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Potential of oligosaccharides from inulin in human nutrition and health

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Abstract

Inulins are linear fructan polymers which contain fructose units joined by β-2,1 glycosidic bonds, typically terminating in a glucose residue linked by an α-1,2 bond as in sucrose. The major source of inulin is plants like Jerusalem artichoke and chicory root. Fructo-oligosaccharides consist of a fructose units polymerized to different extent and can be formed *in vitro* from substrate such as inulin. These oligosaccharides can be produced from the enzymatic hydrolysis of inulin by inulinase under controlled reaction conditions. In recent years, the oligosaccharides production has revolve around it's cost effective production from inexpensive and abundantly available raw materials. Inulin is a very promising source for oligosaccharide production. An exoinulinase and invertase activities free endoinulinase is required to acts on inulin because these two enzymes contaminate the final products with release of free sugars, which subsequently require more stringent purification protocols. Oligosaccharides obtained from inulin have similar chemical structures to fructo-oligosaccharides which were obtained by reaction of fructosyltransferase on sucrose. These oligosaccharides are regarded as a soluble dietary fiber, non-cariogenic, of low caloric value and showed strong bifidus-factors. They have proven health benefits which include role in absorption of calcium and minerals, replacement of sugar and fat in food products, reduction in cholesterol and ability to control cancer.

1. Introduction

The name inulin was given after this compound was first isolated from *Inula helenium* (Azis *et al*., 1999). Inulin is the second most abundant storage carbohydrate after starch in plants and many plants have been shown to make inulin as a storage polysaccharide. Inulin is a linear fructan polymer which mainly comprises of β-2, 1-D-fructofuranose linked with a glucose unit at the terminal end. It is a part of dietary fiber and does not get digested by human. Large quantity of inulin is found in plants like Jerusalem artichoke and roots of chicory, asparagus, burdock, yacon, camas and dandelion. Inulin is also present in common plants, vegetables and fruits like garlic, banana, onion, leek, wheat, rye, barley, jicama, salisfy and coneflower (Mensink *et al*., 2015). This fructan is a potential substrate for generation of high fructose syrup and prebiotic inulo-oligosaccharides (IOSs). These value added products can be produced using microbial inulolytic enzymes. Inulin is acted upon by two types of inulinases, *i.e.*, endoinulinase (2,1-β-D-fructanfructanohydrolase, EC 3.2.1.7) and exoinulinase (β-D-fructanfructohydrolase, EC 3.2.1.80). Exoinulinases hydrolyze the terminal linkages of inulin to yield fructose as the main product (Germec and Turhan, 2020) while endoinulinases produce IOSs as the main product (Figure 1). Inulo-oligosaccharides (IOSs) are a novel food additive and health products which represent a promising alternative to antibiotics. IOSs as prebiotics can be obtained by endoinulinase mediated hydrolysis of inulin.

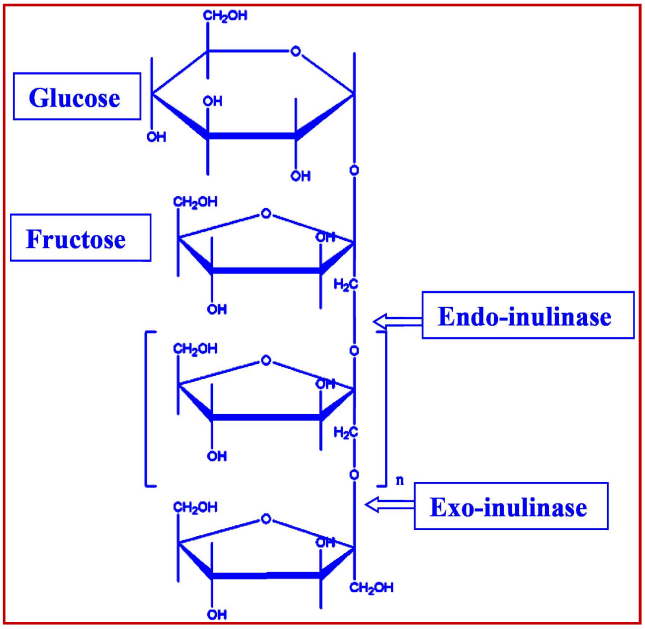

Figure 1: Structure of inulin, a linear fructosyl polymer linked by β-(2,1) bonds (n=3-65) attached to a terminal glucosyl residue by an α-(1,2) bond. The exo-inulinase catalyzes removal of the terminal fructose residues from the non-reducing end of the inulin molecule in one step, producing fructose and glucose. The endoinulinase hydrolyzes inulin to produce IOSs from inulin.

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The fructo-oligosaccharides (FOSs) derived from inulin are referred to as inulo-oligosaccharides but it's chemical structure is similar to fructooligosaccharides. FOSs consist of a fructose units polymerized to different extent. Oligomers with two, three and four fructose units are called as 1-kestose, 1-nystose and 1-fructofuranosyl-nystose, respectively. The sugars are linked by β-2, 1 position of sucrose. FOSs have been designated as prebiotics due to their bifidogenic nature. They also possessed many health-promoting properties when consumed in suggested amounts recommended by health practitioners (Nguyen *et al*., 2011). Majority of health benefits and nutritional applications of these oligosaccharides in human are well recognized. These include the resistance to various infections by activation of the immune system, enhanced calcium absorption in the gastrointestinal tract and provide support in the synthesis of vitamin B-complex (Yun, 1996; Tanriseven and Aslan, 2005).

Probiotics are potentially beneficial bacteria (mainly *Bifidobacterium* and *Lactobacilli*) that commensal to the colon of a person. Prebiotics have the capability to stimulate the multiplication of probiotics by the associated suppression of potentially pathogenic bacteria (Van Laere *et al*., 2000). However, synbiotics nutraceuticals is the combination of prebiotics and probiotics in food and other fermented dairy products such as yogurt, that have the ability to influence and improve the gastrointestinal health of humans (Huebner *et al*., 2007). The main feature of prebiotic food ingredient is that it should not be hydrolysed or absorbed in the upper part of the gastrointestinal tract of a person. Further, it should act as a selective substrate to only few probiotics and have the ability to alter the colonic microflora to potentially more healthy micro-organisms.

The importance of FOSs as food ingredients is due to the various biological properties they possessed (Villegas and Costell, 2007). These oligosaccharides have very low sweetness intensity as they are about one third as sweet as sucrose. This property is useful in the various foods especially for diabetic persons where the use of sucrose is restricted by its high sweetness. FOSs have low calorie levels as it does not get digested by human and are not used as an energy source in the body and due to this thay are safe for consumption by diabetics (Sangeetha *et al*., 2005). The FOSs also encourage the growth of the *Bifidobacterium* and *Lactobacilli* as prebiotics and discourage the growth of potentially harmful micro-organisms that have a tendency to cause diseases. The formation of lactic, acetic and other short-chain organic acids is the possible reasons of the suppression of the growth of harmful bacteria in the gut (Biedrzyka and Bielecka, 2004). These molecules may act as antagonist to the potentially pathogenic intestinal competitors. FOSs are noncariogenic. They are not used by *Streptococcus mutans* to form acids and insoluble β-glucan which are the major factor in the formation of dental caries.

2. Biotechnological production of inulo-oligosaccharide

Prebiotics IOSs can be produced enzymatically from sucrose elongation or *via* enzymatic hydrolysis of inulin by endoinulinases. Inulin is a naturally occurring storage polysaccharide present in numerous plants, such as Jerusalem artichoke and IOSs can be obtained by endoinulinase mediated hydrolysis of it. Inulin and oligofructose have wide applications in various types of foods like confectionery, fruit preparations, milk desserts, yogurt and fresh cheese, baked goods, chocolate, ice cream and sauces (Cabezas *et al*., 2002; Kaur and Gupta, 2002). IOSs are novel food additive and health product and also represent a promising alternative to antibiotics. IOSs as prebiotics can be obtained from inulin by endoinulinase catalyzed hydrolysis. Nonetheless, enzymatic catalysis is not a very feasible option industrially because of the required catalytic conditions and cost. In recent years, researcher's attention has been shifted to use of micro-organisms for conversion of naturally and abundantly available raw materials for the production of oligosaccharides. In this regard, inulin is a promising source for oligosaccharide production when subjected to the action of endoinulinase enzyme of microbial origin. The absences of exoinulinase or invertase activities are prerequisite as presence of these enzymes in micro-organism form undesirable side products. It has been reported that many filamentous fungi and bacterial strains can produce endoinulinase (Chi *et al*., 2009). The chemical structures IOSs obtained from inulin is similar to FOSs from sucrose and they have been used as a soluble dietary fiber. The endoinulinase can be applied to hydrolyze inulin to produce IOSs but Hughes *et al.*, (2017) have observed that a microorganism requires an extracellular inulinase to hydrolyze the glycosidic bonds to release fermentable monosaccharides in order to directly utilize inulin as its carbon and energy source. Some of the microorganisms and their optimum conditions for IOSs production have been summarized in Table 1.

Shukla, (2019) suggested that free inulinase has restricted applications at the industrial level because of its limited functional and storage stability and difficulty in recovery from the reaction mixture. Free enzyme also undergoes irreversible inactivation due to aggregation. Hence, the use of immobilized enzyme has generally been considered as better option for biotransformation reactions. Continuous production of IOSs from pure inulin was achieved by the use of immobilized endoinulinase obtained from *Pseudomonas* sp. The immobilized endoinulinase was found to be quite stable and can work for 15 days at 55°C. This continuous system record oligosaccharide yield of 83% without any loss of initial enzyme activity (Yun *et al*., 1997a). IOSs were also produced from inulin by using a purified commercial endoinulinase with 96% yield of oligosaccharide. The degree of polymerization (DP) of the major oligosaccharides obtained was 3 and 4 (Yun *et al*., 1997b). The endoinulinase gene (inul) of *Pseudomonas* sp. was cloned and expressed in *Escherichia coli* HBlOl and was used to produce IOSs from inulin (78% yield). This recombinant *E. coli* expressing endoinulinase enzyme was immobilized on a polystyrene carrier material. The immobilization of endoinulinase results in enhanced thermal stability of the enzyme. A bioreactor packed with the immobilized cells was used for continuous production of IOSs from inulin. The continuous production of IOSs was successfully achieved with the productivity of 150 g/l/h for 17 d at 50°C (Yun *et al*., 1999).

Batch mode of production of IOSs from inulin was attempted by an endoinulinase obtained from *Xanthomonas* with a yield of about 86%. The major IOSs components in the reaction were of DP 5 and 6 (Park *et al*., 1999). Pure inulin and chicory extract were used to hydrolyze for IOSs production by endoinulinase from *Xanthomonas oryzae* No. 5. DP5 and higher oligosaccharides were found to be major reaction products in case of both chicory extract and pure inulin as the substrates (Cho *et al.*, 2001). Inulotriose with a yield of 70% was obtained as the main product by the action of an endoinullnase P-II produced by *Penicillium* sp. TN-88 (Nakamura *et al*., 1997). Further, this endonuclease does not show any activity toward other sugars like sucrose, raffinose or levan. Mutanda *et al*., (2008) used purified endoinulinase (60 U/ml) from *Aspergillus niger* to hydrolyse inulin (150 mg/ml) at 60°C for 48 h. The major oligosaccharides obtained from inulin were inulotrioses, inulotetraoses and inulopentaoses with yield of 70.3, 38.8 and 3.5 mM, respectively.

Table 1: Some microbial endoinulinases used for IOSs formation from inulin

Source of endoinulinase	Reaction pH	Hydrolysis temperature	Incubation time	Substrate used	DP of formed oligosaccharides	Reference
Recombinant *Pichia pastoris*	6	60	8h	400 g/L Inulin	2-5	He *et al*., 2014
pseudomonas sp.	5.5	55	5h	50 g/L Inulin	2-7	Kim *et al*., 1997
Pseudomonas mucidolens	7.0	50	30h	-	2-5	Kim *et al*., 2006
Recombinant *Bacillus subtilis*	7.4	32	48h	20 g/L Inulin	3-5	Jiang *et al*., 2019
Recombinant *S. cerevisiae*	5	40°C	24	200 g/L chicory	3-6	Wang *et al*., 2016a
Recombinant *E. coli*	4.6	55	24	15 g/L Inulin	3-7	Wang *et al*., 2016b
Recombinant *E. coli*	5	55	24	50 g/L Inulin	3-4	Chen *et al*., 2012
Aspergillus ficuum	5	45	72	50 g/L Inulin	2-8	Jin *et al*., 2005
Chrysosporium pannorum	6-7	50	24	30 g/L Inulin	3-5	Xio *et al*., 1989
Xanthomonas sp.	7	37	22	5 g/L Chicory powder	-	Park and Yun, 2001
Pseudomonas Sp.	6.5	42	22	5 g/L Chicory powder	-	Park and Yun, 2001
Xanthomonas campestris pv. *phaseoli* KM 24	6.0	50	2	5 g/L Inulin	3-5	Naidoo *et al*., 2015
Bacillus safensis AS-08	5.5	50	15min	20 g/L Inulin	-	Singh *et al*., 2013
Aspergillus niger	6.0	60	8h	400 g/L Inulin	3-6	Xu *et al*., 2016
Commercial enzyme (Novozyme 230)	5.0	55	24	50 gm/L Inulin	2-6	Yun *et al*., 1997b

A partially purified and purified endoinulinase from *A. ficuum* were used to produce IOSs from inulin by Jin *et al*., (2005). The 74% of inulin (initial 50 g/l) was hydrolyzed by the partially purified endoinulinase (10 U/g substrate) under the optimal conditions at 45°C and IOSs yield over 50% was observed after 72 h. However, 89% of inulin in the Jerusalem artichoke juice as substrate was hydrolyzed with IOSs production of 80% after 72 h. The difructose anhydride III was produced as main product by inulin fructotransferase enzyme of soil bacterium *Arthrobacter aurescens* SK 8.001. Nystose was found to be the smallest substrate for this enzyme and this inulin fructotransferase provides a promising way to utilize inulin for the production of difructose anhydride III (Zhao *et al*., 2011).

A simple, efficient and one-step bioprocess for IOSs production from inulin through extracellular heterologous endoinulinase by *Bacillus subtilis* was developed by Jiang *et al*., (2019). The gene inuQ of *Pseudomonas mucidolens* encoding endoinulinase was cloned into *Bacillus subtilis* WB800-R, with the simultaneous deletion of gene sacC encoding levanase. The maximal IOSs yield after hydrolysis of the crude extract of inulin was 68 g/l with conversion rate of 75%. The DP of major IOSs obtained was between 3 and 5. The *Saccharomyces cerevisiae* has many applications in food industry and comes under Generally Recognized as Safe category. The endoinulinase gene (inu1) from *Pseudomonas mucidolens* was expressed in the cells of *S. cerevisiae* and was used to hydrolyze inulin for production of IOSs with a yield of 71% under optimized condition after 30 h of reaction (Kim *et al*., 2006). This enzyme was found to be stable towards denaturation and DP of formed IOSs a result of the reaction with inulin mainly consist of 4 (inulopentaoses). An efficient conversion of inulin to IOSs through endoinulinase from *Aspergillus niger* by encoding endoinulinase from *A. niger* DSM 2466 into *Pichia pastoris* KM71 was reported by Xu *et al*. (2016). Maximum activity (858 U/ml) of the recombinant endoinulinase was obtained at 120 h of fermentation. The yield of IOSs was found to be 91.3% and IOSs with different DP (3-6) were distributed in the final reaction mixture.

3. Application of oligosaccharides produced from inulin

The oligosaccgarides obtained from inulin (*i.e.,* IOSs) have a number of desirable features such as low calories, no cariogenicity, safe sweetener for diabetics and promote growth of gut microflora (Figure 2).

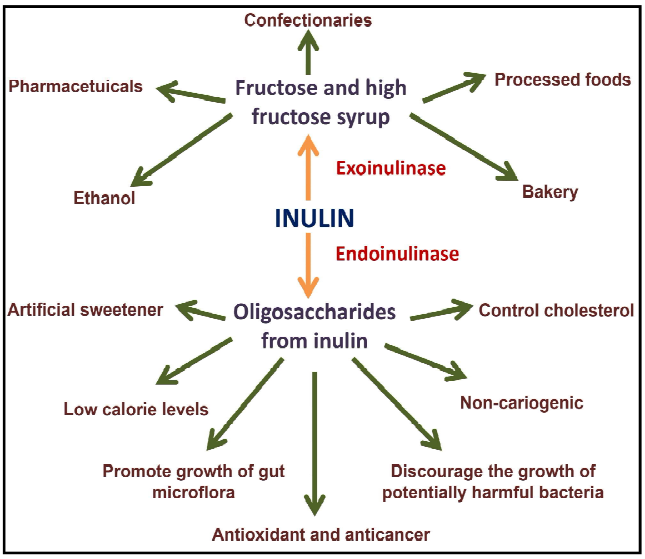

Figure 2: Hydrolysis of inulin by inulinases and major applications of products obtained from inulin.

3.1 Promotion of growth of the gut micro-oranisms

The diet and its composition have major impact on gut and its microflora. Any kind of change in the diet affects the metabolism of the inhabitants. The dietary fibres like oligosaccharides exert a combined effect on both the pH environment of the gut and the metabolism of bacterial community (Flint *et al*., 2007). A study on

Bifidobacterium conducted by (Palframan *et al*., (2003) showed that FOSs are preferred carbohydrates as it allow maximum growth and metabolic activities of this beneficial flora in human intestine. The prebiotics such as inulin, FOSs, sorbitol, and arabinan were found to stimulate the growth of *Bifidobacterium pseudocatenulatum* G4. The fractional factorial and central composite design was found to be very effective tool for optimization of medium for growth of Bifidus. Even isomalto-oligosaccharides were found to stimulate the growth of *Lactobacilli* as major intestinal microflora of rats.

3.2 Potential artificial sweetener for diabetics

Diabetes is one of the major lifestyle associated disorders which and involves malfunctioning of the endocrine system. Diabetes can lead to cardiovascular diseases, renal failure, blindness and even premature death. Apart from many health benefits, FOSs also has artificial sweetness and low caloric as value they are rarely hydrolysed by digestive enzymes. Artificial sweeteners are constantly in demand as person suffering from diabetes and health conscious consumers are major user. Initially this demand was satisfied by aspartame or natural sweeteners palatinose. The popularity of these molecules among common users is major reason for poor exploitation of as artificial sweetener. (Mussatto *et al.*, 2009). Although, all oligosaccharides are exhibiting prebiotic properties but FOSs has gained much attention as artificial sweeteners because they provide sweet taste to the consumer and do not increase the blood glucose level because their unique biological properties that they are remain unutilized in digestive tract. Therefore, they find important place in the food of diabetics and used as artificial sweeteners with functional properties apart from sweetness similar to that of natural sweeteners. Mabel *et al*., (2008) were able to synthesize mono-to pentasaccharides by *Aspergillus oryzae* with the possibility of its application as a food ingredient as no toxic microbial metabolites are formed in the process. The diabetic rats were fed on FOSs in order to see its use as an alternative non-nutrient sweetener without any deleterious effects. FOSs did not increase the sugar level in diabetic animals and were also found to decrease the loss of blood protein (Mabel *et al.*, 2008).

3.3 Other health benefits

The other important physiological roles of FOSs in human beings include the control of osteoporosis and reduction in the levels of serum cholesterol, phospholipids, and triglycerides. Slevin *et al*., (2014) reported that the supplementation of these oligosaccharides along with calcium to post menopausal women shown to improve bone mineral density which help in control of osteoporosis. Pierre *et al*., (1997) have found that supplementation of FOSs may help in protection of colorectal cancer. The protective action of FOSs in the colon might be due to the activity of a short chain fatty acid (butyrate) which has been produced by FOSs in the colon. This butyrate also play role in prevention of tumor growth, cell differentiation and up-regulation of apoptosis. The feeding FOS reported to reduce the development of intestine tumor (Pierre *et al*., 1997). The anti-cancer effect of FOSs is also due to the immuno-modulation in Peyer's patches (Roller *et al*., 2004). The supplementation of *Lactobacillus acidophilus* ATCC 4962 along with the prebiotics was evidently found the remove cholesterol (Liong and Shah, 2005). The first-order, second-order polynomial regression and quadratic models were applied to determine the best combination out of six prebiotics including FOSs in effective removal of cholesterol. The inulo, galacto and fructooligosaccharides were found to be very suitable for growth of *Bifidobacterium* and *Lactobacilli* (Macfarlane *et al*., 2008). Their health benefits include anti-cancer properties, calcium and other mineral absorption, lipid metabolism, anti-inflammatory and immune-modulatory effects.

The antioxidant properties of soy protein isolates and FOSs under different testing conditions were studied and glycation and cross-linking of protein was estimated (Mesa *et al*., 2008). The LDL oxidation and oxygen radical absorbance capacity assays was conducted. It was reported that peptides derived from soy protein scavenged peroxyl radicals and did not protect LDL against copper oxidation. The neoantioxidants formed by thermal degradation of FOSs prevent the LDL oxidation and scavenged peroxylalkyl radicals. Treatment of various infectious diseases or prevention of infection with antibiotics especially penicillin, cephalosporin, and clindamycin are found to be associated with acute diarrhea due to dislodge of normal protective intestinal microflora (Fekety and Shah, 1993). It was observed that the patients taking FOSs were less likely to develop diarrhea during antibiotic treatment. While determining the efficacy of The FOSs-*Lactobacillus sporogenes* preparation was found to be very effective in prevention of diarrhea due to antibiotics treatment in children (La Rosa *et al*., 2003). This fact leads to addition of FOSs in many of commercial products to enhance and promote the therapeutic benefits of the probiotic organisms. The application of FOSs also changes the gut microflora of infants and alters the large bowel function.

4. Conclusion

Oligosaccharides produced from various inexpensive and abundantly available sources have been considered as a boon due to health benefits they encompass. These oligosaccharides have considered in the health market as nutraceuticals due to the variety of health benefits cthey possessed. The microbial production of enzymes which catalyze the oligosaccharides formation are now targeted by the researchers for their optimum production and novel micro-organisms producing potential endoinulinase enzymes are being explored for their capabilities in IOSs production. The scale-up of process from laboratory to production scale is always problematic and challenging. More scale-up studies should be conducted for the development of economically viable bioprocess for production of IOSs at industrial level. The bioprocess improvement should be inculcated using cheaper agro-industrial wastes as substrates for oligosaccharide production. To develop a commercially feasible bioprocess for cost effective production of IOSs, a genetically stable exoinulinase and invertase free endoinulinase hyperproducer is a prerequisite. Moreover, the ability of microorganism to utilize agro-industrial waste and inexpensive protocol for purification of produced oligosaccharides will further strengthen the bioprocess.

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Conflict of interest

The authors declare that there are no conflicts of interest in the course of conducting the research. All the authors had final decision regarding the manuscript and decision to submit the findings for publication.

References

Azis, B.H.; Chin, B.; Deacon, M.P.; Harding, S.E. and Pavlov, G.M. (1999). Size and shape of inulin dimethyl sulphoxide solution. Carbohydrate Polymer, **38**:231-234.

Biedrzyka, E. and Bielecka, M. (2004). Prebiotic effectiveness of fructans of different degrees of polymerization. Trends in Food Science and Technology, **15**:170-175.

Cabezas, M.J.C.; Bravo, R.S. and Shene, C. (2002). Inulin and sugar contents in *Helianthus tuberosus* and *Cichorium intybus* tubers: Effect of postharvest storage temperature. Journal of Food Science, **67**:2860-3865.

Chen, X.M.; Xu, X.M.; Jin, Z.Y. and Chen, H.Q. (2012). Expression of an endoinulinase from *Aspergillus ficuum* JNSP5-06 in *Escherichia coli* and its characterization. Carbohydrate Polymers, **88**:748-753.

Chi, Z.M.; Chi, Z.; Zhang, T.; Liu, G.L. and Yue, L. (2009). Inulinase expressing micro-organisms and applications of inulinases. Applied Microbiology and Biotechnology, **82**:211-220.

Cho, Y.J.; Sinha, J.; Park, J.P. and Yun, J.W. (2001). Production of inulooligosaccharides from chicory extract by endoinulinase from *Xanthomonas oryzae* No. 5. Enzyme and Microbial Technology, **28**:439-445.

Fekety, R. and Shah, A.B. (1993). Diagnosisand treatment of *Clostridium dijicile* colitis. Journal of American Medical Association, **289**:71-75.

Flint, H.J.; Duncan, S.H.; Scott, K.P. and Louis, P. (2007). Interactions and competition within the microbial community of the human colon: Links between diet and health. Environmental Microbiology, **9**:1101-1111.

Germec, M. and Turhan, I. (2020). Enhanced production of *Aspergillus niger* inulinase from sugar beet molasses and its kinetic modeling. Biotechnology Letters, https://doi.org/10.1007/s10529-020-02913-1(0123456789().,-volV() 0123458697().,)

He, M.; Wu, D.; Wu, J. and Chen, J. (2014). Enhanced expression of endoinulinase from *Aspergillus niger* by codon optimization in *Pichia pastoris* and its application in inulooligosaccharide production. Journal of Industrial Microbiology and Biotechnolohy, **41**:105-114.

Huebner, J.; Wehling, R.L. and Hutkins, R.W. (2007). Functional activity of commercial prebiotics. International Dairy Journal, **17**:770-775.

Hughes, S.R.; Qureshi, N.; Lopez Nunez, J.C.; Jones, M.A.; Jarodsky, J.M.; GalindoLeva, L.A. and Lindquist, M.R. (2017). Utilization of inulin-containing waste in industrial fermentations to produce biofuels and bio-based chemicals. World Journal of Microbiology and Biotechnology, **33**:78-92.

Jiang, R.; Qiu, Y.; Huang, W.; Zhang, L.; Xue, F,; Hao Ni, Ho.; Mei, D.; Gao, J. and Xu, H. (2019). One-Step bioprocess of inulin to product inulo-oligosaccharides using *Bacillus subtilis* secreting an extracellular endoinulinase. Applied Biochemistry and Biotechnology, **187**:116-128

Jin, Z.; Wang, J.; Jiang, B. and Xu, X. (2005). Production of inulo-oligosaccharides by endoinulinases from *Aspergillus ficuum*. Food Research International, **38**:301-308.

Kaur, N. and Gupta, A.K. (2002). Applications of inulin and oligofructose in health and nutrition. Journal of Biosciences, **27**:703-714.

Kim, D.H.; Choi, Y.J.; Song, S.K. and Yun, J.W. (1997). Production of inulo-oligosaccharides using endo-inulinase from a *pseudomonas* sp. Biotechnology Letters, **19**:369-371.

Kim, H.C.; Kim, H.J.; Choi, W.B. and Nam, S.W. (2006). Inulooligosaccharide production from inulin by *Saccharomyces cerevisiae* strain displaying cell-surface endoinulinase. Journal of Microbiology and Biotechnology, **16**:360-367.

La Rosa, M.; Bottaro, G.; Gulino, N.; Gambuzza, F.; Di Forti, F., Ini, G. and Tornambe, E. (2003). Prevention of antibiotic-associated diarrhoea with *Lactobacillus sporogenes* and fructo-oligosaccharides in children. A multicenter double-blind *vs.* placebo study. Minerva Pediatrics, **55**:447-452.

Liong, M.T. and Shah, N.P. (2001). Optimization of cholesterol removal, growth and fermentation patterns of *Lactobacillus acidophilus* ATCC4962 in the presence of mannitol, fructo-oligosaccharide and inulin: A response surface methodology approach. Journal of Applied Microbiology, **98**:1115-1126.

Mabel, M.J.; Sangeetha, P.T.; Platel, K.; Srinivasan, K. and Prapulla, S.G. (2008). Physicochemical characterization of fructooligosaccharides and evaluation of their suitability as a potential sweetener for diabetics. Carbohydrate Research, **343**:56-66.

Macfarlane, G.T.; Steed, H. and Macfarlane, S. (2008). Bacterial metabolism and health-related effects of galacto-oligosaccharides and other prebiotics. Journal of Applied Microbiology, **104**:305-344.

Mensink, M.A.; Frijlink, H.W.; van der Voort Maarschalk, K. and Hinrichs, W.L.J. (2015). Inulin, a flexible oligosaccharide I: review of its physicochemical characteristics. Carbohydrate Polymer, **130**:405-419.

Mesa, M.D.; Silvan, J.M.; Olza, J.; Gil, A. and del Castillo, M.D. (2008). Antioxidant properties of soy protein–fructo-oligosaccharide glycation systems and its hydrolyzates. Food Research International, **41**:606-615.

Mussatto, S.I.; Aguilar, C.N.; Rodrigues, L.R. and Teixeira, J.A. (2009). Fructo-oligosaccharides and β-fructofuranosidase production by *Aspergillus japonicus* immobilized on lignocellulosic materials. Journal of Molecular Catalysis B Enzyme, **59**:76-81.

Mutanda, T.; Wilhelmi, B.S. and Whiteley, C.G. (2008). Response surface methodology: Synthesis of inulooligosaccharides with an endoinulinase from *Aspergillus niger*. Enzyme Microbial Technology, **43**:362-368.

Naidoo, K.; Kumar, A.; Vikas Sharma, S.; Permaul, K. And Singh, S. (2015). Purification and Characterization of an Endoinulinase from *Xanthomonas campestris* pv. *phaseoli* KM 24 Mutant. Food Technology and Biotechnology, **53**:146-153.

Nakamura, T.; Shitara, A.; Matsuda, S.; Matsuo, T.; Suiko, M. and Ohta, K. (1997). Production, purification and properties of an endoinulinase of *Penicillium* sp. TN-88 that liberates inulotriose. Journal of Fermentation and Bioengineering, **84**:313-318.

Nguyen, Q.D.; Rezessy-Szabo, J.M.; Czukor, B. and Hoschke, A. (2011). Continuous production of oligofructose syrup from Jerusalem artichoke juice by immobilized endo-inulinase. Process Biochemistry, **46**:298-303.

Palframan, R.; Gibson, G.R. and Rastall, R.A. (2003). Effect of pH and dose on the growth of gut bacteria on prebiotic carbohydrates *in vitro*. Anaerobe, **8**:287-292.

Park, J.P. and Yun, J.W. (2001). Utilization of chicory roots for microbial endoinulinase production. Letters in Applied Microbiology, **33**:183-187.

Park, J.P.; Bae, J.T.; You, D.J.; Kim, B.W. and Yun, J.W. (1999). Production of inulo-oligosaccharides from inulin by a novel endoinulinase from *Xanthomonas* sp. Biotechnology Letters, **21**:1043-1046.

Pierre, F.; Perrin, P.; Champ, M.; Bornet, F.; Meflah, K. and Menanteau, J. (1997). Short-chain fructo-oligosaccharides reduce the occurrence of colon tumors and develop gut-associated lymphoid tissue in Min mice. Cancer Research, **57**:225-228.

Roller, M.; Rechkemmer, G. and Watzl, B. (2004). Prebiotic inulin enriched with oligofructose in combination with the probiotics *Lactobacillus rhamnosus* and *Bifidobacterium lactis* modulates intestinal immune functions in rats. Journal of Nutrition, **134**:153-156.

Sangeetha, P.T.; Ramesh, M.N. and Prapulla, S.G. (2005). Recent trends in the production, analysis and application of Fructo-oligosaccharides. Trends in Food Science and Technology, **16**:442-457.

Shukla, P. (2019). Synthetic biology perspectives of microbial enzymes and their innovative applications. Indian Journal of Microbiology, **59**:401-409.

Singh, R.S.; Singh, R.P. and Yadav, M. (2013). Molecular and biochemical characterization of a new endoinulinase producing bacterial strain of *Bacillus safensis* AS-08. Biologia, **68**:1028-1033.

Slevin, M.M.; Allsopp, P.J.; Magee, P.J.; Bonham, M.P.; Naughton, V.R.; Strain, J.J.; Duffy, M.E.; Wallace, J.M. and Mac Sorley, E.M. (2014). Supplementation with calcium and short-chain fructo-oligosaccharides affects markers of bone turnover but not bone mineral density in postmenopausal women. Journal of Nutrition, **144**:297-304.

Tanriseven, A. and Aslan, Y. (2005). Immobilization of Pectinex Ultra SP-L to produce fructo-oligosaccharides. Enzyme and Microbial Technology, **36**:550-554.

Van Laere, K.M.J.; Abee. T.; Schools, H.A.; Beldman, G. and Voragen, A.G.J. (2000). Characterization of a novel β-galactosidase from *Bifidobacterium adolescentis* DSM 20083 active towards transgalacto-oligosaccharides. Applied and Environmental Microbiology, **66**:1379-1384.

Villegas, B. and Costell, E. (2007). Flow behaviour of inulin-milk beverages. Influence of inulin average chain length and of milk fat content. International Dairy Journal, **17**:776-781.

Wang, D.; Li, F.L. and Wang, S.A. (2016a). A one-step bioprocess for production of high-content fructooligosaccharides from inulin by yeast. Carbohydrate Polymers, **151**:1220-1226.

Wang, P.P.; Ma, J.F.; Zhang, Y.; Zhang, M.; Wu, M.K.; Dai, Z.X. and Jiang, M. (2016b). Efficient secretory overexpression of endoinulinase in *Escherichia coli* and the production of inulo-oligosaccharides. Applied Biochemistry and Biotechnology, **179**:880-894.

Xiao, R.; Tanida, M. and Takao, S. (1989). Purification and some properties of endoinulinase from *Chrysosporium pannorum*. Journal of Fermentation and Bioengineering, **67**:244-248.

Xu, Y.; Zheng, Z.; Xu,Q.; Yong, Q. and Quyang, J. (2016). Efficient Conversion of inulin to inulo-oligosaccharides through endoinulinase from *Aspergillus niger*. Journal of Agricultural and Food Chemistry, **64**:2612-2618.

Yun, J.W. (1996). Fructooligosaccharides occurrence, preparation, and application. Enzyme and Microbial Technology, **19**:107-117.

Yun, J.W.; Choi, Y.J.; Song, C.H. and Song, S.K. (1999). Microbial production of inulo-oligosaccharides by an endoinulinase from *Pseudomonas* sp. expressed in *Escherichia coli*. Journal of Bioscience and Bioengineering, **81**:291-295.

Yun, J.W.; Kim, D.H.; Kim, B.W. and Song, S.K. (1997a). Production of inulo-oligosaccharides from inulin by immobilized endoinulinase from *Pseudomonas* sp. Journal of Fermentation and Bioengineering, **84**:369-371.

Yun, J.W.; Kim, D.H.; Uhm, T.B. and Song, S.K. (1997b). Production of high content inulooligosaccharides from inulin by a purified endoinulinase. Biotechnology Letters, **19**:935-938.

Zhao, M.; Mu, W.; Jiang, B.; Zhou, L.; Zhang, T.; Lu, Z.; Jin, Z. and Yang, R. (2011). Purification and characterization of inulin fructotransferase (DFA IIIforming) from *Arthrobacter aurescens* SK 8.001. Bioresource Technology, **102**:1757-1764.

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