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Review

Inulin-type fructans: A review on different aspects of biochemical and pharmaceutical technology

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ABSTRACT

Inulin is a natural storage polysaccharide with a large variety of food and pharmaceutical applications. It is widely distributed in plants, being present as storage carbohydrate in more than 30,000 vegetable products. Due to their wide distribution in nature and significant role in industry, the extraction, isolation and characterization of inulin-type fructans are gaining attention in recent years. Inulin sources have recently received increasing interest as they are a renewable raw material for the production of bioethanol, fructose syrup, single-cell protein and single cell oil, obtainment of fructooligosaccharides and other useful products. This review focuses on the state-of-the-art of biochemical and pharmaceutical technology of inulin-type fructans.

Contents

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1. Introduction

Inulin is a natural, plant-derived storage polysaccharide with a large variety of food and pharmaceutical applications. It is a substitute for sugar or fat having a very low caloric value, acts in a similar way as dietary fibers and contributes to improve gastrointestinal system conditions. Among other possible pharmaceutical applications are its use as an orally delivered drug targeting the colon, to delay absorption of drugs with adverse effects on stomach, or the treatment of diseases that show a peak in symptoms in the early morning (Barclay, Ginic-Markovic, Johnston, Cooper, & Petrovsky, 2012). Because of these properties, food and pharmaceutical industries have been finding applications of inulin and its derivatives such as fructooligosaccharides (FOS) in the production of functional foods, nutritional composites and drugs (Barclay, Ginic-Markovic, Cooper, & Petrovsky, 2010; Barclay et al., 2012; Cummings, Macfarlane, & Englyst, 2001; Judprasong, Tanjor, Puwastien, & Sungpuag, 2011; Laparra, Tako, Glahn, & Miller, 2008; Matusek, Meresz, Le, & Oersi, 2009; Morris & Morris, 2012).

Inulin is widely distributed in a variety of plants as storage carbohydrate, being present in more than 30,000 vegetable products (Wichienchot et al., 2011), among which are the tubers of *Helianthus tuberosus* (Jerusalem artichoke), *Cichorium intybus* (chicory), *Dahlia pinnata* (dahlia) and *Polymnia sonchifolia* (yacon) (Braz de Oliveira et al., 2011). It was discovered by the German scientist Valentine Rose, in the early 1800s, as a carbohydrate source from the roots of *Inula helenium*, and after named inulin by Thomson in 1817. The plant physiologist Julius Sachs, who was a pioneer in fructan research, was able in 1864 to detect, using a microscope, the spherocrystals of inulin in the tubers of *D. pinnata*, *H. tuberosus* and *I. helenium* after precipitation with ethanol (Franck & De Leenheer, 2005). It was shown to be a mixture of oligo- and/or polysaccharides composed of fructose units with β-configuration of the anomeric C_2, which makes inulin-type fructans resistant to hydrolysis by human intestinal digestive enzymes that have specificity for α-glycosidic bonds. For this reason all these compounds have been classified as nondigestible oligosaccharides (Roberfroid, 2007).

Plant inulin has chains incorporating from 2 to 100 fructose units, whose length, composition and polydispersity depend on the plant species, the phase in its life cycle, the harvesting date and the extraction and post-extraction procedures (Barclay et al., 2010; Ronkart et al., 2007). Inulin can be hydrolyzed by both endo- and exo-inulinases. The exo-inulinases remove the terminal fructose residues from the non-reducing end of chain, while the endo-inulinases act on the internal linkages (Braz de Oliveira et al., 2011; Ertan, Ekinci, & Aktac, 2003; Ronkart et al., 2007).

This review focuses on the state-of-the-art of biochemical and pharmaceutical technology of inulin-type fructans with emphasis in their biosynthesis. Moreover, the methods for isolation and characterization of inulin from different vegetal species are described and biotechnological applications of these carbohydrates are related.

2. Fructans: origin and role in plants

Inulin-type fructans are water-soluble fructose-based polymers that result from extended sucrose metabolism (Weyens et al., 2004). In plants, they are frequently stored in leaves and others organs acting as carbohydrate reserve (Ritsema & Smeekens, 2003). These fructan-containing plant species are found in a number of mono and dicotyledonous families such as Liliaceae, Amaryllidaceae, Gramineae and Compositae. In Liliaceae, Amaryllidaceae and Compositae, inulins are usually stored in bulbs, tubers and tuberous roots (Braz de Oliveira et al., 2011). Besides this, fructans have been reported to play a fundamental role also in osmoregulation, to act as protectants against dehydration induced by drought or freezing and to be involved in abiotic stress–tolerance (Livingston, Premakumar, & Tallury, 2006; Ritsema & Smeekens, 2003).

These substances play an important role in the quality control of fruits because several pathways that link the synthesis and breakdown of these carbohydrate reserves are in dynamic equilibrium and determine fruit quality during storage. Alterations in the pattern of soluble sugars are often associated with increased cold hardiness in a wide range of plant species (Gibson, 2005). The stress/tolerance response by changes in FOS accumulation in tablet grape was monitored after high CO_2 treatment, during low temperature storage, and the results showed an increasing FOS accumulation (Blanch, Sanchez-Ballesta, Escribano, & Merodio, 2011)

Some species growing in arid habitats develop photosynthetic adaptive processes such as the crassulacean acid metabolism (CAM) that allow them to efficiently uptake CO_2 at night and use water. Fructans are photosynthetic product of CAM and act as osmoprotectants during drought (Borland, Griffiths, Hartwell, & Smith, 2009). Fructans of these species include inulin, levans, neo-series inulin and highly branched structures (Waleckx, Gschaedler, Colonna-Ceccaldi, & Monsan, 2008), whose main function is energy storage and to act in abiotic stress tolerance in plants (Arrizon, Morel, Gschaedler, & Monsan, 2010; López, Mancilla-Margalli, & Mendoza-Diaz, 2003; Leach & Sobolik, 2010).

A large number of agave species possess a CAM, which explains the recent efforts to achieve inulin-type fructans from them (López & Urías-Silvas, 2007). Heads of plants belonging to the Agave genus have high contents of fructan oligomers, composed mainly of fructose units linked to a sucrose molecule, which can be easily degraded by thermal or enzymatic treatments leading to free sugars, mainly fructose. Many patents have been granted on the use of fructans from Agave species as a raw material for many purposes (Narvávez-Zapata & Sânchez-Teyer, 2009).

3. Chemical structure of fructans

Fructans are present in plants as heterogeneous mixtures with different degrees of polymerization (DP) and various chemical structures. The type of fructans found in plants (oligomeric or polymeric molecules) and the presence of a specific type of fructan are species-dependent and related with the environmental conditions and developmental stage of the plant (Mancilla-Margalli & Lopez, 2006). Five types of fructans with different structures were described in higher plants: inulin-type fructans (1-kestose), levan-type fructans (6-kestose), fructans of the inulin neoseries (neokestose), mixed-type levans (bifurcose) and fructans of the levan neoseries also called mixed-type levans (mixed-type F_3 fructan), whose shortest representatives, mentioned between brackets, have their chemical structures illustrated in Fig. 1 (Van Laere & Van den Ende, 2002).

These authors reported that inulin-type fructans are fructose polymers that have mostly or exclusively β-(2→1) fructosylfructose linkages, whereas levan-type fructans have mostly or exclusively β-(2→6) fructosylfructose linkages. Although these fructan types are essentially linear molecules, a low degree of branching can occur through β-(2→6) linkages in the case of inulins or β-(2→1) linkages in levans. In case the terminal glucose molecule is absent (Fn-type fructans), there are reducing compounds in contrast to the regular type fructans (G-Fn), and the terms inulo-n-oses [β-(2→1) linkages] and levan-n-oses [β-(2→6) linkages] are used.

Without any doubt, inulin is the best-known and studied fructan (Van Laere & Van den Ende, 2002), and the