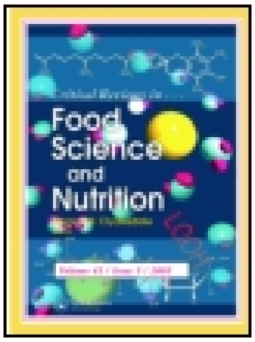

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Functional and therapeutic potential of inulin: A comprehensive review

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ABSTRACT

Inulin as a heterogeneous blend of fructose polymers is diversely found in nature primarily as storage carbohydrates in plants. Besides, inulin is believed to induce certain techno-functional and associated properties in food systems. Inulin owing to its foam forming ability has been successfully used as fat replacer in quite a wide range of products as dairy and baked products. Furthermore, it is known to impart certain nutritional and therapeutic benefits that extend apart to improve health and reduce the risk of many lifestyle related diseases. Additionally, as a functional ingredient, Inulin has been adopted in various efficacy studies involving animal and human studies to function as a prebiotic, in promoting good digestive health, influencing lipid metabolism and has some beneficial roles in ensuring optimum levels of glucose and insulin. This review article is an attempt to present a comprehensive overview on both techno-functional and therapeutic potential of inulin.

KEYWORDS
Inulin; chicory; Jerusalem artichoke; fat replacer; hypercholesterolemia; glycemia

Introduction

Health and nutrition is the most challenging arena in this era and would persist in the forthcoming years. Maintaining and increasing the nutritional value of food has always been an important area for research. Although dense, energy rich or refined foods provide comfort but deprive some of the rightful nutrients that lead to onset of various ailments such as hyperglycemia, hypercholesterolemia, colorectal cancers and irritable bowel diseases. Over the last few decades, tremendous increase in the demand of functional foods have evoked the food processing industries to develop novel methods for maintaining the nutritional quality and functional characteristics of food (Das et al., 2012). Of the various issues being faced by the mankind, diet linked diseases are among the most significant one and need serious efforts to pull up the danger of these physiological maladies. Keeping in view the present conditions, novel health strategies have been devised aimed at highlighting the positive aspects of such healthy diet.

In this scenario, inulin belonging to the class of dietary fiber known as fructan is believed to attract substantial attention owing to its therapeutic, preventive and physioprotective assertions. Though a concentrated review is accessible on different attributes of dietary fiber and inulin but the most relevant literature related to the current study has been reviewed under the following sections:

1. Diet health linkages and functional foods
2. Fructans: origin and structure
3. Inulin
4. Major sources of inulin
   a. Jerusalem artichoke
   b. Chicory
5. Extraction and precipitation of inulin
6. Physicochemical properties of inulin
7. Characterization of inulin based food
8. Functional/ health attributes of inulin as dietary fiber
9. Case Studies

Diet health linkages and functional foods

Adequate nutrition is the foundation of any civilized society as it forms an integral part of preventive healthcare. Consumers are now more aware about healthy diet and perspectives of therapeutic foods as dietary intervention. This arousing interest is interlinked with extensive understanding of the mechanisms in which diet affects various ailments (Das et al., 2012). Drastic changes in dietary pattern and life style have led to the onset of various ailments such as hyperglycemia, hypercholesterolemia, colorectal cancers and irritable bowel diseases. Moreover, such complications are inter-dependent and affect the occurrence and severity of each other as it has been observed that 80% of the diabetic subjects are susceptible to cardiovascular diseases (CVDs) (Strandberg et al., 2006).

These health ailments are now rapidly plaguing the developing countries where there are no dietary guidelines for various segments of population. The high disease burden can be attributed to lack of access to proper medication, life style, dietary pattern and associated risk factors such as hypertension, pollution and smoking. Dietary interventions including food diversification, dietary supplementation as well as functional foods and nutraceuticals can be helpful to fight these diseases (Butt et al., 2009).

The dietary interventions based on low cost fiber supplementation are one viable solution for countries where huge socio-

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economic disparities exist (Anderson et al., 2000). Different cereals and vegetable based soluble and insoluble fibers can be used for this purpose. Fiber enriched diets have the potential of increasing the peripheral insulin sensitivity in healthy individuals. In addition, soluble fiber can delay the absorption of glucose into blood consequently leading to decreased postprandial glucose concentrations. Inulin belonging to the wide category of fructan possess tremendous potential as soluble dietary fiber to curtail these health challenges (Dunn et al., 2011). Hence one possibility to develop therapeutic foods is the use of inulin which is one of the promising bioactive compounds and has numerous food applications (Barclay et al., 2010).

Fructan: Origin and structure

Fructan can be best described by using the term polyfructosylfuctose. In the old literature, above 50 generic names of fructan are present some of which are cited as inulin, levan and phlein while there are few other suggested names which are not used now-a-days such as fructosan, fructoholoside, graminin, inulein, lavulan, levulosan, levosin and pseudo-inulin etc. (Roberfroid 2005) (Table 1).

These fructose based polymers commonly termed as storage products of plants are frequently found as carbohydrate reserves in plant leaves and other organs e.g. tubers, bulbs and roots (Ritsema and Smeekens 2003; Weyens et al., 2004). Some families of mono and dicotyledonous plants such as *Compositae, Liliaceae, Gramineae* and *Amaryllidaceae* contain higher proportion of fructan as food reserves (de Oliveira et al., 2011). Chemical composition and degree of polymerization (DP) of fructan shows the heterogeneity in their structure. Environmental conditions and plant development stages specifically determine the type and amount of fructan in plant tissues as well (Mancilla-Margalli and López 2006).

Inulin

Inulin is basically a linear fructan (polysaccharide in nature) composed of fructosyl units [β (2→1) linkage] and usually contains one terminal glucose moiety [α (1→2 linkage] per molecule (Kays and Nottingham 2007). In the beginning of 19th century, it was first discovered from the roots of a plant known as *Inula helenium* by Germen scientist Valentine Rose who found it as storage carbohydrate while Thomson named this carbohydrate as inulin. In 1864, plant physiologist Julius Sachs detected the ethanol precipitated spherocrystals of inulin under the microscope. Afterwards, these crystals were also separated from different tubers such as *Inula helenium, Dahlia pinnata* and *Helianthus tuberosus* (Franck and De Leenheer 2005).

About 45,000 plant species (15% of flowering plants) contain inulin as major storage carbohydrate (Van Laere and Van den Ende 2002). Tubers of *Helianthus tuberosus* (Jerusalem artichoke), *Dahlia pinnata* (dahlia), *Polymnia sonchifolia* (yacon) and *Cichorium intybus* (chicory) are common examples of plants containing significant amount of inulin (de Oliveira et al., 2011).

Inulin is comprised of oligo- and polysaccharides having fructose monomers linked by glycosidic linkages with β-configurations at anomeric C2 and this β-configuration makes inulin resistant to hydrolysis by human gastrointestinal enzymes. Therefore, inulin type fructans have been placed under non-digestible carbohydrates (Roberfroid 2007). The DP of fructan ranges from 2–60 units with an average value of 10–12 units. The DP value is important to consider as it may affect its functionality and mainly depends on plant source, harvesting time, climatic conditions, growing season and duration of storage after harvest (Saengthongpinit and Sajjaanantakul 2005). Oligofructose or fructooligosaccharides exhibit the low DP values i.e. 10 units or below. Furthermore, chicory based inulin has lower DP values as compared to those obtained from artichoke and globe thistle (Leroy et al., 2010).

Major sources of inulin

A number of mono and di-cotyledonous families like *Liliaceae, Amaryllidaceae, Compositeae* and *Gramineae* are major sources of inulin stored in bulbs, tuberous roots and tubers. Moreover, two species of *Compositeae* family named as chicory and Jerusalem artichoke are used preferably for industrial production (Kaur and Gupta 2002; Leroy et al. 2010) (Table 2).

Jerusalem artichoke

The Jerusalem artichoke (JA) also called as sun choke, sun root, topinambur or earth apple belonging to the *Compositeae* family is native to temperate regions of North America. It was named as ground pear by Žaldarienė et al. (2013). Ecologically, it is much more flexible crop therefore, has a great scope for its cultivation at diverse climatic condition. Jerusalem artichoke can preferably grow within a pH range of 5.0–7.4 and is little sensitive to soil reactions. Chemical composition of fresh Jerusalem artichoke tubers includes about 80% water and 1–2% protein (Kocsis, Liebhard, and Praznik 2008). In addition, tubers also contain high proportion of inulin content i.e. 17–20.5%.

The chemical composition of Jerusalem artichoke powder (JAP) indicates that it contains 5.0 ± 0.4% water, 0.9 ± 0.2% lipids, 4.3 ± 0.3% ash and 6.6 ± 0.3% protein (Praznik, Cieślik, and Filipiak−Florkiewicz 2002). Tubers can also contain a

Table 1. Chemistry and natural origin of fructans.

Name	Linkage	Chemical Structure	Natural Origin	References
Inulin	β(2,1)	Linear, branched, cyclic	Plant, bacteria, Fungi	(Roberfroid 2005)
Levan	β(2,6)	Linear, branched, cyclic	Plant, bacteria, Fungi	(Apolinario *et al.* 2014)
Graminan	β(2,1) & β(2,6)	Linear, branched	Plant	(Verspreet *et al.* 2015)
Inulin neoseries	β(2,1)	Linear, branched	Plant, Fungi	(Livingston *et al.* 2009)
Levan neoseries	β(2,6)	Linear, branched	Plant	(Livingston *et al.* 2009)

Table 2. Sources and chain length of inulin.

Plant	Inulin g/100g	Degree of Polymerization (DP)
Rye	4.5–6.4	DP > 9
Wheat	1.5–2.3	DP ≤ 5
Barley	1.6	DP 5–15
Jerusalem Artichoke	17–20.5	DP 2–50
Chicory	15–20	DP 2–65
Globe Artichoke	2–7	DP 5–200
Garlic	9–16	DP ≥ 5
Leek	3–10	DP 12 is most frequent
Onion	1–7.5	DP 2–12
Banana	±1	DP < 5

(Hansen *et al.* 2002; Franck and De Leenheer 2005; Roberfroid 2005; Huynh *et al.* 2008; Costabile *et al.* 2010; Jenkins *et al.* 2011; Verspreet *et al.* 2015)

considerable proportion of minerals particularly iron (0.4 to 3.7 mg. 100 g^{-1}), calcium (14 to 37 mg.100 g^{-1}), potassium (420–657 mg.100 g^{-1}) and sodium (1.8 to 4.0 mg.100 g^{-1}) (Kocsis, Liebhard, and Praznik 2008).

JA tubers exhibits low calorie value due to presence of relatively small amount or no starch and fat. Being rich with inulin, tubers can also be considered as a prime source of dietary fiber. Most of the carbon in JA is present in the form of inulin as it is the chief carbohydrate reserve in the tubers. Pure inulin contains 3% glucose and about 97% fructose units (Singh et al. 2010). Most of the inulin (52%) present in JA has DP of less than 9 making it suitable for fermentation. Moreover, inulin with medium DP (42% with 10–40 DP) and high DP (6% with DP>40) is also present in tubers which makes it suitable for fat replacement (Kays and Nottingham 2007).

The benefits of JA in decreasing cholesterol, maintaining healthy intestinal microflora, suppressing intestinal infection, combating obesity, maintaining blood sugar levels in diabetic patients and improving blood lipid composition have been firmly established (Hidaka, Adachi, and Hirayama 2001; Tungland 2003). Furthermore, inulin and fructo-oligosaccharide supplements can boost the immune system and help in preventing a wide range of diseases such as ulcerative colitis, inflammatory bowel diseases and colorectal cancer (Hidaka, Adachi, and Hirayama 2001; Kanauchi et al. 2003).

Chicory

Cichorium intybus L., commonly known as chicory belongs to family Asteraceae and is widely distributed in Asia and Europe (Bais and Ravishankar 2001). It is high yielding crop and can be grown throughout the temperate regions. All parts of this plant possess great medicinal value owing to the presence of various compounds such as alkaloids, coumarins, chlorophyll pigments, flavonoids, inulin, saponins, sesquiterpene lactones, unsaturated sterols, vitamins and tannins (Molan et al. 2000; Nandagopal and Kumari 2007; Muthusamy et al. 2008; Atta et al. 2010). Fresh chicory normally contains 68% inulin, 14% sucrose, 5% cellulose, 6% protein, 4% ash and 3% other compounds as compared to the dried chicory which contains 98% inulin and 2% other compounds. Besides, phenolic compounds, vitamins (A, C) and minerals (potassium, calcium, phosphorus) are important constituents of chicory leaves (Mulabagal et al., 2009). Moreover, cichoric acid present in chicory is of foremost importance since it not only stimulates the immune system but also prevents the bacterial infections and inflammations (Ahmed 2009). Chicory has been conventionally used for the management of diarrhoea, fever, gallstones and jaundice (Abbasi et al. 2009; Afzal et al. 2009).

Numerous research investigations conducted by employing the monogatric animals have revealed that chicory possesses anti-hepatotoxic, anti-diabetic (Saggu et al. 2014), anti-bacterial (Nandagopal and Kumari 2007), anti-inflamatory (Cavin et al. 2005), hyperglycaemic and anti-ulcerogenic activities (Rifat-uz-Zaman and Khan 2006). Although chicory is a plant whose tuberous roots are manifested due to the presence of inulin as a major ingredient and have the ability to substitute fat or sugar but still there is no commercial production of inulin from chicory (Kaur and Gupta 2002). Chicory roots also contain well proportion of mineral content i.e. P (178.6), Ca (156.3), K (2705.1), Mg (76.4), Na (57.4), Fe (2.84), Cu (0.41), Mn (1.61), Al (3.38), Co (1.47), Ni (1.98) and Zn (2.58) as mg.100 g^{-1} dry weight (Park et al. 2007).

Extraction and precipitation of inulin

Due to the growing industrial use of inulin in nature, the extraction, quantification and utilization of inulin is capturing focus (Yang et al. 2011). Many research investigations have focused on optimum extraction conditions e.g. temperature, extraction time and solvent/ solid ratios to improve the yield of inulin (Toneli et al. 2008; Abozed et al. 2009; Paseephol and Sherkat 2009; Abou-Arab et al. 2011; Saengkanuk et al. 2011).

By increasing the extraction temperature, solubility of inulin is increased remarkably as it is insoluble at 25°C but can solubilize up to 35% as temperature is raised to 90°C. Thus, most of the industrial extraction involves the use of hot water diffusion system (Kim et al. 2001). Almost all extraction methods work on the principle of using hot water diffusion with a small variation in extraction time and temperature (Paseephol et al. 2007). Hot water diffusion method can also involve continuous stirring to improve extraction efficiency (Toneli et al. 2008). Globally, inulin is usually extracted from JA by using distilled water at 80–85°C for 1 hr and pH 6.8 to avoid inulin hydrolysis which is common phenomenon at pH < 6 (Ronkart et al. 2010; Saengthongpinit and Sajjaanantakul 2005).

Recently, ultrasound-assisted extraction has been proposed by employing different variables such as temperature, sonication amplitude and time to improve extraction as this was observed during inulin extraction from burdock roots. The extraction efficiency was improved by increasing the sonication amplitude and extraction time without significant change in temperature. The time for sonication was 25min, sonication amplitude 83.22% and temperature 36.76°C (Milani et al. 2011). During extraction, care must be taken to avoid the fragmentation of inulin because of direct ultrasounds action. Conclusively, use of direct waves is preferred for deploymerization of inulin thereby getting low molecular weight byproducts. However, indirect method is better suited to get intact inulin (Lingyun et al. 2007).

For direct extraction, a probe is simply inserted into a vessel containing sample, while indirect extraction involves immersing the sample in an ultrasound cleaning bath with continuous shaking on orbital shaker. Inulin recovery usually starts with its precipitation after extraction which can be performed by either lowering temperature or using different solvents followed by centrifugation (Lingyun et al. 2007; Abozed et al. 2009). Phase seperation is common problem faced when concentrated inulin solution is frozen or even cooled to low temperature. This problem can be avoided by inulin precipitation through freezing or cooling, afterwards, subjecting it to centrifugation followed by spray drying to get powder form of inulin. The main impediment in the use of this process is energy expenditure because before drying, the liquid concentrate must be evaporated and temperature should be kept lower to favor inulin precipitation (Toneli et al. 2008). In addition, freezing/thawing of inulin followed by centrifugation can be adopted as another method for inulin precipitation (Yang et al. 2011).

High concentrations of organic solvents e.g. ethanol, acetonitrile, methanol, acetone and propanol can be used for the precipitation of long chain inulin molecules. Among these solvents, acetone shows better results in order to keep the natural DP of inulin followed by methanol and ethanol (Dalonso et al. 2009).

The boiling point of acetone is also very low (56.5°C) which makes its recovery easy through distillation process (Moerman et al. 2004). For improved precipitation of inulin from Jerusalem artichoke tubers, acetone along with ethanol has proved to be good solvent (Abozed et al. 2009). In general, acetone and acetonitrile are considered to be more effective solvents but ethanol is considered as better choice among all solvents for food applications due to its GRAS status (Ku et al. 2003; Paseephol et al. 2007). By using ethanol, inulin with DP of 25 and 40 has been recovered from chicory and dahlia respectively (Moerman et al. 2004). Extraction yield of inulin powder can vary due to the differences in plant species and methods used for its extraction (Mudannayake et al. 2015).

Physicochemical properties of inulin

Inulin possess the unique technological and functional characteristics along with health benefits. Purposely, food industries are commercializing the use of inulin as food ingredient. The DP and branching pattern define the functional and physicochemical properties of inulin i.e. melting point, gelation property, glass transition temperature and gel integrity (Bot et al. 2004). Hence, fractionation based on DP results in products with desirable properties (Yi et al. 2010). Oligofructose are more soluble and sweet in taste with improved mouth-feel. Owing to their improved sweetness (about 30–35% of sucrose) and lower calorific values (1–2kcal/g) they can be used for partial or complete replacement of sucrose (Tárrega et al. 2010). While the long chain inulin fractions are slightly soluble and relatively viscous so can be used as fat replacers in low fat dairy products (Guggisberg et al. 2009). The long chain inulin also has the ability to form microcrystals when sheared in milk or water. These microcrystals interact and provide a creamy texture with fat like sensation (López-Molina et al. 2005; Kalyani Nair, Kharb, and Thompkinson 2010). Thus inulin has been widely used to substitute sugar and fat in the food products such as baked items, ice creams, spreads, fillings, confections and salad dressings. Although the inulin is soluble in water yet its solubility is entirely dependent on temperature i.e. ~6% at 10°C and 35% at 90°C. It can be dispersed in water but due to its hydroscopic nature, clump formation can occur that can be averted to a small extent by mixing it with sugar or starch. Hazing is observed when Raftiline ST inulin is dissolved in water. This probably is due to presence of high-DP crystalline fractions of inulin that do not dissolve readily (Bot et al. 2004). Poor solubility especially for higher molecular weight fractions tends to increase at higher temperatures (Glibowski 2010).

Viscosity of inulin containing solutions is directly linked with its concentration. A little increase in viscosity is observed when concentration of inulin is increased from 1 to 10% followed by continuous increase in thickness with the increase in concentration up to 30 % but with no obvious signs of gel formation. By increasing the concentration beyond 30%, gelation is observed due to the presence of discontinuous particles. Since the rate of gelation is enhanced at higher inulin concentration, an abrupt increase in gel formation is observed at 40 to 45% of inulin. Resultant gel is creamy in texture and exhibits the similar characteristics as imparted by fat. At concentration of up to 50%, gels becomes firm and rigid but still possess the ability of retaining the fat like attributes (Saengthongpinit and Sajjaanantakul 2005).

Inulin presents the greatest viscosity at a temperature <80°C which can be reduced to a considerable extent when temperature is raised beyond 80°C because at high temperature inulin is more prone to solubility (Kim et al. 2001; Abou-Arab et al. 2011; Mudannayake et al. 2015). Inulin is unable to form gel at low concentration as compared to the agar solutions and corn starch. It is suggested that formation of inulin gel is directly proportional to its concentration and the gelation occurs as a result of precipitation and crowding effect of inulin. The inability to form the gel is also linked to the low degree of polymerization.

In general, inulin gels are formed as a result of interaction between dissolved inulin chains. However, simultaneous presence of undissolved microcrystals is also witnessed. These microcrystals can interact with each other leading to the formation of discontinuous network which can interact with both the solvent and inulin particles thereby increasing the gel strength (Kim et al. 2001; Bot et al. 2004; Ronkart et al. 2010; Mensink et al. 2015). High molecular weight inulins are better gel formers than their lower molecular weight counterparts (Kim and Wang 2001).

Inulin can also act as a good bulking agent or thickener in icecream, sandwich spreads, chocolate products and mayonnaise and an additive for improving textural and sensorial characteristics of yogurt (Yi et al. 2010). It can particularly substitute probiotics in yogurts which may not survive beyond the stomach to contribute to colon microflora (Graham-Rowe 2006). Inulin-containing foods are useful for increasing mineral absorption as well (Hidaka, Adachi, and Hirayama 2001).

The oil holding capacity of inulin shows that it can replace fat in various food formulations containing the lesser quantity of fat. Besides, it can also act as stabilizer in wide range of emulsions containing high fat content. According to Mudannayake et al. (2015), pH of commercial inulin is reported as 5.53±0.05. Regarding color, too much variation exists between the colors of inulin samples that can be attributed to the presence of variable amount of phenolic compounds in different sources such as commercial inulin appears white to the naked eye, while inulin extracted from *Asparagus falcatus* (AF) and *Taraxacum javanicum* (TJ) exhibits pale-white and brownish-yellow color respectively. Due to these facts, inulin has been used preferably without any limitation in many countries to replace fat or sugar in ice creams, table spreads, fillings, dressings, confections and baked goods (Rodríguez et al. 2006).

Cake properties e.g. shelf life, volume, firmness, crumb structure, tolerance to staling and gelatinization temperature are highly influenced by these factors (Gomez et al. 2007). Textural profile of baked items is an important criterion in terms of product quality. Textural properties of cakes are the measure of their hardness, firmness, springiness, adhesiveness, cohesiveness, gumminess and chewiness (Rodríguez-García et al. 2014). Textural profile analysis (TPA) is commonly used to measure these textural properties of baked items such as cakes.

Other important quality parameters of cakes are color, moisture, pH, temperature and density. The pH of the cakes is usually linked with the leavening agents used in the formulation of cakes. pH is one of the fundamental measurements that greatly influences the taste and structure of cakes *i.e.* excessively low pH produce cakes with bitter taste and acidic flavor. On the other hand, high pH results in the cakes having soda and soapy taste (Baik et al. 2000). Food manufacturers have to face the challenges to develop low fat items with quality characteristics similar to normal foods. Fat has distinct functional properties (creaminess, appearance, palatability, texture and lubricity) that can influence eating and processing attributes of food item, hence, these functions must take into account when lowering the fat in a product (Johnson 2008; Karimi et al. 2015).

Quality characteristics of cakes; with inulin as fat replacer

Fat is very important ingredient in cake making process because it provides unique functional and technological properties to cakes e.g. enhanced mouth feel and crumb softness. Fat also assists in air incorporation and helps to leaven or moisten the product. Typically, cakes contain fat content in the range of 15–25% on batter weight basis (Matsakidou, Blekas, and Paraskevopoulou 2010). Advancement in technology and research is leading towards the development of foods containing low fat contents. In this quest, fat is replaced with ingredients (dietary fibers) which can mimic the techno-functional properties of fat and possess low caloric values. Within past few years, dietary fibers have drawn considerable attention of researchers and industry to be used as fat replacers due to their beneficial effects in the reduction of many chronic diseases e.g. CVD's, diabetes and gut neoplasia (Peressini and Sensidoni 2009).

Often, traditional techniques are employed to replace fat in food products such as use of lean meats, baking instead of frying of snacks and use of skim milk in frozen desserts instead of whole milk. Different types of fat replacers e.g. protein, carbohydrates and lipids based can be used in different food formulations either alone or in combinations. Generally, fat replacers are divided into two categories: fat substitutes and fat mimetics. Ingredients having somewhat fat-like physicochemical properties and chemical structure are known as fat substitutes while fat mimetics are the ingredients having distinct chemical structure different from fats. Fat substitutes are mostly indigestible and provide low calories per gram basis (Ognean, Darie, and Ognean 2006). On the other hand, fat mimetics are commonly carbohydrates or protein based ingredients with diverse physicochemical and functional properties that mimic some of the attributes of fat such as mouthfeel, appearance and viscosity (Johnson 2008) (Table 3).

Long chain inulin molecules have the unique property to act as fat mimetic and are commonly employed as fat replacers to design the low-fat foods. The fat replacing ability of inulin lies in its ability to form microcrystals. These microcrystals form a network by entrapping large amount of water leading to the formation of small aggregates that can agglomerate into extensive gel network (Bayarri et al., 2011).

Dietary fibers e.g. oat bran (rich source of β-glucan), flaxseeds and oatrihm (blends of both the β-glucan and amylodextrins) are under continuous investigation to be used as fat replacers and several attempts have been made to replace fat by their incorporation in bakery products (Lee, Inglett, and Carriere 2004; Lee, Kim, and Inglett 2005; Psimouli and Oreopoulou 2013). Similarly, barley and oat concentrates have been investigated to replace shortening in the cakes. Additionally, the use of hydrocolloids i.e. xanthan gum, polydextrose and guar gum in producing the low-fat cakes has been studied (Kocer et al., 2007; Zambrano et al., 2004). These studies indicate that characteristic cakes can be prepared at low level of fat replacement only.

Table 3. Various fat replacers along with their food uses.

Carbohydrate-based fat replacers	Foods
Inulin	Yogurt, cheese, frozen desserts, baked goods, icings, fillings, whipped cream, dairy products, fiber supplements, processed meats
Maltodextrins	Dairy products, salad dressings, spreads, sauces, frostings, fillings, processed meat, frozen desserts, extruded products
Dextrins	Salad dressings, puddings, spreads, dairy-type products, frozen desserts
Gums	Bakery products, frozen desserts, sauces, soups, meats, pie fillings, yogurts, meats
Fiber	Frozen reduced fat bakery products
Polydextrose	Baked goods, chewing gums, confections, salad dressings, frozen dairy desserts, gelatins, puddings
Carrageenan	Low fat deserts, cheeses, ground beef
Protein-based fat replacers	**Foods**
Microparticulated Protein (simplesse)	Dairy products (ice cream, butter, sour cream, cheese, yogurt), salad dressing, margarine- and mayonnaise-type products, baked goods, coffee creamer, soups, sauces
Modified Whey Protein	Milk/dairy products (cheese, yogurt, sour cream, ice cream), baked goods, frostings, salad dressing
Microparticulated Protein (simplesse)	Dairy products (ice cream, butter, sour cream, cheese, yogurt), salad dressing, margarine- and mayonnaise-type products, baked goods, coffee creamer, soups, sauces
Fat-based fat replacers	**Foods**
Salatrim	Confections, baked goods, dairy
Emulsifiers	Cake mixes, cookies, icing, dairy products
Glycerol	Baking, frying
Olestra	Salty snacks and crackers

(Ognean, Darie, and Ognean 2006)

Table 4. Food applications of inulin as a fat replacer.

Application	Functionality	Dosage level inulin (% w/w)
Dairy products	Sugar and fat replacement, Synergy with sweeteners, Body and mouthfeel, Foam stability, Fibre and prebiotic	2–10
Frozen desserts	Sugar and fat replacement, Texture and melting, Synergy with sweeteners, Fibre and prebiotic	2–10
Table spreads	Fat replacement, Texture and spread ability, Emulsion stability, Fibre and prebiotic	2–10
Baked goods and breads	Fibre and prebiotic, Moisture retention, Sugar replacement	2–15
Breakfast cereals	Fibre and prebiotic, Crispness and expansion	2–20
Fillings	Sugar and fat replacement, Texture improvement	2–30
Dietetic products	Sugar and fat replacement, Synergy with sweeteners, Low caloric value, Body and mouthfeel, Fibre and prebiotic	2–15
Chocolate	Sugar replacement, Fibre and Heat resistance	5–30

(Franck 2002)

Recently, Rodríguez−García et al. (2012) developed an acceptable product by replacing the fat up to 70% with inulin.

Findings of Rodríguez−García et al. (2012) reported the negative impacts of higher level of inulin in terms of cake texture and the possible reason behind this phenomenon was found to be the bubble size distribution. From the results it was concluded that the cakes prepared with 0%, 35% and 50% inulin as a fat replacer resulted in significantly softer texture due to narrow bubble size distribution in smaller regions while at 100% replacement the crumb texture became hard and the bubble size became widen. Use of fat replacers result in irregular matrix due to decreased availability of lubricant thus hindering the starch granules to embed on their full extent. Inulin also makes the cake structure irregular by limiting the hydration of gluten and starch networks during mixing and baking (Table 4).

Psimouli and Oreopoulou (2013), compared the bubble size distribution of control batter or the batter prepared with 100% fat replacement by image analysis and concluded that fat replacers significantly affect the size of air bubbles. The control batter containing 0% fat replacer had 87% of the air bubbles in an area of 10–30 μm diameter while the batters prepared with 100% fat replacement exhibited the broader bubble size distribution. The starch gelatinization plays a key role in the development of well aerated and porous structure. The main underlying factor is the settling of starch at higher temperature due to which air bubbles receive the maximum time for their expansion consequently resulting in the development of aerated product. Specific volume being an indicator of the porous structure of the products was also found to be lower in the batters containing fat replacers i.e. inulin and maltodextrin. Hence, negative correlation is found between the specific volume and batter density because with increased fat replacement, viscosity of the batter decreased leading to less air holding capacity of the batters during baking.

On the other hands, elasticity of the cakes increased with increasing level of fat replacers (Zahn, Pepke, and Rohm 2010) suggesting that the increase of viscosity was due to increased bond strength in three dimensional structure of crumb. Fat present in the batter coats the starch and protein molecules thereby hindering the complete hydration and formation of continuous gluten-starch networks. Replacement of shortening enhances the development of crumb networks because the fat replacers can increase the hydrogen bonding or interactions with the starch or among their molecules (Bárcenas, De la O-Keller, and Rosell 2009).

Batter viscosity has an important effect on bubble incorporation and movement which govern the final cake volume (Sanz et al. 2009). This was also observed in rice flour cakes prepared with different types of gums, where low apparent viscosity batters result in the migration of air bubbles to the surface (Turabi et al. 2010). Zahn, Pepke, and Rohm (2010) also replaced 50% fat with inulin in muffins and showed a volume reduction without affecting significantly the weight loss during baking. From the recent findings, it has been reported that inulin and oligofructose can be used as sugar replacers as well (Struck et al., 2014).

Functional/ health attributes of inulin as dietary fibre

In 1953, E.H. Hipsley termed the indigestible portion of plant cell walls as dietary fiber. American Association of Cereal Chemists (AACC) illuminated that edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine are termed as dietary fiber (Kalyani Nair, Kharb, and Thompkinson 2010). Dietary fiber comprises of lignin, oligosaccharides, polysaccharides and associated plant substances having the potential of exhibiting physiological functions in the human body such as lowering of blood cholesterol or glucose level and providing laxation. The recommended level of dietary fiber for healthy diet plan is 30 g for person utilizing 2500 kcal and 25 g for person utilizing 2000 kcal per day. World Health Organization has recommended 27–40 g/day of total dietary fiber and 16–24 g/day of non-starch polysaccharides (Table 5).

Dietary fibers may be classified as water-soluble gel and water insoluble fibers. The cell walls of grains and some vegetables contain insoluble fiber in form of hemicelluloses, lignin and cellulose, whereas, soluble fiber in form of noncellulosic portion (mucilages, gums and pectins) is present in legumes,

Table 5. Relative sweetness of inulin and oligo-fructose.

Sweetener	Relative sweetness (Sucrose = 1)	Energy (kcal g-1)	Characteristics	References
Inulin	0–0.3	1.5	DP > 9 Utilized as fat replacer, Prebiotic	(Devereux *et al.* 2003)
Oligo-fructose	0.4–0.5	1.5	DP < 9 Relative sweetness 0.25 when DP = 3	(Ronda *et al.* 2005)

barley, oat, fruits and dried beans (Elleuch et al., 2011; Esposito et al., 2005; Saeed et al., 2011). Insoluble fibers have limited impact on body cholesterol/glucose metabolism, while soluble fibers have hypocholesterolemic and hypoglycemic properties and are linked with lipid and carbohydrate metabolism. Soluble fiber is also capable of producing the short chain fatty acids (acetate, propionate, and butyrate) by the underlying colonic fermentation which have a pivotal role in lipogenesis and lipogenolysis. Acetates and propionates exhibit the antagonistic effects in fat synthesis as acetate acts as a substrate for fatty acids, whereas propionates hinder the lipogenesis (Delzenne et al., 2002; Kalyani Nair, Kharb, and Thompkinson 2010).

Inulin and oligofructose have thus always been part of the normal human diet. They are legally classified as food or food ingredients (not as additives) in all EU countries. The Authorities in Australia, Canada and Japan have also come to the same conclusions. In USA, a panel of recognized experts has confirmed the GRAS (Generally Recognized As Safe) status of chicory inulin and oligofructose. In all these countries, they can be used without specific limitations as ingredient in foods and drinks. Most countries have also agreed that inulin and oligofructose may be labelled as dietary fibres (Franck 2002) (Table 6).

Japan utilized fructooligosaccharides as food supplements and marketed inulin based food items in 1983 by considering their ability to facilitate the gastrointestinal health and absorption of minerals (Hidaka, Adachi, and Hirayama 2001). Inulin being a soluble dietary fiber enters the large intestine without any digestion in the upper gastrointestinal tract, but in colon it undergoes the bacterial fermentation leading to the production of short chain fatty acids, increased fecal biomass alongside lowering the pH of colon (Murphy 2001). Brief description about health effects of inulin has been described in various case studies as explained under.

Case studies

Prebiotic effects of inulin

Technically, the indigestible food materials which can selectively promote the activity and growth of particular native bacteria of the digestive tract are termed as prebiotics (Gibson et al., 2004). These are the fermentable ingredients capable of producing definite changes in activity as well as composition of gastrointestinal microflora (Lactobacilli and Bifidobacteria). Most of the changes occur in bifidobacteria due to their presence in large numbers in the human colon and higher preference for oligosaccharides as compared to the Lactobacilli. For a component to be termed as prebiotic, it must resist the gastric secretions and absorption in the upper gastrointestinal tract while fermentable by intestinal microflora to benefit the host (Slavin 2013). Primarily, prebiotics are non-digestible carbohydrates such as inulin, oligosaccharides and polysaccharides. In addition, some non-carbohydrates also fall in this category.

Number of health benefits are associated with these prebiotics e.g. improved gut microbiota, increased mineral absorption, stimulation of immune functions, reduced risks of irritable bowel diseases and constipation (Bielecka, Biedrzycka, and Majkowska 2002; Gibson et al., 2004; Scholz-Ahrens, Açil, and Schrezenmeir 2002)), besides, they also possess the potential to lower the cholesterol and colorectal cancer (Kelly 2008). Prebiotics exert these health benefits by improving the functioning of gastrointestinal microflora i.e. lactobacilli and bifidobacteria (Mulabagal et al., 2009). About 300–500 bacterial species reside in the human gastrointestinal tract which become denser up to 10^{11} microbial cells/g of luminal content while approaching the large intestine (Guarner and Malagelada 2003). Majority of colonic bacteria obtain their nourishment by fermenting the food materials. In this context, main fermenting agents are the non-digestible carbohydrates i.e. inulin, oligosaccharides, fibres, resistant starches and non-cellulosic polysaccharides which generally remain intact throughout small intestine but are subjected to fermentation in the large intestine. Short chain fatty acids (SCFAs) (acetates, propionates, butyrates) produced as a result of fermentation are captured by the colonic mucosa and play a key role in fulfilling the energy needs of the host. Acetates are generally metabolized in the kidney, heart, brain and muscles whilst propionates serve as a promising precursor of glucogenesis that hinder cholesterol synthesis and is cleared off by the liver. Butyrate is used by colonic epithelium where it contributes towards cell differentiation and regulation (Macfarlane, Steed, and Macfarlane 2008; Sangwan et al., 2011; Slavin 2013).

Addition of prebiotics in food is a natural approach to improve the health of consumers. Most of the prebiotics can also give the desired functionality to the food items (Courtin et al., 2009) such as short chain prebiotics serve the same function as exhibited by sugars and hence can contribute largely to the crispiness & browning of the product. On the other hand, long chain prebiotics can act as fat replacers (Franck 2002). Moreover, majority of prebiotics are not damaged by food processing operations thus retain their functionalities (Böhm et al., 2005).

Bifidogenic concept of inulin

Inulin/fructo-oligosaccharide supplemented food ingredients can improve intestinal health by decreasing the colonization of harmful microflora. Therefore, utilization of such ingredients can impart the desirable features to gut health (Sonnenburg et al., 2010). The gastrointestine with healthy microflora plays a key role in the development of body's immune system. Gut-associated lymphoid tissues (GALT) which provide protection against pathogens and toxins by acting as physical barrier between internal and external environment are beneficially affected by the intake of inulin and oligofructose (Meyer and Stasse-Wolthuis 2009). Human gut microflora is specifically of

Table 6. Different classification of dietary fibre.

Fibers	Classification
Soluble Fibers	B-glucans, Gums, Wheat dextrin, Psyllium, Pectin, Inulin
Insoluble Fibers	Cellulose, Lignin, Some pectins, Some hemicelluloses
Viscous Fibers	Pectins, B-glucans, Psyllium
Non-viscous Fibers	Polydextrose, Inulin
Fermentable Fiber	Wheat dextrin, Pectins, B-glucans, Guar gum, Inulin
Non-fermentable Fibers	Cellulose, Lignin
Functional Fiber	Resistant dextrins, Psyllium, Fructooligosaccharides, Polydextrose, Isolated gums, Isolated resistant starch

(Slavin, 2013).

diverse nature comprising of more than 90% cells from phylum bacteroides or firmicutes (Dethlefsen et al., 2008; Hooper 2009; Louis et al., 2007; Turnbaugh et al., 2009).

Number and variety of intestinal microbiota can vary with the different factors such as antibiotic treatment, obesity, inflammation and weight loss problems. Likewise, genetics, diet, nutrient availability, host health, age, intestinal integrity, resistance to pathogens, changes in metabolic profile, transit time and frequency of defecation are among the major contributors towards functionality and composition of microbial population in gastrointestinal tract. The alteration in the composition and functions of intestinal microflora is associated with many metabolic aliments and gut infections (Albers et al., 2005; de Graaf and Venema 2007; Meyer and Stasse-Wolthuis 2009).

The bifidogenic role of inulin has been investigated in healthy volunteers by giving them a diet enriched with minimum dose of 5g/day chicory inulin (Bouhnik et al., 2007; Kolida, Meyer, and Gibson 2007) or oligofructose (Menne and Guggenbuhl 2000) and 9g/day long cahin inulin (Harmsen et al., 2002). At the end of this study, findings suggested that inulin containing diet showed positive impact on the growth of biofidobacterium. Bifidogenic effect was also found in case of short chain fructo-oligosaccharides. In another study, adult participants were given chocolate drink having 8g/day maltodextrin or 5 and 8g/day inulin for about 14 days. At the end of this study, the result showed a considerable increase in the bifidobacterial count as compared to control group (Kolida, Meyer, and Gibson 2007).

It is well established that initial bifidus population in infants is established by the consumption of mother milk because it contains higher proportions of oligosaccharides for the growth and proliferations of microflora (Knol et al., 2005a). In order to introduce better prebiotic ingredients, mixture of inulin and fructo-oligosaccharides has been used for children with better bifidogenic effects (Brunser et al., 2006). Another study was conducted by Kim, Lee, and Meyer (2007) revealing the bifidogenic effects of native inulin on formula fed babies (having the age of 12 weeks) and in this case dose was kept 1.5g/day. Furthermore, infant formulation blends with fructo-oligosaccharides and galacto-oligosaccharides (1: 9) were prepared and found to be very effective in promoting the gut microbiota similar to breast fed babies. The tested group's fecal material showed higher levels of short chain fatty acids and bifidus population with improved stool frequency and consistency (Knol et al., 2005b).

Inulin and lipid metabolism

Elevated levels of triglycerides and cholesterol along with hypertension and insulin resistance are the major factors responsible for metabolic disorders. Cholesterol can be considered as the main causative agent for the fat deposition in the inner walls of arteries thus can contribute towards vascular dysfunctions, arteriosclerosis, strokes and cardiac disorders. It has been estimated that increased cholesterol level in blood is the underlying factor of approximately 18% strokes and 56% cardiovascular complications (Yasmin et al., 2015).

In the recent scenario, scientists are introducing the dietary guidelines to cut down the elevated levels of triglycerides and cholesterol in blood. This task is gaining more focus due to expensive medication and the side effects of drugs. Inulin and fructooligosaccharides are helpful in decreasing the triglyceride concentrations especially by reducing the very low density lipoproteins (VLDL) in post absorptive condition (Lin et al., 2014).

Underlying mechanism behind hypocholestrolemic effects of inulin and oligofructose involves the inhibition of triglyceride synthesis by reducing the phenomena of lipogenesis and favoring the production of SCFAs as a result of colonic fermentation (Kaur and Gupta 2002). The acetates and propionates are absorbed by the mucosal lining of colon and brought into liver where acetate acts as a substrate for cholesterol synthesis whereas, propionates hinder the lipogenesis by interfering with enzymes involved in cholesterol and triglyceride synthesis. Hence, the ratio of acetates and propionates is very essential in accessing the overall triglyceride reducing capability. Diet containing 1–5% chicory extract and 5% inulin can exert the significant effects in declining the lipid content, cholesterol and bile secretions as compared to fiber free diet. The target groups represented high HDL/LDL ratio in comparison to the control group (Yasmin et al., 2015).

An 8-week study consisting of twenty-two young healthy volunteers receiving 11% inulin enriched pasta was carried out to check its effectiveness against gastrointestinal motility as well as lipid and glucose metabolism (Russo et al., 2010). At the termination of their study, marked variations were noticed between the control and treated group in terms of glucose and lipid levels (HDL/LDL ratio, cholesterol, triglycerides) with a significant reduction in these parameters in treated group in comparison to control group. In addition, a delay in gastric emptying was also observed together with proved insulin sensitivity in the people receiving inulin enriched diet.

Effect of inulin against glycemia

Scientific evidences indicate that prevalence of diabetes is increasing at an alarming rate in the developing countries. Obesity and the weight gain are among the major risk factors of metabolic ailments such as insulin resistance which is increasing at a striking rate. The obesity imparts insulin resistance in the liver, muscle cells and adipose tissues resulting in malfunctioning of insulin targeted cells. The high glycemic diet and consumption of sucrose enriched soft drinks may further augment the incidence of dysglycemic episodes (Yasmin et al., 2015). Various studies have revealed that the consumption of high fiber diet can increase the bulkness leading to increased gastric emptying time. Additionally, they also slow down the glucose absorption due to which sugar is released more slowly in the body thus can decrease the postprandial insulin level. Fiber rich diet remains intact after passing from the upper gastrointestinal tract but is fermented in the intestine (colon) into short chain fatty acids that modulate the gluconeogenesis and insulin sensitivity.

Epidemiological findings have shown continuous increase in the occurrence of diabetes in both Western and Asian countries. The diabetes mellitus is a metabolic disorder which mainly occurs due to abnormal insulin activity followed by increased blood glucose level. In the year 2000, almost 171 million people (2.8% of world's population) were found to be suffering from this disease (Nakamura and Omaye 2012). Hence, it is very important to recognize the potential health hazards and risk factors involved in the development of this disease. Consequently, inulin and fructo-oligosaccharides have been found to be effective in the stabilization of glycemic response and have positive effects on lipid metabolism by absorbing bile salts from small intestine (Abad Alegria and Gonzalez Vivanco 2003).

The positive role of inulin against diabetic rats (alloxan induced diabetic rats) was explored by involving the experimental group receiving a diet containing Jerusalem artichoke powder at a rate of 5, 10 and 15 % respectively. At the end of this study, a significant decrease in blood glucose was found in all groups as compared to the control. The kidney and liver functioning was also improved. Conclusively, the Jerusalem artichoke powder is considered an ameliorating agent against hyperglycemia due to its soluble fiber contents mainly fructo-oligosaccharides and inulin (Zaky 2009).

Recently, a report has shown that obesity, oxidative stress and intake of high fat or glycemic diets are the main causes of type 2 diabetes and insulin resistance (Styskal et al., 2012). Diabetes is linked with various complications such as blindness, nerve damage, neuropathy and cardiac diseases. Moreover, it is highly dependent on age as according to an estimation, about 20% people older than 60 years suffer from diabetes.

Relationship of inulin and bowel habits

Inulin and oligofructose are labeled as dietary fibers worldwide in terms of their compliance with most of the definition of dietary fiber. They possess the ability to ferment in colon and selectively stimulate the growth of beneficial intestinal microflora in addition to improve the bowel functioning. Since their fermentation can increase the bacterial population, the resulting microflora can contribute largely towards fecal biomass and water content of stool leading to bowel peristalsis, facilitated excretion, increased stool frequency and output (Alexiou and Franck 2008; Scholtens et al., 2006). As inulin type fructan can regulate the bowel functioning, their regular consumption can improve the intestinal health and provide relief from constipation (Den Hond, Geypens, and Ghoos 2000). Constipation frequently persists in older age and can be attributed to change in dietary pattern, liquid intake, less utilization of high fiber diet, excessive intake of laxatives and drugs, reduced intestinal functioning and physical inactivity (Kaur and Gupta 2002). A study on healthy human subjects by providing them inulin containing diet showed an increase in stool weight and colonic motility (Den Hond, Geypens, and Ghoos 2000).

Laxation and regularity

It is well established that fiber improves laxation by increasing stool weight as larger and softer stools are linked with ease of defecation and reduced transit time. Generally, cereal fibers are considered more effective in terms of stool weight such as wheat bran is placed under gold standard in case of fecal bulking (Slavin and Feirtag 2011). The major ocncern regarding the consumption of fiber is its gastrointestinal tolerance because different fibers have different effects on the GI tract. The dietary intake of fructo-oligosaccharides even at lower concentrations i.e. 10g can cause flatulance and gas troubles (Bonnema et al., 2010) whereas, other fibers such as polydextrose and resistant starch can be consumed up to 50 g without any complications (Grabitske and Slavin 2008).

Nutritional benefits of Inulin; Enhanced host resistance and colonic protection

The useful effects of inulin type fructans are not only attributed to the growth and proliferation of beneficial intestinal microflora but stimulation of systemic response through the production of SCFAs and many other unidentified metabolites. They also influence the native bacterial enzymes and end products of fermentation positively (Alexiou and Franck 2008).

Numerous evidences suggest the positive role of biofidobacteria in body towards increasing resistance against pathogens. Inulin and oligofructose can hinder the proliferation of harmful pathogens such as *E.coli, Campylobacter jejuni, Salmonella enteritidis* or *Clostridium perfringens* besides increasing the number and growth rates of biofidobacteria (Fooks and Gibson 2002). Results from human studies indicate that the fructans e.g. inulin and fructo-oligosaccharides have positive impact on the gut-associated lymphoid tissues which in turn help to build up immunity against harmful pathogens. The underlying effects are linked with resistance towards translocation and colonization of pathogens, increased recovery of gastrointestinal tract after disturbances and amelioration of disease symptoms (Alexiou and Franck 2008).

The most important role of inulin type fructans lies in their beneficial effects on the population suffering from intestinal disorders such as patients hospitalized with diarrhea (Clostridium difficile-associated diarrhea). The positive effects of increasing bifidal counts and decreased relapses of diarrhea have been reported (Lewis, Burmeister, and Brazier 2005). In addition to the bifidogenic effects, inulin can reduce the inflammation associated with ulcerative colitis (Furrie et al., 2005).

In a double blind placebo controlled trial, fermentable fibres were used synergistically with medicines to achieve promising results in patients suffering from colon cancer. In addition, fermentable fibres e.g. inulin type fructans can increase the mineral absorption. They also positively influence the enteroendocrine functions and are involved in the regulation of hormones related with appetite and satiety (Rafter et al., 2007).

Conclusion

Conclusively, it can be inferred that inulin holds promising technological and functional characteristics that can truly be imparted in certain food applications (bakery and dairy products). Additionally, dietary sources of inulin can be sought as promising health promoting ingredient as rich in dietary fiber and can be tailored to develop various therapeutic and functional food recipes. Additionally, inulin as fat replacer can be effectively utilized to formulate low calorie foods without imparting any deleterious effects on consumer's health thereby reducing the risk of hypercholesterolemia and hyperglycemia. Conclusively, it can be summarized that inulin supplemented designer foods have immense potential to attenuate various lifestyle related disorders.

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