Current developments in functional foods and gut health: probiotics and prebiotic

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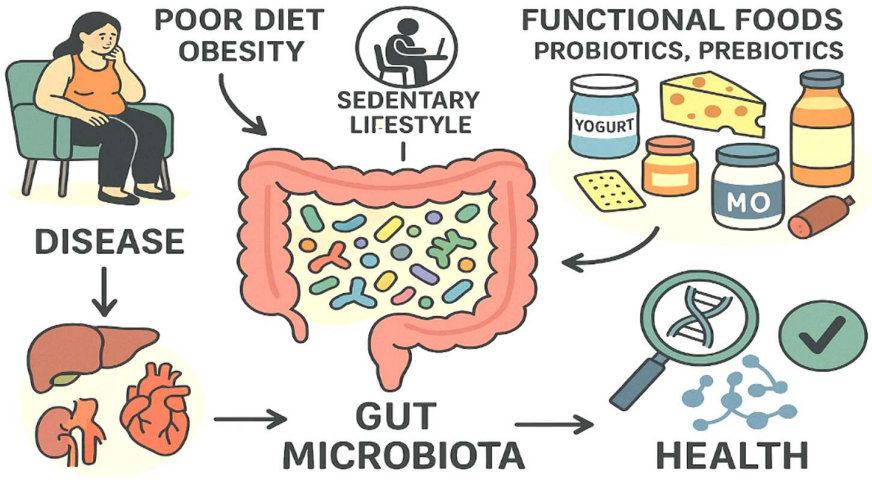
Abstract

Natural microbiota diseases, particularly intestinal ones, are significantly impacted by poor diet, obesity, and a sedentary lifestyle. Numerous organ dysfunctions may follow from this. Over 500 different kinds of bacteria make up the gut microbiota, which accounts for 95% of all bacterial species of human body cells, thereby greatly enhancing the host's resistance to infectious diseases. Consumers today have resorted to buying foods, particularly those that include prebiotics or probiotic bacteria, which make up a portion of the rapidly growing functional food business. Probiotics can be found in a wide range of items, including yogurt, cheese, juices, jams, biscuits, salami sausages, mayonnaise, nutritional supplements, and more. Therefore, during the past ten years, the development of DNA sequencing technology and the bioinformatics processing that follows has helped to thoroughly characterize the enormous richness of the gut microbiota. their makeup, their relationship to the human body's homeostasis, or physiological function, and their role in a number of illnesses. Thus, in this study, we emphasized the thorough examination of recent scientific studies about the relationship between the composition of the intestinal microbiota and the kinds of functional food that contain probiotics and prebiotics in the diet. As a result, this study can serve as a guide in the ongoing endeavour to track the quick advancements in this subject and serve as the basis for a new research direction based on trustworthy data from the literature.

Keywords: gut microbiota, microencapsulation, probiotics, prebiotics, functional foods, and dysbiosis



Graphical abstract

Introduction

In order to avoid the development of human microbiota dysbiosis and, consequently, diseases linked to it, consumers are now purchasing functional foods. In the context of diet, a person's daily nutrition has an effect on his health. It calls for the consumption of "functional foods," or foods that offer more advantages than just energy, mineral salts, trace elements, and vitamins [1,2]. More precisely, the idea of marketing functional meals was first introduced in Japan in 1984 as research showed a link between taste satisfaction, nutrition, and the activation of physiological processes (including immunity) and fortification of food. Later, studies on these goods' designs shifted to Europe and America [3]. The fact that different classifications of these items exist is one of their characteristics. Functional foods are defined "officially" as follows: a food is considered functional if, in addition to its fundamental nutritional activity, it improves one or more physiological functions, such as overall health and/or to lower the chance of contracting an illness. As a result, many meals have health advantages in addition to their nutritional value. These foods can be enhanced with vitamins, minerals, probiotics, prebiotics, and fibres in addition to their nutrient-dense constituents (such fruits and vegetables) [4,5]. Probiotics are microorganisms that, when consumed in enough amounts, improve the host's health and are the subject of both research and business initiatives. The market in the area of The market for functional foods is always growing, especially those that include probiotic bacteria, which make up 60% of all functional foods. These days, probiotic products are gradually gaining market share, mostly in industrialized nations like America, Japan, Australia, and Europe [6]. Probiotic strains are being included into or encapsulated in a variety of food products, including cheeses, biscuits, jams, juices, yoghurt varieties, and food supplements. Microorganisms gain greatly from encapsulation. such as strength, protection, energy, and functionality. Additional bioactive components including plant sterols and stanols, which reduce cholesterol, are included in some probiotic meals [7,8]. Although there is currently no formal definition of probiotics, some authors have attempted to provide their own definitions in recent years. Certain criteria must be understood in order to design probiotics with desired effects, including in particular the gastrointestinal tract's prevalent disorders. This study aims to provide a summary of the findings of probiotics and prebiotics in functional foods. As a result, we have emphasized the thorough examination of recent scientific studies concerning the relationship between the kinds of functional foods that contain probiotics and prebiotics in the diet and the intestinal microbiota's makeup.

Principles of Prebiotics and Probiotics:

Probiotics were first applied to food and whey, but they were also utilized to help patients' health. Fuller (1989) described a probiotic as a food supplement containing living microorganisms that benefits the host by enhancing the host's gut bacteria equilibrium. He went on to define probiotics in 1991 as single or mixed cultures of living microorganisms that increase the characteristics of their acquired endogenous microbial presence and have a positive effect when given to people or animals [9]. A team of researchers suggested in 1998 that probiotics are dietary ingredients made of live microorganisms with positive health effects [10]. One of the most straightforward and widely acknowledged reasons was put out by an expert panel made up of representatives from the World Health Organization and the United Nations Food and Agriculture Organization, which claims that "probiotics are microbes that exhibit positive effects on the patient's health when given in adequate amounts. Thus, they help the patient avoid and prevent dysbiosis, which results in eubiosis of the gut microbiota. Probiotics

are now defined as living bacteria that colonize the human gut, stick to epithelial cells, and exhibit resistance to pancreatic, biliary, and stomach secretions. Probiotics are thus bacteria that are good for your health now have clinical consequences as well [11]. Certain formulations (supplements), dairy-functional meals (yoghurt, cheese, ice cream, and other items), and non-dairy products can all be used to consume probiotics [11]. Healthcare professionals and consumers alike have shown a favourable attitude toward probiotics because they are not regarded as medications. However, it should be mentioned that in order to assess the safety and effectiveness of probiotics, the Probiotic dosage and amount, consumer characteristics (such as the study of his gut microbiota's metabolic profile), and the rationale for probiotic consumption. For these reasons, it is essential to look into a customized probiotic regimen for every person [11-13]. Food digestion produces prebiotics, which are beneficial to the host's health. Accordingly, their goal is to alter the intestinal microbiota's makeup to promote the growth of probiotic bacteria and prevent the formation of undesirable or unwelcome microorganisms [13,14]. Prebiotics are beneficial nutritional components that can be synthesized by enzymatically converting carbohydrates or found naturally in vegetable diets [10]. The human microbiome selectively metabolizes these food substances, which are often composed of soluble fibres or sugars. Inulin derivatives like fructooligosaccarides (FOS) and galattooligosaccarides (GOS) are the most often utilized prebiotics in Europe [13]. The lactose-derived GOS is present in human milk and vaccinations, but it is also added to a wide variety of other meals, including cereals and dairy products [15]. FOS are hydrolytic inulin derivatives called fructus, which contain a minor amount of fructose monomers. Plant foods like onions, asparagus, wheat, and artichokes contain them in significant concentrations [15,16]. Prebiotics found in foods like raw oats, soybeans, and chicory roots, such as cellulose, lignin, and oligosaccharides, must withstand stomach acids and be able to pass through the large intestine in order for the intestinal microbiota to ferment them and promote the growth of beneficial intestinal species [9]. In this situation, indigestible carbohydrates may function as prebiotics, promoting the development of certain species that support the host's health [17]. Therefore, prebiotics help the host by enhancing host mucosal immunity, reducing pH and the formation of Short Chain Fatty Acids (SCFAs), preventing the growth of pathogenic microbes, and fortifying the integrity of the intestinal mucosal barrier [18]. Prebiotic usage also contributes to the management of obesity. Along with the synthesis of anti-inflammatory cytokines, the presence of prebiotics in the gut is linked to the development of SCFAs and protective mucus. Additionally, it is linked to satiety hormone secretion, which inhibits overeating [19]. Moreover, oligomers of certain sugars such lactulose, soy, and maltose, as well as oligosaccharides comprising galactose, xylose, and mannose, can be used. Honey is regarded as a prebiotic food, to sum up. You can get prebiotic oligosaccharides. by (a) biotechnological manufacture or enzymatic synthesis, (b) enzymatic hydrolysis of polysaccharides, and (c) separation from plant source materials. A large number of commercially accessible prebiotic oligosaccharides are generated on an industrial basis [13]. In fact, the most researched prebiotics are (1-2) fructus, which include inulin and/or fructo-oligosaccharides, and can be found in a variety of foods, including leeks, onions, garlic, artichokes, asparagus, shallots, Wheat and bananas [17]. They have been identified as dietary fibres in the majority of countries, and their average daily intake in a typical diet is thought to be a few grams. Radish roots are extracted in hot water and then refined to produce inulin for industrial use & drying by spraying. It is commercially marketed as a white powder with high inulin (>90%). It is produced industrially by partially hydrolysing inulin with a unique endonuclease, just like oligofructose [20]. Moreover, transfructosylation of sucrose can also

result in the production of fructooligosaccharides (FOS). Commercial oligofructose formulations come in white powder and sticky syrup forms, with varying concentrations up to 95%. Regarding Soy oligosaccharides are made by directly extracting and purifying soy milk whey, which is a by-product of making soy protein concentrate. They are sold as a syrup with 52% sucrose, glucose, and fructose, 6% raffinose, and 18% stachyose [21]. Certain components of galactooligosaccharides (GOS) have been found to naturally present in human milk in amounts of roughly 3 mg/L [13]. Utilizing a-galactosidase, lactose is synthesized into industrially transglucosylase oligosaccharides [22]. Because probiotics and prebiotic elements work in concert in foods, they are frequently used together in practice. This results in the creation of symbiotic products that help the user by allowing certain live bacteria to survive and establish themselves in the digestive tract [21,23].

Probiotic

Bifidobacterial and lactobacilli are the two bacterial genera most frequently utilized as probiotics. Nowadays, probiotics are usually only found in fermented dairy products like yogurt or freeze-dried microorganisms, although they might eventually be present in meats and vegetables that have undergone fermentation. Certain probiotics survive and temporarily establish themselves in the large intestine after passing through the stoma and small intestine. In fact, taking probiotics may alter the colon's fermentation ability, and consuming specific lactic acid bacteria orally may increase the number of numbers of bifidobacterial or lactobacilli in human excrement. Probiotic consumption has been linked to a number of health benefits, according to two human nutrition studies conducted by various study teams. These effects can be used to support claims of decreased illness risk or functional claims [24-27].

Enhancement of functionality:

Recovery from lactose intolerance

As lactose acts as an osmotic, indigestible carbohydrate for around 70% of the world's population with inadequate intestinal galactosidase activity, lactose intolerance is a concern. It has been demonstrated that probiotics enhance lactose digestion by lowering the symptoms of intolerance and delaying orocecal transit [24].

Immune boosting

The length of rotavirus-induced diarrhea is decreased in infants fed with a strain of *Lactobacillus casei* because of their higher levels of circulating immunoglobulin A (IgA) [28]. Consumption of *Bifidobacterium bifidum and L. acidophilus* also considerably increases the circulating blood granulocytes' nonspecific immunological phagocytic activation [29]. The enhancement of intestinal IgA antibody responses in babies may be partially explained by this later impact. It is true that phagocytic activity has a role in both natural immunity and because as cells that deliver antigens, phagocytes are involved in antibody immune responses. Lastly, yogurt consumption has been demonstrated to increase blood mononuclear cells' cytokine output.

Effect of hypocholesterolemia

There is debate over the hypocholesterolemic effects of probiotics. Research conducted during the 1970s and 1980s consistently documented 5–17% decreases in serum cholesterol levels. trations after consuming fermented milk products daily for two to four weeks, but the findings of more recent studies—nearly all of which found no significant effect—have called into

question these findings. The following were these earlier research' main limitations: 1) the large amounts of yogurt (0.5–8.4 L) that were consumed every day in the majority of the positive studies; 2) the inability to evaluate or account for the subjects' prior dietary and exercise habits; 3) the inability to randomize groups for confounding factors; 4) the absence of run-in periods where volunteers adjusted to the diet; 5) the absence of multiple baseline measurements; and 6) modifications in the control groups[30].

lowering the chance of getting sick : Probiotic use has been shown to reduce the incidence of only two diseases: rotavirus-induced diarrhea and perhaps colon cancer. Researchers from several teams have repeatedly found that people who consume probiotic fermented dairy products have a lower chance of contracting rotavirus diarrhea or experience fewer episodes of the illness [26]. The only evidence available for colon cancer comes from experimental animals, where it was demonstrated that *lactobacilli* and *bifidobacteria* reduced the quantity of aberrant crypt foci, a sign of cancer development risk following exposure to a chemical carcinogen [31].

Prebiotic: Prebiotics that have enough information generated to assess their potential classification as functional food ingredients are limited to inulin-type fructans, which consist of natural inulin, inulin or oligofructose hydrolyzed by enzymes, and artificial fructooligosaccharides [32,33]. The polydisperse carbohydrate substance known as inulin is primarily, if not entirely, composed of -(2-1)fructosyl-fructose bonds. Numerous monocotyledonous and dicotyledonous families, such as the Liliaceae, Amaryllidaceae, Gramineae, and Compositae, contain plant species that produce inulin. But only one plant species—the chicory, Cichorium intybus—is utilized for industrial inulin production. The number of fructose units in chicory inulin ranges from 2 to >70, and both Gpy-Fn (-D-glucopyranosyl-[-D-fructofuranosyl] n 1 -D-fructofuranoside) compounds are regarded as belonging to the same nomenclature. The food industry processes native inulin to create either long-chain fructans using an industrial physical separation technique or short-chain fructans, specifically oligofructose (degree of polymerization: 2–10; average: 5) as a result of partial enzymatic hydrolysis (inulinase, EC 3.2.1.7). Inulin and oligofructose in plants and food items may now be measured analytically. This approach was accepted as Association of Official Analytical Chemists method 997.08: "Fructans in food products, ion exchange chromatography method" following a multicentre validation ring test [34]. Significant levels of inulin and oligofructose can be found in a variety of edible fruits and vegetables; the typical daily intake in the US and Europe has been estimated to be 1-4 g and 3-11 g, respectively. The most popular sources include leeks, wheat, onions, bananas, and garlic [35]. A variety of products, including fermented dairy products, desserts like jellies and ice creams, bakery goods like cookies, breads, and pastries, spreads, and baby formulas, use inulin-type fructans as sugar substitutes, fat stabilizers (inulin only), and to add texture, improve mouthfeel, or stabilize foam. Fructons of the inulin type were categorized as nondigestible oligosaccharides in a recent consensus study [36].

Enhancement of functions

The gastrointestinal tract's fate:

Inulin-type fructans are resistant to digestion in the upper gastrointestinal system due to the arrangement of the anomeric C-2 in their fructose monomers. Furthermore, there is proof that they are not significantly absorbed. As a result, it has been suggested that they be referred to

as colonic foods—that is, foods that penetrate the colon and operate as a substrate for the endogenous bacteria, giving the host immediate access to energy and metabolic substrates.
In addition to confirming the generation of lactic and short-chain carboxylic acids as fermentation byproducts, several in vitro (both analytical and microbiological) and in vivo studies support the notion that bacteria inhabiting the large bowel ferment inulin-type fructans. Inulin-type fructans are the precursors of prebiotics since it has been demonstrated in human in vivo investigations that this fermentation results in the selective stimulation of the growth of the bifidobacteria population [37].

impact on the absorption of minerals:
Certain nondigestible carbohydrates (like inulin-type fructans) may enhance mineral absorption and balance due to an osmotic effect that moves water into the large intestine, increasing the volume of fluid in which these minerals can dissolve, even in the absence of any binding or sequestering of minerals. Additionally, because these carbohydrates undergo prolonged fermentation, they acidify the colonic content, which increases the concentration of ionized minerals—specifically, Ca^{2+} and Mg^{2+}—and promotes passive diffusion. Lastly, research on ileostomy patients revealed that inulin-type fructans do not hinder the small intestine's ability to absorb minerals [38]. It has been noted that inulin-type fructans improve ionic iron and Zn^{2+} balance, as well as Ca^{2+} and Mg^{2+} absorption in developing rats, without significantly affecting Cu^{2+} bioavailability [39]. Inulin and oligofructose have been shown to have a positive impact on the balance and absorption of dietary calcium, but not iron, magnesium, or zinc, according to more recent in vivo human investigations. 9 men (mean age: 21.5 ± 2.5 years) who took 850 mg Ca/d and a 40 g/d inulin dietary supplement showed a significant rise in calcium balance (100 mg/d) and apparent absorption (±12%) without a significant change in urine output, according to the first published data[39]. In the second research, 12 guys aged 15 to 18 years who took 16.8 g of oligofructose daily saw an 11% rise in their calcium balance ($P = 0.09$) using the double stable isotope technique, with no discernible impact on their urine excretion[40].

impact on the lipid metabolism:
Both humans and animals have had their triglyceridemia levels examined in relation to inulin-type fructans. Rats' serum triglyceridemia decreased in both the fed and fasted states, and this was consistently reported in multiple investigations; only fasting triacylglycerol was measured in healthy humans, and only one study altered it. For patients with hypertriglycerides, no data have been published. There is little information available on how inulin-type fructans affect lipoproteinemia or cholesterolemia[31]. Two effects are proposed to explain a potential impact of inulin-type fructans on the regulation of triacylglycerol metabolism. Since dietary manipulation of lipogenesis is frequently associated with such physiologic changes, the first effect is the alteration of glucose or insulin concentrations. In fact, insulin amplifies the stimulation of lipogenic enzymes by glucose, which happens through an increase in gene transcription. This correlation has also been demonstrated with resistant starch, which in rats lowers postprandial insulinemia by lowering serum triacylglycerol concentrations and fatty acid synthase activity by 20%[41].

Lowering the risk of disease:
Claims that inulin-type fructans lower the risk of disease are only conjectural and require additional research to substantiate and validate. Among these assertions are the following:

- Relief from constipation brought on by fecal bulking and potential impacts on intestinal motility.
- Repression of diarrhea, particularly when intestinal diseases are involved
- Lowering the chance of obesity and type 2 diabetes, which are both known to be linked to insulin resistance.
- If inulin-type fructans increase calcium's bioavailability and this functional effect is accompanied by a more physiological shift in peak bone density and mineral bone mass, the risk of osteoporosis is decreased.

Finally, more research on the potential of inulin and oligofructose to lower illness risk should focus on cancer. In two investigations, rats fed inulin had a much lower incidence of the so-called aberrant crypt foci caused by colon carcinogens like dimethylhydrazine and azoxymethane[42,43].

Conclusion

The human microbiota has gained attention recently and is now being viewed as a supplementary "micro-organ" that affects a variety of bodily biological processes. New high-resolution technologies have made it possible to access compositional data and the components of the microbiota are shown to be functional. The function of microorganisms in chronic non-communicable diseases has been established by available clinical and experimental data. Furthermore, probiotics and prebiotics are frequently used to improve the gut microbe’s microbiota. various genes and proteins as well as environmental elements such bioactive dietary ingredients. A complex mechanism that can be linked to variations in gene and/or protein expression underlies the shift from a healthy to a sick phenotype. The most researched chronic illnesses over the past century and their connections Obesity, metabolic syndrome, type 2 diabetes, cardiovascular disease, chronic renal disease, osteoporosis, neurological illnesses, and cancer are all linked to eating patterns. These are all multifactorial illnesses brought on by interactions between several genes, proteins, and environmental elements including bioactive food ingredients. Thus, we tried to examine the interaction between probiotics, prebiotics, and nutrition as well as the gastrointestinal microbiota, concentrating on the differences between the two. combination of the fundamental components of a daily, balanced diet that supports healthy functioning. Additional clinical trials are required for the intake techniques, followed by a more thorough investigation of how probiotics and prebiotics influence the gut microbiota and how this affects the host's health.

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