Possible actions of inulin as prebiotic polysaccharide: A review

Tadesse F. Teferra

School of Nutrition Food Science and Technology, College of Agriculture, Hawassa University, Ethiopia

Correspondence
Tadesse F. Teferra, School of Nutrition Food Science and Technology, College of Agriculture, Hawassa University, Ethiopia.
Email: tadessefikre@gmail.com

Abstract
This review summarizes the nature, types, and properties of inulin polysaccharides and their applications as prebiotic dietary fibers. Natural food and commercial plant sources of inulin and extraction methods are presented. The physicochemical and functional properties of inulin are summarized. The prebiotic roles of inulin and their mechanisms of action are detailed. Inulin acts as prebiotic dietary fiber with multiple putative health benefits. It reduces caloric intake and contributes to reduced blood glucose and plasma lipid/cholesterol levels when used as sugar and fat replacers. It also stimulates immune systems and protects the colon mucosa against carcinogenesis and inflammation. Inulin also alters the composition and population of the gut microbiota. It stimulates the growth and activities of health beneficial microorganisms while inhibiting enteropathogenic bacteria. The beneficial microorganisms ferment inulin and produces acids including short-chain fatty acids that lower the pH in the colon and inhibit pathogens. The health beneficial bacteria also produce other metabolites that positively influence human health. The consumption of inulin is however, associated to symptoms of gastrointestinal discomfort, when consumed at higher levels to meet the daily recommendation of dietary fiber. Potential solutions to the limitations are forwarded as future research ideas and policy inputs.

Keywords
bifidobacteria, dietary fiber, fat replacer, fructans, inulin, prebiotics, sugar replacer

1 | INTRODUCTION

1.1 | What is inulin?

Inulin is a naturally occurring polysaccharide as a storage carbohydrate in tens of thousands of plants. Unlike starch, which is the most abundant storage polymer of glucose, inulin has mainly fructose as monomeric units and a glucose endpoint. Inulin is found in more than 30,000 plants and the main commercial sources are tubers of Jerusalem artichoke (Helianthus tuberosus) and dahlia (Dahlia pinnata) as well as roots of chicory (Cichorium intybus) and yacon (Polymnia sonchifolia) (Apolinário et al., 2014; Wichienchot et al., 2011) (Figure 1a, b, c, and d, respectively). In plants, inulin naturally exists as a mixture of oligo- and polysaccharides of fructose ranging from 2 to 100 units depending on plant species, age and extraction techniques (Barclay et al., 2010).
1.1.1 History

Inulin was discovered by Valentine Rose (German Scientist) in the 1800s as a plant carbohydrate from the roots of *Inula helenium* and named in 1817 (Apolinário et al., 2014). Rose found this peculiar polysaccharide as a water-soluble extract and was able to isolate it from plant sources using boiling water. Later in 1864, a German plant physiologist and a pioneer researcher in fructans, Julius Sachs, showed the spherocrystalline structure of inulin from different plant roots. Inulin has a long history of being used as a sweetener for diabetic patients (Saeed et al., 2015).

1.1.2 Chemical and physical characters

Inulin belongs to the fructan carbohydrate group (fructose-based polymers) and is composed mainly of β-D-fructosyl subgroups linked by (2→1) glycosidic bonds and the molecule usually ends with a (1→2) bonded α-D-glucosyl group (Beneke et al., 2009) (Figure 2). The length of the fructose chains varies and usually ranges for inulin between 2 and 60 monomers, but can reach 100. The fructans are often represented by the general formula GFn, where G represents the units of glucose, F represents fructose units, and n refers to the number of fructose linked together to form the entire carbohydrate chain (Lopes et al., 2015).

Inulin with the glucose end have no aldehyde or ketone (carbonyl group) and hence does not have any reactive or reducing terminal, which makes it fairly stable. However, inulin usually represents mixtures of different forms of fructose polymers and it is inevitable that fructans with no glucose ends exist including mono- and disaccharides, which can take part in many reactions including the Maillard type browning (Mensink et al., 2015). Inulin is completely hydrolyzed into the monomeric units at acidic pH (< 3) and high temperature (90–100°C) in a matter of 30–40 minutes (Matusek et al., 2009). In the pH ranges relevant to food application, however, there was no degradation at a temperature as high as 100°C for extended time (55 minutes) (Glibowski & Bukowska, 2011), which suggests that inulin can be used as ingredient in many food systems and still remain stable under severe processing conditions.
The physicochemical and functional properties of inulin are linked to degree of polymerization (DP) as well as the presence of branching in the structure. The short-chain inulin fraction, (oligofructose [OF], DP < 10), is much more soluble and sweeter than native and long-chain inulin, and can contribute to improved mouthfeel as its properties are closely related to those of other sugars (Apolinário et al., 2014). The degree of sweetness of low-DP inulin groups is comparable to fructose. Inulin with higher DP is used as a fiber-type prebiotic with numerous putative health promoting effects (Van Laere & Van den Ende, 2002).

The crystalline structure of inulin has a fivefold helical structure and can be produced in two differently shaped morphologies: obloid and needle-like, by varying the cooling temperature of inulin from solutions (Mensink et al., 2015). The needle-like crystals increase viscosity, while the obloid ones improve lubricity (mouthfeel) of foods.

Similar to many other polymers, the solubility of inulin is dependent on DP. The solubility of inulin decreases with increase in DP. Solubility was also reported to increase with temperature (Wada et al., 2005). Wada et al. (2005) also demonstrated that enzymatically synthesized inulin (from sucrose) with higher DP (16–18 units) had higher solubility than native counterpart.

Inulin exists in different favored conformations in solutions depending on various factors. Helical conformation was reported to be favored for lower DP inulin (DP ≤ 5) (Andrew et al., 1994; Oka et al., 1992). The stability of zigzag and many other conformations were also reported by Vereyen et al. (2003), implying the flexibility of inulin as ingredient in foods where the favored conformational arrangement of the ingredients plays roles in stability or specific properties of the system.

1.1.3 | Types of fructans

The term "inulin-type fructan" refers to all β-(2–1) linked linear fructose polymers (Figure 2) including native inulin (DP 2–60, MDP = 12), oligofructose (OF) (DP 2–8, MDP = 4), and inulin HP (high performance [DP 10–60, MDP = 25]) as well as Synergy 1, a specific combination of OF and inulin HP (Roberfroid, 2007). The different subcategories of inulin-type fructans, varying in their DP, are appealing for different applications in the food industry. Detail of the application of inulin in the food industry will be given in this review.

The other major group of fructose polymers are called "levan-type fructans," which are characterized by their β-(2-6)-linked fructose residues (Figure 3). Levans are also called phleins in plants and are found in abundance in the grass families (Ritsema & Smeekens, 2003). They play closely similar roles as inulin-type fructans, although they have not been as extensively studied. Dahech et al. (2011) showed the antidiabetic, hypocholesterolemic and antitumorigenic activities of levans in animal models. Other studies reported that levan-type fructans can be used as food ingredients for different functional purposes such as color and fragrance carrier as well as fat replacers (De Vuyst et al., 2001; Han, 1990; Song et al., 2000; Van Geel-Schutten, 2006; Zannini et al., 2015). For the interest of this review, however, discussions are limited to the inulin groups as prebiotic agents in human health.

1.1.4 | Sources and extraction

The levels of inulin in human diets vary depending on geography and diet differences. The western diet is reported to provide a range of values (1–10 g/day), where the range for the US population was indicated to be lower (between 1.3 and 3.5) compared to European diet (3–11 g/day) (Bonnema et al., 2010). Commonly consumed plant-based foods such as onion, leek, garlic, banana, wheat, rye, and barley provide appreciable quantities of inulin in human diets (Mensink et al., 2015). The major plant sources, tubers of dahlia and Jerusalem artichoke, as well as roots of chicory and yacon (Figure 1), have fairly higher contents (Lachman et al., 2003; Zhu et al., 2016) (Table 1), for they use inulin as energy reserve and are used for commercial extractions. Many commonly consumed vegetables and fruits as well as cereals have varying levels and types of inulin. From the data summarized in Table 1, it can be noted that, if consumed frequently in adequate amounts fresh fruits like banana (Judprasong et al., 2011; Loo et al., 1995) and vegetables like asparagus and leek (Loo et al., 1995), as well as cereals like wheat barley and rye (Loo et al., 1995), can greatly contribute to the daily dietary fiber and prebiotic requirements for humans. Spice-vegetables like garlic and onion are also important contributors, although, their amount included in foods is limited.

The conventional extraction of inulin is done almost exclusively from chicory roots due to its suitability and desired DP of the extract (Zhu et al., 2016). The production of inulin is achieved in three major steps extraction, purification and drying (Figure 4). The extraction process begins with cleaning and size reduction operations. After size reduction (slicing or pulping) diffusion of the granules will follow, which is achieved by heating to 80–90°C for 90 minutes. The purification process involves liming, carbonation, filtration, demineralization, and decolorization. The purified slurry is then gently evaporated and finally spray-dried.

1.2 | Food applications

Inulin is used as ingredient in foods for many purposes. The main applications are for texture modification, prebiotic action, sugar replacement and/or bulking agent for intense sweeteners, fat replacement, and dietary fiber roles (Saeed et al., 2015; Wang, 2009). The low-molecular weight inulins such as fructooligosaccharides (FOS) or OF
### TABLE 1  Inulin content of different plant sources including common vegetables, spices, and cereals

| Plant source                  | Plant part | Inulin (% FW) | Literatures          |
|-------------------------------|------------|---------------|----------------------|
| Delpha (Dahlia pinnata)       | Tuber      | 10–12         | Zhu et al. (2016)    |
| Jerusalem artichoke (Helianthus tuberosus) | Tuber | 14–18 |                      |
| Chicory (Cichorium intybus)   | Root       | 14.9–18.3     |                      |
| Yacon (Polymnia sonchifolia)  | Root       | 13.1–13.9     | Lachman et al. (2003) |
| Asparagus (fresh) (Asparagus officinalis) | Stems | 2.0–3.0 | Loo et al. (1995) |
| Leek (Allium ampeloprasum)    | Bulb       | 3.0–10.0      |                      |
| Banana (ripe) (Musa acuminata) | Fruit | 0.58–1.09  | Loo et al. (1995), Judprasong et al. (2011) |
| Garlic (A. sativum)           | Cloves     | 16.6–24.9     |                      |
| Onion (red) (A. cepa)         | Bulb       | 3.09–4.96     |                      |
| Wheat (Triticum aestivum)     | seed       | 1.0–4.0       | Loo et al. (1995)    |
| Barley (Hordeum vulgare)      | Seed       | 0.50–1.50     |                      |
| Rye (Secale cereale)          | Seed       | 0.50–1.0      |                      |

FW = fresh weight.

---

**FIGURE 4** Flow diagram for conventional Inulin production from chicory roots, reconstructed based on information from Zhu et al. (2016) (permission, 5076721373821, Elsevier)

(DP 2–8) are known to have excellent solubility and possess as good sweetness as glucose or 35%–55% as sweet as sucrose (Saeed et al., 2015). These properties make the lower molecular weight inulin, ideal sugar replacers for diabetic patients, or bulking agents for intense sweeteners.

The higher molecular weight inulin, specifically the inulin HP (PD > 10), are known for their limited solubility and no taste (no sweetness). They impart smooth mouthfeel and this makes them important fat replacers (Saeed et al., 2015; Wang, 2009). Inulin HP cut caloric intake and serve as prebiotic and dietary fiber when used in foods and are believed to greatly contribute to improved human health. Their importance as prebiotics for direct actions on immune stimulation, antitumorigenic property, and improvement in nutrient (minerals) absorption as well as their indirect action via alteration of the gut microbiota has gained greater attention over the last decades (more on this later).

## 2 PREBIOTIC ROLES OF INULIN

### 2.1 What are prebiotics?

The term prebiotics has been defined for the first time in 1995 by (Gibson & Roberfroid, 1995). There have, however, been inconsistencies in
the definitions of prebiotics over the years. The basic concept that prebiotics being indigestible components of foods that selectively stimulates the growth and activities of health beneficial groups of gut microbiota such as *Bifidobacterium* and *Lactobacillus* among others 16, 23, 35, 36, 48 remained the backbone of all definitions used in literatures. In August 2017, experts’ consensus statement on the definition of prebiotics was released by the International Scientific Association for Probiotics and Prebiotics (ISAPP) and now a prebiotic is defined as “a substrate that is selectively utilized by host microorganisms conferring a health benefit” (Gibson et al., 2017).

Prebiotics are characterized to have three defining criteria (Gibson et al., 2004): (i) indigestibility—resistance to gastric acidity, enzymes, and absorption; (ii) fermentation by health promoting intestinal microflora, and (iii) selective stimulation of the growth and activities of groups of bacteria associated with improved health and well-being of humans or animals. Inulin-type fructans are resistant to digestion by human enzymes and are selectively fermented in the colon by health beneficial microbes. They therefore increase the diversity and population of the health promoting bacteria, while inhibiting pathogenic groups (Roberfroid, 2007; Wichienchot et al., 2011).

Inulin was also reported to have antioxidant activities and exert protective action against oxidative damages to digestive organs. Pasqualetti et al. (2014) demonstrated that inulin’s protective action against lipopolysaccharide (LPS)-induced oxidative damage to the human colon mucosa regardless of cooking and digestion treatments, showing greater stability, which adds to their prebiotic properties.

### 2.2 Mechanisms of action: direct and indirect impacts

The mechanisms by which inulin and other prebiotics benefit host has been studied for over three decades now and is still on going. For the purpose of this review, the mechanisms of inulin action on host health are classified into direct and indirect types. The direct actions are those immediate effects of the consumption of the prebiotic inulin on the health of the host. One of the ways inulin plays health beneficial roles on humans’ body is by reducing caloric intake when used as fat and sugar replacers (Franck, 2002). Inulin is also known for its antioxidant activity (Pasqualetti et al., 2014) and anti-inflammatory (protective) effects (Femia et al., 2002). Inulin also plays roles in reducing plasma lipid and cholesterol levels. All these are immediate and direct impacta of inulin consumption.

The effect of inulin on the population and diversity of colon bacteria is considered slow and indirect action, which is by far the most studied area. The general understanding so far is that inulin and other prebiotic dietary fibers selectively stimulate the growth of the health beneficial groups of colon microorganisms in the expense of the harmful ones. The major health beneficial bacterial groups (with examples) of great interest to human health includes (Gibson & Roberfroid, 1995; Ramirez-Farias et al., 2021):

- Lactobacilli (*Lactobacillus acidophilus, L. casei, L. delbruekii*)
- Bifidobacteria (*Bifidobacterium bifidum, B. adolescentis, B. longum, B. infantis*)
- Streptococci (*Streptococcus salivarius* subspecies thermophilus, *S. lactis*)

The consumption of inulin was reported to alter the proportion of the different groups of bacteria in human colon (Figure 5). Supplementation of prebiotics (fructooligosaccharides) was shown to increase the proportion of bifidobacteria by 3.67 times and decreased the percentage of harmful bacteria (bacteroides, clostridia, and frusobacteria) by 5–10 times.

The mechanisms by which health beneficial bacterial groups such as *Bifidobacterium* and *Lactobacillus* potentially promote the health and well-being of the host are many and the major ones are summarized in Table 2. It is believed that the microorganisms produce acids including short-chain fatty acids (SCFA) that lower the pH of the colon, which inhibits the growth and activities of the harmful bacterial groups (Reddy, 1999). Butyrate is preferentially used by the colonocytes as energy source, which helps them fight inflammation and carcinogenesis. Similarly, propionates are also known to interfere and inhibit cholesterol production by liver of the host (Slavin, 2013), which helps cut the plasma cholesterol level and reduces chances of cardiovascular disease (CVD) complications. The health beneficial groups of microbes have also been shown to produce different peptides and proteins that are directly toxic to the pathogenic groups. Saulnier et al. (2009) reported that lactic acid bacterial groups produce components such as lantibiotics (class I), bactriocins (class II), bacteriolysins (class III), that directly inhibit the growth of enteropathogens including *Escherichia coli*. It was also indicated that *L. reuterii* secretes reuterin, another effective toxicant against the pathogenic groups. This is evident that the health beneficial microbes may produce many more toxic substances that inhibit growth of the pathogenic groups. More recent publications also confirm the indirect prebiotic actions of inulin against inflammatory bowel diseases (Akram et al., 2019) and gastrointestinal disorders (Guarino et al., 2020). There are more recent reports on the nutritional and therapeutic roles of inulin (Ahmed & Rashid, 2019; Wan et al., 2020).

### 2.3 Inulin intolerance

Basically, inulin is safe for consumption and there is no reported toxicity either in animals or humans. However, ingestion of inulin at higher levels (20–30 g/day to attain the recommended daily dietary fiber recommendations) was reported to cause gastrointestinal (GI) intolerance (Carabin & Gary Flamm, 1999). Studies also showed that increased flatulence and bloating were experienced by human subjects in different studies. In a study conducted to see the effect of inulin on the blood lipid level (Pedersen et al., 1997), daily intake of 14 g inulin caused various GI symptoms and could not result in targeted hypolipidemia. In a similar study, 18 g/day inulin incorporated to low-fat diet was fed to human subjects and was reported to cause increased flatulence, abdominal cramping, and bloating compared to a control diet.
Similar observations were documented in studies involving supplementation of inulin levels of 10 g/day or more. Other studies indicated that consumption of 10–15 g/day of inulin was tolerable in humans (Bonnema et al., 2010; Ripoll et al., 2010), with great individual variations.

For optimal health benefits, it seems evident that as much native inulin as can be tolerated by individuals together with frequent consumption of adequate levels of foods rich in inulin may be advisable. Systematic delivery of the tolerable levels of inulin as supplementation or fortification should be practiced with recommendation of frequent consumption of foods rich in inulin. Promoting frequent consumption of the good inulin sources such as garlic, onions, asparagus, leeks, bananas, artichokes, and chicory root should be integral part of the health and nutrition plan for communities with low dietary fiber intake like the US population. Research may be required if combining the supplementation and/or fortification of the 15 g/day and having the dietary sources can help avoid the intolerance. Frequent consumption of other soluble dietary fibers of similar functions on human health with no or minimal GI discomforts need to be researched.

Another possibility of having optimal health benefits, which may need to be investigated, is the possibility of in vitro fermentation of inulin by cocktail of the health beneficial groups of bacteria and supplying them (entire broth: metabolites and bacterial cells) with different foods. This requires intensive investigation in terms of suitable carrier foods, safety, and the ability of those target organisms and their metabolites passing through the extreme conditions of the upper GI sections with minimal degradation. Propagation of the microbial cells using inulin as substrate and administering them (probiotic form) in encapsulated forms may also be looked into as an alternative delivery mechanism.

### 3.1 | Brief summary

Inulin is a naturally occurring polysaccharide derived from plants, which makes it a safe and label friendly food ingredient. The process of extracting and purifying inulin from natural sources is apparently easy, clean, and also cheap. Inulin was found to be very stable to various extreme conditions (temperature and pH) and enzyme actions that give it versatility for use in wider range of food, nutraceutical, and pharmaceutical products.

The use of inulin as prebiotic fiber and its associated benefits have been documented (previous sections of this review). The drawbacks and proposed resolutions are briefly. Due to its resistance to digestive enzymes, stability to low stomach and high intestinal pH, as well as due to its exclusion from absorption in the lower GI, inulin consumption directly contributes to lower caloric intake and blood glucose level. Consumption of inulin is associated to other positive health benefits. Inulin is also protective against carcinogenesis of the colon and breast cells. It was also well established that inulin has immune stimulating effect and its consumption is associated to better resistance to different forms of diarrhea. Inulin consumption is also related to improved mineral absorption.

The main and probably the most important prebiotic action of inulin is its ability to selectively stimulate the growth of health beneficial bacteria in the expense of pathogenic groups, which is considered indirect impact in this review. This means that inulin completely alters the diversity and population of gut microbiota within few weeks of consumption (5 g/serving, 3 times a day). The health beneficial bacteria ferment inulin and convert it into lactic and acetic acids. Production of lactic acid is associated with a range of health benefits, including improved gut function, immune system enhancement, and reduced inflammation. Inulin has been shown to promote the growth of beneficial bacteria such as Bifidobacterium and stimulate production of short-chain fatty acids, which are important for gut health.

![Figure 5: Change in the microbial population proportions after prebiotic supplementation for 2 weeks (3 × 5 g/day) of inulin, data extracted from Gibson and Roberfroid (1995) with permission (5076740476767, Oxford University Press)](image-url)

**Figure 5** Change in the microbial population proportions after prebiotic supplementation for 2 weeks (3 × 5 g/day) of inulin, data extracted from Gibson and Roberfroid (1995) with permission (5076740476767, Oxford University Press)
TABLE 2  Direct and indirect mechanisms of prebiotic action on host health and well-being

| Categories | Mechanisms | Literatures |
|------------|------------|-------------|
| Direct     | Reduced caloric intake—weight control: inulin is not digestible by human enzymes and also not absorbed in the small intestine, hence does not contribute to caloric intake | Al-Sheraji et al. (2013), Mensink et al. (2015), Morris and Morris (2012), Saeed et al. (2015) |
|            | Stimulating the immune system against infections causing diarrhea (travelers’ diarrhea, acute diarrhea, and antibiotic associated diarrhea) | Al-Sheraji et al. (2013), Barclay et al. (2010), Charalampopoulos and Rastall (2012) |
|            | Better nutrient (mineral absorption) by human body and modulating the plasma lipid levels | Al-Sheraji et al. (2013) |
|            | Antioxidant and anti-inflammatory effects of inulin protecting the colon tissues against carcinogenesis | Femina et al. (2002) and Pasqualetti et al. (2014) |
| Indirect   | Selective stimulation of the growth and action of health beneficial colon microorganisms, while inhibiting the pathogenic groups | Gibson and Roberfroid (1995), Ramirez-Farias et al. (2021), Salazar et al. (2015), Tremaroli and Bäckhed (2012) |
|            | The health beneficial microbes produce SCFA that inhibits tumorigenesis of the colon and breast cells; mechanism: production of surface proteins that coats and protects the colon mucosa against attack by pathogens or their toxic excreta | Barclay et al. (2010), Reddy (1999), Saulnier et al. (2009), Wollowski et al. (2001) |
|            | Lactic and acetic acids as well as SCFA produced by the health beneficial bacteria lowers the pH of and this inhibits the growth of putative enteropathogenic bacteria, leads to reduced carcinogenesis | Reddy (1999), Saulnier et al. (2009) |
|            | Production of direct antimicrobial proteins or peptides by beneficial groups (e.g., by lactic acid bacteria [LAB]: lantibiotics, bacteriocins, bacteriolysins, reuterin), that directly inhibits the pathogens | Saulnier et al. (2009) |
|            | The metabolites of inulin after fermentation by the gut microbes, have positive impact on host (e.g., propionates inhibit cholesterol production by liver) | Slavin (2013) |

of SCFA as metabolites is also common. Extensive production of the acids results in inhibition of the pathogens by lowering the colon pH. The health beneficial bacterial groups (bifidobacteria and lactobacilli) also produce peptides and proteins that have inhibitory effects on the pathogens.

High stability to extremes of conditions and physical properties such as sweetness of low DP makes inulin a good sugar replacer or a competitive bulking agent for high-intensity sweeteners. The smooth mouthfeel imparted to food matrices also makes inulin a natural and healthy alternative additive as fat replacer. Moreover, high DP inulins such as inulin HP categories do not have flavor and their addition to foods does not affect the sensorial taste desirability. Inulin solubility depends on the DP and can be used as additive (as functional or nutraceutical) in foods to a desired consistency.

The major limitation of inulin application in foods causes GI symptoms including flatulence, bloating, nausea, abdominal cramping, and other complications to various degree in humans at higher doses. This limits the prebiotic application of inulin to only 10–15 g/day, which is half way below the recommended daily allowance (RDA) for dietary fibers. However, it can be assumed that, if 100 g of the other food sources (vegetables, fruits, cereals, and spices) (Table 1) can be consumed per day (separately or in combination), the remaining 50% can easily be attained. This could lead to the realization of the RDA levels of dietary fiber by the community. But this may still cause the GI
discomfort and the possible remedies will be discussed in the next subsection.

3.2 Future research focuses

It is known that inulin is important for human health as a prebiotic dietary fiber. There are, however, many aspects of its optimal applications for human benefits that are yet to be understood. Future research should look into ways of modifying inulin delivery to minimize the intolerance symptoms experienced by consumers at higher doses. The influence of DP on the GI discomfort also needs to thoroughly be investigated. Other methods of reducing the intolerance symptoms and increasing inulin dose to meet the RDA of dietary fiber should be looked into. For instance, coating the inulin or attaching it with some proteins that modulates the interaction of inulin with the receptors in the upper and middle GI may help reducing the discomfort and allow administration of increased doses.

Alternative ways of utilizing inulin that need to be studied may include in vitro fermentation by the health beneficial bacterial groups and administering the entire fermentation broth (microbial cells and metabolites) in to the human GI. This and other ways of optimizing the benefits of inulin as prebiotic are of great interest to avoid the GI discomfort. However, extensive researches in developing systems that meet the safety standards and testing them in animal and human subjects are required and with greater priority. Alternatively, the characteristics of the in vitro fermentation system need to be researched for compatibility with food systems including fermented dairy products (yoghurt, cheese) and others like pickles and sausages.

Researchers and professional communities may need to lobby for policy-level commitments for funding. Inulin-type prebiotic dietary fibers need to be seriously taken into considerations in planning interventions. Mandatory fortification of the tolerable-level inulin in to staple foods and strong recommendation and promotion of the consumption of inulin rich sources are crucial for rapid improvement of community health in countries with regular diets far below RDA for fiber.

CONFLICT OF INTEREST

The author has no conflict of interest

ACKNOWLEDGMENT

The author appreciates the support provided by the research and technology transfer directorate of Hawassa University.

ORCID

Tadesse F. Teferra https://orcid.org/0000-0003-1977-2169

REFERENCES

Ahmed, W., & Rashid, S. (2019). Functional and therapeutic potential of inulin: A comprehensive review. Critical Reviews in Food Science and Nutrition, 59, 1–13, https://doi.org/10.1080/10408398.2017.1355775

Akram, W., Garud, N., & Joshi, R. (2019). Role of inulin as prebiotics on inflammatory bowel disease. Drug Discoveries & Therapeutics, 13, 1–8. https://doi.org/10.5582/ddt.2019.01000

Al-Sheraji, S. H., Ismail, A., Manap, M. Y., Mustafa, S., Yusof, R. M., & Hassan, F. A. (2013). Prebiotics as functional foods: A review. Journal of Functional Foods, 5, 1542–1553, https://doi.org/10.1016/j.jff.2013.08.009

Andrew, J. L., Waterhouse, L., & Jeny Chattertoni, N. (1994). Do inulin oligomers adopt a regular helical form in solution? Journal of Carbohydrate Chemistry, 13, 859–872. https://doi.org/10.1080/072830940811686

Apolinário, A. C., De Lima Damasceno, B. P. G., De Macêdo Beltrão, N. E., Pessoa, A., Converti, A., & Da Silva, J. A. (2014). Inulin-type fructans: A review on different aspects of biochemical and pharmaceutical technology. Carbohydrate Polymers, 101, 368–378, https://doi.org/10.1016/j.carbpol.2013.09.081

Barclay, T., Ginic-Markovic, M., Cooper, P., & Petrovsky, N. (2010). Inulin—A versatile polysaccharide with multiple pharmaceutical and food chemical uses. Journal of Exipients and Food Chemicals.

Beneke, C. E., Viljoen, A. M., & Hamman, J. H. (2009). Polymeric plant-derived excipients in drug delivery, Molecules, 14, 2602–2620, https://doi.org/10.3390/molecules14072602

Bonnema, A. L., Kolberg, L. W., Thomas, W., & Slavin, J. L. (2010). Gastrointestinal tolerance of chicory inulin products. Journal of the American Dietetic Association, 110, 865–868. https://doi.org/10.1016/j.jada.2010.03.025

Carabin, I. G., & Gary Flamm, W. (1999). Evaluation of safety of inulin and oligofructose as dietary fiber. Regulatory Toxicology and Pharmacology, 30, 268–282. https://doi.org/10.1006/rtph.1999.1349

Charalamopoulos, D., & Rastall, R. A. (2012). Prebiotics in foods. Current Opinion in Biotechnology, 23, 187–191, https://doi.org/10.1016/j.copbio.2011.12.028

Dahech, I., Belghith, K. S., Hamden, K., Feki, A., Belghith, H., & Mejdoub, H. (2011). Antidiabetic activity of levan polysaccharide in alloxan-induced diabetic rats. International Journal of Biological Macromolecules, 49, 742–746. https://doi.org/10.1016/j.ijbiomac.2011.07.007

Davidson, M. H., Maki, K. C., Synecki, C., Torri, S. A., & Drennan, K. B. (1998). Effects of dietary inulin on serum lipids in men and women with hypercholesterolemia. Nutrition Research, 18, 503–517. https://doi.org/10.1016/S0271-5317(98)00038-4

De Vuyst, L., De Vin, F., Vanigelgem, F., & Degeest, B. (2001). Recent developments in the biosynthesis and applications of heteropolysaccharides from lactic acid bacteria. International Dairy Journal, 11, Elsevier, 687–707, https://doi.org/10.1016/S0958-6946(01)00114-5

Femia, A., Pietro, Lucherini, P., Dolara, P., Giannini, A., Biggeri, A., Salvadori, M., Clune, Y., Collins, K. J., Paglierani, M., & Caderni, G. (2002). Antitumorigenic activity of the prebiotic inulin enriched with oligofructose in combination with the probiotics Lactobacillus rhamnosus and Bifidobacterium lactis on azoxymethane-induced colon carcinogenesis in rats. Carcinogenesis, 23, 1953–1960. https://doi.org/10.1093/carcin/23.11.1953

Franck, A. (2002). Technological functionality of inulin and oligofructose. British Journal of Nutrition, 87, S287–S291. https://doi.org/10.1079/bjn2002550

Gibson, G. R., Hutkins, R., Sanders, M. E., Prescott, S. L., Reimer, R. A., Salminen, S. J., Scott, K., Stanton, C., Swanson, K. S., Cani, P. D., & Reid, G. (2017). Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. Nature Reviews Gastroenterology & Hepatology, 14, 491–502. https://doi.org/10.1038/nrgastro.2017.75

Gibson, G. R., Probert, H. M., Loo, J. Van, Rastall, R. A., & Roberfroid, M. B. (2004). Dietary modulation of the human colonic microbiota: Updating the concept of prebiotics. Nutrition Research Reviews, 17, 259–275. https://doi.org/10.1079/nrr200479

Gibson, G. R., & Roberfroid, M. B. (1995). Dietary modulation of the human colonic microbiota: Introducing the concept of prebiotics. Journal of Nutrition, 125, 1401–1412, https://doi.org/10.1093/jn/125.6.1401
Reddy, B. S. (1999). Possible mechanisms by which pro- and prebiotics influence colon carcinogenesis and tumor growth. *Journal of Nutrition American Institute of Nutrition, 129*, 14785–14825. https://doi.org/10.1093/jn/129.7.1478s

Ripoll, C., Flourié, B., Megnin, S., Hermand, O., & Janssens, M. (2010). Gut microbacterial tolerance to an inulin-rich soluble roasted chicory extract after consumption in healthy subjects. *Nutrition, 26*, 799–803. https://doi.org/10.1016/j.nut.2009.07.013

Ritsema, T., & Sneekens, S. (2003). Fructans: Beneficial for plants and humans. *Current Opinion in Plant Biology, 6*, 223–230. https://doi.org/10.1016/S0961-9565(03)00347-4

Roberfroid, M. B. (2007). Inulin-type fructans: Functional food ingredients. *Journal of Nutrition, 137*, American Society for Nutrition, 2493S–2502S. https://doi.org/10.1093/jn/137.11.2493s

Saeed, M., Yasin, L., Pasha, I., Randhawa, M. A., Khan, M. I., Shabbir, M. A., & Khan, W. A. (2015). Potential application of inulin in food industry: A review. *Pakistan Journal of Food Sciences, 25*, 110–116.

Salazar, N., Dewulf, E. M., Neyrinck, A. M., Bindels, L. B., Cani, P. D., Mahillon, J., de Vos, W. M., Thissen, J.-P., Guelmonde, M., de Los Reyes-Gavilán, C. G., & Delzenne, N. M. (2015). Inulin-type fructans modulate intestinal bifidobacterium species populations and decrease fecal short-chain fatty acids in obese women. *Clinical Nutrition, 34*, 501–507. https://doi.org/10.1016/j.clnu.2014.06.001

Saulnier, D. M., Spiner, J. K., Gibson, G. R., & Versalovic, J. (2009). Mechanisms of probiosis and prebiosis: Considerations for enhanced functional foods. *Current Opinion in Biotechnology, 20*, 135–141. https://doi.org/10.1016/j.copbio.2009.01.002

Slavin, J. (2013). Fiber and prebiotics: Mechanisms and health benefits. *Nutrients, 5*, 1417–1435. https://doi.org/10.3390/nu5041417

Song, K. B., Bae, K. S., Lee, Y. B., Lee, K. Y., & Rhee, S. K. (2000). Characteristics of levan fructans from *Arthrobacter ureafaciens* K2032 and difeructose anhydride IV formation from levan. *Enzyme and Microbial Technology, 27*, 212–218. https://doi.org/10.1016/S0141-0229(00)00135-6

Tremaroli, V., & Bäckhed, F. (2012). Functional interactions between the gut microbiota and host metabolism. *Nature, 489*, 242–249. https://doi.org/10.1038/nature11552

Van Geel-Schutten, G. H. (2006). Use of a polysaccharide as bread improver. Pat. no. WO 62410, A1.

Van Laere, A., & Van den Ende, W. (2002). Inulin metabolism in diots: Chicory as a model system. *Plant, Cell & Environment, 25*, 803–813. https://doi.org/10.1046/j.1365-3040.2002.00865.x

Veryenek, J. J., Van Kuik, J. A., Evers, T. H., Rijken, P. J., & De Kruiff, B. (2003). Structural requirements of the fructan-lipid interaction. *Biophysical Journal, 84*, 3147–3154. https://doi.org/10.1529/biophysj.0306-3495(2003)084<3147::AID-BIOPHJ>3.0.CO;2-M

Wada, T., Sugatani, J., Terada, E., Ohguchi, M., & Miwa, M. (2005). Physico-chemical characterization and biological effects of inulin enzymatically synthesized from sucrose. *Journal of Agricultural and Food Chemistry, 53*, 1246–1253. https://doi.org/10.1021/jf048711u

Wan, X., Guo, H., Liang, Y., Zhou, C., Liu, Z., Li, K., Niu, F., Zhai, X., & Wang, L. (2020). The physiological functions and pharmaceutical applications of inulin: A review. *Carbohydrate Polymers, 246*, 116589. https://doi.org/10.1016/j.carbpol.2020.116589

Wang, Y. (2019). Prebiotics: Present and future in food science and technology. *Food Research International, 42*, 8–12. https://doi.org/10.1016/j.foodres.2008.09.001

Wichienchot, S., Thammarutwasik, P., Jongjareonrak, A., Chansuwon, W., Hmadhlu, P., Hongpattarakere, T., Itharat, A., & Ooraikul, B. (2011). Extraction and analysis of prebiotics from selected plants from southern Thailand. *Songklanakarin Journal of Science and Technology, 33*, 517–522.

Wollowski, I., Reckemmer, G., & Pool-Zobel, B. L. (2001). Protective role of probiotics and prebiotics in colon cancer. *American Journal of Clinical Nutrition, 73*, American Society for Nutrition, 451s–455s. https://doi.org/10.1093/ajcn/73.2.451s

Yang, L., He, Q. S., Corssen, K., & Udenigwe, C. C. (2015). The prospects of Jerusalem artichoke in functional food ingredients and bioenergy production. *Biotechnology Reports, 5*, 77–88. https://doi.org/10.1016/j.btre.2014.12.004
Zannini, E., Waters, D. M., Coffey, A., & Arendt, E. K. (2015). Production, properties, and industrial food application of lactic acid bacteria-derived exopolysaccharides. *Applied Microbiology and Biotechnology*, 100, 1121–1135. https://doi.org/10.1007/S00253-015-7172-2

Zhu, Z., He, J., Liu, G., Barba, F. J., Koubaa, M., Ding, L., Bals, O., Grimi, N., & Vorobiev, E. (2016). Recent insights for the green recovery of inulin from plant food materials using non-conventional extraction technologies: A review. *Innovative Food Science and Emerging Technologies*, 33, 1–9, https://doi.org/10.1016/j.ifset.2015.12.023

How to cite this article: Teferra, T. F. (2021). Possible actions of inulin as prebiotic polysaccharide: A review. *Food Frontiers*, 1–10. https://doi.org/10.1002/fft2.92