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Review

Application of inulin in cheese as prebiotic, fat replacer and texturizer: A review

Reza Karimi[a,b,*], Mohammad Hossein Azizi[b,**], Mehran Ghasemlou[c,***], Moharam Vaziri[a,d]

[a] Department of Food Science, College of Agriculture, Sanandaj Branch, Islamic Azad University, Sanandaj, Iran
[b] Department of Food Science and Technology, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-336, Tehran, Iran
[c] School of Packaging, Michigan State University, East Lansing, MI 48824, USA
[d] Department of Food Science and Technology, Ferdowsi University of Mashhad, Mashhad, Iran

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ABSTRACT

Inulin is a food ingredient that belongs to a class of carbohydrates known as fructans. Nutritionally it has functional properties and health-promoting effects that include reduced calorie value, dietary fiber and prebiotic effects. Inulin is increasingly used in industrially processed dairy and non-dairy products because it is a bulking agent for use in fat replacement, textural modification and organoleptic improvement. Addition of inulin to different kinds of cheese can be beneficial in the manufacture of a reduced- or low-fat, texturized, symbiotic product. This paper gives an overview of some aspects of the microstructural, textural, rheological, prebiotic and sensorial effects of inulin incorporated in cheese as fat replacer, prebiotic and texture modifier.

Contents

* Corresponding author. Tel.: +98 9128494366.
** Corresponding author. Tel.: +98 21 48292477; fax: +98 21 48292200.
*** Corresponding author. Tel.: +1 517 8027743; fax: +1 517 353 8999.
E-mail addresses: rzakarimi@gmail.com (R. Karimi), azizit_m@modares.ac.ir (M.H. Azizi), ghasemlo@msu.edu (M. Ghasemlou), moharam.vaziri@gmail.com (M. Vaziri).

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1. Introduction

Inulin and oligofructose belong to a class of carbohydrates known as fructans (Kaur & Gupta, 2002). In other words, these are a carbohydrate polymer of fructose units (2–60 fructose units) built up from β(2,1)-linked fructosyl residues mostly ending with a glucose residue (Modzelewska-Kapitula & Klebukowska, 2009). Inulin is used for a variety of purposes, including as a replacement for fat and sugar (Kocer, Hicsasmaz, Bayindirli, & Katnas, 2007; Rodríguez-García, Salvador, & Hernando, 2014), a low-caloric bulking agent and a texturizing agent. Inulin is legally considered as a food ingredient rather than an additive in Europe, Australia, Canada and Japan (Franck, 2002). It is also used for its physiological features as a soluble dietary fiber, and for its prebiotic properties (Tungland & Meyer, 2002). The prebiotic concept is defined as "the selective stimulation of growth and/or activity(ies) of one or a limited number of microbial genus(era)/species in the gut microbiot a that confer(s) health benefits to the host" (Gibson & Roberforid, 2008; Roberfroid et al., 2010).

Inulin, oligofructose (Kolida, Tuohy, & Gibson, 2002), lactulose (Grajek, Olejnik, & Sip, 2005), galactooligosaccharides (GOS) (Torres, Goncalves, Teixeira, & Rodrigues, 2010; Tzortzis & Vulevic, 2009) and synthetic fructooligosaccharides (FOS) are examples of such prebiotics (Revathy, Mythili, & Sathiavelu, 2011; Roberfroid, 2007a); inulin, which consists of soluble and fermentable fibers, is the best known (Oliveira, Perego, Converti, & Oliveira, 2009a,b). It has been shown to exert a protective effect toward *Lactobacillus acidophilus* (Kaplan & Hutkins, 2000), *Lactobacillus casei* (Donkor, Nilmini, Stolic, Vasiljevic, & Shah, 2007), *Lactobacillus paracasei* (Makras, Van Acker, & De Vuyst, 2005), *Lactobacillus rhamnosus* (Jyoti, Suresh, & Venkatesh, 2004), *Lactobacillus plantarum* (Modzelewska-Kapituła, Kłębukowska, & Kornacki, 2007) and *Bifidobacterium* spp. (Akalin, Fenderya, & Akbulut, 2004), improving their survival and activity during storage. It has been reported that inulin has more-pronounced prebiotic effects than oligofructose toward both fermentation activity and bacterial community composition in a simulator of the human intestinal microbial ecosystem (van de Wiele, Boon, Possemiers, Jacobs, & Verstraete, 2007). Inulin is a fermentable fiber that cannot be digested by amylase or other hydrolytic enzymes in the upper section of the intestinal tract (Carabin & Flamm, 1999). Inulin and other FOS are frequently employed in studies, as they resist digestion by gastric acid and pancreatic enzymes in vivo (Cummings, Christie, & Cole, 2001a). Probiotic bacteria are live microorganisms, which when added in adequate amounts confer a health benefit to the host (WHO/FAO, 2002). A symbiotic has been defined as a mixture of probiotics and prebiotics that has a beneficial effect on the host by improving the survival and implantation of live microbial dietary supplements in the gastrointestinal tract (Gibson, 2004). It is also necessary to mention that inulin is used to produce foods with low fat content, while oligofructoses are employed to produce low-calorie foods, as well as to balance the sweetness and mask the residual flavor of the high-intensity sweeteners used in food preparations (Niness, 1999). Oligofructose is an inulin-type with short chains and is fermented in the more proximal part of the colon. Long-chain inulin (average chain length of 25) could more be fermented with slow rate and has its bifidogenic effect in the distal colon (Gibson & Delzenne, 2008). This difference is the basis for the development of a new oligofructose-enriched inulin and a combination of fractions of short and long inulin chains which provides a sustained bifidogenic influence across the entire colon (Van Loo, 2004). Oligofructose which is also known as raftilose can be obtained via enzymatic hydrolysis of inulin to give a product consist of linear glucosyl-fructose and fructose chains with average DP of 4. Thus, contrary to what is seen in inulin chains which have terminal glucose units, oligofructose can have linear fructose chains which are lack of any glucose in addition to the glucosyl-fructose chains. Due to the shorter chain length and higher contents of fructose, oligofructose is much more soluble and moderately sweet compared to the inulin (Aluko, 2012). In addition to oligofructoses, as sweetness degree of inulin is very low, it can also be used with high intensity sweeteners as bulking agent.

Although versatile dairy products represent the most highly studied food matrices for supplementation with probiotic and prebiotic ingredients (Akalin, Unal, Dinkci, & Hayaloglu, 2012; Cruz, Cadena, et al., 2012; Cruz, Freitas, et al., 2012; Granato, Branco, Cruz, Faria, & Shah, 2010), cheeses show some technological advantages with respect to their supplementation with probiotic cultures and prebiotic ingredients (Karimi, Mortazavian, & Amiri-Rigi, 2012; Karimi, Mortazavian, & karami, 2012b). Cheese has some good potential for prolongation of the survival of probiotics in the product and delivery of them into the human intestine because of its special chemical and physical properties (in comparison to fermented milks) such as higher pH value and lower titrable acidity, higher buffering capacity, more fat content, more nutrient availability, lower oxygen content, and denser texture matrix (Karimi, Mortazavian, & Cruz, 2011; Karimi, Sohrabvandi, & Mortazavian, 2012c).

Several studies have examined the addition of inulin in cream cheese (Alves et al., 2013; Buriti, Cardarelli, Filisetti & Saad, 2007; Miri, Habibi & Najafi, 2011), wheyless cream cheese (Fadaei, Poursharif, Daneshi & Honarvar, 2012), fresh Portuguese cheese (Rodrigues et al., 2011), petit-suisse cheese (Cardarelli, Buriti, Castro & Saad, 2008), cottage cheese (Araujo, de Carvalho, Leandro, Furtado & de Moraes, 2010), imitation cheese (Hennelly, Dunne, O'sullivan, & O'Riordan, 2006), fresh kashar cheese (Koca & Metin, 2004), mozzarella cheese (Pagliarini & Beatrice, 1994; Wadhwani, 2011), cheddar cheese (Wadhwani, 2011) and Karish cheese (Alnemr, El-Razek, Hasan & Massoud, 2013). There are extensive reviews of the introduction of inulin (Roberfroid, 2005a,b), its prebiotic effects (Kalyani, Kharb & Thompkinson, 2010; Kelly, 2008; Kolida et al., 2002), chemical modification (Stevens, Meriggi & Booten, 2001), technological functionality (Franck, 2002; Roberfroid, 2007b), inulin derivatives (Madrigal & Sangronis, 2007), physiological (Roberfroid, 1993) and dietary effects (Flamm, Glinsmann, Kritchevsky, Prosky & Roberfroid, 2001; Kaur & Gupta, 2002) and caloric value (Roberfroid, 1999), but no review has been previously reported about the incorporation of inulin in cheese. The main purpose of this paper is to overview the recent investigations about the different aspects of inulin as a prebiotic, fat replacer and texturizer in cheese.

2. Health effects of inulin

Inulin and FOS are considered functional food ingredient, since they affect physiological and biochemical processes, resulting in better health and reduction in the risk of many diseases. It has been reported that the caloric value of inulin and oligofructose are between 1.0 (4.2) and 1.5 (6.3) kcal g^{-1} (kJ g^{-1}) (Gibson & Roberforid, 1995). Other observations have stated a caloric value of 1.5 kcal g^{-1} (6.3 kJ g^{-1}) for inulin (Roberfroid, 1999; Niness, 1999). Inulin has a low glycemic index of 46 and a caloric value of 1.5 kcal g^{-1}(Mcdevitt-Pugh & Meyer, 2005). Inulin is also used as a texturizer, thereby enhancing sensory properties, and is useful in recipes that aim for a low glycemic index (Chawla & Patil, 2010). Experimental studies have examined the health effects of inulin in different sections. Table 1 indicates the details regarding these health effects. Possible negative effects associated with overconsumption of fructans include laxation and abdominal discomfort arising from increased fermentation in the colon (Devereux, Jones, Mccormack & Hunter, 2003). Beneficial effects on interesting health

Table 1
Physiological effects of the inulin on the body.

Application area	Effects	Reference
Intestine	Stimulating the body's immune system	Lomax and Calder (2009)
	Decreasing the levels of pathogenic bacteria	Buddington, Donahoo, and Buddington (2002)
	Enhancing resistance to infections	Buddington et al. (2002)
	Relieving constipation	Hond, Geypens, and Ghoos (2000)
	Reducing the incidence of colon cancer	Kato (2000)
	Decreasing the symptom of irritable bowel syndrome	Paineau et al. (2008)
	Increasing the stool frequency	Kapiki et al. (2007)
	Decreasing β glucuronidase activity	Van Dokkum, Wezendonk, Srikumar, and Van den Heuvel (1999)
Cardiovascular system	Reducing the risk of atherosclerosis	Rault-Nania et al. (2006)
	Reducing the incidence of cardiovascular disease	Larsson et al. (2009) and Viuda-Martos et al. (2010)
Blood	Lowering blood urea and uric-acid levels	Younes, Remesy, Behr, and Demigne (1997)
	Lowering blood-serum lipids	Brighenti (2007)
Bone	Decreasing the risk of osteoporosis	Coxam (2007)
	Increasing the calcium absorption	Meyer and Stasse-Wolthuis (2006)
	Increasing the magnesium absorption	Tahiri et al. (2001)
	Increasing the copper absorption	Ducros et al. (2005)
	Increasing the iron absorption	Yap, Mohamed, Yazid, Maznah, and Meyer (2005)
	Increasing the zinc absorption	Yap et al. (2005)
Skin	Improving the severity of atopic dermatitis	Rahmati-Roudsari, Karimi, and Mortazavian (2014)
Weight management	Increasing feelings of satiety	Parnell and Reimer (2009)
	Smaller increase in body mass index	Abrams, Griffin, Hawthorne, and Ellis (2007)
Lipid metabolism	Decreasing the total cholesterol, LDL-, VLDL-cholesterol, and triglycerides	Balcazar-Munoz, Martinez-Abundis, and Gonzalez-Ortiz (2003)
	Lowering the synthesis of triglycerides and fatty acids in the liver	Delzenne and Kok (1999)
	Favorable impact on lipid and glucose metabolism	Boutron-Ruault, Marteau, and Lavergne-Slove (2005)
	Decreasing aspartate aminotransferase	Daubioul, Horsmans, Lambert, Danse, and Delzenne (2005)

properties depend on the average chain length of the fructans consumed. Some studies have observed that a combination of short-chain and long-chain fructans is physiologically more active than the individual fractions (Van Loo, 2004). Because of their large number of health-promoting functions, inulin has wide applications in various types of foods (Franck, 2000; Kaur & Gupta, 2002; Meyer, De Wolf, & Olivier, 2007). Fig. 1 has classified the applications of inulin in 3 groups including fermented dairy products, non-fermented dairy products and non-dairy products.

3. Structural and rheological aspects

Physically, inulin is colorless and odorless, and has a pleasant, slightly sweet taste with moderate solubility in water, dependent

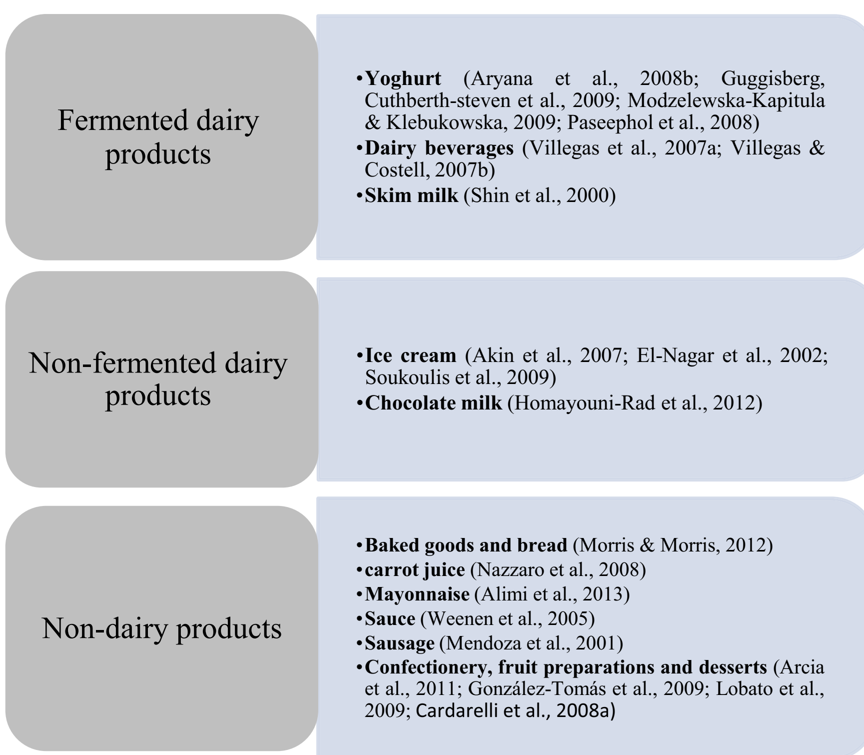

Fig. 1. The applications of inulin in different types of foods. See refs. Alimi, Mizani, Naderi, and Shokoohi (2013), El-Nagar, Clowes, Tudorica, Kuri, and Brennan (2002), González-Tomás, Bayarri, Coll-Marqués, and Costell (2009), Homayouni-Rad, Delshadian, Arefhosseini, Alipour, and Asghari-Jafarabadi (2012), Lobato, Grossmann, and Benassi (2009), Mendoza, Garcia, Casas, and Selgas (2001), Morris and Morris (2012), Nazzaro, Fratianni, Sada, and Orlando (2008), Paseephol, Small, and Sherkat (2008), Soukoulis, Lebesi, and Tzia (2009), Villegas and Costell (2007a), Villegas, Carbonell, and Costell (2007b) and Weenen, Jellema, and DeWijk (2005).

on temperature. Also, inulin comes under the categories of both soluble as well as insoluble fiber, depending on the degree of polymerization (DP) (Chawla & Patil, 2010). FOS substances such as inulin are the means of carbohydrate storage in a large number of plants (Delzenne, 2003; Ritsema & Smeekens, 2003) especially dicotyledonous plants (Tungland & Meyer, 2002) and several special fruits and vegetables. The inulin sources that are most widely used by the food industry are chicory (*Cichorium intybus*) and Jerusalem artichoke (*Helianthus tuberosus*) (Kaur & Gupta, 2002), along with some other plants such as garlic, asparagus root, dahlia tubers (Rocha, Catana, Ferreira, Cabral, & Fernandes, 2006), onions, leeks (Williams, 1999) and bananas (Niness, 1999). Side chains linked via β-2,6-bonds may be present in some plant inulins (Vijn & Smeekens, 1999). As previously mentioned inulin is consisted of a linear polymers of fructose with β(2,1) bonds. 1-kestose is the inulin precursor which is formed by the addition of fructosyl residues in a β(2,1) bond to sucrose. Levans are also linear polymers of fructose, but they are composed of β(2,6) fructosyl-fructose linked molecules and side chains (Grube, Bekers, Upite, & Kaminska, 2002). The first intermediate of levan biosynthesis is 6-kestose. It is formed by the addition of a fructosyl residue to sucrose with a β(2,6) bond. In some plants, mixed levans named gramminans have both β(2,1) and β(2,6) linked fructosyl residues. The precursor of mixed levans is the tetrasaccharide bifurcose (Velazquez-Hernandez et al., 2009). In inulin neo-series (neo-kestose type), fructosyl units (chains) may be linked to the terminal sucrose via its glucosyl moiety by a β(2,6) bond (Lafraya, Sanz-Aparicio, Polaina, & Marín-Navarro, 2011; Tamura et al., 2009). The structural diversity of fructans implies an extensive variety of special usage. Application of fructosyltransferases to synthesize fructans with the required DP and type of glycosidic bonds lead to opening new approaches, opportunities and strategies. Inulin is processed by the food industry to produce either short-chain fructans, namely oligofructose (DP, 2–10; average 5) as a result of partial enzymatic (endoinulinase EC 3.2.1.7) hydrolysis, or long-chain fructans by applying industrial physical separation techniques (De Leenheer, 1996). Native or medium-chain inulin as it is present in chicory has a DP ranging from 3 to 60 monosaccharide units, with an average of about 10 (Murphy, 2001). Some studies have reported that oligofructose has a DP ranging from 2 to 8, with an average of about 4 (Falony et al., 2009). Long-chain inulin with a DP ranging from 10 to 60 and an average of about 23 can be produced from native inulin by applying specific separation techniques (Meyer, Bayarri, Tárrega, & Costell, 2011). The physico-chemical properties of inulin are linked to the DP. The short-chain fraction, oligofructose, is much more soluble and sweeter than native and long-chain inulin, and can contribute to improved mouthfeel because its properties are closely related to those of other sugars.

The solubility of oligofructose is generally higher than sucrose but it presents about 30–50% of the sugar sweetness (Kaur & Gupta, 2002). Also, oligofructose in combination with high intensity sweeteners can balance sweetener profile and cover the acesulfamek or aspartame after taste. On the other hand, inulin has much lower solubility, improves the stability of foams and emulsions and exhibits exceptional fat-like properties when utilized under the form of a gel in water (Franck, 2002). Bland to sweet taste of inulin means that it can be used as a low calorie bulking agent (Barclay, Ginic-Markovic, Cooper, & Petrovsky, 2010). The solubility of inulin depends on the oligomer chain length, and then shorter one is much more soluble than long chain one (Blecker, Fougnies, Van Herck, Chevalier, & Paquot, 2002). Special abilities of inulin like water solubility make it suitable for using as bulking agent. Hydroxyl groups in molecular structure showed higher capability to interact with water than other parts (Blecker et al., 2001). This leads to some surfactant properties of inulin which gives ability to form stable gels with water at concentrations of 13–50% (Castelli et al., 2008). These types of gels present palatability, good mouth feel and similar textual characteristics to fat (Roberfroid, 2005a).

Solubility of inulin at room temperature is only up to 10 (Franck, 2002) to 15% solids (Bishay, 1998), while solubility of oligofructose is about 80% in water at room temperature (Franck, 2002). At below 15%, inulin shows Newtonian behavior typical of soluble, low molecular weight systems. Above 15% solids, the viscosity dramatically enhances depending on inulin concentration. At 20% solids, a small quantity of suspended inulin does not change the Newtonian behavior. Considering the 25% solids and above, inulin shows strong shear thinning behavior. However when it goes above 35% solids, the rapid increase in viscosity tapers off. At this stage, the increase of the gel strength is much less dramatic than what is expected from increasing the inulin content (Bishay, 1998). HP inulin is insoluble at low temperatures. At 50 °C solubility of HP inulin is 1.2%. At 90 °C solubility of HP inulin increases up to 34% (Kim, Faqih, & Wang, 2001). In a 20% HP inulin suspension/solution, apparent viscosity increased with stirring time especially at 20–40 °C. This can be due to water absorbance and swelling by inulin particles (Isikili & Karababa, 2005), which is because of the changes occurred in inulin structure from amorphous to crystal one. At higher temperatures, stirring inulin suspension/solutions results in slower increase of viscosity as a consequence of partial inulin dissolution (Glibowski, 2010). Increase of temperature results in deterioration of gel firmness due to the decrease of the number of seeding crystals (Glibowski & Wasko, 2008).

In the linear chains of inulin, only one atom of the polymer is attached to the fructose ring causing inulin flexible in conformation for a polysaccharide (Barclay et al., 2010). It makes inulin assembling into a wide range of structures, rotational ability of the primary hydroxyl groups and high polydispersity of inulin (Silva, Cooper, & Petrovsky, 2004; Roberfroid, 2005b). As previously noted, long-chain inulin is less soluble and more viscous than the native product (Wada, Sugatani, Terada, Ohguchi & Miwa, 2005). It has been stated that only the longer chains – those with DP > 10 – participate in gel formation, while smaller chains remain dissolved (Hébette et al., 1998). Regardless of the type of structure, gel formation depends on inulin concentration, temperature, presence of ions (for example, calcium), pH and the presence of other rheology modifiers in the food system (Tungland & Meyer, 2002). As inulin compounds interact with water differently, this interaction is generally described as water uptake, hydration, adsorption, absorption, binding, or holding; most of these interactions also have water-binding capacity (WBC). The inulin source does not directly influence the WBC; rather, the source determines the inulin ingredient's physicochemical properties, such as inulin length, particle size and porosity. These properties in turn influence the WBC and the conditions of its use in cheese. However, other factors in the cheese, such as pH, ionic strength, concentration of the inulin and interaction with other water-binding ingredients, can also influence WBC (Tungland & Meyer, 2002). In cream cheese, processed cheese and table spread, excellent results are obtained in water-in-oil spreads with a fat content ranging from 20 to 60%, as well as in water-continuous formulations with 15% fat or less (Franck, 2002). Dave (2012) studied the effects of inulin as a fat replacer on the rheological and textural properties of low-fat processed cheese spread. He found that low-fat cheese spreads with 7% and 8% inulin had significantly higher yield-stress values than either the full-fat cheese-spread control (20% fat without inulin) or low-fat spreads with relatively low inulin contents. Inulin also showed a positive effect on the spreadability of the low-fat cheese spreads. The results indicated that the low-fat processed cheese spreads with 7% and 8% inulin achieved yield-stress values and spreadability similar to the full-fat processed cheese spread. However, the low-fat cheese spread with a 6% level of inulin resulted in a mushy product (Dave, 2012). Guggisberg, Cuthberth-steven, Piccinali, Bütikofer, and Eberhard (2009) indicated that yoghurt samples with 3.8% protein, 4% inulin and 2% fat had lower values of complex viscosity and force than products with 2% inulin and 3.5% fat. They also noted that inulin contributes to the creation of a less compact structure with larger pores in low-fat or full-fat yoghurt (Guggisberg et al., 2009). The different effect of inulin and fat on milk gel texture is due both to the specific physical properties of these two substances and their different ways of interfering with the formation of protein networks (Salvatore, Pes, Mazzarello, & Pirisi, 2014).

4. Prebiotic effects

Prebiotics are defined as "selectively fermented ingredients that allow specific changes, both in the composition and/or activity in the gastrointestinal microbiota that confers benefits upon host well-being and health" (Gibson, 2004). In another definition, prebiotics are non-digestible carbohydrates that resist hydrolysis and absorption in the upper parts of the gastrointestinal tract, and are metabolized selectively by at least one type of probiotic in the colon (Mattila-Sandholm et al., 2002). After passing through the mouth, stomach and small intestine, the fiber arrives in the large intestine unchanged. Upon anaerobic fermentation by gut microflora, inulin produces short-chain fatty acids and gases, while increasing bacterial mass (Blaut, 2002).

The use of blends of short- and long-chain inulin enhances fermentative and prebiotic effects, as they are selectively metabolized in different sections of the large intestine. Metabolization of short- and long-chain inulin occurs in the proximal and more distal colonic regions, respectively (Coudray, Tressol, Gueux, & Rayssiguier, 2003; Biedrzycka & Bielecka, 2004). The blend/mixture of short- and long-chain inulin at a 50:50 ratio has some advantages in improving prebiotic effectiveness (Arcia, Costell, & Tárrega, 2011a). It decreases the amount of generated gas while enhancing or maintaining its prebiotic effect (Ghoddusi, Grandison, Grandison, & Tuohy, 2007). Blends of short- and long-chain inulin are expected to modify sensory properties, especially flavor and texture (Arcia, Navarro, Costell, & Tarrega, 2011b). The sensory changes depend on the blend ratio (Cardarelli, Aragon-Alegro, Alegro, de Castro, & Saad, 2008; Tarrega, Rocafull, & Costell, 2010).

4.1. Effects of inulin on metabolic pathways of probiotics

Regardless of this fact that certain metabolites throughout fermentation may result in adaptation to special growth conditions, there are some metabolic pathways of inulin fermentation. The main product of inulin fermentation is butyrate, while the main products of the fermentation of the FOS are acetate and lactate (Rossi et al., 2005). Also, clostridial populations may be responsible for an increase of production of gas such as CO_2 and H_2 as a consequent of fructan fermentation, via direct degradation or cross-feeding of inulin (Duncan, Louis, & Flint, 2004). One of the important short chain fatty acids produced by intestinal microflora from inulin is butyrate. The metabolic pathway for generation of butyrate includes condensation of two molecules of acetyl coenzyme A and the reduction of them to butyryl-CoA (Duncan, Barcenilla, Stewart, Pryde, & Flint, 2002). Butyrate can be generated with a butyrate kinase (Diez-Gonzalez, Bond, Jennings, & Russell, 1999). In another metabolic pathway, butyryl-CoA:acetate CoA transferase can move the CoA to extrinsic acetate, resulting in the generation of butyrate and acetyl-CoA (Louis et al., 2004). Metabolic investigations of butyrate producers with the pathway of butyryl-CoA:acetate CoA transferase have indicated a high diversity among these microorganisms regarding their requirements for external acetate as a cosubstrate (Falony et al., 2009). H_2 and CO_2 are the main gases produced in inulin-type fructan fermentation. H_2 is produced with combinational mediation of a pyruvate:ferredoxin oxidoreductase and a hydrogenase action (Herrmann, Jayamani, Mai, & Buckel, 2008). Metabolite production profiles of some intestinal bacteria in vitro have indicated that acetate consumption is negatively correlated with H_2 production (Falony et al., 2009). Some other pathways have been reported for production of high amounts of lactate without H_2. Throughout preliminary glycolysis lacking hydrogenase enzyme, two pathways are speculated for regeneration of NAD^+ out of the $NADH^+H^+$. These pathways are butyrate generation by the butyryl-CoA:acetate CoA transferase with production of acetate, butyrate and CO_2 (Duncan et al., 2004), and generation of lactate out of pyruvate via lactate dehydrogenase (Macfarlane & Macfarlane, 2003). Although prebiotic activity of fructans have been extensively studied as functional food ingredients, little information is available regarding the correlation between the fermentative capability of intestinal bacteria and chain length of fructans. Bifidobacteria have indicated the high degradation ability on the longest chains of inulin but have not present strict selectivity based on DP (Rossi et al., 2005). Bifidobacteria can also release glycosyl hydrolases acting on nondigestible oligosaccharides (Schell et al., 2002). Also, β-fructofuranosidase is one of the enzyme of bifidobacteria (Warchol, Perrin, Grill, & Schneider, 2002; Omori et al., 2010; Jedrzejczak-Krzepkowska, Tkaczuk, & Bielecki, 2011) that hydrolyzes fructose moieties from the terminal β-2,1 positions and contributes to fructan hydrolysis (Ehrmann, Korakli, & Vogel, 2003). A relationship has been reported between chain length and β-fructosidase activity in *B. adolescentis* ATCC 15703, *B. longum* ATCC 15070, *B. thermophilum* ATCC 25525 (McKellar & Modler, 1989). Some bifidobacteria and lactobacilli selectively use various fructans according to chain length, especially the smaller FOS chains. FOS transporters have been identified on *L. paracasei* 1995 (Kaplan & Hutkins, 2003) and *L. acidophilus* (Barrangou, Altermann, Hutkins, Cano, & Klaenhammer, 2003). Transporter assays indicated that FOS transport is selective for chain length. This could be the reason for selective utilization of the shorter chains (Birkett & Francis, 2010). FOS substances cannot be hydrolyzed by enzymes of human digestive. No enzyme is able to split this glycosidic linkage secreted by salivary glands, the pancreas or in the small intestine of humans (Cherbut, 2002). Indigestibility of FOS and inulin is due to β(2–1) glycosidic bonds because human do not have inulinase enzymes (Franck & De Leenheer, 2002). They undergo fermentation by the bacteria of the colon and stimulate the growth of bifidobacteria (Sangeetha, Ramesh, & Prapulla, 2005a,b; Roberfroid, 2007b) and lactobacilli that have inulinase activity (Kuzuwa et al., 2012). In other words, inulin remains relatively intact after transition through the digestive system. In large intestine it is digested by hydrolytic enzymes of bifidobacteria such as β-fructofuranosidases (Pokusaeva, Fitzgerald, & van Sinderen, 2011). This is why that inulin cannot be digested except through bacterial activity. Inulin can alter the composition of human gut flora by noted specific fermentations that results in a community predominated by bifidobacteria (Wang & Gibson, 1993). As previously mentioned, the degree of polymerization of inulin typically ranges from 3 to 60 (Murphy, 2001), which renders fermentation of this fructan by *Lactobacillus* species difficult (Buriti et al., 2007). It is important to emphasize that the ability to ferment inulin type fructans is strain-specific for lactobacilli (Makras et al., 2005). The prebiotic effectiveness of inulin-type fructans not only depends on the degree of polymerization, but also on the dietary dosage (Van Loo, 2004).

4.2. Prebiotic effects of inulin on bifidobacteria and lactobacilli

It has been demonstrated by in vivo and in vitro studies that in humans, fermentation of fructans and inulin leads to the selective stimulation of growth of the bifidobacteria population (Cummings, Macfarlane & Englyst, 2001b). The normal recommendation for supplementation of inulin for the increase of healthy bacterial microflora is a daily dose of 2.5–10 g. As it happens in a dose-dependent manner, 2.5–5 g daily seems to be low for bifidogenic effects (Kelly, 2009). It has been reported that both *Lactobacillus casei* and *Bifidobacterium lactis* are able to grow in a basal medium supplemented with FOS or inulin (Su, Henriksson, & Mitchell, 2007). Huebner, Wehling, and Hutkins (2007) conducted a study to select which prebiotics (FOS, inulin and GOS) supported selective growth of lactobacilli and bifidobacteria. They found that only certain combinations between probiotics and prebiotics gave high scores; these included *Lactobacillus paracasei* 1195 grown on inulin (Huebner et al., 2007). Alves et al. (2013) investigated the application of inulin in cream cheeses as a symbiotic food carrier. In their study, cream cheese was incorporated with *Streptococcus thermophiles*, *Bifidobacterium animalis* Bb-12 and *Lactobacillus acidophilus* La-5. *Streptococcus thermophilus* showed good viability (6.66–9.38 log cfu g^{-1}), whereas *Bifidobacterium animalis* remained above 6 log cfu g^{-1} during the 45-day storage period. However, *Lactobacillus acidophilus* showed an accentuated decline, registering values of 3.1 log cfu g^{-1} at the end of the storage period (Alves et al., 2013). They observed that the different concentrations of inulin had no effect on the viability of the probiotics. This can be considered as an advantage, as the inulin will then only be degraded in the intestinal tract by the probiotic bacteria, modulating the composition of the intestinal flora of the consumer in a positive way (Alves et al., 2013). Interaction between the probiotic culture and the added lactic cultures could be the reasons for probiotic population variations (Vinderola, Mocchiutti, & Reinheimer, 2002); also, interactions are dependent on the strain (Karimi et al., 2012a, 2011) and the food matrix (Alves et al., 2013) used as the vehicle for supplementation. Cardarelli et al. (2008a) investigated the influence of inulin, oligofructose and oligosaccharides on the probiotic viable count of symbiotic petit-suisse cheese containing *Bifidobacterium lactis* and *Lactobacillus acidophilus*. They found that probiotic populations varied between 7.20 and 7.69 log cfu g^{-1} for *Bifidobacterium lactis* and 6.08 and 6.99 log cfu g^{-1} for *Lactobacillus acidophilus*, and that the probiotic population decreased during storage for both probiotic bacteria; the decrease in counts during storage was never above 0.74 for *Lactobacillus acidophilus* and 0.37 log cfu g^{-1} for *Bifidobacterium lactis*. They found that an oligofructose:inulin:honey proportion of 1:0:0 and 1/3:1/3:1/3 led to a slight reduction in loss of viable counts of *Bifidobacterium animalis* subsp. *lactis* and *Lactobacillus acidophilus*, compared to the control trial during a 28-day storage period (Cardarelli et al., 2008a). Flimelová, Kňazovická, Čanigová, and Benczová (2013) incorporated *Lactobacillus acidophilus* and inulin (1%) into fresh cheese and studied its physico-chemical properties at 7 ± 2 °C during 15 days. In their study, pH values ranged from 5.86 to 5.88 in the first day following cheese production. After 15 days of storage, the pH values in all samples decreased by 0.4. Counts of lactic-acid bacteria increased until the sixth day of storage, and then decreased. After the 15th day of storage, higher microbial counts were found in the control sample (without the probiotic culture and inulin) compared with other samples (Flimelová et al., 2013). Reduction of microbial counts was related to intensive production of lactic acid and refrigerated storage temperature (7 ± 2 °C). The reduced counts indicated that adding probiotic culture or probiotic culture in combination with inulin did not have a significant negative influence on the overall quality of the cheese samples compared with the control sample (without probiotic culture and inulin). Modzelewska-Kapituła et al. (2007) incorporated *Lactobacillus plantarum* and inulin in soft cheese. They revealed that the number of *Lactobacillus plantarum* was affected by the addition of inulin. The count of *Lactobacillus plantarum* was at the range of 7.27–7.66 cfu g^{-1}. In cheese samples containing inulin, the mean number of *Lactobacillus plantarum* was higher than in cheese samples without inulin over the entire 45-day period of storage (Modzelewska-Kapituła et al., 2007). Salem, Abd El-Gawad, Hassan, and Effat (2007) studied the effect of 1% inulin on growth and stability of *Lactobacillus reuteri* B-14171, *Lactobacillus johnsonii* B-2178 and *Lactobacillus salivarius* B-1950 with yoghurt starter cultures in Labneh cheese during 30 days of storage at 5 °C. They indicated that inulin has no influence on the growth pattern of both *Streptococcus thermophiles* and *Lactobacillus delbreuckii* ssp. *bulgaricus* during cold storage of Labneh cheese. They also indicated that the viability of all three probiotic strains decreased during storage. However, the viability of these probiotics in trials containing inulin was higher than that of the control (without inulin). The highest viability recorded for samples with inulin was 87.8% for *Lactobacillus reuteri*, 81.68% for *Lactobacillus johnsonii* and 79.16% for *Lactobacillus salivarius*. In contrast, the control samples containing no prebiotics had average survival rates of 77.8% for *Lactobacillus reuteri*, 74% for *Lactobacillus johnsonii* and 76% for, *Lactobacillus salivarius* (Salem et al., 2007). Akin, Akin, and Kirmaci (2007) observed that the addition of inulin in probiotic ice cream had no effect on *Streptococcus thermophiles* and *Lactobacillus delbrueckii* ssp. *bulgaricus* counts, while *Lactobacillus acidophilus* and *Bifidobacterium lactis* counts increased (Akin et al., 2007). Rodrigues et al. (2011) investigated the prebiotic effect of inulin (50:50 inulin:FOS mix) and FOSs on the viability of probiotic microorganisms via characterization of glycolysis, proteolysis and lipolysis of curdled-milk matrices throughout the 60 days of ripening to the manufacture of symbiotic cheeses. Inoculated probiotic bacteria were *Lactobacillus casei* 01, *Lactobacillus paracasei* L26, *Lactobacillus acidophillus* L10, *Lactobacillus acidophilus* La-5, *Lactobacillus acidophilus* Ki, *Bifidobacterium lactis* B94, *Bifidobacterium lactis* Bo and *Bifidobacterium animalis* BB-12. Prebiotic compounds did not significantly affect the survival of all strains studied, except *Lactobacillus acidophilus* La-5. Proteolysis indices showed considerable casein degradation in probiotic and symbiotic matrices inoculated with *Bifidobacterium lactis* B94 and *Lactobacillus casei* 01. Lower proteolysis indices were achieved in those inoculated with *Lactobacillus acidophilus* La-5. Lipolytic activity was apparent in the case of *Lactobacillus acidophilus* La-5 and *Bifidobacterium lactis* B94, and much less for *Bifidobacterium animalis* BB-12 and *Lactobacillus acidophilus* Ki (Rodrigues et al., 2011). The higher prebiotic effect of inulin has been attributed to stimulatory effect on metabolism of bifidobacteria (Bruno, Lankaputhra, & Shah, 2002; Özer, Akin & Özer, 2005) and lactobacilli (Desai, Powell & Shah, 2004) to release the further nutrients such as amino acids in dairy products (Donkor et al., 2007; Makras et al., 2005). Table 2 shows the survival of probiotic bacteria incorporated in different cheeses with various content of inulin during storage.

4.3. Application of inulin in microencapsulation of the probiotics

Microencapsulation of the probiotic microorganisms in addition to the prebiotic has been used to increase the probiotics' survival in the developed symbiotic food (Aqilah, 2010). In some studies inulin has been used as a thermal protective agent in the form of symbiotic microcapsules to improve the thermal resistivity of prebiotics on probiotics (Babu & Nithyalakshmi, 2011). It has been proven that inulin provides higher heat resistance to *Lactobacillus casei* MTCC 1423 than does high-resistance maize starch (Babu & Nithyalakshmi, 2011). High-resistance maize starch 2% and inulin 3% has been reported to be a good combination of prebiotics to provide thermal resistance to *Lactobacillus casei* (Babu & Nithyalakshmi, 2011). Okuro, Thomazini, Balieiro, Liberal, & Fávaro-Trindade (2013) evaluated solid lipid microparticles (SLM) for co-encapsulation of *Lactobacillus acidophilus* with inulin or polydextrose to improve the stability of the probiotic and its resistance to exposure to simulated gastric and intestinal fluids. They revealed that the inclusion of either inulin or polydextrose does not affect

Table 2
Survival of probiotic bacteria in cheeses containing inulin.

Cheese type	Probiotic cultures	Source of probiotics	Initial inoculation of probiotics	Inulin content ($g\,kg^{-1}$)	Viable count ($\log cfu\,g^{-1}$)[a]	Storage period	Reference
Cream cheese	*L. acidophilus La-5*, *B. animalis Bb-12*, *S. thermophilus* TH-4	Chr. Hansen (freeze-dried cultures)	0.5, 0.7, 1.0, 1.3 and 1.5 ($g\,kg^{-1}$) 7 log cfu g^{-1}	3, 5, 10, 15, 17	5.4–3.10 6.93–6.04 9.38–6.66	4 °C 45 d	Alves et al. (2013)
Petit-suisse cheese	*L. acidophilus* Lac4, *B. lactis* BL04	Ezal Dried, Danisco FloraFit, Danisco (freeze-dried cultures)	30 mg L^{-1} 20 mg L^{-1}	33.3, 50, 100	6.99–6.08 7.69–7.20	4 ± 1 °C 28 d	Cardarelli et al. (2008a)
Fresh cheese	*L. acidophilus*	Laktoflora	0.1%	10	6.9–6.5	7 ± 2 °C 15 d	Flimelová et al. (2013)
Cottage cheese	*L. delbrueckii* UFV H2b20	–	–	80	∼8–8.20	5 °C 20 d	Araujo et al. (2010)
Fresh cream cheese	*L. paracasei* ssp. *paracasei* LBC 82, *S. thermophilus* TA040	Danisco	10 mg L^{-1} (9 log cfu L^{-1})	80	7.12–7.39 ∼9.5–9.5	4 ± 1 °C 21 d	Buriti et al. (2007)
Fresh cheese	*Saccharomyces boulardii* CDBB-L-1483	ATCC-MYC-797 Cinvestav-Ipn	10^{10} cfu g^{-1}	–	9.04–6.15 (unencapsulated) 9.17–7.50 (encapsulated)	4 °C 30 d	Zamora-Vega et al. (2013)
Soft cheese	*L. plantarum* 14	Isolated from the gastrointestinal tract of a healthy infant	20 mL kg^{-1} (10^8 cfu mL^{-1})	25	7.27–7.61	6 °C 45 d	Modzelewska-Kapituła et al. (2007)
Labneh cheese	*L. reuteri* B-14171, *L. johnsonii* B-2178, *L. salivarius* B-1950	Obtained from Northern Regional Research Laboratory, Illinois, USA	–	10	8.9–7.9 9.1–7.5 9.6–7.6	5 ± 1 °C 30 d	Salem et al. (2007)

[a] The viable counts were considered from the beginning to the end of the storage period.

the morphology of the SLM (Okuro et al., 2013). They also showed that the presence of polydextrose significantly increases cell viability compared to the presence of inulin or no prebiotic during storage. In their study, SLM improved the viability of *Lactobacillus acidophilus* during storage at freezing or refrigeration temperatures with controlled relative humidity (11%). In another study, Fritzen-Freire et al. (2012) microencapsulated bifidobacteria with inulin, oligofructose and oligofructose enriched with inulin using spray-drying technology (Fritzen-Freire et al., 2012). Zamora-Vega et al. (2013) studied the incorporation of *Sacharomyces boulardii* and inulin, both encapsulated with sodium alginate and cactus mucilage, in fresh cheese. They reported that after 30 days of keeping the cheeses at 4 °C, the viability of the probiotic microorganism added in encapsulated form was greater than that shown by the microorganism added unencapsulated. They concluded that the microcapsules made with inulin, sodium alginate and cactus mucilage had a protective effect on the probiotic microorganism. The viability of microorganisms during all cheese shelf life satisfied the minimum recommended for this cheese to be considered as a probiotic food (Zamora-Vega et al., 2013).

4.4. Inhibitory effects of inulin on pathogens

FOS and inulin can inhibit the growth of harmful bacteria and the generation of potentially harmful metabolites. FOS fermentation generates short-chain fatty acids that reduces the pH, and thereby prevent the growth of pathogenic bacteria. FOS changes the intestinal metabolic balance toward carbohydrate versus protein fermentation, reducing the generation of harmful by-products like phenols (Birkett & Francis, 2010). *Lactobacillus plantarum* 0407 and *Lactobacillus pentosus* 905 combined with FOS, inulin, XOS and mixtures of inulin:FOS and FOS:XOS are effective in inhibiting the growth of *Escherichia coli* and *Salmonella enterica* serovar Enteritidis (Fooks & Gibson, 2002). Preventive effects of FOS have been also revealed against the growth and activity of pathogens, such as *Salmonella typhimurium* and *Clostridium difficile* (Birkett & Francis, 2010). FOS, inulin, XOS and their mixtures, have all been reported to cause greater inhibition than lactulose, lactitol, starch and dextran, perhaps suggesting a structure-to-function relationship in terms of the prebiotic used. The type of bond links and the constituent monomers, in view of specific cleavage enzymes being required for fermentation of the carbohydrate, may affect fermentation rate and thereby determine the speed at which potential inhibitory metabolic end products are released (Aachary & Prapulla, 2011). The prebiotic compounds like inulin contribute to higher lactic acid production. A similar accelerating effect and a reduction by 10% of the fermentation time of different binary co-cultures have been reported for inulin (Oliveira et al., 2009b). The addition of prebiotics and the levels of primary metabolites have been shown to vary depending on the probiotic strain (Bruno et al., 2002; Desai et al., 2004).

5. Application of inulin as a fat replacer

The presence of fat in dairy products plays an important role in their physical, rheological, and textural properties (Barclay et al., 2010; Brennan & Tudorica, 2008; Dave, 2012). Fat, apart from its nutritional significance in cheese, contributes to the sensory and functional properties of dairy products (Miočinović et al., 2011), However, consumers are increasingly demanding foods with dietetic and functional properties, such as those with low calories, low or reduced fat and health benefits (Gonzalez-Tomás, Coll-Marqués, & Costell, 2008). Also, low-fat food plans have been recommended for weight loss and maintenance (Carmichael, Swinburn, & Wilson, 1998; Peterson, Sigman-Grant, Eissenstat, & Kris-Etherton, 1999). On the other hand, there is a widely held view that low-fat or reduced-fat foods are less desirable because they have poor organoleptic qualities (Hamilton, Knox, Hill, & Parr, 2000; McEwan & Sharp, 2000). There are some reviews about specific applications and potential effects of fat replacers (Akoh, 1998; Ognean, Darie, & Ognean, 2006).

The challenge of using fat replacers in cheese while keeping the same functional and organoleptic properties as full-fat cheeses has attracted great attention (Kebary, Salem, El-Sonbaty, & El-Sissey, 2002). Removal of fat from cheese causes rheological, textural, functional and sensory defects such as rubbery texture, lack of flavor, bitterness, off-flavor, poor meltability and undesirable color (Mistry, 2001; O'Connor & O'Brien, 2011). It is not easy to make low-fat or fat-free cheeses with desirable properties (Fadaei et al., 2012). As fat content decreases, the protein matrix becomes more compact and the cheese texture is more chewy. When fat ingredients are reduced in food formulations, other ingredients are often required to fulfill its functional role in maintaining organoleptic qualities (Mattes, 1998). A strategy proposed for improving the flavor and texture of low-fat cheese is the use of fat replacers (Sandrou & Arvantoyannis, 2000). The Codex Commission on International Trade has set a maximum limit of 50% reduction in fat from a referenced variety for a cheese to be labeled as reduced-fat (FAO/WHO, 2008). In Europe, cheese can be labeled as reduced-fat when the reduction in fat content is at least 30% compared with a similar product (EU, 2006). In the United States, a reduced-fat cheese requires at least a 25% reduction in fat level from the traditional level of the referenced variety. Inulin is widely used as texturizing agents in low-fat foods, particularly in the European Union and increasingly in the U.S.A. and Australia (Devereux et al., 2003).

Inulin seems particularly suitable for fat replacement in low-fat cheeses, as it may contribute to an improved mouthfeel (Meyer et al., 2011). The fat-substituting property of inulin is based on its ability to stabilize the structure of the aqueous phase, which creates an improved creaminess (Ibrahim, Mehanna, & Gad El-Rab, 2004). A creamy mouthfeel is achieved when inulin is used as a fat replacer in dairy products due to its interactions with whey protein and caseinate (Bot, Erle, Vreeker, & Agterof, 2004; Karaca, Güven, Yasar, Kaya, & Kahyaoglu, 2009). High performance (HP) inulin with long chain and high molecular weight is the most desirable as a fat replacer. Longer chain lengths reduce the solubility of inulin-type fructans and result in the formation of inulin microcrystals when mixed with water or milk; these microcrystals are not discretely perceptible and have a smooth, creamy mouthfeel. HP inulin has an average DP of 25 and a molecular distribution ranging from 11 to 60. Thus, the residual sugars as well as the oligomers have been removed. The fat-mimetic property of HP inulin is double than standard inulin, while it has no sweetness (Niness, 1999). The different functional attributes of inulin and oligofructose are due to the difference in their chain lengths. As noted above, due to its longer chain length, inulin is less soluble than oligofructose, and has the ability to form inulin microcrystals when sheared in water or milk. Inulin has therefore been used successfully to replace fat in dairy products (Kaur & Gupta, 2002), especially cheese (Salvatore et al., 2014). Long-chains of inulin form microcrystals (insoluble sub-micron crystalline) which interact with each other forming small aggregates in the water phase (Franck, 2002; Guggisberg et al., 2009). They cause a smooth and creamy texture through encapsulating a great amount of water (Bot et al., 2004). Inulin can also form parts of the protein structural network by complexing with protein aggregates (Kip, Meyer, & Jellema, 2006).

Koca and Metin (2004) considered the possibility of obtaining low-fat fresh kashar cheese with a 70% fat reduction using long-chain inulin. They reported that their low-fat control cheese, due to its high protein content, was significantly harder, more elastic, gummier and chewier than the full-fat control cheese. Fat breaks the protein matrix and acts as a lubricant to provide a softer texture (Koca & Metin, 2004). It has been shown that adding 5% inulin to the low-fat cheese resulted in a significantly lower hardness compared to the low-fat control cheese, but slightly higher than that of the full-fat control cheese. This softening effect could be attributed to both the higher ratio of moisture to protein and the increase in filler volume, which decreases the amount of protein matrix. In general, inulin improved the cheese texture until the 30th day of storage, but reduced its shelf life (Koca & Metin, 2004). The ability of inulin as fat replacer is not only related to the modification of rheological behavior or the thickness or hardness of the product, but also to changes in other mouthfeel attributes, such as creaminess or smoothness (Meyer et al., 2011). When inulin is added to food in low concentrations, the rheological properties and the sensory quality of the product will not be affected strongly due to inulin's neutral or slightly sweet taste and its limited effect on viscosity (Kalyani et al., 2010). To obtain low-fat products with rheology and thickness close to those of full-fat products, higher concentrations of inulin are needed than is necessary to merely mimic their creaminess or smoothness (Meyer et al., 2011). Fadaei et al. (2012) studied the chemical characteristics of low-fat wheyless cream cheese containing inulin as a fat replacer. No significant difference was found in the pH and salt values of cream cheeses. They indicated that an inulin proportion of 10% was enough to obtain a low-fat cream cheese with chemical attributes near to those of high-fat cream cheese that does not contain inulin. They also reported that inulin has an excellent water binding capacity which inhibits syneresis in spreads and fresh cheeses (Fadaei et al., 2012). It is expected that long chain inulin versus short chain has considerable water binding/retention capacity and capability to prevent syneresis. Wadhwani (2011) conducted several preliminary studies to select the most efficient fiber type from four fibers – inulin, low-methoxy pectin, polydextrose and resistant starch – to improve the quality of low-fat mozzarella and cheddar cheeses. Results from their preliminary studies indicated that inulin had better efficacy in cheese systems than the other three fibers. They also found that incorporating inulin led to improved texture in low-fat cheese by decreasing hardness and gumminess while maintaining cohesiveness, adhesiveness and springiness (Wadhwani, 2011). Salvatore et al. (2014) evaluated the effect of replacing fat with 2, 3 and 7% long-chain inulin (DP > 23) on the textural and microstructural properties of a fresh caprine milk cheese. Using scanning electron microscopy and penetrometry, it was shown that cheese samples containing inulin had more open structure compared to full-fat cheese due to the decreased fat distribution in the matrix of protein. Positioning of inulin in casein network appeared as structures embedded in the gel system and the size of which increased with higher concentration of inulin in cheese. Inulin interrupts the casein network, resulting in a softening effect, which increases with increasing levels of inulin to replace fat. According to their findings, samples containing inulin were characterized by lower values for compressive force, stiffness, viscosity and adhesiveness (Salvatore et al., 2014). Overall, studies have shown that the effect of fat replacement on cheese texture depends on the nature of the fat being replaced (Lobato-Calleros, Vernon-Carter, & Hornelus-Uribe, 1998).

6. Effects of process and process conditions

There are various methods for the incorporation of inulin into cheese. In petit-suisse cheese, incorporation of inulin is after the draining step, in order not to loss inulin in whey (Cardarelli et al., 2008b). In a study in fresh cream cheese, inulin was incorporated into the cheese after whey draining through homogenization resulting to form a smooth and homogeneous cream cheese (Buriti et al., 2007). In another study on cream cheese, the curd mass was mixed with remaining ingredients such as salt after completing whey removal, and inulin was then added in the desired amounts followed by mixing (Alves et al., 2013). For reconstitution milk protein powder in low fat UF cheese, dissolution, hydration and intensive mixing of milk powders need to be performed at 50 °C within 1 h, followed by heating of concentrate obtained at 85 °C. Inulin content should be added in cheese production before inoculation of milk protein concentrate (Miočinović et al., 2011). In Karish cheese skim milk was heated at 74 °C for 15 s and inulin was added to warm milk (Alnemr et al., 2013). It has been suggested for low fat fresh cheese spreads that inulin should be added to the cream, heated to approximately 80 °C and mixed during several minutes to hydrate. This resultant is then mixed to the fresh cheese followed by pasteurization at 80 °C and homogenization at 200 bar (uncited paper, verbal communication with expertise). In the presence of water, increasing the temperature results in the increased hydrolysis of inulin at both neutral and acidic pHs (Blecker et al., 2002; L'Homme, Arbelot, Puigserver, & Biagini, 2003). Moreover, increasing heating temperature enhances minimum inulin concentration needed for gel formation (Kim et al., 2001). The rate of hydrolysis of inulin at neutral pH is not significant for processing time approximately up to 60 °C, but it may be significant at higher degrees of temperature (more than 80 °C) (Shu, 1998; Kim et al., 2001). Also, long heating of inulin solution has negatively affected the rheological characteristics of inulin gels (Schaller-Povolny & Smith, 2002). As the heating temperature increases, higher amount of reducing sugar is produced leading to the increases in non-gel forming components. It suggests that the DP of the inulin chain is decreased (Kim et al., 2001). Different temperatures may be used for homogenization in cheese production. It is necessary to mention that pH value has more important effect than temperature on inulin. It is worth to mention that the effects of temperature on hydrolysis of inulin are expected to be observed in the acidic conditions (Stevens et al., 2001). The most commonly pH range used in inulin hydrolysis processing is 2.0–4.2 (Blecker et al., 2002). This condition is not occurred during processing of diverse types of cheese, because the normal range of pH in different stages of processing and storage of various cheeses varied between 4.3 and 5.6 (Donnelly, 2004). It has been reported that the content of reducing sugar in inulin is very similar in a slightly acidic and neutral environment such as pH 5, 6 and 7 regardless of time and temperature of thermal treatment. Inulin degradation does not occur in the products with pH $\geq$5 heated up to 100 °C (Glibowski & Bukowska, 2011). The pH of the most cheeses in which inulin is used as a fat replacer, are never lower than 4. Also, this acidity appears during cheese ripening or storage in which maximum temperature is at 43–45 °C. Because of the surfactant character, shorter chains can gelate aqueous solutions with >25% of inulin in water and longer chains also do this with >13% of inulin by processing such as cooling a hot dissolved solution or by shearing inulin suspensions (Blecker et al., 2001). The formed gel network has crystalline particles of about 100 nm diameter (Roberfroid, 2005b). It can aggregate to form larger clusters of 1–5 μm and entrap a considerable quantity of water in the gel network. In order to have smaller and more narrowly distributed particle sizes, the thermal methods are preferred because this method provides stronger and smoother gels than the shearing techniques (Kim et al., 2001). During the manufacturing process the degree of hydration depends on the inulin concentration and temperature. The use of oligofructose in recipe is quite straightforward with minor necessity for adaptations to the production process (Bosscher, 2009).

7. Interaction of inulin with casein and whey protein

Emulsifying abilities of inulin are lower than casein, because casein has many hydrophobic sites with emulsifying capabilities. Interaction between casein and inulin has smaller emulsion size compared with emulsion containing only inulin (Saberi, Hashemiravan, & Farhadyar, 2014). Casein has lower water binding capacity compared to inulin, because the numbers of linking groups are different in casein and inulin molecules. Interaction between casein and inulin can co-adsorb on the water interface leading to increase electrostatic stability (Saberi et al., 2014). It is difficult to extrapolate the rheological interaction of inulin and proteins reported in other dairy products such as yoghurt or inulin-whey protein mixed gels to those in cheese. There are some hypotheses regarding the type of bonding between inulin and whey proteins. It has been found that β-lactoglobulin interacts with inulin but not with α-lactalbumin (Steffe, 1996; Schaller-Povolny & Smith, 2002). Interaction between inulin and β-lactoglobulin could be take place on the basis of the structure of β-lactoglobulin with the capability to bind with hydrophobic compounds (Glibowski & Bochynska, 2006). It has been also shown that heating the inulin and whey proteins makes a remarkable decease in surface hydrophobicity which suggests the formation of some complexes among non-polar amino acids residues and non-polar sections of inulin molecules (Glibowski & Glibowska, 2009). Another hypothesis is covalent Maillard reactions which occurred between amino groups of β-lactoglobulin and the reducing groups of inulin. It has been hypothesized that at low concentration of inulin, gelation of the whey proteins is inhibited due to the increased viscosity of aqueous phase by inulin. It is important to note that higher inulin concentration helps whey protein gelation through enhancing the attraction among proteins as a result of inulin hydration (Glibowski & Bochynska, 2006). In a study on inulin–whey protein gels, whey proteins (7%) increased the values of elastic (G') and storage (G'') moduli of the protein gel network, while low concentrations of whey proteins (1–4%) could not form a gel. Low concentrations of whey proteins result in weaker gels because there are stronger bonds between inulin crystals than between inulin crystals and whey proteins (Glibowski, 2009). Whey proteins can interrupt the fine structure and decrease the hardness and the apparent viscosity values of the inulin gels. Also, it has been seen that increasing inulin concentrations (with average DP of 23) from 1 to 15% results increasing the shear stress values for whey protein solutions (Glibowski, 2009). In whey protein concentrates, it has been indicated that adding inulin to 2–3% improves emulsion activity index but instead decreases emulsion stability index (Farrag, 2008).

Inulin gelation can be made through heating–cooling or shearing of the suspension of inulin (Kim et al., 2001). The inulin crystal seeds are essential for growing inulin crystals and gelation propagation (Bot et al., 2004). Inulin dissolution at 80 °C enabled the solution of inulin crystallites which have not been dissolved. Inulin dissolution at 95 °C inhibits inulin gel formation (Bot et al., 2004), although the chemical structure of inulin molecules remains intact (Glibowski & Wasko, 2008). In shear induced gel, hydrogen bond and van der Waals interactions are formed among molecules aggregates in dispersion. While in thermally induced gel, network structure is formed among the molecular chains via entanglement of molecules into smaller particles (Kim et al., 2001). Salt in inulin gel increases the elasticity compared to inulin gel without NaCl and with whey proteins. It indicates that whey proteins hamper the formation of a firm gel by inulin (Glibowski, 2009). On the other hand, screening effect of the salt on electrostatic repulsion between the protein aggregates results in forming gel because of an enhance in the number and thickness of contact points among the filaments (Bryant & McClements, 1998). Inulin has synergistic effect with most gelling agents such as gelatine, alginate, *k* and *i*-carrageenans, gellan gum and maltodextrins (Franck, 2002). It has been shown that $CaCl_2$ increases elastic and storage moduli values in inulin–whey protein gels (Glibowski & Glibowska, 2009). There are differences between Na^+-induced gelation and Ca^{2+}-induced one (Hongsprabhas & Barbut, 1997). Lower percents of divalent ions are required to make aggregation than monovalent ions (Glibowski, Mleko, & Wesolowska-Trojanowska, 2006) due to their higher effects at screening electrostatic interactions and also their ability to form salt bridges (Hongsprabhas & Barbut, 1997).

8. Application of inulin as a texturizer

Highly soluble fibers, those that are highly branched and those that are relatively short-chain polymers, such as inulin, have low viscosities. They are generally used to modify texture or rheology, manage water migration, influence the colligative properties of the food system and enhance the food product's taste, mouthfeel and shelf life without significantly altering its specific application characteristics and improve its marketability as a health-promoting or functional food product (Tungland & Meyer, 2002). As the concentration of inulin increases to more than 15%, it can form a stable gel or cream. This inulin gel or cream mimics a fat-like texture (Phillips & Williams, 2000). As inulin content increases its effect on the product's structure and texture becomes important, because at these higher levels inulin's physicochemical properties can modify the texture of dairy products and may significantly influence their sensory quality. It has been observed that the viscosity of the products increases with increasing levels of inulin (Akin et al., 2007), and that the interaction of hydrocolloids with milk proteins may result in either improvement or deterioration of textural properties (Donkor et al., 2007). Hennelly et al. (2006) compared the use of shear-induced inulin gels and heated inulin solutions to replace 63% of the fat in imitation cheese. Neither the melting behavior, the variation of the elasticity modulus with temperature nor the microstructure of cheese were affected by the form in which inulin was added (gel or solution). They also found that at equivalent moisture levels, the inulin cheeses had significantly higher hardness values than the control sample with fat; however, there was no difference in hardness among the cheeses containing different levels of inulin (5% or 13.75%) (Hennelly et al., 2006). They indicated that values of G' and G'' decreased with increasing temperature, but at temperatures above 55 °C they increased for cheeses containing the higher level of inulin. Hennelly et al. (2006) also found that the added inulin seemed to reduce the level of honeycomb structures evident in electron micrographs; this suggests that the added inulin had bound any loose water, thus preventing the formation of the honeycomb structures. They concluded that inulin can be used at a level of 3.44 g 100 g^{-1} cheese to replace up to 63% of the fat in imitation cheese, and that the preferred method of addition is as a heated inulin solution (Hennelly et al., 2006). Miočinović et al. (2011) studied the physicochemical, microstructural and sensorial properties of ultrafiltered (UF) cheese containing different inulin, lactose and NaCl:KCl mixed salt content during 56 days of storage at 5 °C. They noticed that the texture of the cheeses deteriorated during ripening and storage, followed by significant serum drainage, which resulted in non-homogeneous, granular and mealy cheese curd. Also, the taste of the cheeses was too acidy. The researchers concluded that an excessive drop in pH is unacceptable for low-fat UF cheeses. They further found that adding different amounts of inulin did not have a significant influence on the composition and pH values of the low-fat UF cheeses, and that the microstructure of low-fat cheeses with different inulin contents showed no noticeable difference under scanning electron microscopy. Nevertheless, cheeses manufactured with 3% of inulin were characterized by a more compact structure, denser protein matrix and more uniform disposition of protein chains and the pores between them compared to other cheeses (Miočinović et al., 2011).

It has been speculated that inulin may become part of the protein structural network by complexion with protein aggregates if inulin is present during fermentation and coagulation (Kip et al., 2006) or if water-phase insoluble sub-micron crystalline inulin particles form a particle-gel network (Franck, 2002). According to the study of Juan, Zamora, Quintana, Guamis, & Trujillo (2013) on the sensorial properties of reduced-fat fresh cheese, the addition of 5% inulin in milk resulted in a retention of 3% of inulin in the resulting cheeses. They found that the pH and microbiological quality of cheeses were not affected by the presence of inulin. In their study, cheeses produced with inulin were less hard, springy, cohesive and chewy than reduced-fat cheeses, and more similar to cheeses made from whole milk (Juan et al., 2013). It has been shown that inulin's water-retention capacity could increase the water available for salvation of the protein chains, resulting in a softer, more easily deformed cheese (Creamer & Olson, 1982). The study suggested that the hydroscopic nature of inulin facilitated the water-binding and gel-forming activity within the cheese matrix. As the fat content of cheese decreased, hardness, springiness, cohesiveness and chewiness increased. On the other hand, the addition of inulin modified the texture characteristics of reduced-fat cheeses, making them more similar to full-fat cheeses, with lower hardness, springiness, cohesiveness and chewiness than reduced-fat cheeses (Juan et al., 2013).

In another study, Alnemr et al. (2013) investigated the effect of adding texturizing inulin at levels 2 and 4% on physicochemical properties Karish cheese. The use of inulin significantly enhanced the yield of cheese and moisture content compared to control. They related the increase in yield to the form of a gel network and increase of the ability of water holding in cheese containing inulin. It was found that the pH values of Karish cheese with inulin were higher than that of the control cheese during the storage. They also indicated that higher addition of inulin led to decrease in hardness of Karish cheese (Alnemr et al., 2013). Table 3 indicates the most important rheological remarks of cheeses containing different percent of inulin.

9. Sensorial aspects

The flavor of reduced-fat foods is more likely to be rated lower than that of their full-fat counterparts because of the lack of some of the fat-soluble compounds, which are released during chewing, and which contribute to the overall flavor (Devereux et al., 2003). Consumers' opinion is of great importance when developing a new functional food product and consumer liking is the key to placing a product successfully on the market (Bolenz, Thiessenhusen, & Schape, 2003). Thus, proper fat replacement should consider not only the structure and its subsequent texture, but flavor release (Wijk, Rasing, & Wilkinson, 2003). Additional flavors could be added to enhance the overall flavor of the reduced-fat products (Yackinous & Guinard, 2000). To solve some of the problems associated with fat reduction or elimination, one of the most frequent strategies is the use of fat replacers or fat mimetics to compensate for the shortcomings in texture (Sandrou & Arvantoyannis, 2000). Many fat replacers impart some off-flavors, but inulin can act as a fat replacer without imparting any off-flavor. It forms stable and cream-like particle gel (Dave, 2012).

Table 3
Considerable textural characteristics of cheeses containing inulin.

Cheese type	Inulin content (%)	Remarks	Storage period	Reference
Wheyless cream cheese	8, 10 and 12	Desirable textural attributes using 10% inulin	4 °C	Fadaei et al. (2012)
Imitation cheese	5, 13.75	Higher hardness values of inulin cheeses than the control sample with fat	4 °C	Hennelly et al. (2006)
Fresh kashar cheese	5	Lower hardness of low-fat cheese with 5% inulin compared to low-fat control cheese but slightly higher than that of full-fat control cheese	90 d 4–6 °C	Koca and Metin (2004)
UF cheese	1, 1.5, 2 and 3	Improved cheese texture, uniform microstructure and acceptable sensory properties	5 °C 56 d	Miočinović et al. (2011)
Fresh cheese	3	Less hard, springy, cohesive and chewy of inulin cheese than reduced-fat cheeses, and more similar to cheeses made from whole milk	4 °C 11 d	Juan et al. (2013)
Processed cheese	6, 7 and 8	Low-fat processed cheese spreads with 7% and 8% inulin achieved the yield stress values and spreadability similar to the full-fat processed cheese spread	4 °C	Dave (2012)
Mozzarella cheese, cheddar cheese	5	Incorporation of inulin led to improved texture of low-fat cheese by decreasing the hardness and gumminess while maintaining the cohesiveness, adhesiveness, and springiness	4 °C 90 d and 210 d	Wadhwani (2011)
Ultrafiltered cheese	3	Different amounts of inulin did not have a significant influence on the composition and pH values of the low fat UF cheese	5 °C 56 d	Miočinović et al. (2011)
Fresh cheese	2, 5 and 7	Samples containing inulin were characterized by lower values of compressive force, stiffness, viscosity and adhesiveness	4 °C 20 d	Salvatore et al. (2014)
Karish Cheese	2 and 4	4% inulin gave the highest texture and acceptability score. Hardness decreased from 495 (g) in control to 216 and 143 in Karish cheese made with 2 and 4% inulin	4 °C 14 d	Alnemr et al. (2013)

In different studies, the formulations containing the highest inulin content have been shown to have the lowest moisture contents, as the prebiotic contributed to the total solid contents. (Akalin, Tokusoglu, Gönç, & Aycan, 2007; Alves et al., 2013; Guggisberg et al., 2009). In the study of Cardarelli et al. (2008b) considered consumers' sensory acceptance of potentially symbiotic petit-suisse cheeses. They compared prebiotic ingredients including inulin, oligofructose and oligosaccharides from honey. They found that acceptance increased significantly during storage only for cheeses supplemented with oligofructose and/or inulin; the highest acceptance was observed for the trial containing 10 g 100 g^{-1} oligofructose. The lowest accepted cheese trial had the lowest pH values during storage. Also they concluded that the best symbiotic petit-suisse cheese, considering sensory and technological functional features, was that containing a combination of oligofructose and inulin (Cardarelli et al., 2008b).

Buriti (2005) reported that when inulin was present in fresh cream cheese with *Lactobacillus paracasei*, this cheese was preferred similarly to control cheese (without inulin and *Lactobacillus paracasei*). They also reported that the presence of inulin decreased the perception of residual taste produced by *Lactobacillus paracasei* and improved cheese texture (Buriti, 2005). Also, Buriti et al. (2007) investigated the influence of adding *Lactobacillus paracasei* ssp. *paracasei* and *Streptococcus thermophilus* on the fructan content of a potentially symbiotic fresh cream cheese manufactured with inulin during 21 days of storage at 4 °C. Their results indicated that the metabolism of starter and probiotic bacteria did not significantly degrade the fructan content (Buriti et al., 2007). They stated that *Lactobacillus paracasei* strains are mesophilic bacteria with an optimal growth temperature of 37 °C (Lynch, Muir, Banks, McSweeney, & Fox, 1999), while a refrigerated storage temperature (4 °C) is required for appropriate preservation of fresh cream cheese. They attributed this fact to the absence of inulin degradation by *Lactobacillus paracasei.* Another reason could be a decrease in the solubility of inulin-type fructans (containing 10–65° of polymerization) in water at low temperatures, being almost insoluble at 25 °C or less (Kim et al., 2001). This remarkable thermodynamic behavior of inulin in solution is central to the explanation of differences in the way different fractions influence fermentation (Van Loo, 2004).

Sensory evaluation of UF cheese has indicated that the addition of 1.5% of inulin improves the creaminess of the texture and enables the achievement of a full, rich mouthfeel (Miočinović et al., 2011). The most obvious effect of inulin addition is the overall improvement of the cheese mouthfeel. Sensory improvement may be a result of inulin's capability to form microcrystals when dissolved in water or milk. These microcrystals cannot be felt in the mouth, but they directly influence the formation of the smooth and creamy structure of the product (Niness, 1999). The effect of creaminess has been found to increase with the rise of the inulin content in cheese (Guggisberg et al., 2009).

Araujo et al. (2010) developed a symbiotic cottage cheese with *Lactobacillus delbrueckii* UFV H2b20 and 8% medium-chain inulin. The addition of probiotic bacteria and inulin did not change taste or texture of the cottage cheese after 15 days of storage at 5 °C compared to the control non-probiotic cheese (Araujo et al., 2010). In a study by Flimelová et al. (2013) on fresh cheese containing *Lactobacillus acidophilus* and inulin (1%), sensorial analysis during 15 days of storage (Flimelová et al., 2013) found that color, texture and grain uniformity were convenient with minimal changes during the whole period of storage, and differences were recorded in the smell and taste in all three samples: the control, the sample with probiotic culture and the sample with a combination of probiotic and inulin. The taste and smell of the three samples were perceived positively until the 10th day of storage. After 15 days of storage, undesirable changes in the taste and a fruity smell were marked (Flimelová et al., 2013). It has been reported that the addition of the *Saccharomyces boulardii* and inulin did not alter the chemical composition of the fresh cheese, but improved its organoleptic properties including color, odor, taste and overall acceptability, making it more acceptable to consumers (Zamora-Vega et al., 2013). Juan et al. (2013) studied the effect of inulin addition on the sensorial properties of reduced-fat fresh cheese. No statistical differences were found on the mean scores for color, aroma and flavor intensities in cheeses with and without inulin. They also stated that cheeses produced with inulin had the lowest lightness and the highest yellowness values, although these color differences were not detected by the panelists. Inulin particles can also act as light-scattering centers and increase the opaqueness of cheeses (Juan et al., 2013). Modzelewska-Kapituła et al. (2007) considered the influence of inulin and the potentially probiotic *Lactobacillus plantarum* on the organoleptic properties of soft cheese. In their study, sensory quality was positively affected by the presence of inulin in products. After production and 45 days of storage, the cheese produced with inulin possessed the most desirable properties, followed by the control cheese (Modzelewska-Kapituła et al., 2007). Salem et al. (2007) compared the effects of 1% inulin and other fat replacers (1% Dairy-Lo and 0.1% Dariloid) in the presence of *Lactobacillus reuteri* B-14171, *Lactobacillus johnsonii* B-2178, *Lactobacillus salivarius* B-1950 and yoghurt starter cultures on the sensory attributes of Labneh cheese. They found that both fresh and stored Labneh produced by yoghurt culture and *Lactobacillus reuteri* containing inulin had the highest acetaldehyde and diacetyl contents, followed by that made with yoghurt culture and *Lactobacillus salivarius* containing inulin (Kebary et al., 2002). According to their findings, both fresh and stored Labneh cheese manufactured with yoghurt culture and *Lactobacillus reuteri* containing 1% inulin gained higher scores for consistency and appearance. On the other hand, Labneh made with yoghurt culture and *Lactobacillus johnsonii* without the addition of any prebiotics gained the lowest scores (Salem et al., 2007).

10. Conclusions

Inulin appears as an important food ingredient that could be widely explored in research and by the food industry for the production of functional foods. It has many interesting functional attributes that are useful in formulating cheese. The consumer of today is health-conscious and demands foods with low fat and health benefits. The influence of inulin as a prebiotic on the activity of starter and probiotic cultures and the pH value of cheese depends on the type of bacteria used in the products, as well as the type of inulin. Considering the diversity of cheese manufacturing procedure, most important factors affect the final quality of different types of cheeses containing inulin depends on chain length of inulin, inulin concentration, preparation temperatures and amount of shear. Generally, application of inulin in cheese is of great interest in the development of prebiotic/symbiotic cheese that maximizes nutritional benefits and sensory characteristics to meet consumer demands. The inclusion of inulin in cheese as a fat replacer/texturizer/texture modifier has different influences on the rheological and textural properties depending on the structure and composition of each type of cheese matrix. Sensory properties can vary among the different inulin contents and/or blends. For modification and optimization of different applications of inulin in cheese, an adequate understanding of the physio-chemical characteristics of inulin polymers is needed. The observations and published information in this review about prebiotic effects, fat replacement and the textural, rheological and sensorial attributes of inulin give a distinct direction to future research. More information on versatile aspects regarding to the effects of inulin in different types of cheese is needed before using it on a large industrial scale. Also, further application of inulin should be studied in other dairy systems and with other combinations of oligofructose-type fructans.

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