The effect of inulin and fructo-oligosaccharide supplementation on the textural, rheological and sensory properties of bread and their role in weight management: A review

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The effect of inulin and fructo-oligosaccharide supplementation on the textural, rheological and sensory properties of bread and their role in weight management: A review

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Abstract

There is evidence that fructo-oligosaccharides (FOS) and inulin can impart a range of health benefits if consumed on a regular basis. The health benefits include increased mineral absorption and improved immune response and while there is mounting evidence that prebiotics play a role in colorectal cancer prevention, their role in feeling of satiety and weight management is still being investigated.

In this review we look at the evidence published so far on FOS or inulin supplementation and weight management. We also establish whether prebiotic enriched breads are feasible in terms of dough machinability, bread characteristics and consumers acceptance.

Addition of inulin to bread generally resulted in smaller loaves with a harder crumb and darker colour. The limited sensory studies on those products reflect those findings and acceptability decreased with inulin content. However, a fortification of 5% seems achievable. Despite evidence that yeast invertase and dry heat degrade inulin, the extent to which this is the case and whether the prebiotics maintain their activity is not known.

There is still a great deal of work to be done to establish whether a bread prepared with enough inulin to retain a significant activity can be manufactured without compromising consumer acceptance.

Keywords: Fructo-oligosaccharides (FOS); inulin; bread; satiety; texture; consumer acceptance

Highlights

- There is tentative evidence that inulin supplementation may help a certain proportion of the population actively manage their weight
- Addition of inulin to bread generally resulted in smaller loaves with a harder crumb and darker colour.
- Limited sensory studies on those products reflect those findings and acceptability decreased with inulin content.
- Yeast invertase and dry heat degrade inulin.
- Fructo-oligosaccharides / inulin fortification in bread at a level of 5% seems achievable.

1. Prebiotics: documented health benefits and market growth

There is evidence that prebiotics can impart a range of health benefits if consumed on a regular basis. There have been a number of excellent papers and reviews on the topic of prebiotics and their health benefits (Macfarlane, Macfarlane & Cummings, 2006, Roberfroid et al., 2010). The health benefits include increased mineral absorption (Hawthorne & Abrams, 2008, Rastall, 2010) and improved immune response (Macfarlane, Steed & Macfarlane, 2007, Seifert & Watzl, 2008) and while there is mounting evidence that prebiotics play a role in colorectal cancer prevention (Asad, Emenaker & Milner, 2008) or cancer therapy (Taper & Roberfroid, 2008), their role in feelings of satiety and weight management is still being investigated.

It has been suggested that there is an interaction between body weight and the effect of fibre on satiety and energy intake (Burton-Freeman, 2000). Beyond the direct (prebiotic effect) and indirect (fat / sugar substitution) health benefits to be gained from the incorporation of prebiotics to food, the resulting sensory properties of the final products have to be adequately monitored to ensure that the product as healthy as it is will be liked and purchased by consumers. In 2008, the prebiotics market earned 295.5 million euros and was forecasted to reach 766.9 million euros by 2015 (Feick, 2009), this 2008 figure is greater than the forecast for 2010 obtained from 2003 data (Wells, Saulnier & Gibson, 2008) demonstrating the exceptional market growth for this type of product.

1.1. Prebiotics definition

The concept of prebiotics was first defined by (Gibson & Roberfroid, 1995) and updated (Gibson, Probert, Loo, Rastall & Roberfroid, 2004):

"A prebiotic is a selectively fermented ingredient that allows specific changes, both in the composition and/or activity in the gastrointestinal microflora that confers benefits upon host wellbeing and health."

Thus, the desirable bacteria (*bifidobacteria* and *lactobacilli*) become more prominent in the gut, and this is beneficial for the human host. In addition, some of the fermentation end-products such as short chain fatty acids (SCFAs) help to promote human health. Overall, prebiotics enable a beneficial modification of the host microflora composition.

Therefore a prebiotic should fulfil three criteria (Gibson, Probert, Loo, Rastall & Roberfroid, 2004):

i. "resists gastric acidity, hydrolysis by mammalian enzymes and gastrointestinal absorption;
ii. is fermented by the intestinal microflora;
iii. stimulates selectively the growth and/or activity of intestinal bacteria associated with health and wellbeing."

This concept implies that prebiotics must be stable in the stomach, *i.e.* that acid would not influence them, and they should not be absorbed in the small intestine and thus able to reach the colon, where they are *selectively* fermented by *specific* bacteria which exert the beneficial effect on the host (Roberfroid, 2002).

All prebiotics apart from inulin are short-chain carbohydrates with low degree of polymerisation (DP) often referred to as oligosaccharides (Manning & Gibson, 2004). Oligosaccharides are short–chain of carbohydrates of 3 to 10 monomers. Monosaccharide composition, glycosidic linkage, and DP are important in influencing the prebiotic properties (Mussatto & Mancilha, 2007, Sanz, Cote, Gibson & Rastall, 2006). Glucose, galactose, fructose and xylose are the most common building blocks. Although a number of oligosaccharides have been proposed as prebiotics, only inulin-type fructans, transgalacto-oligosaccharides and lactulose have achieved the prebiotic status (Gibson, Probert, Loo, Rastall & Roberfroid, 2004, Roberfroid, 2007, Roberfroid, 2008). The most commonly investigated oligosaccharides for prebiotic activity are fructo-oligosaccharides (FOS) and galacto-oligosaccharides

(GOS) but lactulose, soybean oligosaccharides, lactosucrose, isomalto-oligosaccharides (IMO), xylo-oligosaccharides (XOS), and palatinose all present prebiotic characteristics (Gibson, Ottaway & Rastall, 2000). Another important prebiotic is the polysaccharide: inulin (DP 11 – 65) with an average DP 12-15 (Macfarlane, Macfarlane & Cummings, 2006). The average degree of polymerization of inulin depends on the source, time of harvest and the process of production (Franck, 2002). Together, fructo-oligosaccharides and inulin are now considered as the model prebiotics (Roberfroid, 2008) despite the fact depending on which colonic bacteria is sought to be enhanced; other prebiotics may be more efficient (Rycroft, Jones, Gibson & Rastall, 2001). Fructo-oligosaccharides have been shown to be completely fermented in the large intestine (Alles, Hautvast, Nagengast, Hartemink, van Laere & Jansen, 1996).

In reviewing the literature, (Roberfroid, 2002) concluded that inulin and oligo-fructose showed evidence of prebiotic activity if consumed at a level of 5 – 15 g/day for a few weeks. Considering that inulin and fructo-oligosaccharides have attracted the most interest in scientific publications and they both have achieved prebiotics status, this review focuses on those two polymers which mainly differ by their degree of polymerization. **Figure 1** shows the structure of fructo-oligosaccharides and inulin.

A number of different prebiotics will be discussed in this review and we will for the purposes of consistency use the same product names as have been used in the original research articles, although some trade names may no longer be in use. The product names, sources and brief descriptions (when supplied in the original article) are as follows:

Fibruline: Inulin (Trades SA, Barcelona, Spain); **Fibrex**: Dietary fibre from sugar-beet (Danisco Sugar, Köpingebro, Sweden); **Frutafit CLR DP8**: Inulin DP: 8 (Sensus, Roosendaal, The Netherlands); **Frutafit HD DP10**: Inulin DP: 10 (Sensus, Roosendaal, The Netherlands); **Frutafit TEX DP5**: Inulin DP: 23

(Sensus, Roosendaal, The Netherlands); **Inulin GR**: Granulated inulin DP ≥ 10 (Orafti Group, Tienen, Belgium); **Inulin HP**: High performance inulin for fat replacement at low temperatures, DP 2-60, average DP: 23 (Orafti Group, Tienen, Belgium); **Inulin HP-gel**: High performance inulin with gelling capability, DP 2-60, average DP: 23 (Orafti Group, Tienen, Belgium); **Inulin HPX**: High Performance inulin for high temperature process, average DP ≥ 23 (Orafti Group, Tienen, Belgium); **Inulin LS**: Low sugar inulin, average DP ≥ 8 (Orafti Group, Tienen, Belgium); **Inulin S**: Inulin, DP 2-60 (Sigma-Aldrich, Gillingham, UK); **Inulin ST**: Standard inulin DP ≥ 10 (Orafti Group, Tienen, Belgium); **Inulin TEX**: Inulin DP: 23 (Sensus, Roosendaal, The Netherlands); **Raftilin HP**: High performance inulin for fat replacement at low temperatures, DP 2-60, average DP: 23 (Orafti Group, Tienen, Belgium); **Raftilin ST**: Standard inulin DP ≥ 10 (Orafti Group, Tienen, Belgium) and **Raftilose P95**: Fructo-oligosaccharides, DP 2-7 (Orafti Group, Tienen, Belgium). It should be noted that the authors do not have any association with any of the aforementioned companies.

1.2. Inulin and fructo-oligosaccharides in food

The average daily consumption of inulin and non-digestible oligosaccharides for a Spanish population was estimated at 1.1g/day (Espinosa-Martos, Rico & Ruperez, 2006) however, there is a huge variation within the population in the consumption of products naturally rich in FOS or inulin such as onions, leeks, artichokes or garlic. The disparity was noted in a previous estimation of oligo-fructose and inulin intake which placed the consumption in the USA at 1 to 4g/day and at 3.2 to 11.3 g/day in Europe (Vanloo, Coussement, Deleenheer, Hoebregs & Smits, 1995). The fructan content of non-fortified bread is ~ 0.6 - 1.9g/ 100g (Whelan, Abrahmsohn, David, Staudacher, Irving, Lomer, & Ellis, 2011).

The difference in structure between inulin and FOS has a major impact on their functionality whereby inulin is able to form gels via small crystallites and is not perceived as being sweet, it has therefore been successfully used as a fat substitute, whereas fructo-oligosaccharides are more soluble, taste sweet (a sweetness of about 30% of that table sugar) and are mainly added as sugar replacement as well as for their prebiotic properties (Coussement, 1999, Niness, 1999). In both cases, they provide low calorie bulk (1.5 kCal/g (Hosoya, Dhorranintra & Hidaka, 1988, Roberfroid, 1999) as fat or sugar replacers and have found a number of uses in food production (Franck, 2008). Inulin, in particular, is an excellent fat replacer in water continuous phase products (Wouters, 2010) and has been successfully introduced in low fat dairy products (Aryana, Plauche, Rao, McGrew & Shah, 2007, Meyer & Peters, 2009) where it is now commonly used (Elleuch, Bedigian, Roiseux, Besbes, Blecker & Attia, 2011). Indeed, yogurt drinks fortified with inulin were preferred to the control in a recent consumer study (Allgeyer, Miller & Lee, 2010). There have been several attempts at introducing inulin and FOS in low fat meat products such as mortadella (Garcia, Caceres & Selgas, 2006) and sausages (Archer, Johnson, Devereux & Baxter, 2004, Beriain, Gomez, Petri, Insausti & Sarries, 2011) with promising results in terms of acceptability (Garcia, Caceres & Selgas, 2006; Beriain, Gomez, Petri, Insausti & Sarries, 2011) and satiety (Archer, Johnson, Devereux & Baxter, 2004). Prebiotics in bakery products have also attracted a lot of interest as fat (Capriles, Soares, Pinto e Silva & Areas, 2009, Devereux, Jones, McCormack & Hunter, 2003, Zahn, Pepke & Rohm, 2010) or carbohydrate (Armstrong, Luecke & Bell, 2009, Brennan & Samyue, 2004, Hempel, Jacob & Rohm, 2007, Taylor, Fasina & Bell, 2008) substitutes.

However, when investigating the feasibility of a systematic supplementation of prebiotics, staple foods need to be considered. In this respect, bread is a good candidate but the introduction of this type of product on the market has not been implemented on a large scale.

1.3. Aim of this review

The aim of this paper is to review the work performed on inulin and fructo-oligosaccharide fortification in bread. First and foremost, the work on prebiotics and satiety/weight management is reviewed to establish whether prebiotics can contribute to weight management beyond the substitution of energy dense ingredients. The feasibility of inulin / FOS fortification in breads is discussed by reviewing existing data concerning dough characteristics, end product properties and sensory evaluation of prebiotic enriched products. Finally, this review examines the evidence regarding FOS or inulin degradation (and potential loss of prebiotics activity) upon baking.

2. Prebiotics, satiety and weight management:

There has recently been some interest in the role of fibres on satiety and weight loss (Weickert et al., 2006, Willis, Eldridge, Beiselgel, Thomas & Slavin, 2009), although the link with satiety is not averred , it is speculated to be part of the mechanism through which weight loss is achieved when consuming high levels of fibres. The mechanisms proposed range from increasing gastric emptying rates, to modulating Peptide YY and ghrelin, colonic fermentation, to a less energy dense diet (Smith & Tucker, 2011).

In order to establish whether FOS or inulin supplementation is desirable from a weight management point of view, the evidence of an effect (or absence of) of FOS / inulin supplementation on weight management and satiety are reviewed. For this purpose, all types of FOS or inulin supplementation media were considered. To date, very few studies have looked into the effect of FOS and inulin on satiety or weight management in humans (**Table 1**).

In a 3-way cross-over design, 33 subjects rated their perception of satiety after a breakfast comprising among other things of either a regular patty or reduced fat patties containing either inulin or lupin-kernel fibre. The subjects were also asked to keep food records of their lunches. While no significant difference in satiety was observed between the control breakfast and the inulin supplemented breakfast, both the subsequent fat and total energy intakes were estimated to be lower after consumption of the breakfast with the inulin patty than with the regular breakfast. It is worth mentioning though that the actual amount of inulin ingested was very low as the patty represented only a small part of the breakfast (Archer, Johnson, Devereux & Baxter, 2004). In a 4-way cross-over design, 21 subjects ate meal replacement bars enriched in FOS and/or beta-glucans over a 2 days period. Three intakes of 8g of FOS did not have an impact on either food intake during *ad-libitum* lunches or self reported hunger ratings acquired over those 2 days. The authors suggested that longer treatments may be required to observe an effect (Peters, Boers, Haddeman, Melnikov & Qvyjt, 2009). More recently, in a randomized double-blind cross-over study, 20 subjects received 2 x 5g or 8g (or a control 0g) of FOS for breakfast and snack and recorded their perceived satiety. Their calorie intake was also measured during an *ad-libitum* lunch and their food intake estimated using food diaries. No significant difference was observed in either satiety or calorie intake over lunch but women who had ingested 2 x 8g of FOS saw their calorie intake during the remaining of the day (food diary) decrease. The opposite was observed for men: their calorie intake was greater after consuming the inulin supplemented drinks and snacks (Hess, Birkett, Thomas & Slavin, 2011). In contrast, studies in which the daily FOS / inulin intake occurred over longer periods of time (2 to 17 weeks) have reported an effect on satiety and energy intake (Cani, Joly, Horsmans & Delzenne, 2006; Parnell & Reimer, 2009). In a single-blind cross-over study 10 adults took 2 x 8g of FOS or placebo daily for 2 weeks, satiety was found to be significantly greater and calories intake was significantly lower (5%) during the FOS treatment (Cani, Joly, Horsmans & Delzenne, 2006). In a longer study (12 weeks), 48 overweight or obese subjects ingested a daily supplement of 21g FOS (or placebo). A significant body weight reduction was observed in the treatment group along with a significant decrease in self reported calorie intake (Parnell & Reimer, 2009). In a longer study (120 days), 55 overweight women took either a daily supplementation of 0.14g/kg of FOS or placebo, a significant decrease in body weight, waist circumference and BMI was observed in the treatment group (**Figure 2**). Satiety sensation was also greater in the treatment group even if no significant difference was observed in nutrient intake (Genta et al., 2009).

In summary: **Table 1** summarises the findings on satiety and weight management. A punctual prebiotic intake does not seem to have an impact on acute satiety; however, prebiotics may increase feelings of satiety over the long term. This would be the case if satiety was linked with the fermentation process induced by those prebiotics. In two studies, treatment over longer periods (84 and 120 days) resulted in significant body weight loss. These results indicate that a FOS / inulin supplementation, in the long run, may be able to help overweight or obese people whose regular diet is poor in FOS and/or inulin, manage their weight. The mechanism through which this is achieved is still being investigated to understand the roles of gut fermentation and links to satiety (Cani et al., 2009, Delzenne & Cani, 2010) but there is evidence that the weight loss is not merely a result of substituting calorie dense ingredients with FOS or inulin. *In vitro*, in a study comparing the effects of different prebiotics on the colonic microflora showed a negative correlation between the increase in *bifidobacteria* (over 24h) and their initial population, consequently the prebiotic effect was more noticeable when the faeces *bifidobacteria* population was low to start off with (Rycroft, Jones, Gibson & Rastall, 2001, Tuohy, Kolida, Lustenberger & Gibson, 2001). This may be an indication that prebiotic fortification may be useful for a certain groups of individuals. We can only speculate on which group that may be but people with a naturally low colonic population in good bacteria or people whose regular diet is poor in prebiotics would be good target groups to investigate the matter further as none of these studies reported the subjects' regular diets or changes in colonic microbiota.

3. Impact of FOS/Inulin supplementation on dough characteristics:

The effect of added ingredients can be beneficial or detrimental to the characteristics of dough (Mirsaeedghazi, Zemam-Djomeh & Mousavi, 2008 and references therein) and therefore introducing prebiotics in bread may be appealing for a number of reasons but it also may be a technical challenge. A number of studies have looked at the rheological properties of dough prepared with FOS or inulin.

3.1. Water absorption:

Water absorption decreased with increasing inulin contents (0 to 4%) (Karolini-Skaradzinska, Bihuniak, Piotrowska & Wdowik, 2007); the same was reported for an addition of 3% inulin although there is no indication on whether the decrease was significant (Wang, Rosell & de Barber, 2002). The addition of 2.5 to 7.5% of inulin (ST; HP; HP-gel) also resulted in a decrease of water absorption as did the addition of 6.8% Raftilose P95 as a powder (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011). This was more pronounced for the shorter chain inulin (ST) which was explained by a lubricating effect of the sugars and oligosaccharides present in inulin ST (Peressini & Sensidoni, 2009). The addition of inulin LS as a gel (5%) and as a powder (2.5%) resulted in a decreased water absorption however, the addition of inulin LS as a gel (2.5%) did not significantly alter water absorption (O'Brien, Mueller, Scannell & Arendt, 2003). Decreased water absorption was also reported for inulin of different degrees of polymerisation (Meyer & Peters, 2009). Stability during heating (using a Mixolab®) was negatively correlated with water absorption; the addition of Fibruline resulted in an increase in stability during heating, suggesting a decrease in water absorption (Rosell, Santos & Collar, 2010). Some authors have added carboxymethyl cellulose (CMC) to the mix to improve the texture of the dough without altering its properties on baking (Meyer & Peters, 2009).

3.2. Dough development:

Dough development time and stability were considerably increased by the addition of 1 to 4% inulin TEX (Karolini-Skaradzinska, Bihuniak, Piotrowska & Wdowik, 2007) resulting in a strengthening of the dough. An increase in dough development time was also reported for the addition of 5% and 7.5% inulin HP and HP-gel and 7.5% inulin ST (Peressini & Sensidoni, 2009). An addition of 3% inulin did not result in any change in dough development time but increased stability time (significance not reported) and both the time to reach maximum dough development and the time at which the gas starts escaping from the dough were shortened. Conversely, the dough volume at maximum development was lower (Wang, Rosell & de Barber, 2002). Dough stability was also increased by the addition of inulin of different degrees of polymerisation (Meyer & Peters, 2009); however the addition of Fibruline did not have an impact on the overall stability (Rosell, Santos & Collar, 2010). In contrast, shorter stability times at final proof were reported for the addition of 5% Fibrex, Inulin HPX and Inulin GR (Filipovic, Popov & Filipovic, 2008; Filipovic, Filipovic & Filipovic, 2010). Dough development height was lower when 3% inulin was added to the dough (Wang, Rosell & de Barber, 2002). Dough expansion was also decreased by the addition of increasing amounts of inulin HP and HP-gel (0 to 7.5%), this was less obvious for shorter chain inulin (ST) (Peressini & Sensidoni, 2009). This was explained by the increased elasticity and solid-like behaviour resulting from the interaction between inulin and the gluten network but also to inulin-inulin interactions contributing to the elasticity (Peressini & Sensidoni, 2009).

3.3. Rheological characteristics:

Resistance at constant deformation, which for good quality dough should be minimal, was higher in dough containing 3% and 4% inulin TEX than in the control but addition of 1% and 2% inulin TEX resulted in lower resistance at constant deformation (Karolini-Skaradzinska, Bihuniak, Piotrowska & Wdowik, 2007). The P value (resistance to deformation) obtained by an alveograph test increased considerably when the dough was prepared with 3% inulin (Wang, Rosell & de Barber, 2002). The addition of Fibruline (1 to 5%) did not have an impact on the dough resistance to deformation (Collar, Santos & Rosell, 2007).

Like resistance to deformation the elasticity of good quality dough should be minimal. Increasing inulin contents (HP, HP-gel and ST) resulted in an increase storage modulus and decrease in tan δ, indicating greater dough elasticity, this was less pronounced for the shorter chain inulin (ST) (Peressini & Sensidoni, 2009) whereas other authors (Wang, Rosell & de Barber, 2002) reported a decrease in elasticity upon addition of 3% chicory inulin. Hager et al. (2011) reported that the addition of 6.8% Raftilose P95 as a powder resulted in a dough less elastic than the control.

The extensibility of dough prepared with 3% and 4% inulin TEX was not found to be significantly different from that of the control, however, addition of 1% and 2% decreased the extensibility which is undesirable (Karolini-Skaradzinska, Bihuniak, Piotrowska & Wdowik, 2007). No difference was reported for an addition of 3% inulin (Wang, Rosell & de Barber, 2002). The addition of Fibruline (1 to 5%) did not have an impact on extensibility of the dough (Collar, Santos & Rosell, 2007).

Stickiness is a particularly undesirable property in good quality dough. One study has shown that the addition of Fibruline (1 to 5%) did not have an impact on stickiness and adhesiveness (Collar, Santos & Rosell, 2007).

In summary: The main results are summarised in **Table 2**. There is evidence that water absorption is decreased by the addition of inulin while conflicting results are reported for other characteristics, those may be attributable to different dough making strategies in terms of water adjunction and consistency. However, taken together, the results suggest that the addition of inulin resulted in an increase in dough elasticity and resistance to deformation. This may be due to inulin-inulin and/ or inulin-gluten interactions contributing to the elasticity of the gluten network and resulting in lower volumes at the end of development. Shorter chain inulins seem to have less of an impact on dough rheology and the structure of the gluten network does not appear to be disrupted by the introduction of inulin as shown by confocal scanning laser microscopy or tan δ results in dynamic rheological measurements (Peressini & Sensidoni, 2009). The addition of inulin did not significantly change the structure of either dough or gluten-free batter (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011). Inulin integrated well to the dough structure and increased its stability (Rosell, Santos & Collar, 2010).

Although the rheological properties of the bread doughs were affected by the addition of inulin, a fortification of about 5% seems achievable without too many detrimental consequences on dough machinability. There are conflicting reports on the effect of the inulin degree of polymerisation on dough quality, with short chain inulins given the preference in some cases (Peressini & Sensidoni, 2009) while longer chain inulins were deemed more acceptable by others (Meyer & Peters, 2009).

4. Characteristics of FOS/inulin fortified bread:

4.1. Bread loaf volume:

Inulin fortification (8% Frutafit CLR DP8, 6.8% Frutafit HD DP10 and 5% Frutafit TEX DP5) all resulted in a decreased loaf volume with the higher DP having the greatest impact (Meyer & Peters, 2009). The addition of 5% Fibrex and 5% inulin GR resulted in smaller loaf volumes while the addition of 5%

inulin HPX resulted in a slightly larger loaf (Filipovic, Popov & Filipovic, 2008; Filipovic, Filipovic & Filipovic, 2010). Inulin LS added as a gel (2.5% and 5%) resulted in identical loaf volumes than the controls (2.5% and 5% fat) whereas inulin LS (2.5%) added as a powder presented a decrease in loaf volume compared to the control (2.5% fat) and achieved the same loaf volume as the fat free control (O'Brien, Mueller, Scannell & Arendt, 2003). When 6% or 10% inulin was added as a fat replacer, a significant decrease in bread volume was observed at the highest concentration (Brasil, da Silveira, Salgado, Souza Livera, de Faro & Guerra, 2011). The addition of 5% and 7.5% of inulin HP resulted in decreased specific volumes but no significant change was observed at 2.5%. The results are less clear with inulin ST as there appears to be an interaction with the flour type: the addition of 2.5%, 5% and 7.5% of inulin ST resulted in a decrease or increase in specific volume depending on the type of flour (Peressini & Sensidoni, 2009). More recently, the addition of 6.8% Raftilose P95 did not result in a significant change in specific volume (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011). An addition of 3% chicory inulin in bread resulted in a large loaf volume decrease: 906ml to 733ml (Wang, Rosell & de Barber, 2002). The addition of 1 to 4% inulin TEX resulted in progressive decrease in bread loaf volume (Karolini-Skaradzinska, Bihuniak, Piotrowska & Wdowik, 2007). This was also observed on bread supplemented with artichoke fibres (Frutos, Guilabert-Anton, Tomas-Bellido & Hernandez-Herrero, 2008) and has been attributed to a dilution effect, while inulin integrates well to the dough structure; it impairs gas retention without increasing gas production (Mandala, Polaki & Yanniotis, 2009, Pomeranz, Shogren, Finney & Bechtel, 1977). However an increase of bread volume was reported upon substitution of flour with 8%, 10% and 12% of FOS (Raftilose P95), inulin (Raftilin ST) and Jerusalem artichoke powder (Praznik, Cieslik & Filipiak-Florkiewicz, 2002). The addition of 5% and 8% inulin (Frutafit) resulted in a slight but significant increase in loaf volume when compared to a gluten free control whereas FOS syrup at the same concentration did not significantly change the loaf volume (Korus, Grzelak, Achremowicz & Sabat, 2006). Breads produced with immature wheat meal (rich in fructo-oligosaccharides) were also found to be smaller (Mujoo & Ng, 2003).

4.1.1. Moisture content:

Water absorption and resulting moisture content have a direct impact on the texture attributes of bakery products and a strong correlation was found between moisture contents and hardness (He & Hoseney, 1990). The addition of 3 to 12% artichoke fibres resulted in increased moisture contents (Frutos, Guilabert-Anton, Tomas-Bellido & Hernandez-Herrero, 2008). Increased crumb moistures were also reported for breads prepared with 8% and 10% of fructo-oligosaccharides (Raftilose P95) but no major difference was observed between the standard bread and those prepared with inulin (Raftilin®ST) or Jerusalem artichoke powders (Praznik, Cieslik & Filipiak-Florkiewicz, 2002). However, when inulin HP or ST was added, this resulted in decreasing moisture contents (Peressini & Sensidoni, 2009). This was also observed upon addition of 3% chicory inulin (Wang, Rosell & de Barber, 2002) and 6.8% Raftilose P95 (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011). The moisture content in the middle of the crumb was found to be the same as the control bread for a bread prepared with 3% inulin although, the inulin bread presented a more moist outer layer (Mandala, Polaki & Yanniotis, 2009).

4.1.2. Crumb hardness / firmness:

Crumb hardness as measured by TPA (Texture Profile Analysis) was increased by the addition of 3% inulin in bread (Wang, Rosell & de Barber, 2002); this was later confirmed for breads made with 3% and 5% inulin (Poinot, Arvisenet, Grua-Priol, Fillonneau, Le-Bail & Prost, 2010) or 6.8% Raftilose P95 (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011). O'Brien, Mueller, Scannell and Arendt (2003) reported a greater increase in crumb hardness when the inulin was added as a powder rather than a gel. Inulin type was also critical in the resulting hardness with a greater increase observed with long chain inulin than short chain inulin in bread (Peressini & Sensidoni, 2009). Increased hardness and chewiness (TPA) were also reported for bread made with increasing amounts of artichoke fibres (Frutos, Guilabert-Anton, Tomas-Bellido & Hernandez-Herrero, 2008). The changes in crumb hardness with addition of prebiotics to gluten free bread were found to be dependent on the level of prebiotics added (Korus, Grzelak, Achremowicz & Sabat, 2006) and 3% inulin (Frutafit, powder) or FOS syrup decreased crumb hardness compared to the gluten free control while the addition of 8% of the same prebiotic resulted in an increased crumb hardness. Increased crumb firmness was reported for bread made with immature wheat meal rich in FOS and a tighter crumb structure was observed (Mujoo & Ng, 2003). Inulin containing breads were described (Mandala, Polaki & Yanniotis, 2009) as having "an elastic crumb, soft crust and relative low specific volume". **Figure 3** shows the effect of inulin addition on normalised crumb hardness (Frutos, Guilabert-Anton, Tomas-Bellido & Hernandez-Herrero, 2008, Peressini & Sensidoni, 2009, Wang, Rosell & de Barber, 2002). The reported increased crumb firmness has been attributed to differences in the elastic properties of the dough (Lee, Inglett & Carriere, 2004) and the reduction in the gas retention capacity due to the interaction of the fibres with the gluten network resulting in a lower bread volume (Sabanis, Lebesi & Tzai, 2009). A later gelatinisation onset is also likely to have an impact by failing to trap the gas bubbles as they form. Brennan & Samyue (2004), suggested that the inulin inhibited starch gelatinization and pasting to explain the decreasing peak viscosity measured using a pasting cycle and RVA. Although, this is at odds with the results obtained on breads prepared with a number of fibres, including inulin (1 to 5g Fibruline), which showed that inulin did not have a significant effect on starch gelatinisation temperature (Santos, Rosell & Collar, 2008).

In puncture tests, the crust of freshly baked, 3% inulin enriched bread was firmer than that of the control. Interestingly the trend was reversed upon freezing of the dough at -18°C indicating that water redistribution may be occurring upon storage (Mandala, Polaki & Yanniotis, 2009).

4.1.3. Maillard reaction: colour and volatiles:

A darker curst colour was reported for all levels of addition (2.5%; 5% and 7.5%) and 2 types of inulin. An enhancement of bread crust coloration was also reported for breads prepared with as little as 3% and up to 10% inulin (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011, Poinot, Arvisenet, Grua-Priol, Fillonneau, Le-Bail & Prost, 2010). No significant difference in crust colour was observed for inulin addition at 3% in freshly baked breads (Mandala, Polaki & Yanniotis, 2009). Darker colours were also reported in gluten free bread (Hager, Ryan, Schwab, Gaenzle, O'Doherty & Arendt, 2011, Korus, Grzelak, Achremowicz & Sabat, 2006) and for breads prepared with artichoke fibres (Frutos, Guilabert-Anton, Tomas-Bellido & Hernandez-Herrero, 2008).

These darker colours have been explained by a greater number of reducing ends involved in a Maillard reaction. Shorter chain inulins result thus in even darker colour as it possesses more low molecular weight fructans (Peressini & Sensidoni, 2009). However, an analysis of the volatiles generated during baking, as well as colour, has led to the speculation that inulin accelerates bread baking (Poinot, Arvisenet, Grua-Priol, Fillonneau, Le-Bail & Prost, 2010).

In summary: **Table 2** recapitulates the findings of different groups on doughs and breads enriched in inulin and fructo-oligosaccharides. On the whole, bread loaf volumes are smaller than their prebiotic free counterparts. Moisture content was shown to increase, decrease or remain constant upon addition of inulin. However, this may be explained by different strategies at the development stage and whether the authors adjusted water content to aim for a specific consistency. Crumb hardness is universally reported to increase, presumably due the increase in dough elasticity and resistance to deformation as well as a dilution of the gluten network which impairs gas retention. The colour of the inulin / FOS enriched products was found to be darker. This may be the result of accelerated baking (Mandala, Polaki & Yanniotis, 2009, Peressini & Sensidoni, 2009, Poinot, Arvisenet, Grua-Priol, Fillonneau, Le-Bail & Prost, 2010). Overall, the appearance and textural properties of breads enriched in FOS or inulin are different to those of the standard breads. Whether these differences have a major impact on the breads sensory characteristics and consumers' acceptance is discussed in the next section.

5. Sensory characteristics:

A number of sensory techniques have been used to characterise prebiotic products during their development and to measure the impact of prebiotics on sensory attributes and consumer liking (Cruz et al., 2010). However, to date, little work has been done on breads both in terms of descriptive analysis or consumer testing.

5.1. Descriptive analysis:

In a recent study, 9 panellists worked on breads prepared with different fibres including 3% inulin GR and hydrocolloids (Polaki, Xasapis, Fasseas, Yanniotis & Mandala, 2010) using Quantitative Descriptive Analysis. A cluster analysis and Principal Component Analysis (PCA) revealed that the fresh bread prepared with inulin was clustered in the same group as the control and in the vicinity of the control on the PCA biplot, however, ANOVA results were not reported so it is impossible to say whether there existed any significant differences between the inulin and control breads on any of the attributes generated by the panel. QDA was also used recently to describe a number of attributes; adding 6% inulin as fat replacer did not significantly affect any of the attributes investigated while a 10% addition resulted in significantly altered volume, crust colour, crumb porosity and texture (Brasil, da Silveira, Salgado, Souza Livera, de Faro & Guerra, 2011).

The organoleptic characteristics of substituted bread (Raftilose P95, Raftilin ST and Jerusalem artichoke powder) were investigated at 2 levels of substitution using a scorecard system and 7 judges looking at the attributes appearance, crumb, crust, taste and smell. All formulations were found to be comparable to the standard bread except at the highest substitution level of fructo-oligosaccharides (10%) (Praznik, Cieslik & Filipiak-Florkiewicz, 2002). When compared to their gluten free counterpart using a score card system (5 panellists), breads made with added inulin (Frutafit) and FOS syrup obtained similar scores at addition levels of 3 and 5% but addition of 8% resulted in a lower class of bread then the gluten free control (Korus, Grzelak, Achremowicz & Sabat, 2006). Five trained panellists rated bread crumb quality using a scorecard system, the addition of 5% inulin HPX resulted in a similar score as the control while the addition of 5% Fibrex and inulin GR resulted in lower scores than the control (Filipovic, Popov & Filipovic, 2008; Filipovic, Filipovic & Filipovic, 2010).

5.2. Consumer testing:

A 10 point hedonic scale was used by 50 panellists to rate the acceptability of breads made with increasing amounts of artichoke fibre, the average overall acceptability was found to decrease linearly with the amount of artichoke fibre added. Although the level of significance is not reported, the authors conclude that the addition of 3% and 6% of artichoke fibre did not affect the acceptability of the bread in a great extent. This was attributed to the increasingly compact texture of the crumb (Frutos, Guilabert-Anton, Tomas-Bellido & Hernandez-Herrero, 2008). However, artichoke fibres are made up of a number of compounds and not purely inulin; those may have an impact on the bread quality. In a different study, bread prepared with 3% inulin scored slightly less than the control using a 9 point hedonic scale, however, the number of judges or level of significance are not reported (Wang, Rosell & de Barber, 2002).

In summary: there is no full consumer study on breads enriched with inulin or FOS. The sensory results reported reflected the instrumental findings and hedonic ratings tended to decrease with increasing inulin / FOS contents, presumably due to smaller loaf volumes, harder crumbs and darker colours. However, there is little information available on enriched breads taste and aroma as opposed to texture which is a parameter easier to estimate instrumentally in a way that relates to consumer perception. Where it is available, data on low fat products made with inulin show a trend to being less liked by panellists. In a consumer study, 62 panellists used a Visual Analogue Scale (like extremely - dislike extremely) to rate a number of attributes including overall acceptance in low-fat foods containing fructans compared to their full-fat counterparts. In all cases the overall acceptability of the low-fat product was less than that of the full fat product even if this trend was only significant in 2 bakery products out of 5. In both cases, the texture was an attribute which was picked up by the panellists as less acceptable (Devereux, Jones, McCormack & Hunter, 2003).

6. Effect of FOS and inulin degradation on baking. Is there any prebiotic activity loss?

The amount of FOS detected in bread made with immature wheat meal rich in fructo-oligosaccharides was considerably lower than expected from the FOS content of the wheat meal used to prepare the bread (Mujoo & Ng, 2003). This suggests that fructo-oligosaccharides are partially hydrolysed during the bread making process even if significant amounts are naturally found in non-enriched breads (Biesiekierski et al., 2011). In gluten free bread, retention levels upon addition of inulin (Frutafit) were found to range between 21.5% and 41.2% (Korus, Grzelak, Achremowicz & Sabat, 2006). A gradual decrease in DP was observed when inulin from Jerusalem artichoke was subjected to high temperatures for 30 minutes. At 195°C, almost no fructose oligomers were detected (**Figure 4)**, however fructose was only formed in very low amounts instead di-D-fructose-dianhydrides were found (Bohm, Kaiser, Trebstein & Henle, 2005). These compounds may have in themselves strong bifidogenic effects (Bohm, Kleessen & Henle, 2006) but their impact on flavour and acceptability is not known. The potential loss of FOS and inulin prebiotic activity under several processing conditions (low pH, heat, in presence of amino groups) was investigated.

pH alone did not have an impact on the prebiotic activity (Glibowski & Bukowska, 2011, Matusek, Meresz, Le & Oersi, 2009) while heating to 85°C combined with a low pH resulted in a decreased prebiotic activity for one type of inulin (Inulin-S). The results suggest that when degradation has occurred, a loss of prebiotic activity was observed, however, under the conditions used in this study, degradation was minimal (Huebner, Wehling, Parkhurst & Hutkins, 2008).

Beyond the chemical (pH, heat) hydrolysis due to food processing, yeast invertase (in bread) can convert inulin to lower DP FOS or fructose. It is therefore crucial to monitor the retention level in the final product. Using a low invertase yeast could increase 3 fold the retention level observed compared to a high invertase yeast and depending on the DP of the inulin used (the lower, the higher the loss), a loss as low as 6% has been reported (Meyer & Peters, 2009). Inulin with greater DP appears to better resist the hydrolysis upon development and baking (Praznik, Cieslik & Filipiak-Florkiewicz, 2002) although this needs to be investigated further.

<u>In summary:</u> the impact of processes typical to those found in food manufacturing on inulin structure (Bohm, Kaiser, Trebstein & Henle, 2005), rheology (Glibowski & Wasko, 2008) and prebiotic activity (Huebner, Wehling, Parkhurst & Hutkins, 2008) have been investigated. The severity of functionality loss was determined by the processing conditions and aggravated by low pH and heating. Overall, a limited number of studies have investigated the potential loss of prebiotic activity upon processing (Bohm, Kaiser, Trebstein & Henle, 2005, Huebner, Wehling, Parkhurst & Hutkins, 2008), they have shown that in the processing conditions used, a loss of activity was not systematic and depended on the extent of the degradation with new molecules formed potentially showing some prebiotic activity. Yeast invertase converts inulin to lower DP FOS or fructose. It is therefore crucial to monitor the retention level in the final product.

7. Conclusions and future perspectives:

The review of the effect of FOS or inulin supplementation on weight management and satiety showed that those prebiotics may have a greater role to play than merely energy dense food substitution and their traditional prebiotics effects. They may help a certain category of people actively manage their weight. Who these people are and what are the optimum dosages still remain unknown. More work is also required on the physiological mechanism linking the prebiotics to weight loss.

It was found that the effect of inulin / FOS substitution on the textural and sensory properties depended on the type of prebiotic added; flour type; substitution level; the degree of polymerisation and how the prebiotic is introduced (*e.g.* powder or gel). In all cases, technical challenges were apparent in terms of dough machinability resulting in end product quality slightly lower than that of the control. The main inulin / FOS impacts reported were lower bread loaf volumes, increased crumb hardness and darker crust. While inulin appears to integrate well to the gluten network, it also dilutes it resulting in lower gas retention ability. A darker colour and increase in aroma compounds characteristic of the Maillard reaction were attributed to a larger number of reducing ends. Those in turn, may be partly due to inulin / FOS degradation upon baking as there is evidence that both yeast invertase and dry heat degrade inulin. Whether prebiotics remain fully active in the end product is still to be established.

A supplementation of 5% inulin appears to be achievable and should contribute 0.7-1.2g of inulin per slice of bread toward daily intake.

8. Acknowledgements

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List of Figures:

Figure 1: Chemical structures of sucrose (GF) and fructo-oligosaccharides (GFn and Fm). G = glucose; F=fructose. Short chain fructo-oligosaccharides are known as oligo-fructose (n = 1 - 8), while medium-chain fructo-oligosaccharides are known as inulin (n = 10 - 13 on the average and 63 at maximum).

Figure 2: Clinical data of subject before and after 120 days of yacon syrup or placebo treatment (adapted from Table 2 in Genta, et al. (2009) and reproduced with permission from Elsevier).

* indicates that results are significantly different at $p < 0.05$.

Figure 3: Effect of inulin / artichoke fibre supplementation on bread hardness (adapted from Table 5 in Wang et al. (2002) [a], Table 3 in Peressini & Sensidoni 2009 [b] and Table 5 in Frutos et al. 2008 [c] and reproduced with permission from Elsevier and SAGE Publications). The hardness values have been normalised against those on their respective controls to present the data on the same scale.

Figure 4: High-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) of inulin from Jerusalem artichoke after 30 min of dry heating at a 135 ℃, b 165 ℃, c 180 ℃ and d 195 ℃ (adapted from Bohm, et al. (2005) and reproduced with permission from Springer).

List of Tables:

Table 1: Summary of published results on the impact of FOS supplementation on satiety and body weight.

Table 2: Summary of published results on the impact of inulin or FOS fortification in bread on dough rheology and bread quality as determined instrumentally and sensorally.

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Study	Prebiotic - dose - duration	Parameters measured	Subjects	Impact
Archer et al. (2004)	Inulin / Lupin kernel / full fat (control). Cross-over, 1 dose of each.	- Acceptance - Satiety	33 with BMI ranging 20.5 – 38.7	No impact on satiety
Cani et al. (2006)	FOS / maltodextrin (control) for 2 weeks, daily intake 2 x 8g Cross-over 2 weeks between treatments.	- Diet evaluation -Food frequency questionnaire -Satiety after 2 weeks -Ad libitum lunch after 2 weeks	10 with BMI 18.5 - 27.4 excluded fibres intake > 30g/d	Significant increase in satiety (FOS)
Peters et al. (2009)	FOS / β-glucans / FOS + β-glucans / control equicalorific bar without FOS or β-glucans Cross-over. 2 doses of 8g of FOS in bars.	- Satiety (over 2 days) - Ad libitum lunch	21 with BMI 21.7 - 30.3	No impact on appetite or energy intake
Genta et al. (2009)	Yacon syrup (=FOS) / carboxymethylcellulose (control) 0; 0.14 or 0.29 gFOS/kg body weight for 120 days No cross-over.	- Food diary - Body weight - Waist circumference - Cholesterol - Serum glucose - Serum insulin	35 overweight women	Significant body weight loss, decrease in serum insulin and LDL cholesterol in treatment group
Parnell et al. (2009)	Daily supplement of FOS (21g) for 12 weeks in drinks before meals. Control: equicaloric maltodextrin. No cross-over.	- Food records - Weight - Waist - Blood - Hunger VAS - Ghrelin - Peptide YY	48 overweight/obese with BMI > 25	Significant body weight loss Decreased ghrelin and increased peptide YY Decreased energy intake No difference in hunger
Hess et al. (2011)	0; 5g or 8g FOS added to hot chocolate or snack twice in a day Cross-over.	-Satiety VAS -Breath H_2 -Ad libitum lunch -Food intake for 20 hours after start	20 BMI 18-26 excluded subjects ingesting > 15g fibres daily	No difference in satiety or food intake at lunch

Reference	Collar et al. (2007)	Rosell et al. (2010)	Filipovic et al. (2010)	Poinot et al. (2010)	Meyer & Peters (2009)	Karolini et al. (2007)	Mandala et al. (2009)	O'Brien et al. (2003)	Peressini & Sensidoni (2009)	Korus et al. (2006)*	Mujoo & Ng (2003)	Frutos et al. (2008)	Praznik et al. (2002)	Wang et al. (2002)
Parameter						**Dough**								
water absorption		-			-	-		-/=	-					-
Dough development						+			+					=
Dough stability		=	-		+	+			+					+
Resistance to deformation	=					+/-								+
Elasticity									+					-
Extensibility	=					=/+								=
Stickiness	=													
						Bread								
Loaf volume			=/-		-	-	=/-	=/-	-	+*	-	-	=/+	-
Yield of bread							+			=/+*			+	
Moisture content							=/+		-			+	=/+	-
Hardness - firmness				+			+	+	+	-*	+	+		+
Cohesiveness										-*		-		=
Springiness										-*				=
Chewiness												+		=
Elasticity							+					+		
Colour				+			=		+	+*		+		
						Sensory								
Score cards			=/-							=/-*			=/-	
Consumer acceptance												=/-		

* Compared to gluten free bread

(+): increase in parameter with addition of prebiotic. For colour, (+): darker colour. For dough development and stability: (+) longer times.

(=): no significant difference reported.
(-): decrease in parameter with addition of prebiotic. For water absorption, (-): water absorption decreased with inulin addition.

[1], [2], [3], [5], [6], [7], [9], [11] and [16]: breads made with added inulin.
[10]: inulin added as fat replacer.
[12]: inulin or FOS added in gluten free bread.
[13]: bread made with immature wheat meal rich in fructo-oligosaccharides.
[14] and [15]: breads made with artichoke fibres.

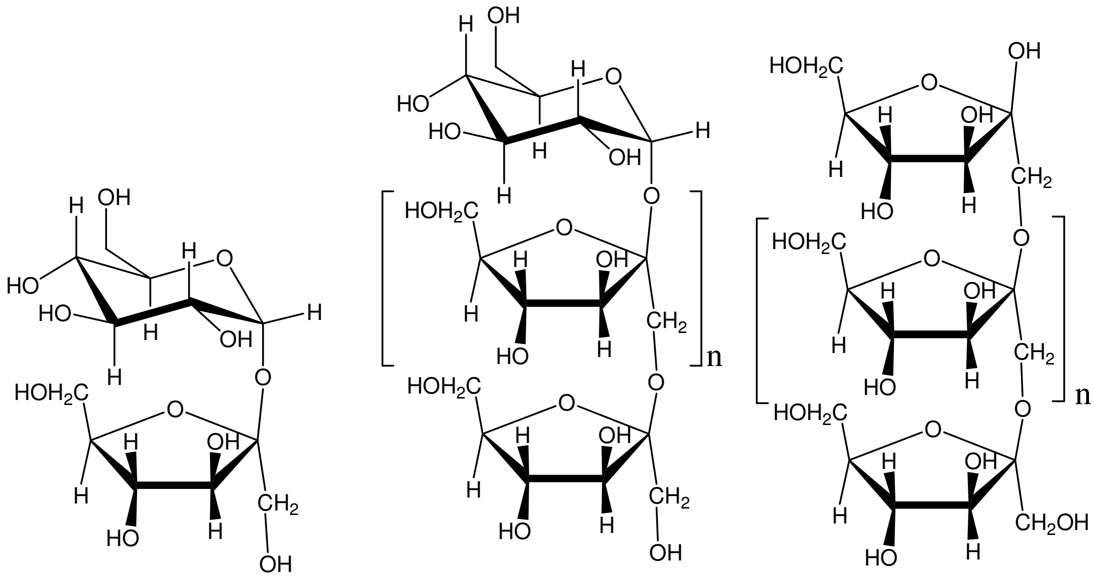

Figure 1: Chemical structures of sucrose (GF) and fructo-oligosaccharides (GFn and Fn). G = glucose; F = fructose. Short chain fructo-oligosaccharides are known as oligo-fructose (n = 1 - 8), while medium-chain fructo-oligosaccharides are known as inulin (n = 10 - 13 on average and ~ 60 - 65 as a maximum). Some of the major fructo-oligosaccharides are kestose (GF2), nystose (GF3), inulobiose (F2), inulotriose (F3), and inulotetraose (F4).

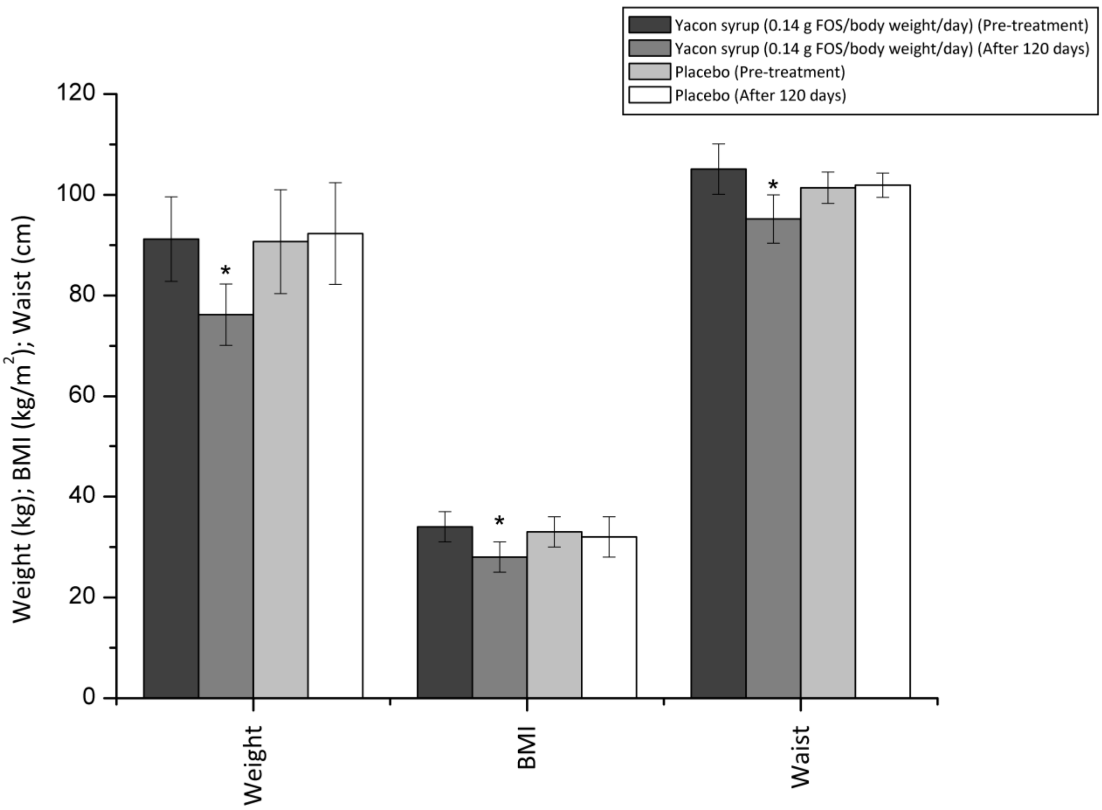

Figure 2: Clinical data of subject before and after 120 days of yacon syrup or placebo treatment (adapted from Table 2 in Genta, et al. (2009) and reproduced with permission from Elsevier).

* indicates that results are significantly different at $p < 0.05$.

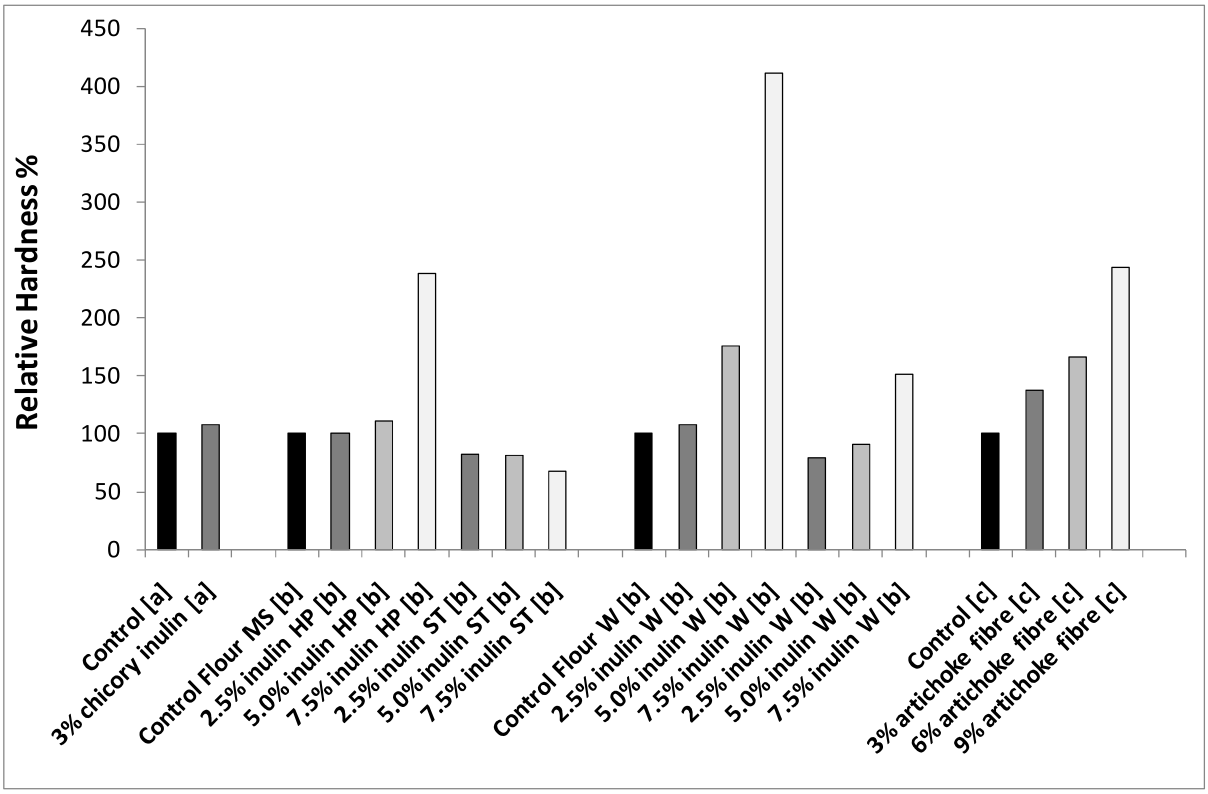

Figure 3: Effect of inulin / artichoke fibre supplementation on bread hardness (adapted from Table 5 in Wang et al. (2002) [a], Table 3 in Peressini & Sensidoni 2009 [b] and Table 5 in Frutos et al. 2008 [c] and reproduced with permission from Elsevier and SAGE Publications). The hardness values have been normalised against those on their respective controls to present the data on the same scale.

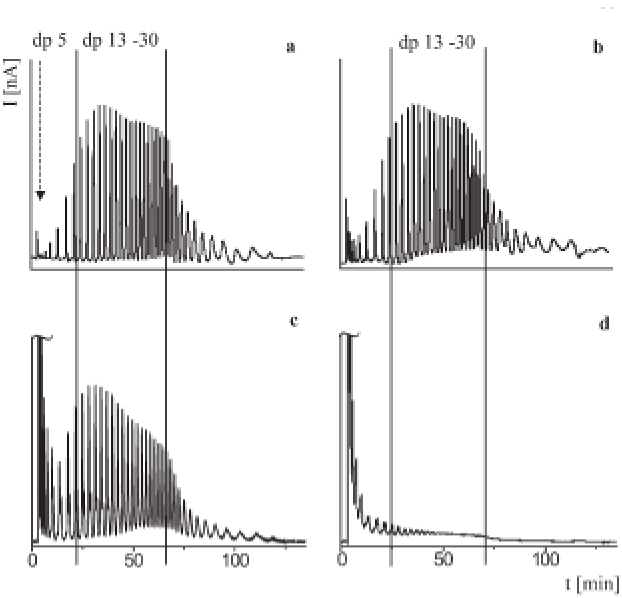

Figure 4: High-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) of inulin from Jerusalem artichoke after 30 min of dry heating at a 135 ℃, b 165 ℃, c 180 ℃ and d 195 ℃ (adapted from Bohm, et al. (2005) and reproduced with permission from Springer).