RESEARCH ARTICLE

Nutriciological Aspects and Quality Control of Non-starch Polysaccharides

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ABSTRACT

Non-starch polysaccharides (NSP) are polysaccharides that are not able to be digested in the human gastrointestinal tract and are not absorbed into the blood. Despite this, NSP plays an important role in digestion and is used in the food and pharmaceutical industries and has a pronounced biological activity comparable to conventional drugs. Because of this, the development of such drugs and methods for their validation is very urgent and in demand nowadays. In this review, the most interesting and important NSP were considered; their biological effects and their use in the food and pharmaceutical industries were described. Further prospects for the standardization of these compounds are outlined, and ways of further work in this direction are proposed.

Keywords: Dietary fiber, Food industry, Non-starch polysaccharides, Pharmaceutical effects, Pharmaceutical industry, Quality control.

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INTRODUCTION

Non-starch polysaccharides (NSP), otherwise called dietary fiber (DF), are a group of plant polysaccharides that are characterized by their inability to be digested in the human gastrointestinal tract. The digestive enzymes of the human GI tract can only hydrolyze α-1,4-glucan bonds; NSP is composed of monosaccharide units linked predominantly by a β-glycosidic bond. Therefore, NSP are not hydrolyzed by amylases, is not absorbed into the blood, and are partially or completely decomposed by the microflora of the colon.[1]

Depending on the chemical structure, NSP are subdivided into 3 groups–cellulose, non-cellulosic polymers (some β-glycans, heteroglycans, mannans, xyloglucan and callose), and pectin polysaccharides. In addition to the NSP themselves, a number of oligosaccharides (raffinose, stachyose, verbascose), fructooligosaccharides, inulins, sugar alcohols, polydextrose, and resistant starch have similar properties. Despite the fact that dietary fiber is not digested, it plays a critical role in digestion and has biological activity. The data obtained allow us to consider some NSP as promising drugs that are not inferior in efficiency to conventional drugs; therefore, research, drug development and validation of methods for the analysis of NSP are relevant.[2] Formulas of main NSP are presented at Figure 1.

Cellulose

Cellulose is a polymer consisting of glucose residues connected to each other by β-1,4-bonds and hydrogen bonds between hydroxyl groups. Cellulose is classified as insoluble DF. The mass of this polymer is 1-million Da. Cellulose is present in the cell walls of all higher plants and is the most abundant biopolymer in nature.[1,3]

Hemicellulose

Hemicellulose is a heterogeneous polymer of pentoses (xylose and arabinose), hexoses (mannose, glucose and galactose) and sugar acids. Hemicellulose is found everywhere and is the second most abundant biopolymer after cellulose. In pharmacy, hemicellulose can be used as a binder, disintegrant, thickener and stabilizer.[4] Along with other NSP, cellulose forms an important component of the diet for the digestive system's proper functioning. When the colon microflora ferments non-starch polysaccharides, short-chain fatty acids (SCFA), methane, hydrogen and carbon dioxide are formed.[5] Through the formation of SCFAs and lowering the pH, NSP

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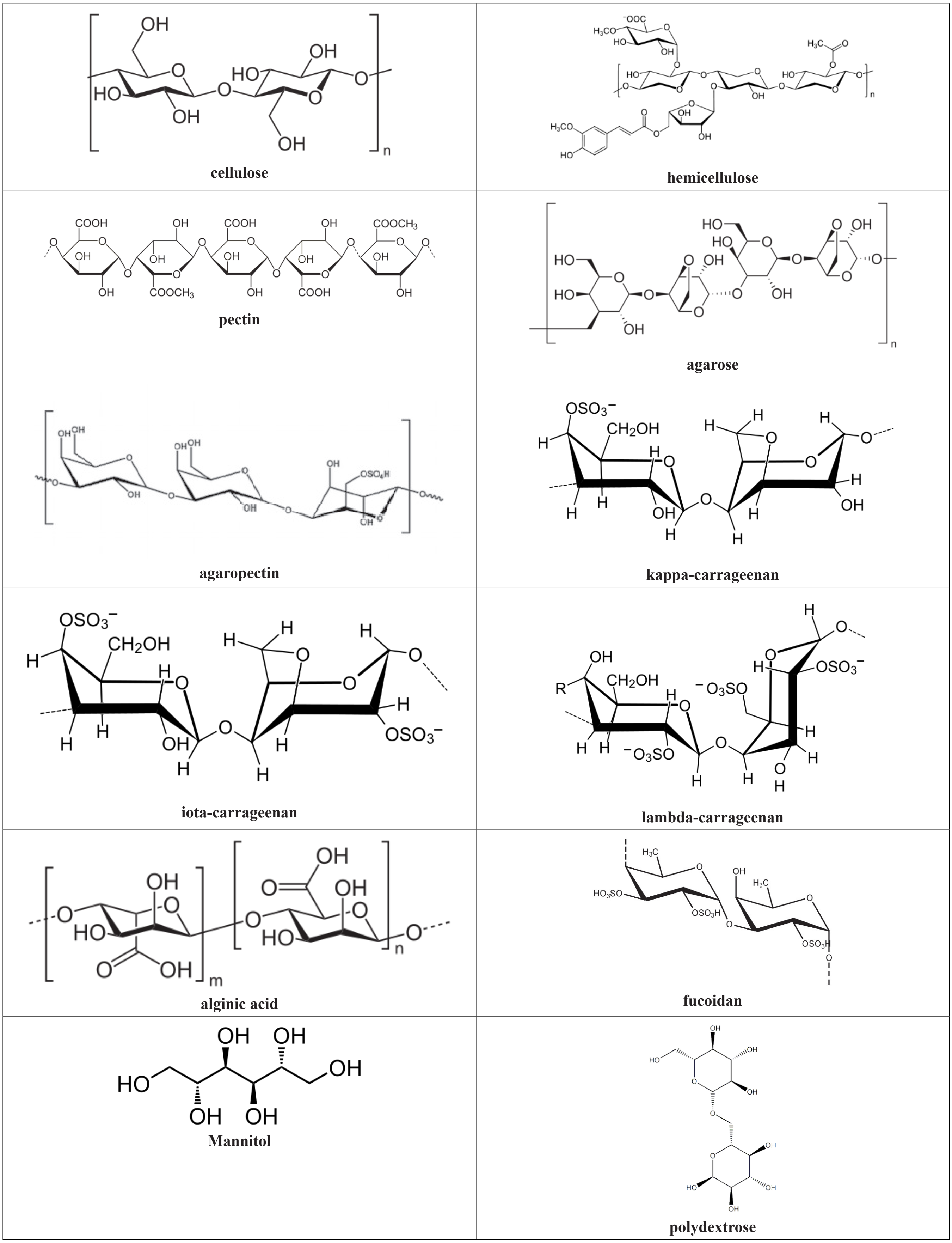

Figure 1: Formulas of NSP.

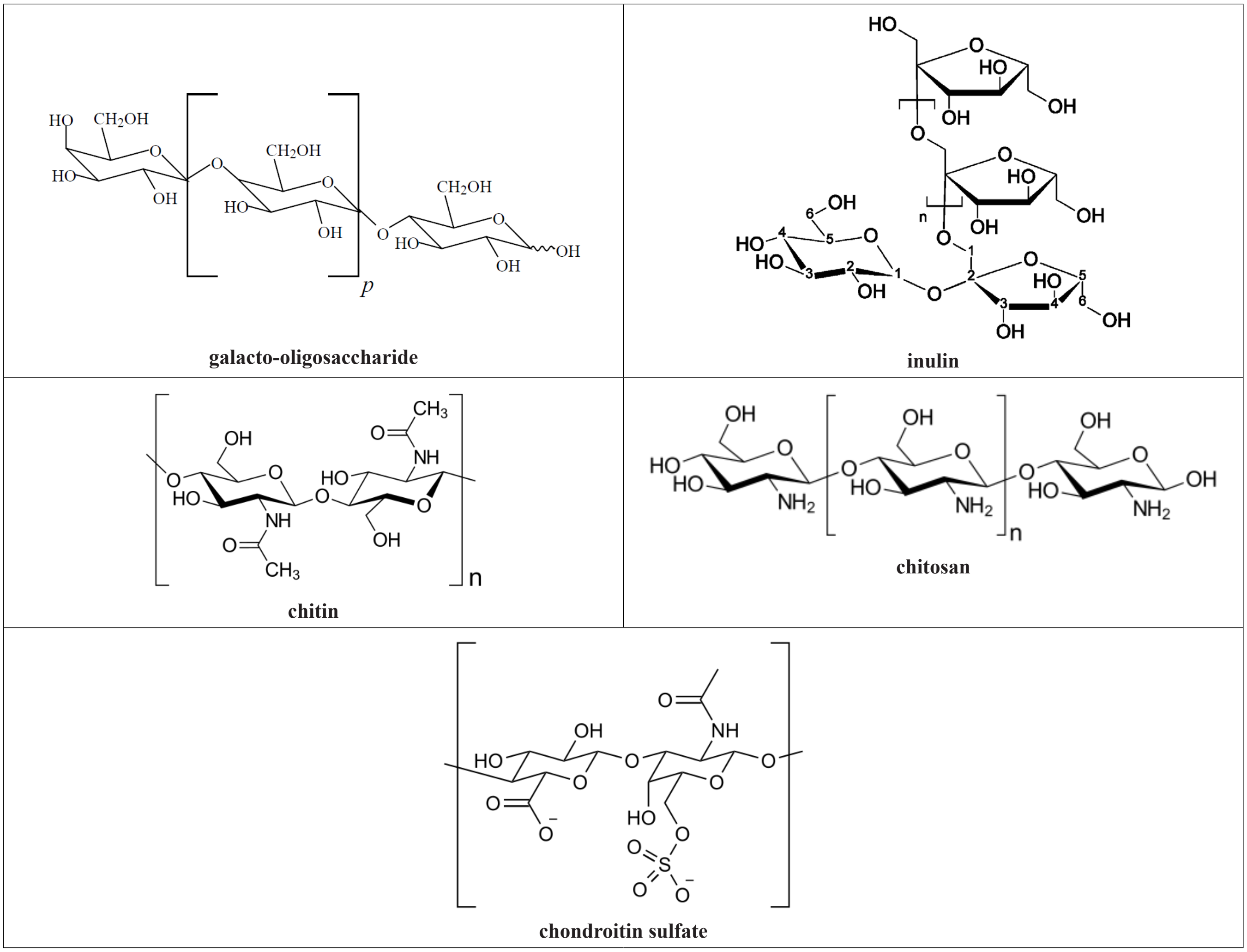

Figure 1: Formulas of NSP.

promotes Bifidobacteria and Lactobacilli's development and inhibit the growth of pathogenic bacteria, providing a prebiotic effect.[6] The increase in fecal mass due to the presence of enzyme resistant DF (especially insoluble ones like cellulose) stimulates colon passage and reduces water reabsorption, which leads to softening of the stool and thus prevents constipation.[7,8]

Pectins

Pectins are heteropolysaccharides, the main chain consists of α-1,4-linked D-galacturonic acid residues interrupted by insertions of 1,2-linked α-L-rhamnopyranose residues. There are 3 types of pectins–linear homogalacturonans, branched rhamnogalacturonans, and rhamnogalacturonan II.[2] Pectins are divided into high-ester pectins and low-ester pectins according to the percentage of galacturonic acid subunits that are methyl esterified. High-ester pectins are characterized by a degree of esterification of more than 50% (usually 60–80%), and low-ester pectins are less than 50% (usually 30–40%). Pectins are part of higher plants' cell wall, where they act as a cementing material for cellulose fibers.[1] Pectin are most preferred as stabilizers for acidic fruit gels due to their acid resistance. High- and low-ester pectins find maximum application in the production of jams and jellies. Low ester pectins are also used for icing production in the bakery industry. Other uses for pectin include both aqueous and milk-based gels. Low-ester pectin can be used to thicken the milk and dairy products because they contain calcium, which catalyzes the gelation of pectin.[9,10]

Pectins reduce serum cholesterol levels, which may be due to the binding of bile acids in the intestinal lumen and inhibition of cholesterol-7α-hydroxylase activity in the liver. Regular intake of pectins by volunteers with hyperlipidemia makes the fibrin network more permeable and easily lysed. It is noted that a drug based on colloidal bismuth and pectin is effective in the treatment of H. pylori-positive duodenal ulcer, which is possibly due to acidic damage to the microbial cell and inhibition of bacterial adhesion to the cellular epithelium. The revealed properties of pectins make it possible to recommend them for use in medical practice to treat acute intestinal infections and for the prevention and correction of dysbiosis, which develops against the background of antibiotic therapy and chemotherapy. Low-ester pectin, like alginates, effectively binds and removes heavy metals.[2,11]

Agar

Agar is a complex water-soluble polysaccharide, a mixture of a neutral fraction of agarose and a charged fraction of agaropectin. Agar is found in red algae of various families.[12] Agar is insoluble in cold water; it dissolves completely only at temperatures above 90°C. When cooled to temperatures of 35–40°C, agar becomes a clear and strong thermoreversible gel. The swelling substance of agar does not decompose in the intestine as it passes through it very quickly.[13] Agar finds its application in almost all areas of the food industry. The addition of salts improves the high melting point of agar gels. Therefore, agar is actively used in baking bakery and confectionery products.[9] Agar has a mild laxative effect, which is based on the fact that the agar significantly expands in volume, fills a large space of the intestine, and thereby stimulates peristalsis.[13,14]

Carrageenans

Carrageenans are sulfated galactans containing D-galactose and its derivatives, the residues of which are connected by regularly alternating β (1→4)-bonds and α (1→3)-bonds. In accordance with the structural features of the repeating unit, there are 6 main types of carrageenan: κ, λ, ι, ν, μ and θ. The carrageenans μ, ν and λ can be converted, respectively, into κ-, ι- and θ-carrageenans by alkaline or enzymatic modification. Real natural NSP rarely correspond to such idealized structures; a combination of two or more structures is usually observed.[15] The source of carrageenan is red algae belonging to the families *Gigartinaceae*, *Solieriaceae*, *Rhabdoniaceae*, *Hypneaceae*, *Phyllophoraceae*, *Petrocelidaceae*, *Caulacanthaceae*, *Cystocloniaceae*, *Rhodophyllidaceae*, *Furcellariaceae*, *Tichocarpaceae* и *Dicranemataceae*.[2] Kappa-carrageenan dissolves in hot water (70–80°C). It is insoluble in cold water. After dissolution and subsequent cooling, kappa-carrageenan gives solid, thermo-reversible gels with high jelly strength. Due to the transparency of the carrageenan gel and the high gelling temperature, this stabilizer is used in the preparation of water-based dessert gels and cake icings. Iota-carrageenan forms fewer firm gels than kappa, but they are much more elastic. Iota-carrageenan solutions have thixotropic properties; therefore, iota-carrageenan is mainly used as a suspension stabilizer. Lambda-carrageenan does not form gels. However, it forms highly viscous solutions, so this fraction is suitable for foams, emulsions and suspensions, especially under changing temperature conditions.[13] Carrageenans are capable of influencing the production of anti-inflammatory cytokines, exerting both immunostimulating and immunosuppressive effects, inhibiting the replication of some viruses, including the hepatitis A virus.[16-18]

Alginic Acid

Alginic acid consists of β-D-mannuronic and α-L-guluronic acid residues linked by (1→4) bonds. The polymer thread of alginates consists of homopolymeric polymannuronic and polyguluronic regions, or blocks, between which alternating residues of both acids can be located. Monovalent metal and ammonium alginates are water-soluble and form viscous, sticky solutions. Alginates of polyvalent metals are both soluble and insoluble. They can be monocationic, when cations of one metal are involved in the formation of alginate, and polycationic, with cations of several metals. Alginic acid and its salts are found mainly in the seaweed of the Phaeophyta family and in red algae of the *Corallinaceae* family. It is now known that bacteria belonging to the genera *Pseudomonas* and *Azotobacter* contain acetylated alginates. In algal thalli, phycocolloids are the primary components of cell walls and extracellular matrix, playing the role of a "skeleton" and providing the tissue's strength and flexibility.[19] Alginates can form gels without preheating since sodium alginate is highly soluble in cold water and these cold gels are thermally stable. This makes alginates preferred stabilizers for restructured products such as custards, puddings and desserts; however, it should be borne in mind that alginates are incompatible with milk.[20,21]

The most promising property of alginates is their ability to bind radionuclides, especially radioactive strontium. Alginates inhibit their absorption in the gastrointestinal tract and enhance the excretion of strontium deposited in the bones. Along with pectins, alginates effectively bind and remove heavy metals from the body without disturbing the absorption of zinc, iron and calcium.[2] Alginates also have a gastroprotective and antitoxic effect in experimental toxic hepatitis; they reduce the level of lipid peroxidation products, normalize cholesterol and triglyceride levels in hyperlipidemia.[22]

Fucoidans

Fucoidans are fucose-containing sulfated polysaccharides found in the extracellular matrix of brown algae, in the egg membranes of sea urchins and in the body wall of sea cucumbers. There are two types of fucoidans. Type I consists of 1,3-linked α-L-fucopyranose residues, and type II consists of alternating 1,3-and 1,4-linked α-L-fucopyranose residues. The main chains can contain carbohydrate (L-fucopyranose, D-glucuronic acid) and non-carbohydrate (sulfate and acetyl groups) components. Galactose, glucose, mannose, xylose, and glucuronic acid may be present as minor components.[2] Fucoidans exhibit immunomodulatory properties, which determine the gastroprotective effect; a complex anti-inflammatory effect and cardioprotective, antioxidant, anticoagulant, and anticancer activities are also noted.[23] Fucoidans exhibit high antiviral activity.[24]

Polyalcohols

Polyalcohols (alditols)–NSP, reduction products of the aldehyde group of monosaccharides. These include sorbitol, mannitol, xylitol, and other compounds. Alditols are found in fruits, some vegetables and mushrooms. In the food industry, they are used mainly as sweeteners and sugar substitutes since they have a lower calorie content; a number of them are used as bulk agents, emulsifiers, stabilizers and anti-caking additives, including in pharmacies. The biological effect of alditols is versatile – they exhibit antioxidant and prebiotic properties, act as laxatives.

Mannitol is used in medicine as a powerful osmotic diuretic.[25]

Polydextrose

Polydextrose is a soluble synthetic polymer with a mass of about 2000 Da, obtained by polycondensation of glucose and sorbitol from a melt in a vacuum. Polydextrose is used as a bulk agent and texturizer and is very low in calories.[26] It was noted that taking polydextrose softened stool, as in the case of other DF.[27]

Galactooligosaccharides

Galactooligosaccharides (GOS) are oligosaccharides composed of D-galactose residues. GOS are found in milk. At the moment, GOS are produced by enzymatic synthesis. Synthetic galactooligosaccharides have unique properties as substitutes for breast milk oligosaccharides in infant formula.[28] The use of galactooligosaccharides of high purity as prebiotics induces adaptive shifts in the microbiome, which allow for the achievement of lactose tolerance in patients suffering from lactose malabsorption.[29]

Fructans

Fructans are water-soluble polymers of fructose that act as storage polysaccharides in some plants. In fructans of the inulin-type, fructose residues are linked by a β-2,1-bond. The short-chain fructans are called fructooligosaccharides. Families such as Liliaceae, Amaryllidaceae, Compositae and Gramineae are the main sources of inulin. Inulin exhibits the ability to foam and is used as a fat substitute in dairy and bakery products. In addition to the prebiotic and laxative effects, inulin and fructooligosaccharides reduce VLDL concentration and glucose in the blood.[30] Fructans exhibit a prebiotic effect due to the decomposition to SCFA and the growth of the microflora of the large intestine. It is noted that low dosages of prebiotics help to reduce the manifestations of irritable bowel syndrome.[31,32]

Chitin, Chitosan

Chitin is a polymer synthesized in animals, mainly in crustaceans, mollusks, and insects as an important component of the exoskeleton, and in some fungi as the main fibrillar polymer of the cell wall.[33] Chitosan is a β-1,4-2-amino-2-deoxy-D-glucose polymer obtained from chitin by deacetylation. Chitosan is notable for its large number of chemically reactive amino groups. The polymer chain of chitosan contains more than 5000 acetylglucosamine and glucosamine residues, which corresponds to a molecular weight of about 1000 kDa. In structure, chitosan resembles cellulose; the difference between them is that chitosan contains an amino group in the C-2 position, while in cellulose there is a hydroxyl group in this position. Chitin and chitosan have a number of unique biological properties. The main advantages are biocompatibility, biodegradability, hypoallergenicity, and lack of toxicity. In addition, chitin and chitosan have antimicrobial, hemostatic and wound healing properties; they can be used in the form of films, gels, and various forms for applying to the surface of the wound.[34-38]

Chondroitin Sulfate

Chondroitin sulfate is a mucopolysaccharide consisting of glucuronic acid and N-acetylgalactosamine. In industry, chondroitin sulfate is mainly obtained by extraction from animal cartilage.[39] Chondroitin sulfate, in combination with glucosamine, has been noted to significantly reduce pain in patients with osteoarthritis of the knee with moderate to severe pain.[40] At the moment, chondroitin sulfate-based redox-responsive nanoparticles are being developed. They act as carriers for docetaxel, an antineoplastic agent. These nanoparticles are highly effective against melanoma.[41]

Gums

Gums are water-soluble non-starch polysaccharides. Chemically, gums are heteropolysaccharides and consist of sequentially linked simple carbohydrates (glucose, galactose, arabinose, rhamnose) or D-galactomannans, and also contain D-glucuronic and D-galacturonic acids. The chemical composition of gums depends on many factors; therefore, it is not possible to establish the exact structure of natural gums. Higher plants produce gum arabic, guar gum, locust bean gum, tara gum, karaya gum, ghatti gum and gum tragacanth. Gellan gum and xanthan gum are obtained by bacterial fermentation.

Gums are widely used in pharmacy as thickeners, stabilizers, emulsifiers or gelling agents in oil emulsions, blood-substituting solutions, and other dosage forms.[42] In addition, gums have biological activity. For example, gum arabic exhibits antioxidant properties, lowers the concentration of glucose, total cholesterol, triglycerides, and LDL in the blood, increases the absorption of water and sodium, and reduces fat deposition in the body and affects macrophages.[43]

Quality Control of Non-starch Polysaccharides

Currently, the identification of NSP in food products is based on rather laborious, low specific techniques. Qualitative reactions based on different solubility of NSP in alkaline solutions, or on the formation of precipitates with calcium, iron, lead, copper, aluminum, ammonium salts are used for identification; TLC identification of acid hydrolysis products with monosaccharide reference standards is used. It is also possible to determine the IR spectra of the purified fractions from the product. A more accurate and specific method is gas chromatography-flame ionization detector (GC-FID) after derivatization (silylation) of hydrolysis products.[44] Quantification of DF is carried out by the gravimetric method, which involves the treatment of the sample with enzymes (α-amylase, protease, amyloglucosidase), and determination of insoluble and soluble fractions of DF.[1,2,42,45-48]

In qualitative analysis, the TLC method with carbohydrate standards can be used; for the quantitative method, the gravimetric method (precipitation of the entire NSP fraction without separation with ethyl alcohol) and the spectrophotometric method (formation of colored hydrolysis products–fructose and glucose with resorcinol and picric acid). A more promising method is HPLC-RID, which allows simultaneous qualitative analysis of the composition of NSP monomers and quantitative assessment after acidic or enzymatic hydrolysis of NSP In the case of using enzymatic hydrolysis in sample preparation (for example, inulin)[49-50], the analysis time is significantly reduced, and its accuracy is increased due to the decrease in losses during acidic destruction of monosaccharides. At present, modern methods of analysis of NSP based on the HPLC-RID method are being developed in the laboratory of food chemistry of the Federal State Budgetary Scientific Institution "Federal Research Center of Nutrition and Biotechnology".

CONCLUSION

NSP is a rather heterogeneous group of compounds that differ in monomers, chemical composition, food, and pharmacological properties, often possessing a pronounced pharmacotherapeutic effect. They have found application in various areas of the food and pharmaceutical industries as emulsifiers, thickeners, stabilizers, binders, disintegrants, gelling agents, foaming agents, anti-caking agents and components of infant formula. The development and quality control of food products and dietary supplements with a high level of NSP content are important areas of research work based on data on the specific activity of NSP. It should be noted that many NSP have a pronounced ability to lower blood lipids and glucose, reduce the deposition of fat in the body and have prebiotic, laxative, immunomodulatory, gastroprotective, cardioprotective, chondroprotective, hemostatic, diuretic, anti-inflammatory, anticoagulant, anticancer, antibacterial, antiviral, antioxidant and antitoxic effects. Thus, the development of new dietary supplements and drugs based on NSP seems to be a very urgent task.

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