Review

Trends in the Use of Plant Non-Starch Polysaccharides within Food, Dietary Supplements, and Pharmaceuticals: Beneficial Effects on Regulation and Wellbeing of the Intestinal Tract

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Abstract: As the demand for healthy products targeted to prevent or ameliorate bowel disease and digestive disorders of the intestinal tract is increasing, this review describes non-starch polysaccharides, such as β-glucan, arabinoxylan, galactomannan, fructan, and heteropolysaccarides from mucilages, as useful sources for adequate and tailor-made products aimed for regulation of the colon and wellbeing effects on the gut microbiota. Their monosaccharide composition, structure, molecular dimensions, physicochemical characteristics and growth stimulation of lactobacilli and bifidobacteria in the gut microbiota is reported. Arabinoxylan from wheat and rye grains is discussed as an ingredient for gluten and lectin-free bread and baked goods. Galactomannans from legumes and their partially hydrolysed products are presented as sources for specific healthy products against bowel disease and digestive discomfort. Commercial fructan products obtained from inulin, fructan of agave, and fructooligosaccharides are discussed in detail as a selective substrate for fermentation by health-promoting bacteria in the colon, such as lactobacilli and bifidobacteria. Structurally different heteropolysaccharides from mucilages of traditional medicinal plants, such as seeds from psyllium, flax, chan, chia, and basil or cladodes from *Opuntia* spp., are discussed as useful sources of dietary fibre, with prebiotic characteristics and digestive regulation in the intestinal tract as well.

1. Introduction

Over the last two decades, maladies of the intestinal tract such as constipation, diverticulitis, or irritable bowel syndrome, have increased worldwide, provoking a heightened interest in health-conscious nutrition. Particularly, elderly people are seriously affected by digestive discomfort and their situation can only be improved or resolved after a detailed analysis of their lifestyle habits. Substantial contributions for the solution of this problem include a fibre-rich diet, or the use of dietary supplements or pharmaceuticals with a high content of specific fibre ingredients possessing the capacity to activate the intestinal peristalsis and improve the balance of the gut microbiota. However, a well-balanced intake of both insoluble and soluble fibre should be postulated for an adequate beneficial effect, depending on the applied diet and choice of adapted commercial products.

Dietary fibre is predominantly composed of insoluble constituents from the plant matrix such as cellulose, high molar mass β-glucan, lignin, partially insoluble fructan, and structurally different heteropolysaccharides. The insoluble dietary fibre passes the intestinal tract without large modification;

however, it is engaged in the regulation and mobility/peristalsis of the intestine. Additionally, the contained polysaccharides, often possessing charged residues, have complex-forming properties, thus being able to fix toxic components and metabolic excreta (e.g., bile acids) for a faster excretion. The water binding capacity of these polysaccharides, capable of increasing their volume 20-fold, may induce a rigorous increase of faecal bulk. This effect prevents possible constipation, digestive discomfort, and thus can avoid or ameliorate bowel diseases. A high content of insoluble dietary fibre is found, for example, in the whole-grain of cereals, cereal brans, seeds, green vegetables, and root vegetables.

The soluble indigestible constituents of plants, called soluble dietary fibre, should be present in a plant-rich diet as well. In this case, water soluble components, such as β-glucan, pectin, fructan, and heteropolysaccharides from gums, mucilages, and hemicelluloses, are predominantly used as carbon sources by the colonic microbiota, particularly by the constitutional lactobacilli and bifidobacteria. A particularly high level of soluble fibre is found in fructan-containing plants, such as asparagus, onion, globe artichoke, and Jerusalem artichoke; as well as in legumes, such as beans, peas, and lentils; and in whole-grain cereals, fruits, diverse seeds, and succulent plants [1].

The most soluble constituents possess a high dispersibility and relatively low viscosity in aqueous systems. Basically, these constituents have little effect on the volume of faeces. However, as available substrates for the microbiota they are responsible for the growth of bacterial mass and therefore generate an increase of the faecal bulk. Additionally, they reduce the transit time of food material through the upper gastrointestinal tract and show a tendency to delay the rate of nutrient absorption, most likely due their ability to fix a high amount of water and to build up viscous, jelly-like solutions, producing a feeling of satiety after the intake of food. Simultaneously, the digestive process and the glucose absorption in the small intestine will be restricted. As to the plasma glucose and insulin level, it can be adequately regulated and the risk for type 2 diabetes is considerably reduced. Like insoluble fibre, the highly viscous, high molar mass soluble fibre can form complexes with toxic substances, particularly bile acids/salts in the intestinal tract, thus rapidly being transported into the faeces. The low concentration of bile acids hence stimulates their synthesis in the liver, which uses cholesterol as a substrate. Therefore, the transformation of cholesterol to bile acids causes a reduction in the level of total cholesterol and undesirable LDL-cholesterol in the blood up to about 5–18% [2,3].

Soluble fibre in the colon selectively stimulates the growth of lactobacilli and bifidobacteria. Moreover, heteropolysaccharides can also be fermented by bacteroidetes, which can act as primary degraders. This can help in maintaining populations of potential pathogens at relatively low levels. The anaerobic fermentation (prebiotic metabolism) produces mainly short-chain fatty acids (SCFAs), such as acetate, propionate and butyrate along with gases and lactate [4–6]. Acetate is used as an energy source (acetate pool); it is transported to the muscle tissues and is a potential precursor for cholesterol synthesis. Contrariwise, propionate inhibits the enzyme cholesterol synthetase, thus reducing cholesterol-, triglyceride-, and LDL levels in the blood. Butyrate serves as an energy source for the colon epithelium and protects colon from cancer and colitis [7]. The SCFAs lower the pH of the colon milieu, allowing a better solubility of minerals, such as calcium, and an increase of their bioavailability, therefore reducing the risk of osteoporosis [8]. Some studies report a positive stimulation of the immune system associated with the colon by use of a high level of soluble fibre [9].

In recent times, the daily intake of dietary fibre is not adequate in many developed countries. The per capita intake of fibres amounts to 15–22 g·day^{-1} in Europe and only 13–16 g·day^{-1} in the USA. The recommended amount, however, is in the range of 25–35 g·day^{-1}; at least 6 g·day^{-1} of soluble fibre are necessary for an adequate beneficial effect on the intestinal tract [10].

Digestive discomfort or colon diseases often appear in people of advanced age who often lack physical activity and/or consume a diet high in fat and/or sugar and low in dietary fibre. These digestive troubles cannot be easily remedied just by a higher level of fibre intake, such as by an increase of fruit, vegetable, and/or cereals consumption in the daily diet. Here, the application of dietary fibre supplements or supporting pharmaceuticals with defined fibre components, such as specific oligo-

and polysaccharides, can be helpful [11]. The trend of using specific non-starch polysaccharides, in particular heteropolysaccharides, in commercial products with regulatory and wellbeing effects on the intestinal tract is increasing and will drive a strong demand in the future [12].

2. Non-Starch Polysaccharides in Cereal Grains and their Application in Healthy Products

A simple way to reach a fibre rich diet is the use of porridge (oat flakes) at breakfast or as a snack during the day. Oat flakes contain around 17% of dietary fibre, mainly β-glucan (5%) and arabinoxylan (3%). Rye flakes show similar results in dietary fibre (20%), containing mainly arabinoxylan (7.6%) and fructan (5.0%) in their composition. The most frequently consumed breakfast cereal, corn flakes, possess a relatively low fibre content (5%), with resistant starch (2%) and fructan (2%) as the main components [13], most likely due to the harsh processing operations during their manufacture and the dietary fibre profile of the corn grains used as raw material.

Oat has several unique properties making its milling different from other cereal grains. The hulls consist mainly of cellulose (30%) and pentosan, particularly arabinoxylan (30%), lignans (15%), and lignin. Within the hulls are located the groats (kernels of oat grain), which are softer than the kernels of other cereal grains, such as wheat, and therefore cannot be separated so easily into germ, endosperm, and bran fractions. The outer layer (bran fraction) includes a high content of β-glucan and the inner endosperm consists of protein, starch, and the germ fraction. The unique physiological structure of oat promotes the use of the whole grain to be processed into products with some unique nutritional qualities, such as oat flakes, steel cut oats, rolled oats, oat flour, and oat bran. Furthermore, the groats or the bran fraction are used to isolate high puritiy β-glucan for dietary supplements. Oat hulls (30% by-product of oat grain) can be applied for specific dietary supplements with a high content of cellulose and arabinoxylan [14].

Cereal β-glucan consists of unbranched β-D-glucopyranosyl units similar to cellulose, but with one 1,3 β-D-linkage for every three to four 1,4 β-D-linkages; it is a mixed-linked (1,3),(1,4)-β-D-glucan. The 1,3 β-D-linkages prevent close packing of the molecules and make β-glucan partly soluble in water [15]. β-glucans are recommended as prebiotics and can modify food texture, allowing their application as a fat substitute. Commercial β-glucan products contain around 35–60% pure β-glucan, with the possibility of being increased to 80–90% after specific chemical and enzymatic treatment. Because of the good balance between soluble and insoluble components, β-glucan are used as an ingredient in food, dietary supplements, and pharmaceuticals. Commercial food products containing a high level of β-glucan include pasta, oat flakes, cereals, and baked products. PromOat[®] is an example of a product containing oats β-glucan, however, the content is only about 35%.

Another source of dietary fibre with commercial interest is wheat bran, a by-product of the wheat starch industry [16]. Wheat bran is composed of approximately 50% fibre constituents (cellulose and lignin 25%, pentosan 23–25%, β-glucan 1%), 13–18% starch, and 15–18% protein. This high level of pentosan, mainly arabinoxylan, makes it an interesting ingredient for different healthy-oriented dietary fibre products.

The heteropolysaccharide arabinoxylan consists of L-arabinofuranosyl residues attached as branching points to β-(1-4) linked D-xylopyranose polymeric backbone chains, substituted or di-substituted on position O-2 or O-3, with a ratio of xylose:arabinose of around 2:1. More L-arabinofuranosyl disubstituted xylose units in the polymer deliver inter- and intra-molecular stability, with better solubility and high viscosity in the solution. The removal of arabinosyl-residues results in higher flexibility in the aqueous system; however, after total removal of the arabinose units, the unsubstituted xylan chains form water insoluble polymers. Ferulic acid residues ester-linked to arabinosyl- residues are found as well [17–19].

The commercial crude pentosan deriving from wheat bran includes 60–70% of arabinoxylan with a molar mass of 20×10^3 to 35×10^3 g/mol and shows high pH and temperature stability with a high prebiotic efficiency. Additionally, the product contains protein and parts of glucan, which can be removed by enzymatic treatment with amylase, cellulase, and protease. In the purified arabinoxylan functional groups of ferulic acid, esters are found, being able to build up higher polymer

components. Alkali treatment removes these esters and allows determining the de facto molar mass of the arabinoxylan polymers. The average molar mass is in the range of 20×10^3 g/mol.

Arabinoxylans are enclosed in wheat- and rye bread, being responsible together with starch and gluten for the dough quality in the bread making processes. High contents of water soluble arabinoxylan in dough generates a high-water binding capacity and delivers a greater volume of bread with excellent crumb structure. Particularly in rye bread, which lacks the gluten matrix, arabinoxylan is preferentially responsible for dough quality [20,21]. Thus, arabinoxylan allows for more and more extended application in the baked goods industry.

For people suffering from celiac, the use of arabinoxylan in the production of gluten- free bread and baked goods is a good alternative [16,22,23]. Celiac disease is an autoimmune regulatory defect caused by incomplete digestion of gluten, a protein fraction from wheat and some other cereals (barley and rye). The gluten peptides activate inflammatory T-cells in the small intestinal mucosa of patients with celiac disease, causing destruction of intestinal villa. Strict gluten-free diets over the lifetime are required [24]. Lectin intolerance can be found as well by intake of cereal grain products and induce negative symptoms in the gut. Heat (baking, cooking for a long time) removes much of the lectin, and thus its impact may be decreased [25]. A lectin-free diet has been the only remedy so far [26].

Production of gluten or lectin-free bread and baked goods with acceptable quality is a common and extreme challenge [27–29]. For the preparation of dough, a combination of rice or pseudo cereal flour with water soluble arabinoxylan delivers viscoelastic properties comparable to regular dough from wheat flour. The network of arabinoxylan/starchy body possesses a high viscosity consistency, aiding in the retention of gas bubbles during the fermentation and baking process. Thus, much research is being directed to the extraction technology of water soluble arabinoxylan from wheat and rye bran towards progress for a higher yield and better quality [22,30,31].

3. Galactomannan in Legumes and their Beneficial Effects in the Well-Being of the Intestinal Tract

The high proportion of dietary fibre in legumes, particularly in their seeds, make this plant family popular for including or increasing fibre intake in a common diet. However, a long water soaking period and/or high temperature cooking (e.g., in a pressure-cooking pot) is required before consumption for the removal of toxic or undesirable substances (e.g., lectins and phytin) and for a better digestibility in the intestinal tract. The content of fibre in cooked beans (e.g., white, black, or kidney) with around 10% dry matter is found to be between 2.5% to 3.5%, similar to peas (3%) and lentils (2.5%) [13]. The high swelling characteristic and water binding capacity is generated by the cellulose matrix, the starchy body, and the fibre material, mainly galactomannan. Water soluble galactomannan is an excellent prebiotic source as it can be fermented by specific probiotic bacteria in the large intestine. However, besides SCFA production, large amounts of gas can be produced, leading to discomfort. This may be caused by the fermentation of *Clostridium butyricum*, which produces gases (specially carbon dioxide) along with a high amount of butyrate [32,33].

Galactomannan consists of β (1,4) linked D-mannopyranosyl residues in the main chain with varying degrees of substituted α (1,6)-linked D-galactopyranosyl residues in the side chain. The ratio of galactose:mannose in the polymer molecules determine the water solubility and its bioavailability after consumption. A lot of legumes have seeds containing endosperms with thick secondary cell walls composed mostly of galactomannans. Aside from the discussed vegetable beans, further species of legumes are commercially used, such as guar (*Cyamopsis tetragonoloba*), locust bean (*Ceratonia siliquia*, carob tree), and tara (*Caesalpina spinosa*) gums [1,34–36]. The gums containing the galactomannans are obtained by removing the seed surface and the embryo. After milling the dry endosperm, the resulting powder contains mainly galactomannan with small proportions of protein and minerals. For further purification, water extraction with subsequent ethanol or isopropanol precipitation can be followed.

The notable structural characteristic of legume galactomannan is caused by the amount of single α-(1,6)-linked D-galactopyranosyl units linked along the mannan backbone as side stubs. Locust bean, tara, and guar gums contain mannose:galactose in ratios of about 4:1, 3:1, and 2:1 respectively [36];

the different numbers of D-galactopyranosyl residues in the structure of galactomannan from guar and locust bean dominate their features. For instance, locust bean gum with mannan chains substituted with only a small number of D-galactopyranosyl units allows for a high inter-chain associations of molecules (crystalline regions), these being responsible for its low solubility in cold water. After solubilization at higher temperatures (around 90 °C) it will be an excellent agent for gel formation in combination with, for example, agar, carrageenan, and xanthan [37]. On the other hand, guar gum with higher numbers of D-galactopyranosyl stubs in the mannan backbone can hydrate rapidly in cold water to form viscous solutions.

Generally, solutions of locust bean, tara, and guar gums, as well as of their products, deliver high viscosities even at low concentrations. So, they are often applied as thickening agents or stabilizers in low concentrations (less than 1% *w/v*) in food, particularly in dairy and bakery products or frozen desserts [36,38]. However, for a useful application of galactomannan as a fibre supplement or pharmaceutical preparation with positive effects on the intestinal tract, products generating low viscosity solutions at concentrations between 5–10% *w/v* are required.

For this purpose, a partial hydrolysis of galactomannan to low molar mass components is needed. Commercial guar gum, already forming viscous colloidal solutions in cold water (viscosity for a 1% *w/v* solution range from 2000 to 3000 mPa·s) is treated with endo-β-mannanase, under controlled conditions, to obtain partially hydrolysed guar gum (PHGG) [39]. The enzyme splits the β (1,4) linked D-mannopyranosyl residues in the main chain to smaller units with significant lower viscosity; a 5% *w/v* solution of PHGG shows a viscosity of less than 10 mPa·s. The molar mass of PHGG is in the range of 1×10^3 to 100×10^3 g/mol (6 to 600 polymer units), with an average molar mass of 20×10^3 g/mol (120 polymer units), approximately one-twentieth of the original dimension of guar galactomannan [40,41]. Specific purification, sterilization, and spray drying are done for commercial products being known under different trade names as Sunfiber®, Benefiber®, Resource®, or OptiFibre® [36].

Generally, PHGG products can be helpful against constipation, diarrhoea, and an unbalanced gut microbiota, i.e., after antibiotic therapy and/or infected bowel diseases. Moreover, daily intake of PHGG lowers the gut milieu pH and thus supports the growth of beneficial bacteria such as lactobacilli and bifidobacteria [32]. This statement is supported by an in vitro study stimulating the growing of specific *Lactobacilli* spp. and bifidobacteria by application of galactomannan oligomers under anaerobic conditions [42]. Simultaneously, the improvement of the balance of gut microbiota helps to avoid infection and colonization by pathogenic microorganisms (e.g., *Salmonella* spp.) and enables a healthy, trouble free intestinal function. Furthermore, the intake of PHGG promotes absorption of minerals, such as calcium, regulates lipid levels (reduced cholesterol and triglycerides) in serum without reduction of protein utilization, and reduces the level of plasma glucose, improving its regulation in conjunction with insulin response [32].

Lastly, the use of PHGG due to its prebiotic properties being useful to ameliorate digestive discomfort, acute and chronic diseases of the intestinal tract, and for the well-being of the bowel system the demand for commercial products on the market has increased. New formulations combining different fibres and/or supplements for healthy nutrition targeted towards specific applications has increased the demand for these products.

4. Plant-Based Fructans, Technological Use, and Prebiotic Effects

The use of fructan-containing plants in the kitchen as traditional vegetables is common worldwide, particularly the roots and shoots of chicory, tubers of Jerusalem artichoke, bulbs of onion and garlic, shoots of asparagus and leek, the flower bud of globe artichoke, banana, grains of cereals, and the stem of agave, all with different levels of fructan. These plants are excellent sources for dietary fibre with prebiotic efficiency [43].

Three types of fructan structure are present in plants: The inulin-type with β (2,1) linked D-fructofuranosyl-residues starting from the trisaccharide 1-kestose; the levan-type with β (2,6)

linked fructan starting from 6-kestose; and the mixed-type fructan containing both β (2,1) and β (2,6) linked D-fructofuranosyl-residues. Fructans are predominantly non-reducing carbohydrates due to their origin from the sucrose pool of plants. The amount of fructooligosaccharides (FOS) in plants (per definition, fructans with three of up to 10 monosaccharide units) varies widely, both in different species and even in different stages of plant development. Mixed type fructan from garlic or agave with a significant branching structure delivers molecules with a random coil characteristic and therefore offer an extremely good solubility in water compared to inulin with its mainly helical crystalline structure [44–47].

All fructan types are not digested in the small intestine, passing without degradation and being transferred directly to the large intestine where they are fermented by the microbiota. Common metabolites include SCFAs and some gases, and they help to establish the proper balance of a beneficial gut flora. No parts of fructan have ever been recovered in faeces. Many publications document the health-promoting effect of inulin and FOS for being a selective substrate for the fermentation by bifidobacteria, which are considered to be, together with lactobacilli, the main health-promoting bacteria in the large intestine [48–50]. Further confirmation comes from recent in vitro studies stimulating the growth of chosen *Lactobacilli* spp. and bifidobacteria by use of fructans from different sources [51–53]. These specific prebiotic characteristic makes it extremely useful for the application of fructan and FOS as soluble fibre (functional fibre) supplements in food and pharmaceuticals being able to support the well-being of the bowel and to avoid digestive discomfort.

Chicory (*Cichorium intybus* L.) and Jerusalem artichoke (*Helianthus tuberosus* L.) are predominantly used to produce inulin and FOS. Chicory roots or tubers of Jerusalem artichoke are washed, sliced, and subjected to hot-water extraction. The extracts are decolorized, demineralized, filtered, and concentrated. The concentrated extracts (40%) are converted to inulin powder by means of spray drying [54]. Inulin products are available in different grades of purity and molecular dimensions, with trade names such as Raftiline®, Frutafit®, and Fibruline®. For the preparation of FOS, native inulin is treated with endo-inulinase. Commercial FOS products are known as Raftilose®, Frutalose®, and Fibrulose® [1]. Most of these products possess a high solubility in water; native inulin (>20 monomer units) requires a high temperature treatment (more than 80 °C) for dissolving. The viscosity of 5–10% *w/v* solutions is very low and thus allows a broad field of application of fibre in food and pharmaceuticals [54,55].

To produce fructan from agave (*Agave tequilana* var. Weber), the stems of the plant (five to eight years old) are sliced and subjected to extraction with hot water (ca. 75 °C). The water extract is decolorized, filtered, and evaporated under vacuum to a syrup (containing 70% of dry matter). The spray drying of the syrup results in a white, amorphous powder of agave fructan [56]. Agave fructans can be further purified by splitting the native fructan into a high and a low molecular dimension product. Native agave fructan is commercially available under different brands (e.g., Oligofructine®), while high MW fructan and FOS can be commercially obtained with the trade names Metlin® and Metlos®.

Application of fructan and FOS isolated from agave deliver similarly successful health promoting effects as to inulin products from chicory or Jerusalem artichoke [57–59]. One of the advantages compared to inulin is their much higher solubility in cold water, without substantial influence on the viscosity. This behaviour makes it, besides inulin, an excellent source of soluble fibre for use in food and pharmaceuticals as well.

5. Heteropolysaccharides from Plant Mucilages and their Potential for Use in Healthy Products

Traditional medicine of the indigenous population from Asia, America, Australia, and part of Europe delivers hints in the use of mucilages (from seeds and leaves) against bowel diseases and digestive disorders. Their high content of soluble heteropolysaccharides, which both stimulates the growth of beneficial bacteria in the microbiota and generates highly viscous solutions at low concentrations, supports bowel peristalsis and increases faecal bulk and volume [1,34].

In Western countries, psyllium (ispaghula, *Plantago ovata* L.) or its husks, as well as flaxseed (also called linseed) (*Linum usitatissimum* L.), are often used in small portions (one teaspoon) in the daily diet as muesli preparations, particularly at breakfast. With this regular intake, constipation or mild diarrhoea can be avoided and the well-being of the intestine tract is basically supported. Generally, these supplements produce a viscous and mucilaginous solution with a palatable taste after swelling in cold water or milk. The existing heteropolysaccharides in these mucilages are responsible for the health promoting properties.

Psyllium is mostly cultivated in India today. The mucilage (6–8% of seeds) can be obtained by milling the seeds and is often referred to as husk. It contains around 60–70% heteropolysaccharides with acid and neutral constituents. Its composition is made up of a main chain of β-1,4-linked D-xylopyranosyl residues with branching in position O-2 and/or O-3 substituted by α-L-arabinofuranosyl residues with a ratio of xylose:arabinose of 3:1 [60]. This heteropolysaccharide is similar in structure to the arabinoxylan extracted from cereals (wheat and rye). In psyllium, arabinoxylan partly side stubs, including D-glucoronic- or D-galacturonic residues in the terminal position, are found. This highly branched characteristic as well as the anionic charged residues are responsible for an excellent solubility and a highly viscous behaviour in solution [61,62]. Despite the high viscosity, a regular treatment of psyllium mucous polysaccharide in hypercholesterolemic men causes a reduction of cholesterol and LDL level in serum of about 20%. These results indicate that psyllium products are an effective and well-tolerated therapy for mild to moderate hypercholesterolemia as well [63–65].

Flax seed mucilage (8–12% of seeds) contains around 70% heteropolysaccharides with an acid and a neutral polysaccharide fraction. The anionic charged polysaccharides (70% of the total polysaccharides) are responsible for the highly viscous characteristic of its solutions. The molar mass is between 500×10^3 and 600×10^3 g/mol [66–68]. The acid polysaccharide, rhamno-galacturonan I, is composed of the repeating disaccharide unit, (1,4)-α-D-galacturonic acid-(1,2)-α-L-rhamnose, with the rare L-galactopyranosyl units linked to O-3 of many of the L-rhamnosyl residues. The neutral fraction is an arabinoxylan with β-(1,4)-linked D-xylopyranosyl residues in the main chain and L-arabinofuranosyl residues attached simultaneously to O-2 and/or O-3 of the D-xylopyranosyl residues with highly branched characteristics [69–71].

In the common diet of the indigenous population in America and Asia, particularly India, Thailand, Puerto Rico, and Mexico, the seeds of chan (*Hyptis suaveolens* L.), chia (*Salvia hispanica* L.), or basil (*Ocimum basilicum* L.), all belonging to the Lamiaceae family, are applied to drinks or food with beneficial health effects. Recently, in Western countries, the trend is to increase their use and so are heavily marketed as super foods.

In Europe, chia seeds are being more and more integrated in food preparations with weight losing and slimming claims for people with active exercise regimes and controlled nutrition intake. Likewise, people with a controlled, health-conscious nutrition have a high interest in its application. The chia seeds are very small (2–3 mm diameter), but swell extremely in cold water, and deliver a mucilage with high viscosity and stability already at a low concentration. In fact, the seeds of chan, chia, and basil deliver similar mucilage consistencies; however, they contain a totally different composition of heteropolysaccharides, and with different prebiotic activity.

The mucilage of chan seeds (7% to 10% of seeds) contains approximately 60% heteropolysaccharides, with acid and neutral polysaccharide fractions showing a ratio of almost 1:1 [72]. The acid polysaccharide is composed of β-1,4-linked D-xylospyranose units in the main chain with branching points on C-2 with 4-O-methyl-D-glucuronic acid units and on C-3 with 2-O-L-fucopyranosyl-D-xylopyranose units [73,74]. This fraction possesses an average molar mass of 350×10^3 g/mol and is responsible for the swelling and viscous behaviour. In the neutral fraction, two polysaccharides-galactoglucan (25%), with a main chain of only D-glucopyranosyl residues, and galactoglucomannan (75%), with a main chain of random alternating D-glucopyranosyl and D-mannopyranosyl residues, are present. The side chains are composed only of D-galactopyranosyl residues in α- and β-linkages mainly linked to the D-mannopyranosyl residues in the main chain. The high level of terminal β-linked

D-galactopyranosyl residues with around 18% is representative. The average molar mass of the fraction is 47×10^3 g/mol [72].

The availability of β-linked D-galactopyranosyl residues in the neutral polysaccharides stimulates the growth of probiotic bacteria, mainly lactobacilli. The neutral polysaccharide was found to induce significantly the growth of most applied lactobacilli strains (11 out of 14), but with different prebiotic effectiveness, ranging between 10 and 20%. It can be concluded that the prebiotic activity of this polysaccharide is in its close relationship to the content of β-galactosidase in the lactobacilli strains [75–77]. A similar prebiotic characteristic was observed with poly- and oligosaccharide fractions being produced by endo-β-1,4-mannanase cleavage of the original neutral polysaccharide fraction [78]. The low viscosity of these fractions with prebiotic activity promises new approaches for their application in dietary supplements and pharmaceuticals with tailor made characteristics.

The mucilage of chia seeds (*Salvia hispanica* L.) (7–12% of seeds) contains around 65% of heteropolysaccharide consisting of only anionic charged polysaccharides, easily producing highly viscous solutions at low concentrations after soaking in cold water and possessing a molar mass of approximately 800×10^3 g/mol. The monosaccharide composition is D-xylose, D-glucose, and 4-O-methyl-α-D-glucuronic acid, in a ratio of 2:1:1, and supports the tentative structure of a basic polysaccharide as a tetrasaccharide with 4-O-methyl-α-D-glucoronosyl residues occurring as branches of β-D-xylopyranosyl residues in the main chain. This structure forms super molecular structures with highly viscous properties [79,80].

For this heteropolysaccharide, a low prebiotic effect on selected lactobacilli strains was found. The healthy properties lie in its ability to swell rapidly in aqueous media, e.g., forming voluminous viscous bulk for peristaltic activation in the human column tract [81]. Because of this property, the application of this acid polysaccharide in food and pharmaceutical products is particularly convenient.

The mucilage of basil seeds (8–12% of seeds) contains around 60% of heteropolysaccharide with an acid and a neutral polysaccharide fraction in the ratio of approximately 1:1 [82,83]. The average molar mass is 270×10^3 g/mol for the acid fraction and 56×10^3 g/mol for the neutral fraction. The monosaccharide composition is found to be L-arabinose, L-rhamnose, D-xylose, and D-galacturonic acid in the ratio of 1.5:1:2.5:1 with trace amounts of 4-O-methyl-α-D-galacturonic acid, D-galactose, and D-glucose for the acid fraction. The neutral polysaccharide shows L-arabinofuranosyl, D-galactopyranosyl, D-glucopyranosyl, and D-mannopyrosyl residues in the ratio of 1:4:2:1.5, with a high level of terminal β-linked D-galactopyranosyl residues (15%). Similar to the neutral polysaccharide of chan mucilage, the neutral basil polysaccharide induces the growth of selected lactobacilli strains as well, indicating that the neutral polysaccharide of basil may be a further prebiotic source for application in pharmaceutical formulations [84].

Another source of mucilage are the cladodes of nopal (*Opuntia* spp.) from the Cactaceae family. Depending on the species and age of the cladode the content of soluble fibre is between 1–2.5% by fresh weight. The mucilage of *Opuntia* is a highly branched polysaccharide, with a molar mass of 23×10^3 g/mol, and the monosaccharide composition includes arabinose, galactose, xylose, rhamnose, and galacturonic acid in a ratio of 8:3:4:1:1 [85]. The D-xylanopyranosyl and L-arabinofuranosyl residues are found as branches of the main backbone, composed of rhamnose, galactose, and galacturonic acid [86]. However, the structure of the mucilage is probably affected by the species and the development stage of the plant.

Among the reported healthy effects ascribed to consumption of *Opuntia* heteropolysaccharide are antihyperglycemic, antihyperinsulinemic, and lipid-lowering effects due to the general mechanisms described before. Moreover, an increase in lactobacilli and bifidobacteria and a slight decrease in pathogenic bacteria has been demonstrated [87,88].

6. Conclusions and Perspectives

The diversity of structures in plant polysaccharides with dietary fibre characteristics and specific physicochemical properties, such as water solubility, water binding capacity, swelling, and rheological behaviour, in solution opens many possibilities for their use in dietary supplements and pharmaceutical formulations. The present discussion of sources, use, and specific functionality of indigestible oligo- and polysaccharides confirms their high potential for pharmaceutical use. In fact, the emerging interest for plant polysaccharides as dietary ingredients, particularly in health-focused products against bowel disease, digestive disorders, and the support of the well-being of the colon, is increasing and thus may lead to a higher demand of new commercial products with specific properties for individual clientele or conditions.

Medical application of effective prebiotics in enteral nutrition products or orally delivered pharmaceuticals shows a positive healthy impact in the normalization and maintenance of bowel function, colon integrity, and in the shift towards a healthy, balanced gut microbiota. Currently, the major group of prebiotics in use are easily soluble fructan, particularly FOS, due to the low-viscous nature in solution and convenient flow characteristic of their solutions [89]. Possible trends in the development of new enteral products and oral drugs may go in the creation of new or modified oligosaccharides or low molecular dimension polysaccharides derived from novel sources, such as galactoglucomannan from the seed mucilage of *H. suaveolens* L. or galactomannan from legume seeds, with prebiotic and physicochemical characteristics similar to FOS. Additionally, oligo- and polysaccharides with different structure and specific functionality can be used as the basis for dietary supplements or pharmaceuticals without or in combination with probiotic active bacteria, predominantly lactobacilli species, for therapeutic application.

By-products from the processing of cereals to produce starch and/or flour, such as bran or hulls, are excellent sources for both insoluble and soluble dietary fibre. Their purified components, such as β-glucan or arabinoxylan, are useful for a specific implementation in effective prebiotic formulations. Moreover, there is an increasing demand of purified arabinoxylan to produce high quality, gluten and lectin free bread and baked products, which can be a valuable tool for people with gluten and lectin intolerance.

Oligo- and polysaccharides of galactomannan extracted from legume seeds are optimal sources for dietary fibre supplements with different viscosity and prebiotic characteristics. In addition, the heteropolysaccharides of mucilages from plant seeds and leaves present new possibilities to produce oligo- and polysaccharides with specific fermentability by the gut microbiota.

Generally, the discussed polysaccharides may be used as ingredients for tailor-made products, including one or more components with specific prebiotic and fibre characteristics, for the protection against bowel diseases and digestive disorders, as an increase in the quality of life by reaching a comfortable and well-regulated state of the intestinal tract.

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