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Fructooligosaccharides: A comprehensive review

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ABSTRACT

Fructooligosaccharides (composed of short fructose chains) are useful for a variety of purposes. They are a type of carbohydrate known as oligosaccharides. Nowadays, people around the world are much more health-conscious and expect the food they consume to be tasty, safe as well as healthy. Fructooligosaccharides have become a prominent player in the functional food industry because of the growing demand for healthy and quality food. Due to its functional properties and health benefits, it is incorporated in various products like Dairy products, Bakery products, Beverages and Juices, Jams and Jellies, Candies, Chocolates, Breakfast cereals, Meat products, Ice cream, Confectionery. This article aims to review the numerous plant sources of Fructooligosaccharides available in nature, its structure, production, mode of action, attention-grabbing properties as well as their application as food ingredients, with special attention is being paid to the health benefits of these compounds.

Keywords: Fructooligosaccharides, Sources of Fructooligosaccharides, Prebiotics, Applications of Fructooligosaccharides, Oligosaccharides, Dietary fiber

INTRODUCTION

Nowadays, nutrition is scientifically proven to be one of the most important aspects of a person's overall health. Consumers all across the world are more and more conscious that "man is what he eats" [1]. Certain foods or food components may give health benefits. These foods are also termed “functional foods” [2]. During the last few years, functional foods have been the subject of much research [1]. They're defined as health-improving, disease-prevention, and disease-treatment products. Among them, Fructooligosaccharides, a type of oligosaccharides that is generally recognized as safe (GRAS) have captured special attention as food ingredients because of their unique properties as well as their advantage in terms of health and more research is being done on their dietary and physiological roles [3].

OLIGOSACCHARIDES

Oligosaccharides are carbohydrates with low molecular weight containing sugar moieties with a degree of polymerization (DP) found in all living organisms in a free or combined forms [4]. Oligosaccharides are oligomers made up of 2–10 monosaccharide residues structurally connected by glycosidic bonds and easily hydrolysed to their constituent monosaccharides by acids or specialised enzymes, according to the IUB-IUPAC nomenclature [5]. Oligosaccharides are obtained from natural sources and can be synthesized. Many common foods contain Oligosaccharides including fruits, milk, honey, sugarcane juice, wheat, soybean, rye, barley, mustard and vegetables like artichoke, chicory, leek, garlic, asparagus, sugar beet, onion, banana, tomato, yacon, as well as in bamboo shoots [4]. The oligosaccharides are obtained by extracting plant tissues, by microbial fermentation, by chemical reaction, or by enzymatic catalysis. The physiological and physicochemical properties of its components have been reported as equivalent to dietary fibers, relating their physiological action with important aspects of human health [6]. Their incorporation into the regular diet has been a good medication for allergic inflammation, source of antioxidants, antibiotic alternative, gastrointestinal normal flora proliferation, immune deficiency, enhancement of immunity, gastric complications, cancer, obesity, dental caries prevention, facilitation of mineral absorption, regulators of blood glucose in diabetics, serum lipids in hyperlipidemia and other health problems [4]. Various types of Oligosaccharides, along with their sources and molecular structures are shown in Table.1.

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Table 1: Different types of Oligosaccharides along with their sources and molecular structure

Types of Oligosaccharides	Source	Molecular Structure	Reference
Fructooligosaccharides (FOS)	Fruits, Vegetables like Sugar beet, Chicory, Asparagus, Garlic, Chicory, Onion, Banana, Wheat, Barley, Tomato, Honey,	$(Fr)_n$-Gu	[5, 29, 38, 39]
Galactooligosaccharides (GOS) and Lactulose Derived galactooligosaccharides (LDGOS)	Human milk, Cow milk	$(Ga)_n$-Gu	[5, 29, 38, 39]
Xylooligosaccharides (XOS)	Fruits, Vegetables, Bamboo, Honey, Milk, husks	$(Xy)_n$	[29, 38, 39, 40]
Lacto-sucrose	Yogurt	Ga-Gu-Fr	[29, 38, 39]
Arabinooligosaccharides (AOS)	Sugar beet arabinan	$(A)_n$	[29, 38, 39]
Raffinose-type oligosaccharide (Stacchyose, Raffinose)	Beet, Soyabean, and Other pulses,	Ga-Gu-Fr	[5, 29, 38, 39]
Lactosucrose, Glycosucrose	Beet	Ga-Gu-Fr	[5, 29, 38, 39]
Isomaltooligosaccharides (IMO)	Honey, Soy sauce	$(Gu)_n$	[29, 38, 39]
Lactulose	Cow milk	Ga-Fr	[5, 29, 38, 39]
Cyclodextrins (CDs)	Cyclodextrins are produced from starch by enzymatic conversion.	$(Gu)_n$	[29, 38, 39]
Maltooligosaccharides (MOS)	Black Potato Starch	$(Gu)_n$	[29, 38, 39, 41]

Gu- Glucose, Ga- Galactose, Fr- Fructose, Xy- Xylose, A- Arabinose

FRUCTOOLIGOSACCHARIDES (FOS)

Definition

Fructooligosaccharides are nondigestible carbohydrates that represent one of the main bifidogenic oligosaccharide classes [7]. Fructooligosaccharides also, known by the common name oligofructose, oligo fructan, fructose oligomers, fructans or glucofructans, the term refer to a series of homologous oligosaccharides with β (2 → 1) fructosyl- fructose glycosidic bonds [8] [9]. Lewis (1993) defined Fructooligosaccharides as a combination of three sugar molecules: 1-kestose (GF2), nystose (GF3) and frutofuranosyl nystose (GF4) where the units fructosyltransferase (F) are combined with sucrose (GF) at the β position (2 →1) [10]. The chain length varies from 2 to 60 [11].

History

The history of Fructooligosaccharides more than 150 years ago. FOS began to exist in the modern era with their discovery by Rose (1804) [12]. Meiji Seika Kaisha Co., Tokyo, in Japan, achieved first commercial success in the commercial production of FOS in 1984 by immobilizing cells of *Aspergillus niger* in calcium alginate gel [13]. Japan has the world's largest commercial market. In 1990, its market volume exceeded 4, 000 metric tons [14]. In 1990, Fructooligosaccharides were introduced as an alternative sweetener. FOS produced by several companies using sucrose or insulin under a variety of names, like Fibrulose®, Neosugar. Orafti®, Frutalose®, NutraFlora®, Profeed®, Meioligo®, and Actilight® [15, 16]. In recent years, FOS research has seen significant progress, especially with the advent of molecular biology tools. In this way, FOS research has developed from being a basic science to an applied one. Over 500 food products contain FOS, resulting in significant consumption every day [17]. This passionate history of FOS about their safety and health benefits continues to arise the interest of scientists who discover their potential as food and ingredient every day [18].

Structure

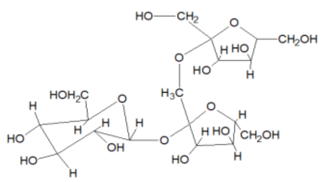
As their chemical structure consists of a chain of fructose units with a terminal glucose unit linked by β-(2-1) glycosidic bonds, they cannot be hydrolysed by human digestive enzymes that are specific for α-glycosidic bonds [11].

Fructooligosaccharides are of three categories, each of these is structurally distinct [19]:

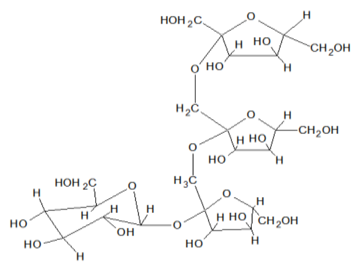
1. The polymerization degree of inulin ranges from 2 to 60 monomers of fructose, with an average of 12 units.

2. Oligofructose is produced by the enzymatic hydrolysis of inulin, which is defined as a fraction of oligosaccharides with a degree of polymerization less than 20, although commercial products tend to have a mean value of 9; these FOS are produced by the enzymatic hydrolysis of inulin and contain of fructosyl chains of different lengths, with glucose and fructose terminals.

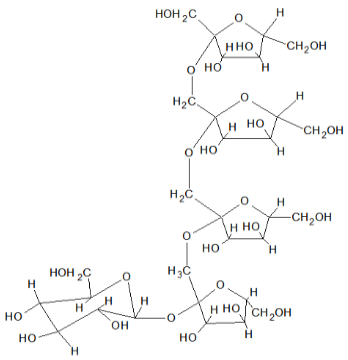
3. Short-chain Fructooligosaccharides are specifically defined as mixed chains of fructosyl with a glucose terminal unit; they have a maximum of 5 units and are derived from sugar through natural fermentation processes, producing 1-kestose (GF 2), nistose (GF 3), and 1-fructosyl – nistose (GF 4) in which the fructosyl units (F) are linked at the β-(2-1) position of sucrose. The chemical structure of the short-chain Fructooligosaccharides are given in Fig.1.



1-Ketose



Nystose



1-Fructofuranosyl Nystose

Figure 1: Chemical structure of the Short-chain Fructooligosaccharides [11]

Sources

Fructooligosaccharides are found in trace amounts in fruits, vegetables and honey as natural components. There are more than 36, 000 plant species containing FOS [20]. They are found in many higher plants as reserve carbohydrates as a series of fructose oligomers and polymers produced from sucrose [14]. The concentration in natural sources varies from 0.15% to 0.75% [20]. Considering its natural presence in widely consumed vegetables, FOS is frequently consumed in foods by humans. FOS intake was estimated to be about 13.7 mg/kg body weight per day or 806 mg/day based on normal consumption of these natural sources [21]. Various plant sources Fructooligosaccharides are given in Table.2.

Table 2: Various plant sources Fructooligosaccharides

Plant Material	Common Name	Family	Part Used	Reference
Allium cepa	Onion	Liliaceae	Bulb, Seed	[26, 28, 42, 43], [44]
Asparagus officinalis	Asparagus	Liliaceae	Root, Stem	[26, 45], [28]
Bromus pictus	Patagonian grass	Poaceae	Shoot	[26, 46]
Dactylis glomerata	Orchard grass	Poaceae	Leaf	[26]
Hordeum vulgare	Barley	Poaceae	Leaf, Shoot, Stem	[26, 47]
Loium perenne	Perennial ryegrass	Poaceae	Seed, Leaf base, Root	[26, 29, 48]
Triticum aestivum	Wheat	Poaceae	Leaf, Shoot, Stem, Root	[26, 49]
Cichorium intybus	Chicory	Asteraceae	Seed, Root, Leaf Disc	[26, 28]
Cichorium endivia L.	Escarole	Asteraceae	Root	[26, 50]
Helianthus tuberosus	Jerusalem artichoke	Asteraceae	Tuber	[26, 28, 51]
Polymnia sonchifolia	Yacon	Asteraceae	Rhizophore, Tuberous root	[26, 52]
Smallanthus sonchifolius	Yacon	Asteraceae	Root	[10]
Taraxacum officinale	Dandelion	Asteraceae	Stem, Root	[26, 28]
Vernonia herbacea Vell.	-	Asteraceae	Rhizophore	[26, 53]
Viguierra discolor	-	Asteraceae	Tuberous root	[26, 53]
Arctium lappa L.	Burdock	Asteraceae	Root	[54]
Coix lachryma-jobi Linn.	Job's tears, Gavedhukaa.	Poaceae	Grains	[55]
Stevia rebaudiana Bert.	Bertoni	Asteraceae	Root, Leaves	[56]
Musa paradisiaca var. sapientum L.	Banana Peel	Musaceae	Peel	[57], [58]
Agave americana	Century plant	Asparagaceae	Stem	[59, 28]
Agave tequilana Weber blue Variety	Blue agave	Asparagaceae	Stem	[60]
Atractylodes lancea (Thunb.) DC.,	Cang Zhu	Compositae	Root	[61]
Codonopsis pilosula (Franch.) Nannf.,	Dang shen	Campanulaceae	Root	[61]
Adenophora tetraphylla (Thunb.) Fisch.,	Japanese lady bell	Campanulaceae	Root	[61]
Morinda officinalis How.,	Indian mulberry	Rubiaceae	Roots	[61]
Arctium lappa L.,	Greater burdock	Compositae	Root	[61]
Rhodobryum ontariense Kindb	Moss	Bryaceae	Whole	[62]
Avena fatua	Oat	Poaceae	Seed	[63]

Properties of Fructooligosaccharides [20, 19]

Various properties of Fructooligosaccharides are represented in Fig. 3.

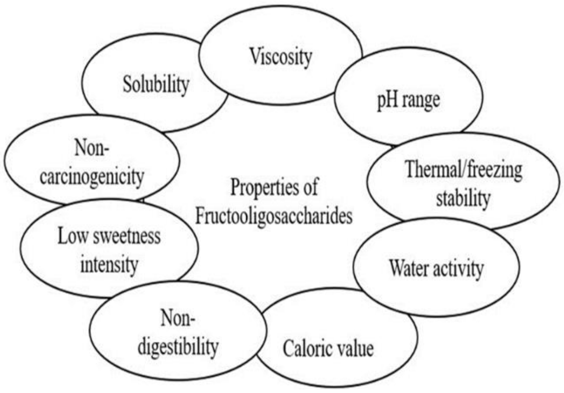


Figure 2: Various properties of Fructooligosaccharides [20, 19]

Solubility: Fructooligosaccharides are highly water-soluble (about 80%) and help to improve the nutritional value of the product in several food applications.

Viscosity: Fructooligosaccharides have a higher viscosity than sucrose at the same concentration due to their greater molecular weight, resulting in an enhanced body and mouth feeling. Increased gastrointestinal viscosity may delay the rate of gastric emptying, digestion, and nutrient absorption.

pH range: With the standard pH range of 4.0–7.0, Fructooligosaccharides show high food stability.

Thermal/freezing stability: Fructooligosaccharides have greater thermal stability than sucrose. At refrigerated temperatures, it is highly stable for one year.

Water activity: Fructooligosaccharides are highly hygroscopic. Sucrose and sorbitol have similar water holding capacities. It has a high capacity for retaining moisture, preventing unnecessary drying and low water activity. It helps control microbial contamination.

Low sweetness intensity: Fructooligosaccharides have a low sweetness intensity and sweeter than sucrose by 0.3-0.6 times. It has a low energy content of 1.5kcal/g. As a result, low to no added sugars are used in the formulation of food products like ice creams, milk desserts, yogurts, and bakery items.

Non-carcinogenicity: Fructooligosaccharides, unlike starch and simple sugars, are not utilised by oral bacteria to produce acids, which act as a matrix for plaque production and eventually lead to tooth caries. As a result, FOS is currently being used to make chewing gum, yogurt, confectionery as well as in beverages as noncarcinogenic sugar substitute.

Non-digestibility: In rats or humans, the Fructooligosaccharides were not hydrolyzed by digestive enzymes such as intestinal mucosal disaccharidases and a-amylase of pancreatic homogenates. Sugar tolerance tests on healthy subjects confirmed that unlike their monosaccharide components, fructose and glucose, Fructooligosaccharides were neither digestible nor absorbable. Sucrose ingestion resulted in quick increases in plasma glucosaemic, fructosaemic, and insulin responses, however Fructooligosaccharides ingestion resulted in no rise in plasma concentration [22].

Caloric value: Fructooligosaccharides are low-calorie, containing 1.0-1.7 calories per gram, or less than half the caloric value of sucrose. FOS are calorie-free because they are not hydrolyzed by digestive enzymes and are not used as an energy source by the body. Thus, they are not harmful to diabetics.

Production

FOS can be produced in two different ways, giving in slightly different end products. The first method involves the transfructosylation of sucrose to produce short chain FOS by fructosyl transferase, On the other hand, the second method include enzymatic hydrolysis of polysaccharide inulin (inulin oligofructose). Production of Fructooligosaccharides from extracts of natural sources are given in Fig.3.

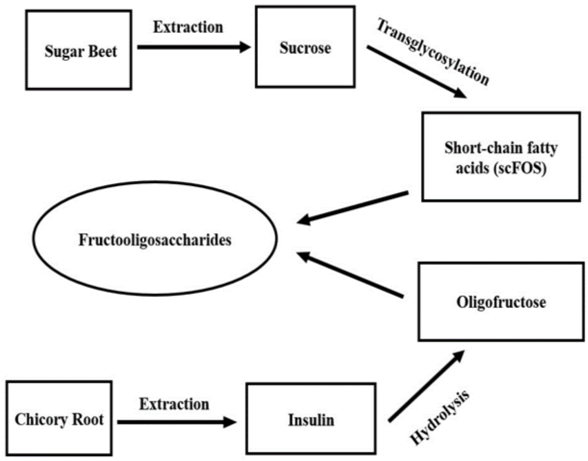


Figure 3: Schematic representation of production of Fructooligosaccharides from extracts of natural sources [24], [38]

In the first technique, fructose oligomers are produced, which are made up of a chain of two to four fructosyl moieties linked by a β (2→1) glycosidic bond and a single glucose unit at the non-reducing end linked by an α (1→2) glycosidic bond. They are known as l-Kestose (Glu-Fru,), l- nystose (Glu-Fru,) and lF-fructofuranosyl nystose (Glu-Fru,). These forms of FOS are called short chain FOS. The transfructosylation of sucrose takes place through the cleavage of the β-(2→1) glycosidic bond and the transfer of the moiety of fructosyl onto any acceptor other than water, such as sucrose or a FOS. Throughout this synthesis, multiple reactions occur simultaneously, both in parallel as well as in series, since fructosyltransferases are also potential substrates. As a by-product, glucose acts as an inhibitor for further production. In order to achieve a high purity product, by-products and unreacted sucrose produced during the reaction are removed using chromatography. To provide prebiotic benefits, these FOS short chains are fermented rapidly in the colon.

In the second technique, FOS production occur through the controlled enzymatic hydrolysis of the polysaccharide inulin (inulin oligofructose). Compared with transfructosylation, this method yields a different FOS mixture. Hence, the oligosaccharide mixture produced is longer than that obtained from sucrose transfructosylation. Additionally, not all fructosyl chains with links β (1→2)- are formed into oligo-fructoses with glucose prepared by inulin hydrolysis. In addition to polysaccharides, Fructooligosaccharides are found in inulin obtained from chicory roots. These longer-chain oligosaccharide products have applications for fat replacement [20].

Technique used for analysis of Fructooligosaccarides

In recent years, several methods for analyzing FOS have been described. A direct method for measuring FOS is HPLC. The result has been the most popular, effective, and fast FOS analysis method. Refractive index detectors for FOS separation of polymerization degrees are widely employed with polar-bonded phases and resin-based columns (DP). While HPLC has been the most widely used technique for FOS analysis, the lack of pure standards has been a major hindrance. In this context, AOAC has reported an enzymatic method for FOS analysis. AOAC's official method for detecting fructans in food and food products includes enzymatic treatment of the samples with an inulinase enzyme [23]. FOS and free sugars were easily separated by using an ion-exchange column (e.g., HPX-87C, Biorad, Richmond, VA, USA). The column temperature was kept constant at 85° C. Water was used as the mobile phase at a flow rate of 0.6 ml min [14]. Also, paper and thin layer chromatography (TLC) may be used for detecting FOS in sucrose, fructose, and glucose [14]. Park *et al*. (2001) reported the quantitative analysis of FOS by TLC using solvent systems: isopropyl alcohol: ethyl acetate: water (2:2:1). As the plates were heated after spraying phenol sulfuric acid, the products were visualized. [23].

Mode of action

The mode of action by which pathogens are inhibited (exogenous or endogenous) by decreasing the pH of the intestinal lumen that results in the formation of short-chain fatty acids from Fructooligosaccharides during fermentation. The reduction in the harmful bacteria like Clostridium, Escherichia coli, Streptococcus faecalis, and Proteus leads to a reduce in toxic metabolites, like nitrosamines, ammonia, indoles and phenols. Modler reported that the addition of NeosugarR (the commercial name of Fructooligosaccharides) to the human diet (15 grams/day) led to Increased bifidobacteria by tenfold as well as the occurrence of these bacteria by 87% to 100%. As a result, the intestinal pH decreased by 0.3 units and the numbers of enterobacteria decreased. In the study by Bouhnik, Fructooligosaccharides at doses of 12.5 g/day for three days resulted in a decrease in the number of anaerobes found in the feces, nitroreductase activity, pH, serum total cholesterol and bile acid concentrations. [24].

Side effects of Fructooligosaccharides

In general, fructo-oligosaccharides are well tolerated. In some individuals, excessive or higher daily intake of FOS can cause stomach discomfort, including bloating, diarrhea, flatulence, intestinal discomfort, stomach cramps and patients with irritable bowel syndrome (IBS) may experience adverse effects. and small intestinal bacteria overgrowth syndrome (SIBO), especially when consume doses of 15 grams or more per day [24].. A person with ankylosing spondylitis, food intolerances, or gut dysbiosis should avoid fructoogliosaccharide supplements. FOS may have more profound effects on some people. These people can also feel aspect results after taking a small amount of FOS.

There are several types of allergic reactions:

- Itching in the throat
- Puffiness in the eyes, face and mouth
- Hives, eczema and scratching
- Dizziness, light-headedness and fainting.

Applications

With the growing demand for functional foods and the possibilities for product development, Fructooligosaccharides are finding promising applications in a variety of fields, including agriculture, food and pharmaceuticals.

Food Applications

FOS is an essential ingredient of functional food because of its improved nutritional, organoleptic, and functional properties [20]. In place of sugar or fat, Fructooligosaccharides are commonly used [25]. They are used in many food products, such as frozen desserts, baked goods, breakfast cereals, fillings, dairy products, fruit preparations, dietetic products, and meal replacements and for sugar and fat replacement, moisture retention, improved texture, synergy with sweeteners, and increased crispness, expansion as well as shelf-life [26]. In these products, FOS dosage levels range from 2 to 50% (w/w). Cookies were developed in which FOS could partially replace sucrose. As a result of the addition of FOS, the cookies achieved a desirable texture and provided 2.6-4.8 g of total fiber including oligofructose per serving (30 g). In accordance with US FDA guidelines, this was considered a good source of dietary fiber, according to which a good source could provide 2.5-4.9 g of fiber [25].

Applications of FOS in Agriculture and Postharvest Fruits

A promising disease elicitor, FOS offers mechanisms for controlling diseases in plants and postharvest fruits, particularly BFO. Using elicitors to induce natural defense mechanisms against postharvest diseases may be the emphasis. Furthermore, it is very fast and efficient to extract most FOS. Water extraction used to obtain many BFO crude extracts, for example. FOS induced resistance in agriculture would lead to an increase in economic productivity. Aside from being nontoxic and biocompatible, FOS have versatile functional properties that correspond to the demands of modern society. In the future, FOS should be applied to induced resistance [8].

Pharmaceutical Applications

According to studies, Fructooligosaccharides possess the following activity such as prebiotic, dietary fiber effect, mineral absorption, obesity, antidiabetic activity, anticancer activity, constipation and diarrhea.

Prebiotic

A prebiotic is defined as a “nondigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon and thus improves the host's health" [27]. Fructooligosaccharides are fantastic prebiotics, and can be incorporated into a variety of foods.

FOS includes all of the following characteristics of a prebiotic:

i) In the upper body of the gastrointestinal tract, Fructooligosaccarides are neither hydrolyzed nor absorbed.
ii) The Fructooligosaccarides act as a selective substrate for one or a group of bacteria that produce probiotics (particularly Bifidobacteria) that stimulate the growth of healthy bacteria and inhibit pathogenic bacteria.
iii) In order to have beneficial effects on the host system, fructooligosaccharides turn the colonic flora into a healthy composition [21, 28].

As a prebiotic functional food additive, fructooligosaccharides are GRAS (Generally Recognized As Safe). The concentrations of prebiotics in most of these sources range from 0.3% to 6% of fresh weight [29].

Dietary Fiber Effect

Another important nutritional attribute of Fructooligosaccharides is their action as dietary fibers. The definition of Dietary fibre as substances containing remnants of edible plant cell polysaccharides that are resistant to hydrolysis by human digestive enzymes [30]. FOS shows that soluble-fermentable fibers have various physiological effects including resistance to digestion enzymes and intestinal fermentation by micro-flora, decreased gastrointestinal transit period, increased fecal weight, decreased fecal pH, predictable reduced caloric value, decreased plasma cholesterol, and delayed or decreased glucose absorption. Additionally, it may improve mucosal defense as well as reduces the gastrointestinal disease risk [20]. Therefore, FOS fits within the concept of dietary fibre.

Mineral absorption

Globally, mineral deficiencies remain a major problem. Scientists have also studied FOS for its ability to enhance mineral absorption as one of the best-known natural nutrients. Calcium (Ca) consumption in many underdeveloped countries is below recommended daily allowances, which contributes to progressive bone loss. Consequently, if the intake of Ca is not sufficient to compensate for compulsory losses, it is difficult to maintain acquired skeletal mass, which can lead to osteoporosis. Magnesium is the second most abundant intracellular cation in vertebrates. Deficiencies of magnesium increase the risk of heart arrhythmias, osteoporosis, angina, atherosclerosis, depression and diabetes. Because FOS can increase magnesium absorption, it can also reduce blood pressure and improve cardiovascular health. Iron (Fe), which causes significant anemia, is another mineral with a low intake. Zinc (Zn) has been widely reported to be important for growth and development. In several experimental animal models, FOS was shown to have beneficial effects on calcium, magnesium, iron and zinc absorption [21].

Obesity and Type 2 diabetes

The typical diseases in modern Western society are obesity and obesity-related type II diabetes. Diabetes mellitus is a severe and lifelong disease generally characterized by abnormally high levels of blood glucose due to insulin production failure or decreased sensitivity to and function of insulin. Latest data predicts that by 2049, 629 million people will be suffering from DM. Type 2 Diabetes mellitus is mostly caused by diet and lifestyle, though family history does play a role. Sugary drinks, carbohydrates but low in fibre and a sedentary lifestyle all contribute to the risk of developing T2DM. Due to the lack of physical activity, less glucose in the blood is taken up by the body for energy production [45]. Hence, the latest guidelines for Type II diabetes and obesity focus on improvement in dietary fiber consumption. Dietary fiber has a viscose and fibrous structure that can help regulate glucose release in the blood over time, thereby assisting in reducing diabetes and obesity [16]. Luo Yperselle, Rizkalla, Rossi, Bornet, and Slama (2000) found that 20 g of FOS daily decreased basal hepatic glucose production without affecting insulin-stimulated glucose metabolism in healthy subjects. Researchers evaluated the effect of chronic FOS intake on plasma lipid and glucose levels, hepatic glucose production, and insulin resistance in type 2 diabetics and FOS did not affect fasting plasma blood glucose levels, insulin levels, or basal hepatic glucose levels. Triacylglycerol, total and HDL cholesterol, free fatty acids, and apolipoprotein A1 and B concentrations were not affected by chronic consumption of FOS. It is believed that purification of FOS by removing the glucose and sucrose from the mixture of FOS would increase its market value, thereby leading to the development of diabetic food products [23].

COLORECTAL CANCER (CCR)

It is the third most common cancer among men and women worldwide and the second largest cause of cancer-related deaths [30]. In the presence of a colorectal cancer (CRC) the colon or rectum becomes cancerous, also called colon cancer, bowel cancer, or rectal cancer (parts of the large intestine). Surgical resection, chemotherapy, and radiation therapy are the main treatments for CRC. Patients who undergo these procedures also suffer some adverse effects, such as nausea, vomiting, hair loss, and fatigue, all of which adversely affect their quality of life. Research indicates that chronic inflammation and gastrointestinal microflora are associated with colon cancer risk. Several studies have shown some benefits of FOS in CRC management, and their antigenotoxicity and anticarcinogenicity have long been appreciated [31]. According to recent studies, FOS can inhibit the growth of colon cancer through the production of SCFAs that are produced during fermentation. As a result, health-promoting bacteria inhibit the development of pathogenic bacteria, which reduces the production of substances that cause cancer and bacterial enzymes that contribute to colon cancer [32].

Constipation

Constipation affects a large part of the population. According to the most common definition of constipation, it is an irregular pattern of feces evacuation, usually occurring less than three times a week. Around 15% of the population suffers from constipation, with a higher prevalence in females and elderly people. In one study examining almost 15 000 women, 14% to 27% of them were constipated, with older women having the highest prevalence [34]. Fructooligosaccharides had a beneficial effect on constipation. Taking FOS on a daily basis can increase the microbial mass and gas production in the colon, increasing the cecal content. For 28 days, Fructooligosaccharides were administered to 15 functionally constipated volunteers, ranging in age from 20 to 82 years old. 11 subjects (73%) improved in terms of constipation after ingesting fructooligosaccharides, all of whom defecated more frequently than once every 3 days. In addition to the relief of constipation provided by non-digestible saccharides, the high osmotic pressure of short-chain fatty acids released by intestinal bacteria may also contribute to the accelerated peristaltic movement [22, 35, 36].

Diarrhea

Traveler's diarrhea is a common problem around the world. A traveler's diarrhea is defined as having three or more unformed stools every day during or after a travel or any number of such stools when accompanied by fever, stomach cramping, or vomiting [37]. FOS has also been suggested for preventing traveler's diarrhea. FOS, however, produced marginal benefits in a broad (244 participants) double-blind trial at a dosage of 10 g daily. A better bet could be probiotics themselves. In another study, FOS was shown to minimize diarrhea, flatulence, and vomiting among pre-schoolers [11].

CONCLUSION

Fructooligosaccharides show a remarkable potential for practical utilization in many fields, including food, agricultural, and pharmaceutical application. In this field, FOS present advantages as compared to other oligosaccharides. With the exploding popularity of functional foods and environmental awareness, the future of FOS fortified products appears very promising. In the future, FOS markets are predicted to boom worldwide. There are still a number of questions unanswered. This comprehensive data on numerous sources, properties, manufacturing, side effects, and health benefits of Fructooligosaccharides give future research a distinct direction.

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Conflict of Interest

None declared.

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Nil.

REFERENCES

1. Monica Butnariu, Ioan Sarac. Functional Food. International Journal of Nutrition.2019:3(3)7-16.
2. Sharanya Rani D, Penchalaraju M. A review different types of functional foods and their health benefits. International Journal of Applied and Natural Sciences. 2016;5(3):19-28.
3. L. M. Tódero, C. G. V. Rechia, and L. H. S. Guimarães. Production of short-chain Fructooligosaccharides (scFOS) using extracellular β-D-fructofuranosidase produced by Aspergillus thermomutatus. Journal of Food Biochemistry. 2019;43(8): 1-12.
4. S. Patel and A. Goyal. Functional Oligosaccharides: production, properties and applications. World J Microbiol Biotechnol 2011; 27:1119–1128
5. P. Gupta, P. Agrawal, P. Hegde. A review on Xylooligosaccharides. International Research Journal of Pharmacy. 2012; 3(8):71-74
6. A. Aparecida, B. Tomal, S. Farinazzo, A. Bachega, A. Bosso, B. Silva, H. Suguimoto. Galactooligosacharides and human health implications. Nutrition and Food Science International Journal. 2019; 9(1):10–13.
7. D. Flores-Maltos, S. Mussatto, J. Contreras-Esquivel, R. Rodríguez-Herrera, J. Teixeira, and C. Aguilar. Biotechnological production and application of Fructooligosaccharides. Critical Reviews in Biotechnology. 2016;36(2): 259-267.
8. M. Guo, G. Chen, and K. Chen. Chapter 5 Fructooligosaccharides : Effects, mechanisms, and applications. © Springer Science+Business Media New York 2016 H. Yin, Y. Du (eds.), Research Progress in Oligosaccharins, 2016: 51-63.
9. M. J. Sánchez-Martínez, S. Soto-Jover, V. Antolinos, G. B. Martínez-Hernández, and A. López-Gómez. Manufacturing of short-chain Fructooligosaccharides: from laboratory to industrial scale. Food Engineering Reviews. 2020; 12(2): 149–172.
10. M. L. Brites and C. P. Z. Noreña. Obtaining Fructooligosaccharides from yacon (smallanthus sonchifolius) by an ultrafiltration process. Brazilian Journal of Chemical Engineering. 2016;33(04):1011-1020.
11. V. Sridevi, V. Sumathi, M. Guru Prasad, and M. Satish Kumar. Fructooligosaccharides - type prebiotic: a review. Journal of Pharmacy Research. 2014;8(3):321-330.
12. C. Kumar, S. Sripada, Y. Poornachandra. Chapter 14 Status and future prospects of Fructooligosaccharides as nutraceuticals. Role of Materials Science in Food Bioengineering. 2018;19:451-503.
13. B. Tungland. Chapter 11 Fructooligosaccharides and other Fructans: Structures and occurrence, production, regulatory aspects, food applications, and nutritional health significance. In Oligosaccharides in Food and Agriculture; Eggleston, G., *et al*.; ACS Symposium Series; American Chemical Society: Washington, DC. 2003;849:135-152.
14. J. W. Yun. Fructooligosaccharides-Occurrence, preparation, and application. Enzyme and Microbial Technology. 1996; 0229(95):107-177.
15. V. Bali, P. Panesar, M. Bera, and R. Panesar. Fructo-oligosaccharides: Production, purification and potential applications. Critical Reviews in Food Science and Nutrition. 2015; 55(11): 1475-1490.
16. A. Dominguez, L. Rodrigues, N. Lima, J. Teixeira. An overview of the recent developments on Fructooligosaccharide production and applications. Food and Bioprocess Technology. 2014; 7(2): 324-337.
17. N. Benkeblia. Fructooligosaccharides and fructans analysis in plants and food crops. Journal of Chromatography A. 2013; 1313: 54–61.
18. N. Benkeblia, N. Shiomi. Fructooligosaccharides of edible alliums: occurrence, chemistry and health benefits. Current Nutrition & Food Science, 2006; 2(2): 181-191.
19. M. Sabater-Molina, E. Larqué, F. Torrella, and S. Zamora. Dietary Fructooligosaccharides and potential benefits on health. Journal of Physiology and Biochemistry. 2009; 65(3): 315-328.
20. S. Khanvilkar and S. Arya. Fructooligosaccharides: Applications and health benefits: A review. Agro Food Industry Hi-Tech. 2015;26(6):8-12.
21. A. Dominguez, L. Rodrigues, N. Lima, J. Teixeira. An overview of the recent developments on Fructooligosaccharide production and applications. Food and Bioprocess Technology. 2014; 7(2): 324-337.
22. H. Hidaka and M. Hirayama. Useful characteristics and commercial applications of Fructo-oligosaccharides. Biochemical Society Transactions. 1991;19(3):561-565.
23. P. Sangeetha, M. Ramesh, and S. Prapulla. Recent trends in the microbial production, analysis and application of Fructooligosaccharides. Trends in Food Science and Technology. 2005; 16(10):442-457.
24. V. Sridevi, V. Sumathi, M. Guru Prasad, and M. Satish Kumar. Fructooligosaccharides - type prebiotic: a review. Journal of Pharmacy Research. 2014;8(3):321-330.
25. C. Kumar, S. Sripada, Y. Poornachandra. Chapter 14 Status and future prospects of Fructooligosaccharides as nutraceuticals. Role of Materials Science in Food Bioengineering. 2018;19:451-503.
26. S. Yildiz. The metabolism of Fructooligosaccharides and Fructooligosaccharide-related compounds in plants. Food Reviews International. 2011; 27(1): 16-50.

27. D. Davani-Davari *et al.* Prebiotics: Definition, types, sources, mechanisms, and clinical applications. Foods. 2019; 8(3): 1-27.
28. T. Mutanda, M. Mokoena, A. Olaniran, B. Wilhelmi, and C. Whiteley. Microbial enzymatic production and applications of short-chain fructooligosaccharides and inulooligosaccharides: Recent advances and current perspectives. Journal of Industrial Microbiology and Biotechnology. 2014; 41(6): 893–906.
29. S. Singh, J. Jadaun, L. Narnoliya, and A. Pandey. Prebiotic oligosaccharides: special focus on Fructooligosaccharides, its biosynthesis and bioactivity. Applied Biochemistry and Biotechnology. 2017; 183(2): 613–635.
30. D. Dhingra, M. Michael, H. Rajput, and R. T. Patil. Dietary fibre in foods: A review. Journal of Food Science and Technology. 2012; 49(3): 255–266.
31. G. Chen, C. Li, and K. Chen. Fructooligosaccharides: a review on their mechanisms of action and effects. Studies in Natural Products Chemistry. 2016; 48: 209–229.
32. M. Shehata. Fructooligosaccharides : as natural sweeteners from Onion and Artichoke. LAP LAMBERT Academic Publishing. 2016.
33. G. Chen, C. Li, and K. Chen. Fructooligosaccharides: a review on their mechanisms of action and effects. Studies in Natural Products Chemistry. 2016; 48: 209–229.
34. K. Winge, D. Rasmussen, and L. M. Werdelin. Constipation in neurological diseases. Journal of Neurology Neurosurgery and Psychiatry. 2003;74(1): 13-19.
35. M. Hirayama, K. Nishizawa, and H. Hidaka. Production and characteristics of Fructooligosaccharides. Inulin and Inulin-containing Crops. 1993; 3(C): 347-353.
36. H. Hidaka, M. Hirayama, and K. Yamada. Review article : Fructooligosaccharides enzymatic preparation and biofunctions. Journal of Carbohydrate Chemistry. 1991;10(4):509-522.
37. A. Dominguez, L. Rodrigues, N. Lima, J. Teixeira. An overview of the recent developments on Fructooligosaccharide production and applications. Food and Bioprocess Technology. 2014; 7(2): 324-337.
38. S. Mussatto and I. Mancilha. Non-digestible oligosaccharides : A review. Carbohydrate Polymers. 2007; 68: 587–597.
39. O. Ibrahim. Functional Oligosaccharides: chemicals structure, manufacturing, health benefits, applications and regulations. Journal of Food Chemistry & Nanotechnology, 2018; 4(4):65-76.
40. T. Souza *et al*, Chapter 2 Biotechnolog*ical* production of Oligosaccharides-Applications in the Food Industry. Food Production and Industry.2015.
41. N. Rahmani, R. Rohana, S. Sukaarno, A. Andriani, And Y. Yopi. Production of Maltooligosaccharides from Black Potato (Coleus tuberosus) Starch by α-amylase from a Marine Bacterium (Brevibacterium sp.). Microbiol. Indones. 2013;7(3):129–136.
42. M. Fujishima *et al.* Isolation and Structural Analysis In Vivo of Newly Synthesized Fructooligosaccharides in Onion Bulbs Tissues (Allium cepa L.) during Storage. International Journal of Carbohydrate Chemistry.2009;2009:1-9.
43. M. Suzuki and J. A. Cutcliffe. Fructans in Onion bulbs in relation to storage life. Canadian Journal of Plant Science. 1989; 69(4): 1327–1333.
44. R. J. Henryf. Differences In Fructan Content And Synthesis In Some Allium Species. New PhytoL. 1981; 87: 249–257.
45. N. Shiomi, J. Yamada, and M. Izawa. Isolation and identification of Fructo-oligosaccharides in roots of Asparagus (Asparagus officinalis L.) Agricultural and Biological Chemistry*,* 1976; 40(3):567–575.
46. F. Del Viso *et al.* Molecular characterization of a putative sucrose: Fructan 6-fructosyltransferase (6-SFT) of the cold-resistant patagonian grass bromus pictus associated with fructan accumulation under low temperatures. Plant and Cell Physiology. 2009; 50(3): 489-503.
47. M. LÜscher, U. Hochstrasser, T. Boller, and A. Wiemken. Isolation of sucrose: Sucrose 1-fructosyltransferase (1-SST) from barley (Hordeum vulgare). New Phytologist 2000; 145(2): 225-232.
48. N. Pavis *et al.* Structure of fructans in roots and leaf tissues of Lolium perenne. New Phytologist. 2001; 150 (1): 83-95.
49. L. Van Riet, V. Nagaraj, W. Van Den Ende, S. Clerens, A. Wiemken, and A. Van Laere, Purification, cloning and functional characterization of a fructan 6-exohydrolase from wheat (Triticum aestivum L.). Journal of Experimental Botany. 2006; 57(1): 213–223.
50. T. B. Mariano *et al.* Prebiotic fructooligosaccharides obtained from escarole (Cichorium endivia L.) roots. Bioactive Carbohydrates and Dietary Fibre.2020.
51. J. I. Islamova. Study of the prebiotic activity of inulin and Fructooligosaccharides allocated from *helianthus tuberosus* in experiences in vivo. American Journal of Medicine and Medical Sciences. 2020; 10(7): 525-527.
52. N. M. Itaya, M. A. M. De Carvalho, and R. De Cassia Leone Figueiredo-Ribeiro. Fructosyl transferase and hydrolase activities in rhizophores and tuberous roots upon growth of Polymnia sonchifolia (Asteraceae). Physiol. Plant. vol. 116, no. 4, pp. 451–459, 2002.
53. M. Angela Machado De Carvalho, L. B. P. Zaidan, and S. M. C. Dietrich. Growth and fructan content of plants of *Vernonia herbacea* (Asteraceae) regenerated from rhizophores. New Phytol. 1997; 136(1): 153-161.
54. X. juan Zhang, S. fang Liu, Y. Lu, J. yue Wang, and K. shan Chen. Immunomodulatory activity of a Fructooligosaccharide isolated from burdock roots. RSC Ad. 2019;9(20):11092-11100.
55. J. Manosroi, N. Khositsuntiwong, and A. Manosroi. Biological activities of Fructooligosaccharide (FOS)-containing *Coix lachryma-jobi* Linn. Extract. Journal of Food Science and Technology. 2014; 51(2)341–346.
56. A. J. B. De Oliveira *et al.* Structure and degree of polymerisation of Fructooligosaccharides present in roots and leaves of *Stevia rebaudiana* (Bert.) Bertoni. Food. 2011;129(2): 305–311.
57. S. Syahpura and A. Syofiana. Analysis of Fructuktooligosaccharide Isolution Banana Peel *(Musa paradisiaca var. sapientum* (L.) as prebiotic in the ration (In Vitro). International Journal of Applied Agricultural Research.2019;14(2): 87-92.
58. O. de la Rosa, A. Flores-Gallegos, D. Muñíz-Marquez, C. Nobre, J. Contreras-Esquivel, and C. Aguilar. Fructooligosaccharides production from agro-wastes as alternative low-cost source. Trends in Food Science and Technology. 2019; 91: 139–146.
59. I. Bhatia and K. Nandra. Studies on fructosyl transferase from Agave americana. Phytochemistry. 1979; 18 (6): 923–927.
60. E. Mellado-Mojica, L. González de la Vara, and M. López. Fructan active enzymes (FAZY) activities and biosynthesis of Fructooligosaccharides in the vacuoles of *Agave tequilana* Weber Blue variety plants of different age. Planta*. 2017*; 245(2): 265–281.
61. J. Li, D. Hu, W. Zong, G. Lv, J. Zhao, and S. Li. Determination of inulin-type Fructooligosaccharides in edible plants by high-performance liquid chromatography with charged aerosol detector. Journal of Agricultural and Food Chemistry. 2014; 62(31): 7707–7713.
62. B. Pejin, M. Sabovljevic, V. Tesevic, and V. Vajs. Further Study on Fructooligosaccharides of Rhodobryum ontariense. Cryptogamie, Bryologie. 2012; 33(2):191-196.
63. D. P. Livingston, N. J. Chatterton, And P. A. Harrison. Structure and quantity of Fructan oligomers in oat (Avena spp.). New Phytologist 1993;123(4)725–734.

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