



Review Article

Physico-chemical Properties, Structures and Biological Applications of Functional Oligosaccharides

MANISH SACHAN¹, PUSHRAJ SINGH^{2*}¹Department of Zoology, Govt. Girls Degree College, Chhibramau, Kannauj-209721, Uttar Pradesh, India²Department of Chemistry, Govt. Girls Degree College Chhibramau, Kannauj-209721, Uttar Pradesh, India

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ABSTRACT

Oligosaccharides are a diverse and complex class of compounds that are broadly distributed in nature. These are the most biologically diverse and important carbohydrate among biological systems. Oligosaccharides of various origin like fruits, vegetables, milk, blood, bacteria, algae, fungi and higher plants have been used extensively both as food ingredients and pharmacological supplements. The non-digestible oligosaccharides have been implicated as dietary fibre, sweetener, weight controlling agent and humectant in confectioneries, bakeries and breweries. Functional oligosaccharides have been found effective in gastrointestinal normal flora proliferation and pathogen suppression, dental caries prevention, enhancement of immunity, facilitation of mineral absorption, source of antioxidant, antibiotic alternative, regulators of blood glucose in diabetics and serum lipids in hyperlipidemics. The enormous biological activities of oligosaccharides such as immunostimulant, anti-tumour, anti-cancer, anti-inflammatory, anti-complementary, anti-viral, anti-microbial, hypoglycemic activity, lipid lowering and regulation of mineral absorption are well reported in medicinal literature. Apart from the pharmacological applications, oligosaccharides have found use in drug delivery, cosmetics, animal and fishery feed, agriculture etc. Keeping in view the importance of the functional oligosaccharides, we present an overview of their natural sources, types, structures and physiological properties. Recent promising developments in this area are presented to facilitate their further exploitation.

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INTRODUCTION

With the advent of recent researches and modernization in medical sciences, everyday invention of new diseases has been accomplished. Since biologists at the one hand invent more and more diseases, its complementary hand is approaching the invention of newer medicines for fighting with the diseases. Chemists and biologists together are trying to find out new target compounds as therapeutic agents, for which they are haunting the synthetic as well as natural sources. Isolation of biologically active compounds from natural sources is not a new approach but it hundreds year old and is still continuing. Based on the data of invented therapeutic agents it was postulated that the compounds either composed of glycans or containing carbohydrate moiety in them become more successful as a drug [1, 2].

With the emphasis on carbohydrate based drug discovery a new stream termed as glycobiology has come out in which chemists and biologists together emphasized on the benefits of sugar based molecules and they invented number of glycosides, glyco-conjugates and oligosaccharides which are either under the process of investigation for future drugs or been marketed as medicine.

Increasing health consciousness of modern consumers has enhanced the demand of specific types of dietary carbohydrates. The health promoting effects of non-digestible carbohydrates such as dietary fibers, oligosaccharides and resistant starch have been well documented [3, 4]. Among the non-digestible carbohydrates, functional oligosaccharides are gaining outstanding popularity owing to their physiological benefits to the consumers. Oligosaccharides (OS) have been commercialised since the 1980s as low-calorie bulking agents.

*Author for Correspondence:

Email: pushpraj1509@gmail.com

More recently, they have garnered much interest in food and pharmaceutical sector owing to overwhelming consumer preference for healthier food. The functional food concept was first introduced in Japan. In 1991, several oligosaccharides were classified as "Foods for Specified Health Use" (FOSHU) in Japan. Recent research findings across the globe, have led to the inclusion of non-digestible oligosaccharides (NDOs) under functional food. China, India and Latin America are emerging functional food markets, where cultural factors, low levels of nutrition knowledge and income constraints limit the popularity of these health foods.

Oligosaccharides are low molecular weight carbohydrates, containing sugar moieties with degrees of polymerization (DP) between 2 and 10, intermediate in nature between simple sugars and polysaccharides [5]. In the non-digestible oligosaccharides, the anomeric C-atoms (C-1 or C-2) of the monosaccharide units have configuration that makes their glycosidic bonds non-susceptible to the hydrolytic activity of human digestive enzymes [6]. The non-digestible oligosaccharides (NDOs) possess important physico-chemical and physiological properties and serve as dietary fibers and prebiotics. Enrichment of diet with NDOs improves gut microecology. Prebiotics are fermented in the colon by endogenous bacteria to release energy, metabolic substrates, lactic and short-chain carboxylic acids as end products of fermentation [7]. These compounds promote the proliferation of probiotics [8]. Probiotics are live microorganisms which when administered in adequate amounts colonize as commensal of the host conferring a health benefit on the host.

Physico-chemical Properties of Oligosaccharides

The oligosaccharides are about 0.3-0.6 times as sweet as sucrose, this low sweetness attribute is exploited in food formulations as a replacement of sucrose. Further, the low caloric densities make the oligosaccharides useful as bulking agents in food formulations. They are used as humectants because of their high moisture-retaining capacity without increasing water activity. Based on their physiological properties, these carbohydrates are grouped as digestible or non-digestible. In addition, as compared to the solutions of mono- and disaccharides, higher molecular weights of oligosaccharides make them more viscous solutions. The stability of oligosaccharides depends on the sugar residue

content, ring form, anomeric configuration and linkage types. Generally β -linkages are stronger than α -linkages and hexoses are more strongly linked than pentoses. Low pH and high temperature tend to impair the physico-chemical properties and reduce nutritional value of oligosaccharides. Such additives of moderate sweetness, organoleptic characteristics and stability over a wide range of pH and temperature are suitable for incorporation into foods. They show exceedingly high structural diversity than oligopeptides and oligonucleotides [9]. The functional oligosaccharides include Fructo-oligosaccharides [10] (FOs), Gluco-oligosaccharides (GOs), Isomalto-oligosaccharides (IMOs), Soybean meal oligosaccharides (SMOs), Mannan-oligosaccharides (MOs), Galacto-oligosaccharides, Gentio-oligosaccharides, Isomaltulose, Lactosucrose, Malto-oligosaccharides [11] (MOs), Xylo-oligosaccharides [12] (XOs), Pectin-derived acidic oligosaccharides [13] (PAOs), Cyclodextrins [14].

Types and Sources of Oligosaccharides

Functional oligosaccharides are found in varying concentrations in milk, honey, sugarcane juice, soyabean, lentils, mustard, fruits and vegetables such as onion, asparagus, sugar beet, artichoke, chicory, leek, garlic, banana, rye, barley, yacon, wheat, tomato and bamboo shoots [15]. Xylo-oligosaccharides are extracted from gram husk, wheat bran, barley hulls, brewery spent grains, almond shells, bamboo, corn cob, staw etc [16]. Oligosaccharides have been produced from plant cell wall polysaccharides viz. soya arabinogalactan, sugar beet arabinan, wheat flour arabinoxylan, polygalacturonan and rhamnogalacturonan fraction from apple [17]. Wichienchot et al. have isolated prebiotic oligosaccharides from unconventional sources like red flesh pitaya [18] (dragon fruit) and Thammarutwasik et al. from jackfruit seed [19]. Two novel oligosaccharides, β -D-fructopyranosyl-(2 \rightarrow 6)- β -D-glucopyranosyl-(1 \rightarrow 3)-D-glucopyranose and β -D-fructopyranosyl-(2 \rightarrow 6)- β -D-glucopyranosyl-(1 \rightarrow 3)-D-glucopyranose have been isolated from a fermented beverage of 50 kinds of fruits and vegetables [20]. High levels of Raffinose family oligosaccharides (RFOs) are extracted from lupin species belonging to Leguminosae family. Algal-oligosaccharide lysates have been derived from algal polysaccharides [21]. Neoagaro-oligosaccharides (NAOs) have been obtained from enzymatic hydrolysis of agarose [22].

Functional properties of oligosaccharides from different sources vary due to their variable monomers, degree of polymerization and glycosidic bonds. Types and sources of common oligosaccharides are presented in Table 1.

Structures, Glycosidic Linkages of Common Oligosaccharides

Nature of oligosaccharide, composition and glycosidic linkages between different monosaccharide units are presented in Table 2.

Table 1: Types, Sources and Biological Applications of Oligosaccharides

S.N.	Oligosaccharides	Sources	Biological Applications
1.	Isomalto-Oligosaccharide [23] (IMOs)	Bacillus circulans T-3040	Prevent dental caries, increase cecal Bifidobacterium population
2.	Soybean meal Oligosaccharides [10] (SMOs)	Soybean seed	Promote competitive exclusion of potential pathogens, reduce oxidative stress, reverse cardio cerebrovascular disease
3.	Fructo-Oligosaccharides [24] (FOs)	Aspergillus, Fusarium, Arthrobacter, Aureobasidium Gluconacetobacter, Bacillus chicory root, fermented beverage of plant extract	Improve gut absorption of Ca and Mg, prevent urogenital infections, sweetener in beverages, acariogenic quality, effect on lipid metabolism, reduce risk of colon cancer
4.	Galacto-Oligosaccharides Lactulose [25]	Bifidobacterium bifidum NCIMB 41171, Kluyveromyces lactis and Sulfolobus solfataricus	Used as prebiotics, lactulose is used in treatment of hyperammonemia and portosystemic encephalopathy, as laxative, infant formulae, prebiotic and low-calorie sweetener
5.	Mannan-oligosaccharides [26] (MOs)	Cell wall fragments of yeast	Modulate gut microbiota of gilthead sea bream fish, alter lymphocyte response <i>in vitro</i> , alternative to antibiotic growth promoters in broiler diets
6.	Gluco-oligosaccharides [27] (GOs)	Leuconostoc mesenteroides NRRL B 1299	Promote beneficial cutaneous flora, used in dermocosmetic industry
7.	Gentio-oligosaccharides [28]	Penicillium multicolor	Useful as prebiotic and taste improver of some beverages
8.	Lactosucrose [29]	Pseudomonas aurantiaca	Increase bifidobacteria population
9.	Malto-oligosaccharides [30] (MOs)	From starch by the action of pullulanase, isoamylase and amylases	Reduce the levels of Clostridium perfringens and family Enterobacteriaceae
10.	Xylo-oligosaccharides (XOs) or Feruloyl-oligosaccharides [31] (FOs)	Aspergillus, Trichoderma, Penicillium, Bacillus, Streptomyces, also from Bengal gram husk, wheat bran and straw, aspen wood, barley hulls, brewery spent grains, almond shells, bamboo, corn cob	Prebiotic, cosmetics, plant growth regulator, antioxidant, gelling agent, treatment of diabetes, arteriosclerosis and colon cancer
11.	Chitosan Oligosaccharides [32] (COs)	Depolymerised products of chitosan	Antioxidant, anti-tumor, anti-hypertensive, anti-microbial and immunopotentiating activities, protect normal cells from apoptosis
12.	Human milk oligosaccharide [7] (HMOs)	Human breast milk	Facilitate preferential growth of bifidobacteria and lactobacilli in the colon of breast-fed neonates
13.	β -Glucan oligosaccharide [33]	Oat-based diet	Exert better lactobacillogenic effect
14.	Gentio-oligosaccharides [34] (GeOs)	By digestion of starch	Improves poebiotic profile
15.	Cyclodextrins [14] (CDs)	Transformation of starch by certain bacteria such as Bacillus macerans	Stabilize deliquescent or volatile compounds in foods and chemicals; emulsify oils; protect against oxidation and photodegradation, mask bitterness in foods and drugs, enhance bioavailability of poorly soluble drugs
16.	Algal-oligosaccharides lysate [21] (AOL)	Polysaccharide extracts (APEs) of Gracilaria	Antioxidant and health food prebiotic effect

Table 2: Monomer Composition and Glycosidic Linkages of Common Oligosaccharides

S.N.	Oligosaccharides	Monomer composition	Glycosidic Linkage
1.	Soybean meal oligosaccharides ^[10] (SMO) (Raffinose and Stachyose)	(Galactose)n-glucose-fructose	α -(1→6)- α -(1→2)- β -fructose linked
2.	Fructooligosaccharides ^[20]	(Fructose)n-glucose	β -(2→1) and α -(1→2) linked
3.	Galactooligosaccharides ^[25]	(Galactose)n-glucose	α -(1→4) and β -(1→6) linked
4.	Xylooligosaccharides ^[31] (XOS)	(Xylose)n	β -(1→4) linked
5.	Gentiooligosaccharides ^[28] (GeOS)	(Glucose)n	β -(1→6) linked
6.	Lactosucrose ^[29]	Galactose-glucose-fructose	β -(1→4)- α -(1→2) β -fructose linked
7.	Arabino-oligosaccharides ^[35] (AOS)	(Arabinose)n	α -(1→5) linked
8.	Isomaltooligosaccharide ^[30]	(Glucose)n	α -(1→6) linked
9.	Maltooligosaccharide ^[30] (MOS)	(Glucose)n	α -(1→4) linked
10.	Chitosan oligosaccharides ^[32] (COS)	(2-Acetamido-D-glucose-2-amino-D-glucose)n	β -(1,4) linked
11.	Cyclodextrins ^[14] (CDs)	Cyclic-D-glucose	α -(1→4) linked

CONCLUSION

Interest in functional oligosaccharides is motivated by their diverse industrial applications. The health benefits of functional oligosaccharides are well known and far reaching. Ranging from use in nutraceutical, pharmaceutical, prebiotics, animal feed and agriculture sector, oligosaccharides have benefits for everyone. Looking at their ever increasing demand, oligosaccharides have been subjected to an intensive and cutting-edge research during the last three decades. With galloping popularity of functional foods and environmental awareness, the future of oligosaccharides fortified products seems to be highly promising. Potential markets for oligosaccharides in future are expected to trigger a major boom across the globe.

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CONFLICTS OF INTEREST

Authors have no conflict of interest to declare.

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