Modulation

Prebiotics have been shown to enhance the defense system through modulating the GALT. This can result in increased production of immunoglobulin A (IgA) and a reduction in systemic inflammation (Macfarlane et al., 2008). Such effects have been linked to reduced susceptibility to infections and improved management of autoimmune conditions.

Metabolic Health

Regular intake of prebiotics has been associated with improved lipid profiles, including reductions in serum cholesterol and triglycerides. Additionally, prebiotics contribute to improved glucose homeostasis, making them beneficial in managing metabolic disorders such as diabetes and obesity (Slavin, 2013).

Mineral Absorption and Bone Health

Prebiotics improve the bioabsorption capacity of minerals in the gut, contributing to improved bone mineral density and a reduced risk of osteoporosis (Scholz-Ahrens et al., 2007).

Applications in Product Development

In product development, prebiotics are used as a humectant, texture improver, and functional component as well. They make the food nutritious for the normal person, people with GIT infections, and also infants.

Dairy Products

In most fermented dairy products, yogurt and kefir prebiotics are commonly added. These components support the fermentation, enhancing the coactive or combined effects of probiotics and prebiotics (synbiotics) (Saad et al., 2013). Inulin in yogurt improves the texture and dietary fiber content in yogurt.

Baked Goods

Value addition of Inulin and FOS in bread and pastries as a humectant, which boosts the dietary content and enhances water absorption of dough. These improvements make backed goods nutritious with good texture in the form of palatability. (Roberfroid, 2007).

Functional Beverages

Juices and smoothies with prebiotic supplements make it easier for consumers to take foods that promote gut health. These products are aimed at the growing consumer need for products that are functional and have the ability to be digested easily, as well as improve the immune system. (Makki et al., 2018).

Infant Formula

Both GOS and FOS added to the formula mimics HMOs providing infants with the goodness of a healthy gut microbiota similar to that obtained from breast milk (Wang et al., 2020).

Snack Foods and Confectioneries

Nowadays prebiotics are increasingly used as ingredient in snack bars, chocolates, and candies to provide the better choice. These products are rich in proteins and their neutrality, and capability to enhance texture makes them suitable for these products. (Manning & Gibson, 2004).

Challenges in Product Development

Dosage and Efficacy

For a better life correct prebiotic dosage administration is very important. Too much can cause gastrointestinal issues like bloating and gas (Roberfroid, 2007).

Stability during Processing

Prebiotics need to maintain their effectiveness during food processing, which often involves high temperatures, pH shifts, or other tough conditions. Recent advancements in encapsulation technologies are helping to overcome these challenges (Patel & Prajapati, 2015).

Regulatory and Consumer Acceptance

Clear labeling and evidence-backed health claims are crucial for gaining consumer trust and securing regulatory approval. Additionally, educating consumers about the benefits of prebiotics can help improve their acceptance in the market (Slavin, 2013).

Prebiotics Mechanisms for Alteration of Gut Microbiota

It is a known fact that prebiotic influence the composition and functioning of the gastrointestinal microbe by providing energy in the form

of prebiotics for existence to the microbe (Flint et al., 2007). Surprisingly, relatedness between species seems not to predict stability of utilization of prebiotics; distantly related bacteria often have convergent, stable metabolism of specific prebiotics (Scott et al., 2013). A recent functional metagenomics study from human microbiota metagenomic library that encored wanted to find genes relating to prebiotic degradation in a host such as *E. coli* (Cecchini et al., 2013).

Some clones of the species of Actinobacteria, Bacteroidetes as well and Firmicutes are known to exert the ability to ferment Prebiotin such as FOS, GOS, and XOS. But other investigators looked at the situation, and they found out that there are some species that are particularly adapted to degrade some prebiotics. For instance, Bifidobacterium species has been reported to metabolize starch (Belenguer et al., 2006, Ryan et al., 2006) and fructans (Rossi et al., 2005). The chain length of prebiotics also determines the ability of the species to ferment the particular prebiotics. For instance, while substances like inulin with a degree of polymerization of up to sixty are little more than resistant starches, FOS with a degree of polymerization of up to ten are depolymerized by multiple types of microorganisms (Scott et al., 2014).

Some of the fermentation by-products of these prebiotics can also be utilized by other types of microorganisms, a phenomenon known as cross-feeding (Belenguer et al., 2006; Falony et al., 2006). For example, *Ruminococcus bromii* is capable of degrading resistant starch, and some species can subsequently utilize the products of this process (Ze et al., 2012).

The fermentation of prebiotics primarily produces acids, which lower the gut's pH. Research has shown that even a small pH shift from 6.5 to 5.5 can significantly impact the gut microbiota's composition (Walker et al., 2005; Dunkan et al., 2009). This pH change can affect acid-sensitive species like *Bacteroide* can be affected *by* a *change in pH,* and Firmicutes promote butyrate production; this process is known as the butyrogenic effect (Walker et al., 2005). Figure 2 elaborates dysbiosis of gut microbiota.

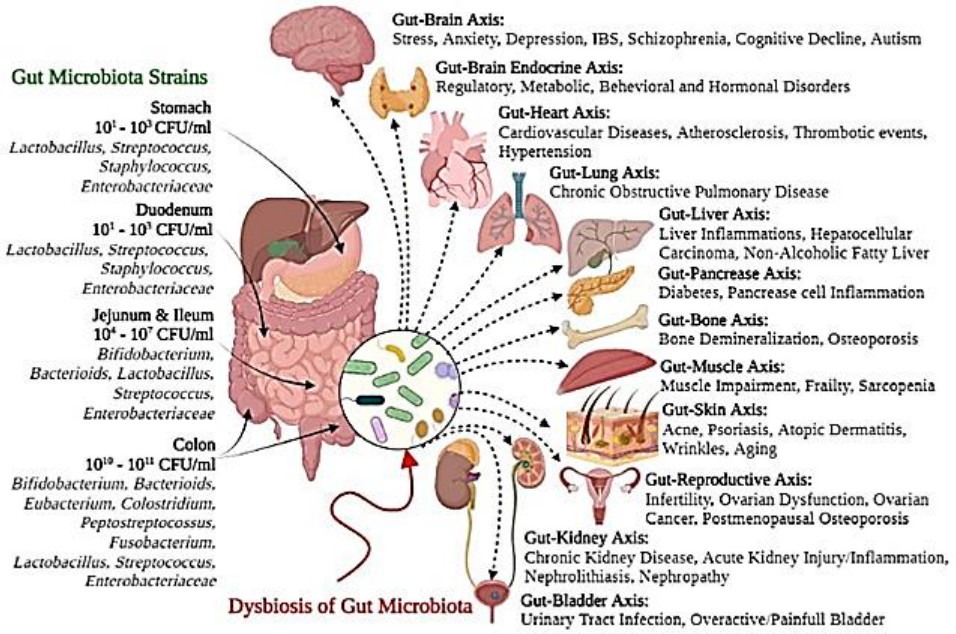

Fig. 2: Dysbiosis of Gut Microbiota.

Prebiotics and Gastrointestinal Disorders

Necrotizing Enterocolitis

NEC is an inflammatory disease, majorly occurring with premature infants where death of bowel tissue leads to high case fatalities (Patel, 2013). FOS and GOS can promote in the colonization of probiotics like bifidobacteria and suppress the pathogenic bacteria in premature infants, which suggests that prebiotics such as FOS could decrease NEC (Boehm et al., 2002; Knol et al., 2005; Kapeki et al., 2007; Patel et al., 2013). in addition, it was established that short chain fatty acids (SCFAs) can regulate feeding tolerance via their influence on stomach motility and intestinal peristalsis (Labayen et al., 2001; Indrio et al., 2009). Four RCT papers were found to assess the effect of FOS, GOS, or both on the raising fecal Bifidobacteria concentrations but increased no effect on the risk and/or the progression of NEC (Table 3) (Srinivasjois et al., 2009). Therefore, more clinical trials are needed to determine the precise effects of prebiotics on NEC.

Irritable Bowel Syndrome and Crohn's Disease

Unfortunately, little has been written regarding the impact of prebiotics in IBS in comparison to CD. IBS refers to a functional gastrointestinal disorder in which the patient presents with bowel pain one day a week for the past three months, and a change in the frequency of bowel movements or the shape and consistency of the stools. Crohn's disease is just another name for a certain type of a relapsing chronic inflammatory bowel disease that can essentially happen at any section of the GI tract. In IBS, research shows that bifidobacteria and faecalibacterium prausnitzii density and Bacteroidetes to firmicutes ratio is lowered (Whelan et al., 2013; Wilson et al., 2017).

Based on a double-blind crossover study, 6 g/day for the oligofructose was ineffective to provide therapeutic benefit to IBS patients, and this trial lasted for 4 weeks (Hunter, 1999). The second study involved a 2000 Randomized, double-blind placebo-controlled study that compared the effects of FOS supplementation with 20 g/day on IBS without any changes being noted (Olesen, 2000). However, two more contemporary, randomized, double-blind studies did record a symptom amelioration of IBS clients who consumed 5 g per day FOS for 42 days

(Paineau, 2008) or 3.5 g/day GOS for 12 weeks (Silk, 2009). In a clinical trial conducted in 2006, Lindsay showed that intake of 15g of FOS daily for three weeks on balance the fecal bifid bacteria and decrease Crohn's disease symptoms. However, several other randomized, double-blind placebo-controlled trials showed no clinical effectiveness of 15 g/day FOS in active CD patients (Benjamin et al., 2011) or 20 g/day of OEI in patients with either a quiescent or only mildly to moderately active CD during a 4-week trial (Joosens et al., 2011).

Table 3: Effect of Prebiotics against diseases.

Prebiotics	Dose	Subjects	Main Results	Reference
FOS	5 g/day for 6 weeks	Patients with IBS	Improvement in IBS syndromes.	Silk et al.,2009
FOS	15 g/day for 3 weeks	Patients with active ileocolonic Crohn's disease	Crohn's disease improvement	Lindsay et al.,2006
FOS	15 g/day for 4 weeks	Patients with Crohn's disease	No effect	Benjamin et al.,2011
GOS	3.5 g/day for 12 weeks	Patients with IBS	improvement in IBS syndromes	Silk et al.,2009
Combination of FOS and GOS	0.8 g/dL of a blend of GOS and FOS, ratio 9:1 for 1month	Infants with good health	Improvement in gastric emptying and bowel motility	Indrio et al.,2009
Combination of FOS and GOS	0.8 g/dL of a blend of GOS and FOS, ratio 9:1 for half month	Infants with good health	Improvement in gastric emptying and bowel motility	Indrio et al .,2009
FOS enriched with Inulin	20 g per day for 28 days	Patients with inactive and mild to moderately active Crohn's disease	No effect	Joosens et al.,2011
Inulin-enriched FOS	Raftilose® Synergy 1 + Bifidobacterium lactis Bb12, Lactobacillus rhamnosus GG	HT29 or CaCo-2 cells	Cell growth inhibition. As a result, this mixture can decrease the progression of colorectal cancer.	Kinder et al.,2014
Inulin-enriched FOS	Varying dose administration	Rats with colon carcinogen	Long-chain inulin effects are dose-dependent on colorectal cancer.	120
Inulin-enriched FOS	Synergy 1 + Bifidobacterium lactis Bb12, Lactobacillus rhamnosus GG	Colon cancer patients and polypectomized patients	Decrease in the progression of colorectal cancer.	Rafter et al.,2007
Lactose	25 g daily for 15 days	Lactose malabsorbers	mprovement in lactose digestion.	Labayen et al.,2001

Colorectal Cancer

CRC is ranked the third common cancer globally, and the disease is polygenic, arising from host genetic mutation leading to the formation of adenomatous polyps and malignant changes or invasive and metastatic cancer. (Candela et al., 2011). Research has shown that SCFA especially butyrate contained in fermentation products of prebiotics may decrease the formation and progression of colon cancer through apoptosis (Davis, 2009; Louis et al., 2009; Candela et al., 2011).

Prebiotics Safety

Prebiotics are generally regarded as safe, with no severe effects. Since intestinal enzymes cannot break down oligosaccharides and polysaccharides, these substances reach the colon where they undergo fermentation. Later on it shows symptoms like osmotic diarrhea, bloating,

Future Directions

The diversification of prebiotic-enriched functional foods remains to be ongoing, owing to shifts in understanding of gut-synthesized microbiome and increasing customer predisposition to improvement foods. Future prospects in prebiotics are extending towards individualized nutrition: prebiotics which are decided depending on the particularities of the microbiota and functional ingredients derived from algae and agricultural waste (Bindels et al., 2015). Such concerns may apply to prebiotics as well. The main issue with the use of probiotics is the potential for bacteremia, sepsis, or endocarditis and is contraindicated in significant immunodeficiency (e.g., HIV/AIDS, cancer, transplanted), severe malnutrition or a degraded mucosal barrier by severe diarrhea, NEC, etc. (Tsai et al., 2019). However, the above-mentioned risks have not been designed or discussed or documented in human trials on prebiotics.

Conclusion

Despite their recognized beneficial properties a significant void exists in the development and commercialization of nutraceuticals containing prebiotics. Progression in bioprocessing and effective marketing of such products are necessary to obtain the maximum benefits of human health. The chronic implications and therapeutic utilities of such PT outsize them and merit more studies.

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