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REVIEW ARTICLE DERLEME MAKALESİ

A RISING STAR PREBIOTIC DIETARY FIBER: INULIN AND RECENT APPLICATIONS IN MEAT PRODUCTS

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Abstract:

Inulin is a soluble dietary fiber extracted by a washing process mainly from chicory roots. In recent years, inulin has been mentioned as an ingredient having an important application potential in various areas such as chemical, food industry and pharmacy. Since there has been a rising demand for consumption of healthier meat products all over the world due to high and saturated fat content of these products, it is important to suggest healthier ingredients that have an ability to compensate for fat replacement. There has been a growing increase in number of studies on the incorporation of inulin in the formulation of various meat products, due to the positive impacts of inulin on textural, sensory and technological quality parameters compared to full-fat products, as well as it has beneficial effects promoting human health. In this review, we have chosen to briefly highlight inulin in terms of its physico-chemical properties, health implications and potential applications in meat products.

Keywords: Inulin, Dietary fiber, Prebiotics, Healthier meat products

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Introduction

Inulin is a natural storage polysaccharide of various plants which are mostly part of the *Compositae* family including chicory, dahlia, and Jerusalem artichoke. Inulin can also be produced by microorganisms including *Streptococcus* and *Aspergillus* species (Barclay et al., 2010; Glibowski and Bukowska, 2011). Other natural sources of inulin are yacon, asparagus, leek, onion, banana, wheat and garlic (Shoaib et al., 2016). Among these sources, in industrial production of inulin, chicory is the most common source. The roots of chicory look like small oblong-shaped sugar beets and their inulin content is more than 70% on dry substance, which is fairly constant from year to year (Franck, 2002).

The industrial production process of inulin involves the extraction of the naturally occurring inulin from chicory roots by diffusion in hot water, followed by purification and then spray-drying. High performance (HP) inulin is produced by removal of the fraction that have low DPs (degree of polymerization) after purification process (Franck, 2002; Shoaib et al., 2016).

Inulin has been a part of our daily food intake for centuries contributing to nutritional properties and exhibits technological benefits (Shoaib et al., 2016). Inulin is a prebiotic dietary fiber showing excellent properties as a carbohydrate-based fat substitute in relation to its ability to increase viscosity, form gels, provide mouthfeel and texture, and to increase water-holding capacity and thus presenting a good application potential in various food product formulations. Additionally, the incorporation of inulin in foods is known to reduce the risk of many diseases in human beings thus promoting health effects (Bodner and Sieg, 2009; Barclay et al., 2010; Rodriguez Furlán et al., 2014).

Chemical structure and physico-chemical properties of inulin

Inulin polymer consists of a long chain made up of 2-60 fructose molecules, which are connected by β-(2-1) bonds. The terminate fructose molecule is linked with a glucose molecule by α-(1-2) bond (Roberfroid, 1999, 2002; Bodner and Sieg, 2009). The degree of polymerization (DP) and branches have an effect on the functionality of inulin. Generally, while plant inulins are found to have chains incorporating 2-100 or more fructose units, chain length and polydispersity depending on plant species, microbial inulin has much larger degree of polymerization ranging from 10.000 to 100.000; furthermore, a bacterial inulin is 15% more branched than the plant inulin (Barclay et al., 2010; Shoaib et al., 2016). When inulin is extracted from the chicory root, it comprises a family of identical linear structures that differ in their degree of polymerization, ranging from 3 to 60 (Bosscher et al., 2006). The chemical structure of an inulin polymer is presented in Figure 1.

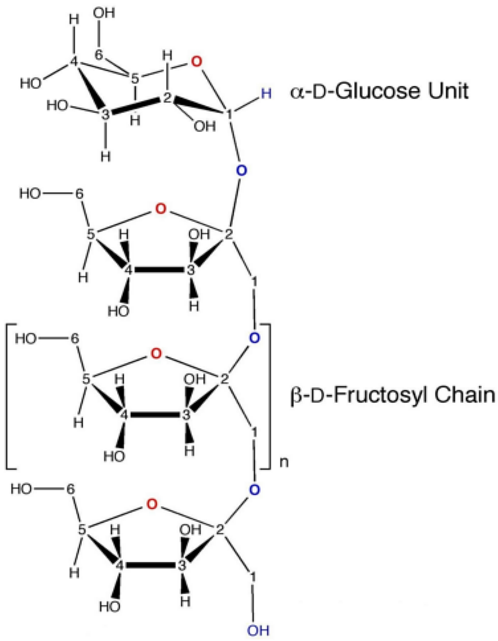

Figure 1. Inulin polymer (α-D-glucopyranosyl-[β-D-fructofuranosyl] (n-1)- D-fructofranoside) (Barclay et al., 2010).

Chicory inulin is a white, odourless powder with a high purity and well-known chemical composition. The physico-chemical properties of standard inulin and HP-inulin are presented in Table 1. Inulin has a bland neutral taste, without any off-flavour or aftertaste. Although standard inulin has a slight sweetness (10% compared to sugar), HP inulin has not due to removal of the fraction with a degree of polymerization lower than 10. Inulin combines easily with other ingredients and moderately soluble in water (Franck, 2002; Shoaib et al., 2016). Glibowski and Bukowska (2011) reported that in a neutral and alkaline environment, inulin is chemically stable independently of pH, heating time and temperature. However, chemical stability of inulin decreases in an acidic environment at pH ≤ 4 due to the heating time and temperature increase, thus limiting inulin applications in acidic foods, especially heated at temperatures above 60°C.

Table 1. Physico-chemical characteristics of chicory inulin (Franck, 2002).

	Standard inulin	**High performance (HP) inulin**
Chemical structure	GF_n ($2 \leq n \leq 60$)	GF_n ($10 \leq n \leq 60$)
Average degree of polymerization	12	25
Dry matter (%)	95	95
Inulin/oligofructose content (% on DM)	92	99.5
Sugars content (% on DM)	8	0.5
pH (10 % w/w)	5-7	5-7
Sulphated ash (% on DM)	< 0.2	< 0.2
Heavy metals (ppm on DM)	< 0.2	< 0.2
Appearance	White powder	White powder
Taste	Neutral	Neutral
Sweetness (*v.* sucrose=100%)	10 %	None
Solubility in water at 25°C (g/l)	120	25
Viscosity in water (5%) at 10°C (mPa.s)	1.6	2.4
Functionality in foods	Fat replacer	Fat replacer
Synergism	Synergy with gelling agents	Synergy with gelling agents

The utilization of inulin as a bulking agent, in particular as a fat replacer, is aided by its ability of water solubility. Parts of the molecular structure, specifically the hydroxyl groups, are more able to interact with water than other parts. This provides inulin with some surfactant character and it is able to form stable gels with water at concentrations of 13-50% (Barclay et al., 2010). When inulin is thoroughly dissolved in water or another aqueous liquid, with a shearing instrument like a rotor-stator mixer or high-shear homogenizer, it forms a particle gel network resulting in a white creamy structure (Franck, 2002; Shoaib et al., 2016). This unique property leads inulin gels provide considerable advantages, due to their similar textural characteristics to fat, allowing it to be used to replace fat, resulting in low fat foods that are palatable and have good mouth feel (Barclay et al., 2010). Franck (2002) emphasized that as far as fat replacement is concerned, HP inulin shows about twice the functionality of standard chicory inulin. Furthermore, inulin was reported as an ingredient working in synergy with most gelling agents such as gelatin, alginate, k- and i-carrageenans, gellan gum and maltodextrins (Franck, 2002).

Inulin gel is composed of a three-dimensional network of insoluble submicron crystalline in water (García et al., 2006). The most critical factors for gel formation of inulin are degree of hydrolysis, concentration and heating temperature (Kim et al., 2001; García et al., 2006). Kim et al. (2001) stated that gel formation could be a key step to produce carbohydrate based fat substitutes including inulin. In their study, they suggested that the heating-cooling process of inulin formed gels with stronger strength, smoother texture, more uniform and smaller particle size as compared to that obtained with a shearing process. In a study by Ronkart et al. (2010), it was reported that gelling properties of inulin-water systems were developed and the viscosity was increased when submitted to a microfluidization treatment, while the applied high shear stress did not induce a chemical composition change of inulin.

Health implications of inulin

Prebiotics are short chain carbohydrates which are capable of achieving the following criteria: (1) resistance to gastric acidity and mammalian enzymes, (2) susceptibility to fermentation by gut bacteria, and (3) ability to enhance the viability and/or activity of beneficial microorganisms (Bosscher et al., 2006; Al-Sheraji et al., 2013). Galactooligosaccharides (GOS), fructooligosaccharides (FOS) and inulin are the prebiotics most commonly known. While GOS are non-digestible and derived from lactose, inulin and inulin-type fructans are known as soluble dietary fibers (Al-Sheraji et al., 2013). The β-configuration of inulin makes it non-digestible to hydrolysis by human digestive enzymes, even those of the small intestine. Thus, undigested inulin reaches the large intestine, the most heavily colonized region of the gastrointestinal tract. Inulin is fermented by bifidobacteria and a wide variety of compounds that affect the intestine and the systemic physiology is produced (Kim et al., 2001; García et al., 2006; Shoaib et al., 2016).

Dietary inulin is known to inhibit development of colon cancers in animal models. Similar tumor-inhibitory effects are seen with fermentation products of inulin, particularly the short chain fatty acids butyric and propionic acids, both of which inhibit growth of cancer cells (Roberfroid, 2002; Barclay et al., 2010).

Dietary inulin has been addressed to exert immune-modulatory effects and induces differentiation in several intestinal cell types to its effects on the gut flora (García et al., 2006; Barclay et al., 2010). Lowering the pH value of intestine, inulin provides assistance in relieving constipation and increasing stool load or rate, which is known as bulking effect (Shoaib et al., 2016). These modulatory effects of inulin possibly include indirect effects like changes in the composition of the intestinal flora, and the promoted synthesis of short chain fatty acids with immune-regulatory actions (Barclay et al., 2010).

Inulin has also been mentioned to reduce risk of cardiovascular diseases presumably by reducing serum concentrations of the proatherogenic molecule, p-cresyl sulphate, or by its favourable effect on plasma cholesterol and glucose levels (Barclay et al., 2010). One of the other impacts of inulin is the potential to decrease the risk of high triacylglycerol concentrations and blood lipogenesis, thereby reducing the risk of atherosclerosis. However, the mechanism that how inulin actually affects lipid metabolism in humans is still under discussion (Shoaib et al., 2016). An additional impact of dietary inulin is increasing calcium and magnesium absorption and bone mineralization in young adolescents (Roberfroid, 2002; Barclay et al., 2010; Al-Sheraji et al., 2013).

Besides the mentioned positive effects of inulin, the question is: are there any toxicity issues regarding this ingredient? Al-Sheraji et al. (2013) stated that numerous animal and human investigation studies had been performed to assess the possible intolerance caused by inulin and oligofructose, and the only biological effects observed had been attributed to their action as non-digestible, fermentable carbohydrates causing self-limited gastrointestinal distress (Barclay et al., 2010). Bodner and Sieg (2009) suggested utilization of lower doses of inulin in meat products to avoid digestive tolerance problems (consumption of inulin at levels higher than 4 g per serving can lead to the formation of unpleasant amounts of gas). Thus, depending on the fact that chicory fructooligosaccharides do not increase morbidity or mortality or cause reproductive or target-organ toxicity, these compounds are not mutagenic, carcinogenic, or teratogenic (Carabin and Flamm, 1999; Barclay et al., 2010).

Application opportunities of inulin in meat systems

Meat is a major source of high biological valued proteins and valuable nutrients. Besides essential amino acids and nutritive factors of high quality and availability; meat can be seen as an important source of many health-promoting compounds like peptides, bioactive hydrolysates, connective tissue components, nucleotides, phytanic acid, conjugated linoleic acids and antioxidants (Olmedilla-Alonso et al., 2013; Young et al., 2013; Hygreeva et al., 2014; Angiolillo et al., 2015). However, meat and meat products are also associated with nutrients and nutritional profiles often considered unfavorable including high levels of fat and saturated fatty cholesterol, sodium and caloric contents (Decker and Park, 2010; Hygreeva et al., 2014), which can increase the incidence of coronary heart disease, obesity, high blood cholesterol and certain types of cancer (Felisberto et al., 2015). Therefore, there has been a growing tendency to investigate the development of healthier meat product formulations. Some of the most investigated issues in relation to meat consumption and health aspects are means of reducing formation of unhealthy compounds like heterocyclic aromatic amines, reducing fat and cholesterol content and/or modification of lipid composition, reducing sodium nitrite and phosphate content, and incorporation of healthy ingredients like prebiotics, probiotics, synbiotics, vitamins and antioxidants (Olmedilla-Alonso et al., 2013; Young et al., 2013).

Fat is one of the essential components of meat products which contributes to the texture and flavour and increases the mouthfeel and juiciness, meanwhile it is responsible for cooking yield and characteristic aroma (García et al., 2006; Choi et al., 2013). Therefore, fat reduction implies technological and commercial problems in the manufacture of meat products with modified texture and sensory characteristics (García et al., 2006). It is of great importance that the ingredients used for fat replacement could compensate for the alterations in quality parameters of low-fat meat products. Utilization of non-meat binders obtained from protein and carbohydrate sources is a common strategy for fat replacement in meat product formulations, which could mimic the behaviors of fat by increasing water binding, emulsification, gelling and thus improving product yield, texture and sensory quality (Brewer, 2012).

Inulin is currently used in several food systems as it can enhance the rheological and textural properties, improving the water-holding capacity and emulsion stability as a fat substitute and energy-reducing agent (Álvarez and Barbut, 2013). Inulin is considered to be a functional food ingredient and its utilization in food products include fat replacement and substitution (meat products, milk products, sauces, candies, etc.), reduction of caloric value (sugar-free chocolate, meat substitutes), water-holding ability (bakery goods), emulsification (margarine) and generally it is used to modify the texture and viscosity of foods (Franck, 2002; García et al., 2006; Glibowski and Bukowska, 2011; Shoaib et al., 2016).

The utilization of inulin can be considered a viable way to replace or reduce animal fat in meat products, by means of using natural ingredients as fat replacers (Bodner and Sieg, 2009; Álvarez and Barbut, 2013). Inulin is mentioned as a promising ingredient that could minimize the sensory and texture modifications caused by fat reduction, while contributing to the physiological benefits as a dietary fiber (García et al., 2006; Bodner and Sieg, 2009). Since inulin has the ability to form a stable gel network, it presents the advantage of being used to mimic some textural properties of fat and contributes a smooth, creamier and juicier mouthfeel when applied to low-fat meat product formulations (Frank, 2002; Bodner and Sieg, 2009). At the same time, inulin contributes few calories to the products, approximately 1 to 1.5 kcal/g (Coussement and Franck, 2001). Angiolillo et al. (2015) also stated that inulin have a neutral taste and is stable over a wide range of pH and temperature; thus presenting a great potential to be used for food applications. Bodner and Sieg (2009) reported that in technological applications of inulin in meat systems, two usage strategies are possible: Pre-activation in water or addition at the beginning of the bowl chopper process. In case of utilization of crystalline inulin, 24 h are required for complete gelling.

Recent research on inulin incorporation in various meat product formulations is summarized in Table 2. The results of the studies so far have indicated that inulin has a great potential, improving overall quality of meat products. As could be seen in Table 2, in various emulsified, minced and fermented meat products, inulin was reported to provide advantages on reduction of animal fat meanwhile enhancing textural, sensory and technological quality parameters. In emulsified meat products, inulin could successfully enhance emulsion stabilization and cooking yield (Álverez and Barbut, 2013; Keenan et al., 2014) and protected texture and sensory parameters (Huang et al., 2011). In dry-fermented products, inulin was effective to cover physical, chemical, microbiological or sensory attributes during storage (Menegas et al., 2013).

In spite of all these advantages, some technological issues have been mentioned regarding the utilization of inulin. It was noted that inulin could result in a white exudate in vacuum-packaged frankfurters during storage, meaning that it was not fully capable of immobilizing water for the duration of shelf life. According to the researchers, based on its molecular weight and particle size, inulin responds to the osmotic pressure and migrated from the meat batter into the purge. To avoid this scenario, it was suggested to use lower doses of inulin in combination with other high water-holding fibers, such as wheat or citrus fiber (Bodner and Sieg, 2009). Angiolillo et al. (2015) found that in meat burgers using FOS and inulin with the oat bran decreased the cooking loss and shrinkage, due to the increased water binding properties of oat fiber combined with FOS and inulin. Felisberto et al. (2015) also suggested simultaneous addition of prebiotic fibers and cassava starch in meat emulsions, due to avoid low stability in the treatments containing inulin.

Table 2. Recent studies on utilization of inulin and supplementary ingredients in various meat products

Ingredient(s)	Research material	Research highlights	Reference
Wheat fiber, oat fiber and inulin	Chinese-style sausage	✓ The type and amount of dietary fiber used did not change chemical composition, colour and total plate counts. ✓ Addition of wheat and oat fibers hardened the texture, while added inulin did not influence the texture of the sausages. ✓ The sausage groups with added inulin had positive scores in sensory characteristics, showing no significant difference from the control group.	Huang et al., 2011
Inulin, β-glucan and their mixtures	Cooked meat batter	✓ Powdered inulin enhanced cook yield and provided advantages in emulsion stabilization, while emulsions containing gel inulin resulted in creamy and softer characteristics. ✓ Appropriate addition of inulin and β-glucan showed synergistic effects compensating for some of the changes brought about by fat reduction, and maintained several of the textural characteristics.	Álverez and Barbut, 2013
Inulin and corn oil	Dry-fermented chicken sausage	✓ The addition of inulin did not change the physicochemical and microbiological parameters. ✓ Inulin resulted in an altered texture profile and a tendency toward lighter and reddish coloration. ✓ Sausages with corn oil and inulin remained stable without a loss of physical, chemical, microbiological or sensory attributes during storage.	Menegas et al., 2013
Inulin	Breakfast sausage	✓ Increasing inulin inclusions decreased cook loss and improved emulsion stability, but also resulted in greater textural and eating quality. ✓ Hardness values increased with increasing inulin concentration, with panellists also scoring products containing inulin as less tender. ✓ Acceptable sausage formulations with low fat content were produced, which would contain sufficient inulin to deliver a prebiotic health effect.	Keenan et al., 2014
Inulin and bovine plasma proteins	Minced meat	✓ A fat reduction of 20-35% was supplied with products enriched with proteins and inulin. ✓ No change was observed in color, flavor or taste among the samples. ✓ In sensory test, the combination of plasma protein and inulin had the best acceptability with respect to consistency. ✓ Plasma protein and inulin usage decreased fat drain from the emulsion.	Rodriguez-Furlán et al., 2014

Fruktooligo saccharide (FOS), inulin and oat bran	Meat burger	✓ Combinations of both FOS and inulin, respectively combined with oat bran minimized the loss of prebiotic compounds during cooking of the meat burger samples. ✓ Addition of prebiotic in presence of foam enriched with oat bran improved the technological and sensory characteristics, giving products that appear to be very prized.	Angiolillo et al., 2015
Inulin, FOS, polydextrose, and resistant starch	Meat emulsion	✓ Low emulsion stability was observed, mainly in the treatments containing inulin and polydextrose. ✓ A compact and dense network was observed in microstructure in formulations containing inulin, due to its chain length, which could also affect the organoleptic properties. ✓ The simultaneous addition of a partial level of cassava starch and the prebiotic fibers was suggested to improve stability.	Felisberto et al., 2015

Conclusion

Today there has been a rising attention paid to specific types of beneficial ingredients like dietary fibers as the consumers are becoming more and more health conscious about foods. Inulin is one of these fibers offering positive effects in terms of product quality and health issues. Although the role of inulin as a nutritional and health beneficial ingredient has been explored in various researches, we specifically focused on its usage as a functional ingredient in meat product formulations within this review. Inulin presents excellent advantages in different meat products especially incorporated with other non-meat binders, and the impacts on quality attributes are mainly related with its physico-chemical properties. In connection with these data, further research is needed regarding meat product quality associated with inulin characterization and interactions with other compounds. In addition, since today there has been a rising demand on natural food ingredients, it is important to perform further research on the direct utilization of alternative natural sources of inulin, such as Jerusalem artichoke in meat product formulations.

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