



Inulin as Prebiotics and its Applications in Food Industry and Human Health; A Review

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Abstract – Interest in consumption of prebiotics and probiotics to improve human gastrointestinal health is increasing. Consumption of beneficial probiotic bacteria combined with oligosaccharides may enhance colonic bacterial composition and improve internal health. Inulin is a polyfructans which is widely used as prebiotic, sugar replacer, fat replacer and texture modifier. It is a significant ingredient used in food industry by virtue of its diversified nutritional and functional properties. Inulin, cellulose, starch, pectin, carrageenan and xanthan gum are of great attention because of their nutritional and technological properties. The inulin concentration enhances product texture; at high concentration inulin can alter the texture profile of products because of its physico-chemical significance. Inulin may also significantly affect the sensory attributes of many products. The physico-chemical significance of inulin is associated with its degree of polymerization. The short chain fraction of inulin possesses more solubility and also contain much more sweetness than the long chain oligosaccharides. It can improve the mouth feel due to its properties which directly relate with those of other sugars.

Keywords – Inulin, Prebiotics, Oligofructose, Synbiotics, Food industry, Medical applications.

I. INTRODUCTION

The food industry is currently facing the challenge of meeting consumer demand for foods that provide additional health benefits and at the same time meet nutritional requirements. Some of the reasons for this increase in demand include the influence of modern lifestyles, the rising costs of health care due to higher life expectancy, and older people's natural interest in increasing their quality of life [1],[2]. Within the classification of functional foods, those classified as "rich" are those with added prebiotics or probiotics [3]. Extensive research has reported that the microbial community in the intestine consists of many species of bacteria, including both beneficial and pathogenic bacteria, with the former, responsible for good intestinal health. However, in circumstances where there is an insufficient quantity of beneficial bacteria, the bacterial balance becomes negative, allowing the pathogenic bacteria to cause problems [4], [5]. There are several ways to restore or maintain a positive balance: a) Incorporating living microorganisms in food; b) Stimulating the growth of

native intestinal microorganisms; and, c) Applying a combination of both the above. These three methods correspond respectively to probiotics, prebiotics and synbiotics [6].

Inulin, a compound extracted from the chicory root, is a fructan of great importance commercially, with a fully proven prebiotic function. Among the health benefits for the host is the fact that fermentation by the bacteria produces short chain organic acids, to which are attributed the reduction effect of lipids and cholesterol, and, therefore, a possible reduction in the risk of hypertension [7], [8]. It has also been suggested that the absorption of lactate in the colon, enhances the absorption of ions such as Fe, Mg, Ca and Zinc [9], [10] and favors both the immune system and digestive health [11]. Although some foods naturally contain prebiotics, are not consumed in sufficient amounts, considered for inulin to be from 5 to 15 g / day for a few weeks [12],[4]. An option to improve the intake of prebiotics is to fortify commonly consumed foods [13]. Prebiotic compounds such as inulin, have the advantage that they can be added to a wide range of commonly consumed foods because of their technological and prebiotics, such as yogurts, cereals, desserts, nutrition bars, beverages, ice cream and others [14]. Many of them are already available on the market. This paper briefly reviews the history and characteristics of inulin, the variety of food in which it has been applied as a prebiotic and functional ingredient, the concentrations used there in, and the tests that have been conducted on fortified foods.

II. PREBIOTICS, PROBIOTICS AND SYNBIOTICS

Gibson and Roberfroid [15] defined prebiotics as "a prebiotic is a non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improves host health". In 2008, the International Scientific Association for Probiotics and Prebiotics (ISAPP), taking into account the extant research in this area, defines prebiotics as "a selectively fermented ingredient that results in specific changes in the composition and/or activity of the gastrointestinal microbiota, thus conferring benefit(s) upon host health" [13]. The requirements that must be met by an ingredient for it to be considered as having a prebiotic effect are: a) resistance to gastric acidity, hydrolysis by

mammalian enzymes and gastrointestinal absorption, b) the ability to be fermented by gastrointestinal microflora c) the ability to selectively stimulate growth and/or activity of the intestinal bacteria associated with health and wellbeing [13]. The probiotic concept was defined as "living microorganisms that administered in adequate amounts confer health benefit on the host" in meetings (2001-2002) of the Food and Agriculture Organization and the World Health [16]. Synbiotic is a term coined to describe a product that contains a combination of prebiotics and probiotics, which work together to promote a beneficial microbial population in the intestine. It is considered, in order for the term synbiotic to be ascribed, that the prebiotic should be associated with a positive effect on the development of the specific probiotic [17]. Examples of these combinations are bifidobacterium-fructo-oligosaccharides, *Lactobacillus* and bifidobacterium-inulin. Synbiotics work in two ways: a) improving the viability of probiotics; and b) providing specific health benefits [18]. As synbiotics have not been widely studied, has not been fully elucidated whether the benefits of each ingredient are added together or that synergistic effect occurs [19],[10].

III. FRUCTO-OLIGOSACCHARIDES (FOS)

The fructo-oligosaccharides (FOS) are oligosaccharides which are composed of D-fructose units linked with β 2-1, not hydrolyzed by human digestive enzymes, and may be present naturally in various plants, such as, leeks, onions, garlic, asparagus, Jerusalem artichokes, dahlias, yacon and chicory [20], [21]. Research reveals that these important compounds meet the requirements for classification as prebiotics. Their stimulation of the growth of bifidobacteria brings great benefits to the health of the host, and, moreover, its sweetness makes it a good substitute for sucrose [22]. Three categories of FOS may be considered, Native chicory inulin, (with a degree of polymerization (DP) running from 2 to 60 fructose units, and 12 on average), and oligofructose (with a DP of from 2 to 8 fructose units and an average of 4) are fructosyl chains featuring different lengths and terminals fructose and glucose molecules [23]. A third category is comprised by the short chain FOS, which are mixtures of fructosyl chains with a terminal glucose unit and which do not include more than 5 units [24], [22]. FOS can be obtained from the hydrolysis of inulin using enzymes (endoinulinase) or by conducting an enzymatic reaction of sucrose transfructosylation residues using the enzyme B-fructofuranosidase [25], [26]. As industrial level, there is a low level of FOS produced using enzymes from plants due to the influence of seasonal conditions, the enzymes used are mainly of fungal origin, such as *Aspergillus niger* or *Aureobasidium* sp [27]-[29].

The health benefits attributed to FOS include: a) increases in the absorption of Ca, Mg, P and Fe; b) a reduction in lipids and/or cholesterol; c) the prevention of osteoporosis; and, d) a reduction in the risk of obesity [30], [20], [11]. Among the main final products of FOS fermentation, are the short-chain fatty acids, acetate,

(which is involved beneficially by being metabolized in muscles, and the kidney, heart and liver) propionate, (a cholesterol synthesis suppressive and possible glucogenic precursor), and butyrate metabolized in the colonic epithelium growth regulator and cell differentiation [15], [31].

IV. INULIN

Inulin is a generic term that includes all straight-chain fructans consisting of fructosyl units linked by β -D (2-1) [32], [33]. Along with fructo-oligosaccharides, lactulose and oligosaccharides, this is one of the most studied compounds, the prebiotic effect of which has been proved through in vitro and in vivo tests [34]. This compound, which is a carbohydrate reserve of many plants, was first extracted from the root of *Inula helenium* by German scientist Rose in 1804 and was later called inulin in 1918 [35]. Inulin is considered within the so-called fructans compounds and is present in fruits and vegetables, with is most common sources being wheat, onions, bananas, asparagus, chicory, garlic and leek, and is a compound that has been tested in high doses on animals with no toxic effects reported [36]. The plant that has been exploited at industrial levels for the extraction of inulin-type fructan is chicory, a plant from the Compositae family, whose fresh root gives unfractionated inulin consisting of glucose, fructose, sucrose and small oligosaccharides [32]. Fructans have a chemical structure consisting of fructosyl units with a terminal glucose moiety and may be linear or branched. Five groups can be observed on the higher plants : inulin, levan, mixed levan, inulin neoseris and levaneoseris. Inulin is composed of fructosyl units with β -D (2-1) linear link [33].

A. Plant Sources of Inulin

Inulin is a naturally occurring non-structural, storage carbohydrate, found in leeks, onions, wheat, asparagus (*Asparagus officinalis*) garlic, Jerusalem artichoke (*Helianthus tuberosus*) and chicory (*Cichorium intybus*) root. Some 36,000 plants from a wide variety of genera contain inulin as an energy reserve, or as an osmoregulator assuring cold resistance. The two species currently used by the industry to produce inulin belong to compositae: Jerusalem artichoke (*Helianthus tuberosus*) and chicory (*Cichorium intybus*), the latter being, by far the most commonly used source. In chicory, inulin is stored as reserve carbohydrate in the fleshy taproot, which is equal to 15–20% inulin; thus, it can be considered as concentrated source of inulin. Chicory inulin contains up to 10% mono and disaccharides, mainly sucrose and fructose, and an oligosaccharide content of approximately 30% [33]. Inulin content of some of the sources is presented in Table 1. Inulin is officially recognized as a natural food ingredient in all European Union and has a self-affirmed Generally Recognized as Safe (GRAS) status in United States.

Table 1. Inulin content of few food sources [37]

Source	Inulin (g/100g)
Raw onion pulp (<i>Allium cepa</i>)	1.1-7.5
Jerusalem artichoke tuber (<i>Helianthus tuberosus</i>)	16.0-20.0
Chicory root (<i>Cichorium intybus</i>)	35.7-47.6
Asparagus raw (<i>Asparagus officinalis</i>)	2.0-3.0
Garlic (<i>Allium sativum</i>)	9.0-16.0
Wheat (flour baked) (<i>Triticum sp.</i>)	1.0-3.8
Barley (raw cereal)-(<i>Hordeum vulgare</i>)	0.5-1.0

B. Chemical Structure of Inulin

Inulin is a polydisperse mixture of molecules all with same basic chemical structure, which can be symbolized as GF_n, where G is the glucosyl moiety, F is the fructosyl moiety and n is the number of fructosyl moiety linked by b(2,1) linkages (Fig. 1). A glucose molecule typically resides at the end of each fructose chain and is linked by an a(1,2) bond, as in sucrose. The degree of polymerization of inulin typically ranges from 2 to 60. The presence of b(2,1) bond prevents inulin from being digested like a typical carbohydrate and is responsible for its reduced calorie value and dietary fiber effects [37].

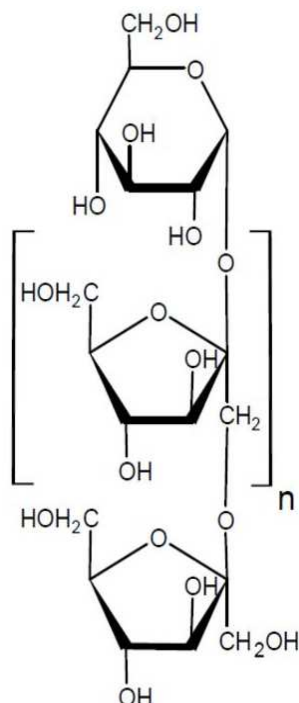


Fig. 1. Structure of inulin, n=2-60.[37]

C. The Prebiotic Potential of Inulin

Prebiotic potential can be evaluated through compound fermentability on the basis of the *bifidobacterium* and *lactobacilli* population native to the colon. It is manifested through changes in the intestinal flora, the decrease in

pathogenic bacteria, and metabolic activity in the production of health promoting metabolites [38], [39]. The activity of inulin as a prebiotic has been widely proven by numerous studies which report selective fermentation by the bifidogenic bacteria [40]. Among the indicators that are more frequently evaluated and that are associated with prebiotic potential are the changes that take place in the composition of the microbial population and the generation of short chain fatty acids (propionate, butyrate, acetate) [41],[4].

D. In vitro and in vivo assays

As a prebiotic ingredient, inulin has undergone extensive testing on its resistance in the upper intestinal tract and on its specific fermentability by bifidobacteria. In vitro studies using anaerobic cultures with human fecal sludge, and as a carbon source fructose, inulin, starch and oligofructose, inulin and oligofructose showed a significant increase in the number of bifidobacteria after 12 hours of incubation [34]. Rossi et al. [42] conducted studies of inulin and fructo-oligosaccharides as a carbon source in batch culture fermentations using pure *Bifidobacterium* strains and fecal sludge and found butyrate as the major product of the fermentation of inulin in fecal sludge culture. Results of SHIME (Simulator of the Human Intestinal Microbial Ecosystem) tests on inulin showed a significant increase in bifidobacteria and a significantly higher butyrate and propionate production [38].

In vivo studies conducted on subjects fed inulin by ileostomy, showed an 86% recovery in terminal ileum [43]. The analysis of the feces of a group of mice fed with inulin, soy oligosaccharides and fructo-oligosaccharides and then administered with probiotic bacterial cultures (*Lactobacillus acidophilus*, *L. casei* and *Bifidobacteriumlactis*), revealed that FOS, inulin and soy oligosaccharides increased the retention time and survival of the three probiotics[44]. Inulin, is also commonly used as a control for the evaluation of new ingredients. Santiago and Lopez [45], assessed the prebiotic effect of fructans from *Agave angustifolia* by quantifying the increase in the population of bifidobacteria and the production of short chain fatty acids, finding the agave fructans more efficient than some commercial inulins. However, studies using agave fructans as prebiotics are recent, and issues relating to in vivo studies are still emerging. According to the above and numerous other reports, it is clear that a food supplemented with inulin has not only prebiotic potential, but also the ability to improve the food's sensory and physicochemical properties.

V. MEDICAL PROPERTIES OF INULIN

A. Physiological Effects of Inulin Fermentation in the Gastro-Intestinal Tract

Inulin is classified as a low calorie food ingredient as it contains less than half amount of calorie content of digestible carbohydrates, providing a calorie value of 1.0-2.0 kcal/g [46]. Therefore, inulin can be used as a suitable food ingredient substitute to lower the total calorie content of daily diet especially for obese people.

In addition, animal in vivo studies have concluded that a diet supplementation with inulin would reduce the cecal pH by production of SCFA (end products of colonic fermentation of inulin), increase the size of the cecal pool for SCFA production, and increase the wall thickness in the small intestine and in the cecum which results in an increase in blood flow [47].

B. Effect of Inulin on Constipation

Constipation is a multi-factorial ailment often encountered in elderly people. Different reasons may contribute to the development of constipation such as aging, medications, inadequate fluid intake, lack of fibre-containing products in a daily diet, inadequate physical activity, and decrease in intestinal motility. Different human studies have suggested that fermentation of carbohydrate stimulate colonic motility [48], [49], and therefore, administration of oligofructose and inulin to a daily diet could improve constipation, abdominal discomfort, and increase in stool frequency. Hidaka et al.[50] observed that the administration of oligofructose relieved constipation and inulin ingestion improved constipation in 9 of 10 subjects. Abdominal discomfort, mainly flatulence, was reported rarely, and by only a few patients. A significant increase in stool frequency was observed in healthy volunteers having one stool every 2–3 days by including inulin with DP more than 25 in the diet [51].

C. Effect of Inulin on Mineral Absorption

Some studies have suggested that chicory inulin as a soluble fibre may increase the body absorption of calcium, improve bone mineral density, and reduce the risk of osteoporosis development. Delzenne and Kok[52] have demonstrated that rats fed with inulin absorbed more calcium and magnesium compared to control rat, despite an increase in total faecal mass. Increased calcium absorption could be due to its increased availability by transfer of calcium from the small intestine into large intestine and the osmotic effect of inulin that transfers water into the large intestine, thus allowing it to become more soluble [46]. The improved absorption was associated with decreased pH of ileal, cecal and colonic contents, resulting in an increased concentration of ionized minerals. Ohta et al.[53] reported that ingestion of inulin improved calcium and magnesium absorption in normal rats, although only magnesium absorption was increased in cecectomized rats. This suggested that the effect of fermentation in the cecum was particularly important for calcium absorption. Other study by Coudray et al.[54] noted that inulin improved the absorption of calcium but not of magnesium, iron and zinc in humans. Mechanism by which ingestion of non-digestible carbohydrates improves mineral absorption is not clear.

D. Effect of Inulin on Glycemia/Insulinemia

The effect of inulin and oligofructose on glycemia and insulinemia are not yet fully understood, and existing data are contradictory, indicating that these effects may be due to physiological nature of the disease [46]. Oku et al. [55] revealed 17% and 26% reductions in postprandial glycemia and insulinemia respectively

among rats after feeding by a diet containing 10% short-chain fructo-oligosaccharides (FOS) for 30 days. The reduction in glycemic response to saccharose or maltose is possibly due to reduction of disaccharidase activity in the gastrointestinal tract. Luo et al.[56] confirmed the previous results and showed that in diabetic rats, ingestion of a diet containing 20% oligofructose for 2 months decreased postprandial glycemia, despite a lack of modification of the glycemic or insulinemic response to a saccharose or maltose load. However, the results from some human studies are not consistent with above studies. For example, Yamashita et al. [57] showed that in diabetic subjects, taking 8 g of FOS/day for 14 days in diabetic subjects led to a decrease in fasting blood glucose. When 10 g of artichoke inulin was added to 50 g of wheat-starch meal in healthy human subjects, the blood glycemic response was lower, despite no apparent interference by inulin on starch absorption [58]. When rats are fed with 10% and 20% FOS in their diet for 6 weeks, the tests showed that mouth to anus transit time was shortened by 25 and 50%, respectively. This reduction in transit time confirms a dose-dependent effect [55], possibly similar to other dietary fibres; inulin and oligofructose influence the absorption of macronutrients, especially carbohydrates, by delaying gastric emptying and shortening small-intestinal transit time.

Boillot et al. [58] have demonstrated the reduced hepatic gluconeogenesis induced by inulin intake could be mediated by the short-chain carboxylic acids, especially propionate. Propionate given in the diet of rats for 4 weeks reduced fasting blood glucose and inhibited gluconeogenesis in isolated hepatocytes, probably via its metabolic conversion into methylmalonyl-coenzyme A (CoA) and succinyl-CoA, both of which are specific inhibitors of pyruvate carboxylase. In addition, propionate may also influence hepatic glucose metabolism indirectly by lowering plasma fatty acid concentration, a factor known to be closely related to gluconeogenesis [59].

E. Effect of inulin on lipid metabolism

Oku et al. [55] have shown that inclusion of inulin in the diet of saturated fat fed rats significantly reduced the high triglyceride content of blood and liver. Delzenne and Kok [52] suggested that triacylglycerol (TG) lowering effect of oligofructose occurs via reduction in very low density lipoprotein (VLDL)-TG secretion from the liver as a result of the reduction in the activity of lipogenic enzymes, and in the case of fatty acid synthase via modification of lipogenic gene expression. Oligofructose decreased serum TG when it was included in the standard, fibre free or high fat diet of rats. Addition of oligofructose in a carbohydrate rich diet reduced the de novo liver fatty acid synthesis [52]. Studies on incorporation of ¹⁴C acetate into TG in hepatocytes isolated from control and oligofructose fed rats also supported the above results [60]. Hepatic glycerol-3-phosphate concentrations were significantly higher in oligofructose fed rats than in controls. This relative increase in glycerol-3-phosphate content of the liver

might be due to its decreased utilization for fatty acid esterification. Indeed, the administration of oligofructose slightly but significantly, reduced hepatocyte capacity to esterify 14 © palmitate into TG [61].

VI. FOOD APPLICATIONS OF INULIN

Inulin is a dietary ingredient widely used in the design of new functional products. It has been applied in a variety of foods, either, individually, or combined with other fructo-oligosaccharides or probiotics to develop symbiotic foods. However, the food's prebiotic potential or prebiotic content after processing are not always evaluated, as there may be variations [62]. This poses a challenge to the correct labeling of foods and in order that adequate intake recommendations are indicated in cases where prebiotic properties are declared. In many foods, inulin has been added only with the aim of improving technological characteristics, without discounting the possibility of its potential as a prebiotic food.

A. Chocolate

Chocolate is one of the products to whose different forms inulin has been added. **Golob et al.** [63] prepared a chocolate formula, and subsequently replaced the sucrose with inulin the amount of which is not reported. Sensory evaluations were carried out to measure consumer acceptability, detect differences between formulations and measure intensity attributes. In general there was a good level of acceptance of the product, and except for the level of sweetness and solubility, no significant difference was found between the new and original product. Another reported experiment using chocolate was conducted by preparing formulations in which sucrose was replaced with inulin, polydextrose and maltodextrin [65]. Physicochemical testing (A_w , pH), mechanical testing (hardness), and sensory attributes testing and acceptability analysis were performed. The samples with inulin and polydextrose had the highest acceptability even though samples with high ratios maltodextrin and polydextrose were softer.

Sugar was substituted for both isomalt and maltitol in chocolate milk supplemented with 9% inulin, which was then tested to ascertain their comparative effects [65]. Conching temperatures of 50, 55 and 600 C were applied and the rheological and physical properties were determined. All properties analyzed were affected and it was found that the yield stress and viscosity properties are important quality parameters that influence the sensory properties of the product, leading to the conclusion that maltitol was more appropriate than isomalt to replace sugar in chocolate supplemented with inulin. With the same purpose of replacing sucrose, a dark chocolate was mixed with different inulin and polydextrose concentrations, following which conching temperatures of 650 C for 10 min and 500 C for 15 min were applied [66]. After the effects were analyzed by measuring the rheological properties, microstructure and physical properties, the optimum mixture was found to be a formulation of 75.3594% polydextrose and 24.6406%

inulin. Results revealed that at higher concentrations of inulin, the formation of larger crystals affected the quality of the chocolate.

Aragon-Alegro et al.[67] developed a synbiotic chocolate mousse adding *Lactobacillus paracasei* subsp. *Paracasei* as a probiotic, and inulin. In test probiotic survival during storage, which was extended beyond 28 days, inulin did not affect probiotic survival and sensory properties were not affected. Mousse is therefore considered a good vehicle for this probiotic. Within their assessments of fortified foods, Kolida et al.[68] evaluated the prebiotic effect on healthy subjects of the daily consumption of inulin at 5 and 8 g / day supplied via a chocolate drink for two weeks. For both doses, a bifidogenic effect was present, with a higher percentage of subjects responding to the higher dose. Except for the in vivo assay of the chocolate drink, which provides information on the sufficient ingested doses required to obtain a beneficial effect, most of the reported studies of chocolate supplemented with inulin were mainly aimed at improving the foods physicochemical or sensory properties, however their prebiotic properties listed.

B. Milk and milk beverage

The dairy sector is one of the areas where inulin has been widely used, because of its prebiotic properties as well as the texture it imparts, which is similar to fat creaminess [69]. Inulin added in three different concentrations to baby milk formula, and administered for 14 days, showed positive results in the analysis of feces, where in all concentrations, there was a reduction of Clostridium bacteria. The concentration of 1.25 g/day caused an increase in the number of bifidobacteria and a reduction of gram-positive cocci while coliform bacteria were also present [70]. Casiraghi et al.,[71] prepared symbiotic skim milk with 2% fat, adding *Lactobacillus acidophilus*, *Bifidobacterium lactis* and 2% inulin. Trials were conducted with 26 healthy volunteer subjects, who, following indicated protocol, consumed 500 mL synbiotic milk or placebo daily for four weeks. At the end of the period, an increase in both probiotic counts in feces was observed, leading to the conclusion that there was a positive modulating effect on the intestinal ecosystem.

Villegas et al. [72] compared the effects of two types of inulin (short and long chain) adding them via concentrations of between 3-8% and 0-8% sucrose to low fat vanilla flavor milk beverages. Sensory attributes were evaluated and the acceptability of the product was optimized. The product attributes influencing acceptability were consistency and sweetness, while the best concentrations for short-chain inulin were between 5 and 8%, and 4-6.5% for long-chain inulin, both with a sucrose concentration between 4 and 6.5%. In the case of milk and milk beverages, the addition of inulin is mainly focused on conferring prebiotic potential, but also on evaluating sensory properties, this mean that the determinations that have been carried out focus on in vivo and microbiological assays. In their study of babies Yap et al.[70] reported that when the initial number of bifidobacteria is high, the increase of bifidobacteria, not significant after the

consumption of probiotic milk, a factor not reported in other studies, and which would be interesting to analyze.

C. Yogurt

Allgeyer et al. [73], conducted experiments to evaluate through descriptive analysis and consumer acceptability, a yogurt supplemented with different combinations of three prebiotics, inulin supplemented at both 1.24 and 2.48% and soluble corn fiber (polydextrose) and two probiotics, *Lactobacillus acidophilus* and *Bifidobacterium lactis*. Consumer preference leaned toward products containing additional probiotics and the ones that contained inulin and polydextrose and showed a high viscosity and a medium level of sweetness. Another probiotic low fat yoghurt was subject to experimentation in which it was supplemented with inulin at concentrations of 1 and 2%. Its sensory properties, and physicochemical and microbiological characteristics were then evaluated at 1, 7 and 14 days of storage [74]. These properties were not affected by the presence of inulin and the viability of the bacteria increased during storage. To evaluate the effect on both texture and rheological properties, inulin of three different degrees of polymerization at a rate of 4%, and two probiotics, *Lactobacillus delbrueckii* ssp. *Bulgaricus* and *Streptococcus thermophiles*, were added to a low-fat yogurt [75].

The rheological properties and texture were evaluated after an overnight at 40C and 28 days of storage. All yogurt supplemented with the three types of inulin presented low values in terms of the consistency coefficients and shear stress, and also demonstrated behavior that deviated from Newtonian flow, as compared with the control. In most cases, the study of yogurt fortified with inulin, is directed at the effect on the product's rheological and textural properties and, when the product is symbiotic, the influence it has on the survival of probiotics. As such, physical, microbiological and sensory tests are preferably carried out, the result of which indicate a good rate of survival for probiotics after the addition of inulin. Trials would be desirable to ascertain the probiotic and prebiotic potential of the product, which would complement the benefits provided by its consumption.

D. Ice Cream

Akalin and Erisir [76] report a study carried out to compare the effect of inulin and oligofructose applied at a level of 4% on the rheological properties of a regular low fat ice cream and a probiotic ice cream. The survival of *Lactobacillus acidophilus* and *Bifidobacterium animalis* during storage at 30, 60 and 90 days was also evaluated. The more favorable texture characteristics, in terms of firmness and melting, were obtained with inulin, while the survival rate of the bacteria was better with oligofructose.

In another study of the preparation of symbiotic ice cream, 3% inulin for the purpose of evaluating its effect on the survival of the probiotic *Lactobacillus acidophilus* [77]. After 7 and 15 days storage at both -18 to 230C, the results showed that the survival of *L. acidophilus* increased with the application of inulin, while the product's sensory properties were not affected. El-Nagar et al. [78] found positive relationships between sensory properties, changes in texture and the rheological characteristics obtained by

adding inulin at 5, 7 and 9% to a frozen yogurt, concluding that blend properties improved as the inulin percentage increased. The addition of inulin ice cream generally improves texture conditions by increasing firmness and reducing melting time, increases the survival of probiotics during the development of symbiotic ice cream, and substitutes fat without altering the product's sensory attributes. However, no trials establishing specific level of consumption that would influence health are reported.

E. Cheese

Using a combination of inulin, oligofructose and honey (at a level of 10% total) with two probiotics (*Lactobacillus acidophilus* and *Bifidobacterium lactis*), a petite-suisse cheesesymbiotic was prepared [79]. In vitro, the prebiotic food effect was evaluated by measuring the changes in the probiotic population after that the simulated human digested of de cheeses was made. In the batch fermentation was used fecal sludge from healthy subjects and the short chain fatty acids were also determined. The results are promising for obtaining a functional cheese in formulations where mixtures of both probiotics and prebiotics were used. Cottage cheese has also been supplemented with prebiotics and probiotics in order to obtain a symbiotic product. Araujo et al., [80] developed a cottage cheese by mixing 8% inulin with a probiotic strain *Lactobacillus delbrueckii*. Alongside physicochemical and sensory tests, were also conducted to establish gastric resistance and quantify the inulin. According to the results, a symbiotic product of acceptable sensory characteristics was obtained. The inulin determination indicates that the content (2.5/portion 50g) is sufficient to consider it prebiotic, and, also taking into account the probiotic's gastrointestinal resistance, the products is considered a food with functional potential.

Buriti et al. [81] worked on the development of a symbiotic cream cheese, using inulin in a concentration of 8% and *Lactobacillus paracasei* mixed with *Streptococcus thermophilus*, subsequently analyzing the inulin content, and the physicochemical and microbiological. The quantification of inulin after 21 days of storage did not reveal significant changes, while the probiotic bacteria count was similar between the fresh and post-storage cheese. These results indicate that this product has symbiotic potential. The application of inulin in cheese is preferably focused at obtaining a symbiotic food. These products were evaluated for inulin the content, resistance in the gastrointestinal tract, and physicochemical and sensory properties. Even when there is more evidence to consider these products as having potential as a functional food, it is necessary to complement this evidence with in vivo assays in order to evaluate indicators confirming consumer benefits.

F. Bread and biscuits

Röble et al. [82] evaluated the effect of inulin and oligofructose as fat replacers on quality attributes in the preparation of quick breads (scones). The results of the experiment indicated that with a mixture of margarine (3.53%), oligofructose (10%) powdered sugar (0.55%) and inulin (5.92%) a product similar to the control was obtained while achieving a reduction in fat and sugar.

Inulin at concentrations of 50%, 75% and 100% was used as a substitute for fat, in the preparation of muffins [83]. The effect on the texture and sensory properties of the product was evaluated, with the results showing that as the percentage of inulin increased, so did moisture and crumb density. With the product's sensory properties negatively affected to a significant degree by higher inulin concentrations, it was concluded that a concentration of up to 50 % inulin can obtain a product similar to the control.

Hempel et al.[84] used as a prebiotic ingredient in wafer cracker, inulin syrup made of Jerusalem artichoke tubers in its commercial form and ultra-filtrated in order to modify the content of free sugar and minerals, both were lyophilized. In the manufacture of wafers were using various types of flour (wheat, spelled wheat, rice and mixtures). The results showed that ultrafiltration syrup, prevented the formation of compounds that affect the color of the wafers. It also became clear that to maintain the sensory quality and physical characteristics of the product, it is necessary to maintain a balance between the inulin treatment and the flour replacement. Inulin is used as a fat substitute in most bakery products and biscuits, and, in greater proportions than in other foods. Almost all cases report that hardness increases with the percentage increases of inulin. No trials of these product's prebiotic potential are reported.

G. Cereal

A ready to eat breakfast cereal, was prepared with 18% inulin and given to 12 volunteer subjects who consumed 50g daily for a period of four alternate weeks [85] . Results showed a negative correlation between changes in blood lipids and the increase in bifidobacteria, while at the same time demonstrating positive effects in terms of secondary bile acid excretion and the decreased in the number of facultative anaerobic microorganisms. The subjects showed no abdominal pain, and there was no effect on the weight of the fecal material or in the number of peristalsis movements.

H. Burger

Inulin has also been applied as an functional additive in meat products. Cegiełka and Tambor[86] added inulin in four formulations of Polish chicken burgers at concentrations of 1, 2 and 3%, and subsequently analyzed their physicochemical and sensory properties. The thermal processing yield and the shear force was not affected by the addition of inulin, and all formulations were sensorially acceptable, with the highest values for the product appearing at a concentration of 1% inulin. In this last group of foods, only in the case of cereal was functional potential analyzed. The results demonstrated the product as having not only a beneficial effect on health by reducing the measured dose of lipid consumed, but also no adverse effects. In the rest of the studies mentioned in this last foods group, only the physicochemical and sensory properties were evaluated.

Table 2. Food products supplemented with inulin

Food	Inulin content	Tests in final product	Reference
Chocolate (milk, rice, hazelnut)	Only specifies that it replaced with sucrose in traditional recipe	Sensory properties	[63]
Chocolate mixtures of inulin, polydextrose and maltodextrin	10.45-41.80% (Aw, pH)	mechanical testing hardness) and sensory properties	[64]
Isomalt and maltitol milk chocolate	9.0%	Rheological and physicochemical (color, hardness, Aw)	[65]
Synbiotic chocolate mousse Inulin and <i>Lactobacillus Paracasei</i> subsp. <i>paracasei</i>	5.0%	Sensory and microbiological analysis	[19]
Chocolate drink	5-8 g/day (two weeks)	(Prebiotic effect in vivo) Stool culture	[68]
Infant formula	0.75, 1.0 and 1.5 g/day in the babybottle	(Prebiotic effect in vivo) Stool culture	[70]
Synbiotic skimmed milk <i>Lactobacillus acidophilus Bifidobacterium lactis</i>	2% (500 mL/day, 4 weeks)	(Prebiotic effect in vivo) Stool culture	[71]
Vainilla milk beverage	3-8%	Sensory properties	[72]
Synbiotic yogurt drink <i>Bifidobacterium lactis Lactobacillus acidophilus</i>	1.24 and 2.48%	Sensory properties	[73]
Low-fat yogurt <i>L. acidophilus, L. delbrueckii</i> sp.	1 and 2%	Microbial and physico-chemical properties	[74]
Low-fat yogurt (<i>L. delbrueckii</i> sp. <i>Bulgarius</i> <i>Streptococcus thermophilus</i>)	4%	Rheological and textural properties	[75]
Synbiotic ice cream added with inulin or oligofructose, <i>L. acidophilus</i> and <i>B. animalis</i>	4%	Survival of the probiotic (in vitro) physico-chemical and rheological properties	[76]
Synbiotic ice cream <i>L. acidophilus</i>	3%	Sensory properties microbiological survival	[77]
Yog-ice cream	5, 7 and 9%	Textural, rheological, melting and sensory properties	[78]

Synbiotic petit-suisse cheese Inulina-oligofructosa-miel <i>Lactobacillus acidophilus</i> <i>Bifidobacterium lactis</i>	10%	Prebiotic effect (in vitro) Stool culture	[79]
Synbiotic cottage cheese <i>L. delbrueckii</i>	8%	Prebiotic effect (in vitro) Gastro-intestinal assay Viability of <i>L. delbrueckii</i> Quantification of inulin Physico-chemical and sensory properties	[80]
Synbiotic cream cheese <i>Lactobacillus paracasei</i> <i>Streptococcus thermophilus</i>	8%	Quantification of inulin Physico-chemical and microbial properties	[81]
Quick breads (scones)	2.5, 3.33, 6.67, 10%	Physical parameters of quality of product	[82]
Muffins	Replaced the fat from a 50, 75, and 100% (original 50% of fat content)	Sensory and physical properties	[83]
Wafer crackers modified inulin (syrup)	15 g / 112.5 g flour	Rheological, physical and sensory properties	[84]
Rice-based breakfast cereal	18% mixed inulin- FOS 50g of cereal per day (4 weeks, 3 alternating periods)	Prebiotic effect (in vivo) composition of feces blood lipids, bile acids profile at breath H ₂	[85]
Chicken burger	1, 2 and 3%	Sensory and physico-chemical properties	[86]

VII. CONCLUSIONS

The data reviewed in this paper show that the application of inulin in foods has been increasing over the past 10 years, for both prebiotic and technological properties. The diversity of foods fortified with inulin is great and the concentrations used ranging widely depending on the type of food from 0.75 to 50%. Undoubtedly, the prebiotic effect of inulin is proven, but the interaction with different food matrices is complex, and is not always technologically favorable for the product. Moreover, additional to evaluations of sensory, physicochemical and rheological characteristics, it is essential to carry out measurements in the food, of such characteristics as prebiotic content, and prebiotic activity in vivo and in vitro, and assess potential adverse reactions in order to define suitable doses of consumption.

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