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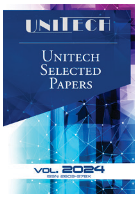

CHARACTERIZATION, FUNCTIONAL PROPERTIES AND APPLICATIONS OF POLYSACCHARIDES.

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Abstract

The natural polysaccharides described in this study are some of the most widely used biopolymers with food, pharmaceutical, and medical applications. The fundamental understanding needed to fully utilize their potentialin in the food and pharmaceutical industries depends on the detailed study of these polysaccharide molecules. Polysaccharides such as inulin and pectin are preferred polymers due to their availability in plant raw materials. As a result, the study will provide detailed information about those natural polymers - inulin and pectin, their biological uses, functional properties and their roles in both the food and pharmaceutical sectors. This study also explores both conventional and innovative, green extraction methods, such as microwave-assisted and ultrasonic extraction, which enhance yield and reduce environmental impact. By examining the functional properties and applications of inulin and pectin, this research highlights their prominent roles in supporting healthier, more sustainable products in food and pharmaceuticals, thereby contributing to the advancement of the bioeconomy.

Keywords: polysaccharide, biopolymers, food, industry, pectin, inulin, properties.

INTRODUCTION

Polysaccharides are important components of higher plants and have attracted increasing attention due to their numerous benefits in the food industry. Fructans are heterogeneous fructose polymers that serve as reserve carbohydrates in various plants, representing one of the most important types of natural polysaccharides. Fructans have various physiological and therapeutic effects that are beneficial to health and have the ability to prevent or treat various diseases, which allows their widespread use in the food and pharmaceutical industries (Wang and Cheong, 2023).

Polysaccharides are carbohydrates formed by the condensation of monosaccharide residues through hemiacetal or hemi-ketal bonds. They also exist as short oligosaccharide chains or polymeric repeating units linked to other biomolecules to form glycoproteins, proteoglycans, peptidoglycans, glycolipids, lipopolysaccharides, teichoic acids, and nucleic acids. Polysaccharides are widely distributed in flora and fauna. In situ, they perform a wide range of functions such as structural role, energy storage, gel formation and many important biological functions. Due to these functional differences, polysaccharides are used in both food and non-food industries.

In terms of physiological functions, polysaccharides can be classified as storage substances, structural substances and protective substances. Starch, glycogen, β-D-glucans, fructans and galactomannans are some examples of reserve polysaccharides that are rapidly metabolized. Structural polysaccharides are further classified into two groups:

1. Fibrous polysaccharides, including cellulose (in higher plants and some algae); chitin (in arthropods, yeasts and fungi); 3-linked-β-D-xylans and 4-linked β-D-mannans (in some plants and algae).
2. Matrix polysaccharides (including gel-forming polysaccharides) are those that provide size/shape and rigidity to the cell wall matrix (Ramesh and Tharanathan, 2003).

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EXPOSITION

Inulin.

Fructans are polysaccharides or oligosaccharides composed of a predominant fructose and glucose molecule. Fructans in nature can be divided into five groups based on the primary trisaccharides 1-kestose, 6-kestose and neokestose. Inulin-type fructans are linear with fructosyls linked by β(2→1) and β(2→6) glycosidic bonds, respectively, extending from 1-kestose and 6-kestose, with a glucosyl molecule at the non-reducing end. Fructans are widely distributed in plants, have a crucial role in energy storage and tolerance to abiotic stress, and act as virulence factors or signaling molecules. Fructans protect plants from drought, salinity and cold stress through their osmoregulatory functions (Dawei et al., 2024).

Inulin is a polydisperse, linear carbohydrate polymer consisting mainly, if not exclusively, of fructose units (F) linked by β(2→1) linkages. Fructan, a more general name, is used for any compound in which fructosyl-fructose linkages constitute the majority of the linkages. An initial glucose unit (G) may be present in the chain, but is not required. The GFn and Fn compounds are included in the same nomenclature and are both mixtures of oligomers and polymers that are characterized by an average and maximum degree of polymerization (DP). In chicory inulin, n, the number of fructose units can vary from 2 to 60. Its molecular structure is shown in Fig. 1 (Imeson, 2009).

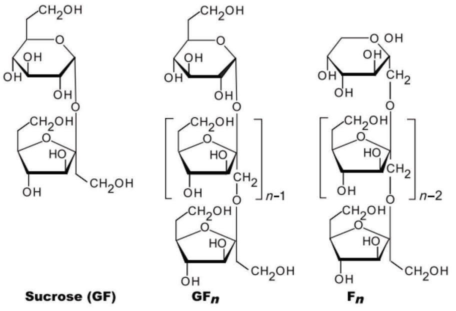

Fig. 1. *Molecular structure of inulin-type fructans (Imeson, 2009).*

Inulin is one of the most widely studied fructans due to its wide distribution, versatile properties and prebiotic effects. It has been used in the food, pharmaceutical, cosmetic, feed and material industries. Many plants that contain inulin are esculent, which also suggests its safe use (Dawei et al., 2024). Inulin has been accepted as "generally recognized as safe" (GRAS) since 2002 and was approved as a dietary fiber ingredient to improve the nutritional value of manufactured food products in 2018 by the Food and Drug Administration (FDA) (Ni et al., 2019). The degree of polymerization (DP) of plant inulin typically ranges from 2 to 60 and is influenced by plant sources, growing periods, harvest time and extraction processes (Ni et al., 2019).

Pectin.

Pectin is a structural polysaccharide found in the cell wall of plants, known as a high molecular weight macromolecule that can transform into a hydrogel and form a flexible network of polymer chains. Commercial pectin is usually extracted from apples and citrus fruits. However, research has focused on the extraction of pectin from various industrial by-products, which is presented as a green option for the valorization of agro-industrial residues, in line with the concept of a circular bioeconomy (Freitas et al., 2021).

Pectin has a complex structure formed by homogalacturonan (HG), rhamnogalacturonan I (RGI), rhamnogalacturonan II (RGII) and xylogalacturonan (XG) (Fig. 2). Despite their common characteristics, pectins can exhibit different structures, varying depending on the source and extraction method. In this sense, it is important to note that pectin is susceptible to physical, chemical and/or enzymatic modifications. The numerous functional groups present in the pectin structure can promote different functionalities and certain modifications allow pectin to have multiple applications, mainly because it is a product considered safe, non-toxic, with low production cost and high availability. Recent studies indicate that pectin derivatives with reduced molecular weight present new functional groups, which could lead to new applications for the use of this polysaccharide, i.e. expanding the applications of pectin (Freitas et al., 2021).

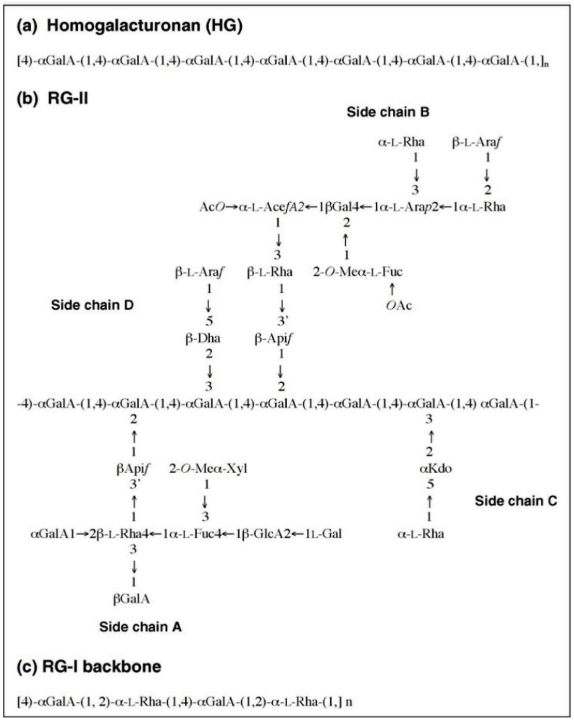

Fig. 2. *Structures of specific domains of pectic polysaccharides (Mohnen, 2008).*

Green methods for the extraction of polysaccharides from plant raw materials.

Inulin extraction.

The extraction of inulin from plants and fungi has attracted the attention of many researchers. Several methods have been developed for the extraction of inulin. A pretreatment method is used, which involves extraction from tubers with boiling water for 10–15 minutes. Hot water treatment is used for classical inulin extraction. It should be noted that hot water extraction of inulin is associated with a long extraction time and high temperature. It is desirable to study and use economical methods for the extraction of inulin that have high yield and activity. The application of ultrasonic and microwave extraction are very promising methods for obtaining high yield and activities, as was concluded from studies on the extraction of proteins and medicinal compounds, etc. (Milani et al., 2011). Microwave extraction (MAE) and ultrasonic extraction (UAE) are considered as improved methods for the extraction and isolation of polysaccharides, especially inulin. These two methods can accelerate the extraction process and improve the extraction of bioactive compounds (Petkova et al., 2017).

Scientists applied ultrasonic technology to the extraction of inulin from burdock root to increase the extraction yield. The results show that the central composite design CCD is a useful tool to optimize the extraction procedure and achieve the desired response variable. It is demonstrated that the second-order polynomial model is suitable for predicting the extraction yield. The optimal conditions for inulin extraction indicate that the use of ultrasonic technique will increase the extraction of inulin from burdock root (Milani et al., 2011).

A microwave-assisted extraction (MAE) procedure has been developed to produce alcohol-insoluble residues (AIR) from artichoke stems and bracts. Compared to using convective heating for AIR extraction, MAE consumes less time and solvent volume and also allows the extraction of higher amounts of total carbohydrates and lower protein content (Domingo et al., 2020). The benefits of applying microwave extraction are based on the reduction in time and solvent volumes when using microwave processing plus the potential for its application to other plant by-products and the scalability of the process, which is currently being investigated (Domingo et al., 2020).

Pectin extraction.

Commercial pectin is produced using a well-established industrial process known as hot acid extraction. This process uses fruit peels and pomace (mainly citrus and apple juice by-products) to produce a “smooth” pectin that is rich in homogalacturon (HG) and has favorable gelling and stabilizing properties for jams and jellies. It is well known that acidic conditions are favorable for the extraction of HG-rich pectin (Mao et al., 2023).

There has been significant progress in the field of microwave extraction of pectin since the last major review in 2017, and this has led to a definite increase in the body of evidence that MAE can provide advantages based on its unique selective and volumetric heating mechanisms, can be selectively applied to different feedstocks to exploit microwave heating mechanisms, and at scale MAE processes can provide higher yields of higher quality pectins with lower environmental impacts compared to conventional extraction processes.

This progress has placed researchers and industry in a position to commercialize this technology and pave the way for the development of a wide range of new products based on pectin from "waste" (Mao et al., 2023).

Inulin applications in the food industry.

In foods and beverages, inulin can be used either for its nutritional benefits or for its technological properties, but it is often applied to offer a dual benefit: improved organoleptic quality and a better balanced nutritional composition. The use of inulin as a dietary fiber is easy and is often used in all types of food products, although it is increasingly used in "functional foods", especially in a whole range of dairy products, as a prebiotic ingredient to stimulate the growth of beneficial intestinal microflora or to increase calcium absorption in the human body (Coudray et al., 1997).

Low amounts of inulin can significantly improve the mouthfeel and creaminess of low-fat dairy products, such as yogurt and cheese, frozen desserts, meat pates, sauces, soups and table bases with a continuous fat content. Long-chain inulin is also able to provide structure in continuously water-containing spreads, such as spreads and cream cheese, and increases the stability of whipped dairy desserts (Imeson, 2009).

There is considerable interest in inulin as a soluble fiber with prebiotic benefits to selectively promote the growth and activity of beneficial bacteria, mainly bifidobacteria (Imeson, 2009).

Applications of pectin polysaccharides in the food industry.

Pectin can be used for a variety of applications, mainly because it is a safe, non-toxic product with low production costs and high availability. Furthermore, its functionalities are influenced by its structure. In this sense, detailed topics on the application of pectin are described below (Freitas et al., 2021).

Pectin is commonly used in the food industry as a gelling, thickening, stabilizing and emulsifying agent. Pectin forms hydrogels and is therefore widely used in hydrated and viscous foods. Popular for use in jams, fruit juices, desserts, dairy products and jellies, the gelling properties of pectin are well known. Its use as a stabilizing agent in colloidal dispersions ranges from emulsions, antioxidant-enriched foods, acidified dairy drinks and high-protein fruit drinks. Pectin also has antioxidant capacity, which may be due to its ability to chelate metal ions. This capacity is influenced by the source and extraction method once it is bound to pectin DE. Adding pectin to food emulsions as an antioxidant can benefit multiple functionalities and reduce synthetic additives and achieve clean label products (Freitas et al., 2021).

CONCLUSION

Polysaccharides, particularly inulin and pectin, are valuable natural compounds that have an important role across various biological and industrial contexts. Inulin, a fructan-type polysaccharide, exhibits significant potential due to its prebiotic properties, compatibility as a dietary fiber, and wide-ranging applicability in enhancing the organoleptic qualities and nutritional profiles of food products. Advanced extraction methods such as microwave-assisted and ultrasonic extraction have improved the efficiency and environmental sustainability of inulin isolation, paving the way for increased application in both food and non-food industries. Similarly, pectin, known for its structural role in plant cell walls, offers valuable gelling, stabilizing, and emulsifying properties, making it a key component in food formulations such as jams, dairy products, and fruit-based beverages. Innovations in green extraction methods, particularly microwave-assisted extraction, have allowed for more sustainable and effective pectin isolation, promoting the use of agro-industrial by-products within the circular bioeconomy framework. The ongoing development of these technologies underscores the importance of polysaccharides as multifunctional biomolecules with expanding applications, supporting a shift towards more sustainable, health-promoting, and high-quality products in the food and pharmaceutical industries.

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