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An Analysis of the Composition, Health Benefits, and Future Market Potential of the Jerusalem Artichoke in Canada

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Abstract

This article presents an overview of the Jerusalem artichoke and its potential uses in consumer food products. Jerusalem artichoke, native to North America, is characterized by its sunflower-like appearance and carbohydrate-rich tubers. For centuries, Jerusalem artichoke tubers were a food source for Aboriginal Canadians and early European settlers. Today, Jerusalem artichoke is used to obtain inulin for addition into food products. Inulin is a polysaccharide that provides several health benefits when consumed. Due to its unique structure of fructose and glucose molecules, inulin is indigestible by the human digestive system. Its benefits are realized when it enters the large intestine and is fermented by microorganisms. This process stimulates prebiotic and dietary fibre effects that improve the growth of beneficial bacteria and promote greater digestive health. Additionally, inulin can act as a sugar or fat substitute in foods, and even facilitates the absorption of minerals in the large intestine. Currently, the use of Jerusalem artichoke inulin in commercial food products is limited. However, trends focusing on healthy living and supporting local industry indicate that Canadian consumers will positively view products made with Canadian-grown Jerusalem artichoke. The advantage that Jerusalem artichoke has over other inulin-rich products is that it can grow on poor land and is also more resistant to extreme weather conditions relative to corn and/or sugar beet; this is significant in the Canadian context. Given these trends and supplementary market data, the potential market size for Jerusalem artichoke-enriched products has been determined. Additionally, prices of currently available inulin-enriched products have been used as guidelines to determine total market potential. Market potential for baked goods, particularly muffins, was found to be $CAD 8,721,788 while market potential for beverages, namely soda, was found to be $CAD 11,707,098. These numbers, though imperfect, indicate that there is strong potential for Jerusalem artichoke-enriched products to be marketed to Canadian consumers.

Keywords: Jerusalem artichoke, inulin, market potential

1. Overview of the Jerusalem Artichoke

1.1 History and Plant Specifics

The Jerusalem artichoke, or *Helianthus tuberosus*, is perennial plant native to North America. Despite its name, the Jerusalem artichoke is neither from Jerusalem nor an artichoke. Instead, it is closely related to the sunflower. It is believed that the plant was misnamed by early European settlers for its artichoke-like taste, while ‘Jerusalem’ was added as a mistranslation of the Italian term for the plant, ‘Girasole’ (Kosaric, Cosentino, Wieczorek, & Duvnjak, 1984). Like the sunflower, the Jerusalem artichoke features thin yellow flowers that bloom on a tall stalk. The plant can grow to a height of eight feet in the wild, while under the right cultivation and care can reach a height of almost 12 feet (Kosaric et al., 1984). The Jerusalem artichoke is visually distinguishable from the sunflower due to its smaller flowers and thinner stalk (Figure 1). Additionally, the Jerusalem artichoke grows from a fibrous root system that bears tubers (Long, Shao, Liu, Liu, & Liu, 2016). Depending on growth conditions, such as moisture levels and soil texture, the tubers can vary significantly in their size, shape, and colour (Kosaric et al., 1984). The tubers also act as nutrient reserves alongside roots to promote healthy growth and reproduction in future seasons, as the plant’s flowers rarely produce seeds (Swanton & Hamill, 1994).

Figure 1. Jerusalem artichoke flowers, leaves and tubers. Permission from Jerusalem Artichoke Association of Canada (JAAC) (2016)

The plant has also developed strong drought and frost resistance, which contributes to its growth capabilities (Bach, Kidmose, Thybo, & Edelenbos, 2013). In fact, research suggests that unless they are carefully controlled, Jerusalem artichoke tubers will provide sufficient yields each season (Ontario Ministry of Agriculture Food & Rural Affair, 2012). The physiology and composition of the Jerusalem artichoke contribute to its resiliency and enable the plant to grow in a variety of climates across the world (Kays & Nottingham, 2007).

Historically, the Jerusalem artichoke has grown naturally across both Canada and the United States. Researchers have noted, however, that growth in Canada is primarily concentrated around southern Ontario and Manitoba (Swanton, Clements, Moore, & Cavers, 1992). As such, the plant played an important role in the diet of Aboriginal Canadians prior to the 16th century. Both the Cree and the Huron peoples of eastern North America grew the Jerusalem artichoke for its tubers (Bock, Kane, Ebert, & Rieseberg, 2014; Kays & Nottingham, 2007; Kosaric et al., 1984). The Hurons termed the plant *skibwan*, or 'raw thing', and it is believed that tubers were eaten raw or cooked into simple dishes (Kosaric et al., 1984). The plant was likely cultivated alongside other edible crops such as corn, beans, squash, sunflower, and tobacco (Turner, Arnason, Hebda, & Johns, 2014). Early settlers to North America transported the Jerusalem artichoke back to Europe in the 1600s, where it was used as a food plant until potato farming became more prominent (Bock et al., 2014; Kays & Nottingham, 2007). Though its popularity decreased, cultivation of the Jerusalem artichoke continued in small quantities in many countries including France, England, Germany, Japan, and India (Bajpai & Bajpai, 1991).

1.2 Nutritional Value

The prominent use of the Jerusalem artichoke (JA) as a food plant for many centuries can be attributed to the plant's tubers and their nutritional value. The tubers contain vitamins, minerals, and the complex carbohydrate inulin which can all promote good health in humans (Bach et al., 2013; Somda, McLaurin, & Kays, 1999). According to the United States Department of Agriculture (USDA) National Nutrient Database, raw JA contains 78% moisture, 10 % total sugars, 0.5% minerals, and 0.01% total lipid (fat). A summary of the composition of raw JA, including mineral composition, can be found in Table 1. The table does not outline the vitamin composition, as this is outside the scope of this study. It is important to note that there are variations in the composition of JA tubers depending on different cultivars, time of harvest, production conditions, and postharvest treatment (Celik *et. al.*, 2013). Based on its composition, Jerusalem artichoke is a valuable plant with diverse applications in food and non-food purposes (Figure 2).

Table 1. Nutritional Value of Fresh Jerusalem artichoke tubers (per 100g)

Proximate	Value (%)
Moisture	78.01
Ash	5.00
Total Dietary Fiber	15.0
Protein	15.0-16.0
Total Sugar	9.60
Mineral	0.50
Lipid	0.01
Minerals	**Value (mg/100g)**
Potassium	429.00
Phosphorous	78.00
Magnesium	17.00
Calcium	14.00
Sodium	4.00

Sources: (United States Department of Agriculture [USDA], 2016; Zalán et al., 2011)

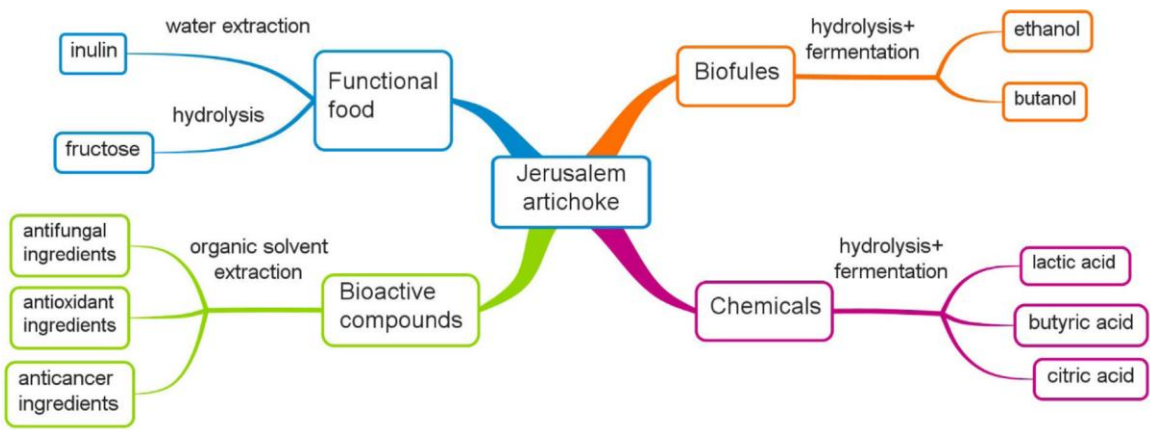

Figure 2. Food and non-food applications of Jerusalem Artichoke. (Permission from Linxi Yang et al., 2015)

1.3 Sources, Extraction, and Characteristics of Inulin

Inulin, a fructan-type polysaccharide (Figure 3), consists of (2→1) linked beta-D-fructosyl residues (n = 2-60), usually with an (1↔2)-beta-D-glucose end group with degree of polymerization (DP, 2-10) are diverse and naturally occurs in several different types of plants. In its natural form, the polysaccharide acts as a storage compound for over 30,000 plant varieties (Apolinário et al., 2014). The content of inulin in these plants varies greatly, as summarized in Table 2.

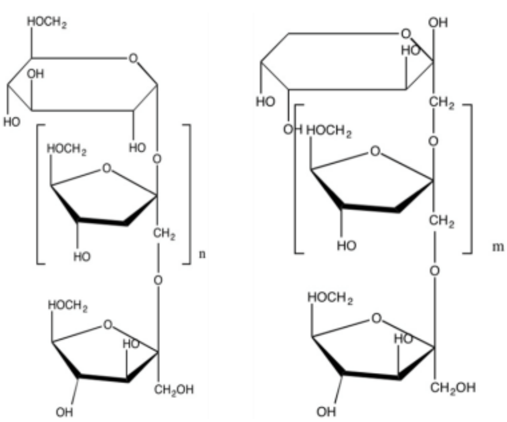

Figure 3. Chemical structure of inulin

Table 2. Major Plant Sources of Inulin, based on g/100g of Fresh Weight contents

Source	Inulin Content
Banana	0.3-0.7
Barley	0.5-1.5
Chicory	15-20
Garlic	9-16
Globe Artichoke	2-3
Jerusalem Artichoke	3-10
Leek	16-20
Onion	1-8
Wheat	1-4

Source: (Meyer & Blaauwhoed, 2009)

Despite the availability of inulin in this variety of plants, chicory remains the most popular source for commercial inulin as it yields relatively high percentages of the compound (Meyer & Blaauwhoed, 2009; Shoaib et al., 2016). Inulin can, however, be extracted from the Jerusalem artichoke as well. Several extraction methods have been used since the 17^{th} century, including crystallization from water and precipitation from alcohol (Willaman, 1922). As technology has evolved, new extraction methods have become available. Researchers have found that though precipitation through alcohol is possible, it does not present an economical extraction method for obtaining inulin for commercial purposes (Lingyun et al., 2007). Lingyun et al. (2007) also noted that indirect sonication, whereby a high intensity ultrasonic bath is used to facilitate the release of inulin from the Jerusalem artichoke, is the most suitable method for extraction. An additional method involving ultrafiltration to separate long-chain and short-chain inulin fractions was patented in 1999, prior to which researchers found the process to be unsuccessful (Laurenzo, Navia, & Neiditch, 1999; Vukov, Erdelyi, & Pichler-Magyar, 1993). Some studies also suggest accelerated solvent extraction, which is faster and more effective than conventional methods (Saengkanuk, Nuchadomrong, Jogloy, Patanothai, & Srijaranai, 2011; Srinameb, Nuchadomrong, Jogloy, Patanothai, & Srijaranai, 2015). However, the potential for these methods on a larger scale is unclear (Luque & Melero, 2012). Given the various extraction methods available, it is likely that in the future, researchers and businesses may use a combination of traditional and advanced extraction methods to obtain inulin from the Jerusalem artichoke.

Typically, inulin compounds contain 2-60 fructose units and one terminal glucose unit (Meyer & Blaauwhoed, 2009; van Loo, Coussement, de Leenheer, Hoebregs, & Smits, 1995). The length of the fructose chain, or the degree of polymerization, is dependent on the plant species, its current life cycle phase, the date the plant was harvested, and the extraction process used to obtain the inulin (Apolinário et al., 2014; Barclay, Ginic-Markovic, Cooper, & Petrovsky, 2010; Ronkart et al., 2007). Meyer and Blaauwhoed (2009) suggest that 'native' inulin can be separated into short-chain and long-chain fractions, which changes the degrees of polymerization and thereby influences the potential uses of the inulin compound. Inulin obtained from Jerusalem artichokes typically has a range of degree of polymerization between 2 and 50, whereas inulin obtained from chicory has a range between 2 and 60 (Meyer & Blaauwhoed, 2009). As such, the inulin compounds from these crops can be used in a variety of ways. One notable application of inulin is within the biofuel industry. The fructose and glucose structure of inulin enable the compound to act as an alternative source for bioethanol (Li, Li, Wang, Du, & Qin, 2013). This process typically involves either converting the inulin into its simple sugar components through hydrolysis and then fermenting the sugars with yeast, or directly fermenting the inulin with specific yeasts that contain inulinase activity (Apolinário et al., 2014; Bajpai & Bajpai, 1991; Matías, González, Royano, & Barrena, 2011). Aside from its use in biofuel production, inulin also holds significant implications as an additive in food products. The health benefits that accompany this polysaccharide are wide-ranging and contribute to its strong potential as a key future ingredient in the Canadian foods industry.

2. Health Benefits of Inulin

The chemical structure of inulin enables the polysaccharide to provide several health benefits when consumed. Several studies have shown that inulin, both in its natural state and as an additive in food, can positively impact various biological functions in humans. Four key benefits have been identified that present the greatest implications for future use of Jerusalem artichoke inulin in consumer food products. Table 3 summarizes these benefits, while more thorough explanations of each benefit have been provided below.

Table 3. Quick Summary of Health Benefits

Prebiotic	Dietary Fibre and Neuroprotection
• Inulin promotes gastrointestinal health by stimulating the development of beneficial microflora and limiting the growth of harmful bacteria within the large intestine.	• Inulin promotes a healthy digestive system, strong cardiovascular health, and improved overall health levels as a dietary fibre, since dietary fibres are linked to low levels of cholesterol and lower risk of conditions such as diabetes and hypertension. • Butyrate, a metabolite intermediate of dietary fibres, has had a beneficial effect on brain disorders ranging from neurodegenerative diseases to psychological disorders.
Sugar & Fat Substitute	**Mineral Absorption Enhancer**
• Inulin can act as a low-calorie sugar substitute because fermentation in the large intestine releases short chain fatty acids which are then absorbed into the body - with a much lower caloric content than traditional digestible carbohydrates. • Inulin can act as a fat substitute due to its low caloric value and ability to emulate the texture of traditional fat - thereby contributing to a diet that may prevent obesity and other medical issues.	• Inulin, given its prebiotic nature, can enhance the absorption of minerals (particularly calcium and magnesium) and thus potentially contribute to improved bone health.

2.1 Inulin as a Prebiotic

The prebiotic nature of inulin can be attributed to its molecular structure. The fructose and glucose units that create inulin are connected through glycosidic β(2-1) bonds, which makes inulin indigestible by humans (Barclay et al., 2010). As a result, inulin often travels completely intact through the digestive system until it reaches the large intestine, where certain microflora can digest the polysaccharide (Apolinário et al., 2014; Shoaib et al., 2016). When inulin is introduced to this organ, it is digested by beneficial bacteria such as *Lactobacilli* and *Bifidobacteria* (Barclay et al., 2010). During this process, the inulin simultaneously stimulates the growth and development of these bacteria and thereby improves the microbial balance and overall health of the intestine (Shoaib et al., 2016). In fact, the development of these strains of bacteria is believed to have an impact on infection resistance as it can limit the presence of pathogenic bacteria in the digestive system (Boeckner, Schnepf, & Tungland, 2001; Ramnani et al., 2010; Vukov et al., 1993). In some instances, these harmful bacteria may even give rise to carcinogens (Boeckner et al., 2001). Thus, inulin as a prebiotic enhances the growth of beneficial microflora while maintaining a balance that prevents harmful bacteria from damaging the system. This suggests that inulin obtained from the Jerusalem artichoke may be useful as an additive in daily food products to promote gastrointestinal health.

2.2 Inulin as a Dietary Fibre and Neuroprotection

Turner and Lupton (2011) define a dietary fibre as a plant-derived material composed primarily of carbohydrates that are indigestible in the small intestine, due to a lack of specific enzymes, but fermentable by the microorganisms of the large intestine and colon. Inulin is one of these plant-derived materials that is only fermented in the latter portions of the gastrointestinal tract. Moreover, one study suggests that roughly 90% of ingested inulin passes through the system intact only to be digested by microflora in the large intestine (Cherbut, 2002). As such, inulin can be categorized as a soluble dietary fibre (Selgas, Cáceres, & García, 2005; Shoaib et al., 2016; van Loo et al., 1995). Dietary fibre is an important contributor to overall health and high fibre intake is associated with lower risk for heart disease, hypertension, diabetes, and obesity (Anderson et al., 2009; Zanteson, 2014). Inulin, in particular, has benefits on cardiovascular health as the polysaccharide has a positive impact on cholesterol and glucose levels (Barclay et al., 2010). Dietary fibre such as inulin decreases circulatory cholesterol concentrations as follows:

- By redistributing cholesterol from plasma to the liver.
- By inhibiting hepatic cholesterol synthesis.
- By binding with the bile acids and thus increasing excretion of the cholesterol.

Inulin can also alleviate constipation and improve regularity, as it promotes the release of short chain fatty acids (SCFAs) that impact sodium and water absorption (Kalyani Nair, Kharb, & Thompkinson, 2010; Shoaib et al., 2016). As with other dietary fibres, inulin promotes a healthy digestive system and positively impacts the overall health of individuals. These particular capabilities of inulin have been recognized by regulatory organizations across the world. In Canada, for example, the Canadian Food Inspection Agency includes inulin on its list of acceptable carbohydrates that can be branded and sold as dietary fibres (Canadian Food Inspection Agency, 2016a). This recognition suggests that there is great potential for inulin to be added as a dietary fibre ingredient to Canadian food products.

Dietary fibres have been shown that their metabolite intermediates such as Butyrate improve gut microbiome (Bourassaa, et al., 2016). Additionally, butyrate has neuroprotection ability to improve brain health. Butyrate also plays a major role of energy in metabolism and mitochondrial activity. Pharmacologically, butyrate has had a strongly beneficial effect on brain disorders ranging from neurodegenerative diseases to psychological disorders (Bourassaa, et al., 2016).

2.3 Inulin as a Sugar and Fat Substitute

The chemical structure of inulin allows it to act as an alternative for traditional sugar and fat sources. Excessive consumption of sugar, typically in the form of sucrose, can lead to issues such as obesity (Pareyt et al., 2009). Unlike carbohydrates that are digestible and absorbed while in the small intestine, such as sucrose, inulin is only absorbed after it is fermented in the large intestine. Fermentation releases SCFAs which are then absorbed into the system, but the total absorption involved in this process constitutes roughly one third of the caloric content of traditional digestible carbohydrates (Meyer & Blaauwhoed, 2009). Thus, inulin can act as a low-calorie sugar substitute. Additionally, the fructose-based composition of inulin makes it an attractive substitute for sugar as the polysaccharide does not provoke a glycemic response (Long et al., 2016; Meyer & Blaauwhoed, 2009). This is of particular importance as it allows inulin to act as a potential sugar substitute for diabetics, as it will not negatively impact blood sugar levels (Cheng et al., 2009; Kosaric et al., 1984; Shoaib et al., 2016). One study has also determined that the fructose and inulin content of the Jerusalem artichoke could contribute to the prevention of type 2 diabetes if consumed regularly (Chang et al., 2014). Another study determined that the arrival of European settlers in Australia prompted a shift away from high fructan foods in the diet of Aboriganal Australians, which ultimately contributed to the rise of type 2 diabetes among this population (Gott, Williams, & Antos, 2015). Plants containing inulin, such as the Jerusalem artichoke, are high fructan foods. This further suggests that an inulin-rich diet could provide significant benefits to type 2 diabetics and those at risk of developing the disease.

Additionally, the low caloric value that inulin provides in comparison to digestible carbohydrates make this polysaccharide a suitable substitute for fat (Shoaib et al., 2016; Tungland & Meyer, 2002). To achieve this, inulin can be thoroughly blended into water to create a fat-like substance for addition to food products (Imeson, 2011). Fat is typically the nutrient that adds the highest energy value in a standard diet, but inulin can provide a similar textural component while providing fewer calories and energy (Selgas et al., 2005). High consumption levels of fat have been linked to poor health and can lead to obesity, cancer, high cholesterol, and coronary heart disease (Pareyt et al., 2009). As such, efforts to identify suitable replacements for fat play a crucial role in preventing these illnesses. The most challenging aspect of replacing fat is often that substitutes are unable to emulate the same texture and taste of real fat (Pareyt et al., 2009; Rößle, Ktenioudaki, & Gallagher, 2011). However, studies have shown that inulin, when transformed into a gel with the addition of water, can provide acceptable taste and texture in certain food products (Barclay et al., 2010; Mensink, Frijlink, Van Der Voort Maarschalk, & Hinrichs, 2015; Stevens, Meriggi, & Booten, 2001). Thus, inulin as a value-added ingredient in food products could provide several health benefits while simultaneously reducing overall sugar and fat levels.

2.3.1 Inulin and Hydrocolloids

Hydrocolloids (gums) can act as thickeners, gelling agents, stabilisers, texturisers in aqueous systems. Most of the hydrocolloids are high molecular weight polysaccharides. Hydrocolloids are divided in three groups: emulsifying (stabilizing) agents, thickening agents and gelling agents. Inulin has different thickening and stabilizing properties from hydrocolloids (Mensink, Frijlink, Van Der Voort Maarschalk, & Hinrichs, 2015). The inulin molecule is much smaller and the water-binding capacity is low compared to hydrocolloids. Gel formation of inulin is also different compared to hydrocolloids. Inulin forms particle gels, similar to those formed by starches. Gel formation of inulin is related to degree of polymerization of inulin, the long-chain inulin (DP 2-60) from chicory roots and inulin from JA (DP 2-50) have different water-binding capacity and provide different gels (Mensink, Frijlink, Van Der Voort Maarschalk, & Hinrichs, 2015).

2.4 Inulin as a Mineral Absorption Enhancer

The fourth health benefit that inulin intake provides is that it facilitates an increase in mineral absorption. Coxam (2005) has noted that the prebiotic nature of inulin can stimulate the absorption of minerals, particularly calcium. When inulin is fermented by microflora in the large intestine and SCFAs are released, the luminal pH level is reduced and thus passive diffusion of calcium improves (Coxam, 2005). A similar result has been noted for the absorption of magnesium (Weaver, 2005). Both calcium and magnesium are important minerals for bone health, and an increase in absorption of these minerals may promote healthier bones and reduce the risk of osteoporosis (Coxam, 2005; Weaver, 2005). Studies on humans have provided limited results, possibly due to the differences in dosage that are given to animals and humans (Schaafsma & Slavin, 2015). Thus, the particular impacts of inulin-enhanced mineral absorption warrant greater investigation. In fact, a 2004 Health Canada survey found that between 45 and 70 per cent of Canadians above the age of 50 had inadequate calcium intake (Garriguet, 2011). The relative inadequacy of calcium in the Canadian diet suggests that inulin may provide a prevention method against mineral deficiencies and possible bone density issues. However, given the lack of current research available regarding the level of impact that inulin has on mineral absorption, it is unlikely that this health benefit will appeal to consumers until further research is conducted.

Osteoporosis is a disease characterized by low bone mass and deterioration of bone tissue. This leads to increased bone fragility and risk of fracture (broken bones), particularly of the hip, spine, wrist and shoulder (Garriguet, 2011). Fractures from osteoporosis are more common than heart attack and stroke. At least 1 in 3 women and 1 in 5 men will suffer from an osteoporotic fracture during their lifetime. Yearly cost to the Canadian healthcare system of treating osteoporosis is $2.3 billion. This cost rises to $3.9 billion when living in long-term care facilities (Coxam, 2005; Weaver, 2005).

3. Applications of Inulin in the Food Industry

Given its various health benefits, it is unsurprising that researchers have already begun investigating the potential uses of inulin in food products. Inulin has been used a successful fat substitute and as a dietary fibre in breakfast cereals, yoghurts, cheeses, and even chocolate (Farzanmehr & Abbasi, 2009; Franck, 2002; Karimi, Azizi, Ghasemlou, & Vaziri, 2015). The polysaccharide has also been applied as a fat substitute in sausages, whereby it reduced fat content while providing prebiotic benefits with few impacts on texture (Keenan, Resconi, Kerry, & Hamill, 2014; Selgas et al., 2005). Though inulin can be added to a variety of foods with relative success, this report focuses two specific types of products: baked goods and beverages. An analysis of documented use of inulin in these products is provided below.

3.1 Inulin in Baked Goods

In baked goods, such as cakes, cookies, and breads, inulin can be used as a fat and sugar substitute while also providing additional health benefits. Inulin in baked goods can also improve moisture retention and thus enable cakes and breads to remain fresh for longer periods (Franck, 2002). Typically, inulin to be used in baked goods is dissolved into a solution and stirred thoroughly for several hours until it obtains a creamy texture (Stevens et al., 2001). Research indicates that short-chain inulin added to low-fat cookies can improve their crispiness (Kaur & Gupta, 2002). Additionally, inulin can be added to baked goods in the form of Jerusalem artichoke powder (JAP) which, when mixed into dough, can provide lower fat and lower sugar alternatives to traditional baked goods (Karklina, Gedrovica, Reca, & Kronberga, 2012). A study on the use of Jerusalem artichoke powder in cakes noted that the smell and color of the powder could be masked but the flavor, chewiness, and sweetness of the cakes were still affected (Celik, Isik, Gursoy, & Yilmaz, 2013). The same study noted, however, that a 5-10% concentration of JAP could provide the health benefits of inulin without drastically affecting overall quality of the cakes for test subjects. Furthermore, a recent study on the production of bread with JAP leavened with a co-culture of yeasts found that the inulin-enhanced bread was viewed as an acceptable substitute for standard bread among semi-trained panelists (Wahyono, Lee, Yeo, Kang, & Park, 2016). In addition to JAP, Jerusalem artichokes can be processed to create flour (LaBell, 1992). In baked goods, this flour can be used to substitute roughly 10% of regular flour to provide the prebiotic effects that accompany Jerusalem artichoke inulin (LaBell, 1992).

One study also found that inulin could act as a substitute for half of the butter content of low-fat corn bread, thereby significantly reducing fat content (Joseph & Ru, 2013). As a substitute for butter, inulin could provide wide-ranging health benefits to consumers without compromising quality and taste. Another study investigated the potential for chicory inulin to be added to scones. Researchers found that a combination of margarine, caster sugar, and commercially produced short- and long-chain inulin could produce texture and moisture levels similar to regular scones, while reducing the overall sugar and fat content of the baked products (Rößle et al., 2011). It was also noted that the inulin scones produced a larger volume, which can be attributed to the ability of inulin's prebiotic characteristics to provide bulk (Rößle et al., 2011; Tungland & Meyer, 2002). However, research indicates that inulin derived from the Jerusalem artichoke may have greater impact than traditional, chicory inulin. A study of inulin-rich carbohydrates extracted from both Jerusalem artichoke and chicory root found that the Jerusalem artichoke inulin had stronger prebiotic properties than its chicory counterparts (Irene A. Rubel, Pérez, Genovese, & Manrique, 2014). A later review determined that inulin-rich carbohydrate powders could yield bread that was not significantly different from bread produced without Jerusalem artichoke inulin, in terms of texture, taste, and smell (I. A. Rubel, Pérez, Manrique, & Genovese, 2015). Overall, Jerusalem artichoke inulin can be added to a variety of baked goods through a range of different processes. Regardless of which method is used, however, the prebiotic, fat replacement, and sugar replacement effects of the inulin are maintained and thereby produce healthier alternatives to traditional baked foods.

3.2 Inulin in Beverages

Though most research regarding the use of Jerusalem artichoke inulin are focused on the polysaccharide's applicability in foods, some studies have analyzed its potential for beverages. For example, Jerusalem artichoke has been used to enhance the characteristics of fermented milk products. One study found that adding Jerusalem artichoke inulin extract to fermented milk promoted the growth of *Lactobacillus salivarius*, prolonging the probiotic effects the drink (Alani, Fraser, Alsharafani, Al-Nouri, & Ibrahim, 2009). Similarly, another study determined that combining inulin with different forms of probiotic bacteria in non-fat fermented milk leads to improved firmness and an increase in viable cells in the substance (Oliveira, Perego, Oliveira, & Converti, 2011). Improved firmness is a positive characteristic as many low- and non-fat dairy products do not appropriately mimic the texture of full fat products, which affects consumers' experiences. The addition of inulin therefore improves texture and palatability of these dairy products (Meyer & Blaauwhoed, 2009). Thus, inulin obtained from the Jerusalem artichoke holds potential to improve the prebiotic and probiotic effects of fermented milk drinks. However, it also holds potential for beverage development in its raw form.

Raw Jerusalem artichokes can be processed through standard kitchen appliances to obtain Jerusalem artichoke juice. Typically, one pound of Jerusalem artichokes will yield 6-8 ounces of juice that offer the same health benefits as the raw tubers (Blauer, 1989). Blauer (1989) also suggests that Jerusalem artichoke juice be combined with other vegetable or fruit juice to improve taste. Additionally, Tiurikova and Peresichnyi (2015) determined that Jerusalem artichoke juice could be combined with other natural juices and walnut extract to provide a nutrient-rich drink that contributes to overall health. Research suggests that Jerusalem artichoke juice, even when blended with other juices, provides prebiotic effects that benefit the gastrointestinal tract (Ramnani et al., 2010). In a recent and novel study, researchers used Jerusalem artichoke juice to create a synbiotic drink. Synbiotic refers to the combination of both prebiotic and probiotic capabilities that largely enhance gastrointestinal functioning (Zalán et al., 2011). The drink was created by fermenting Jerusalem artichoke juice with the probiotic *Lactobacillus plantarum* PCS26, and then combining the resulting liquid with blueberry juice to improve flavour (Dimitrovski, Velickova, Dimitrovska, Langerholc, & Winkelhausen, 2016). Additionally, in a taste test, it was determined that over 80% of participants would purchase the drink and 60% would pay more in comparison to plain fruit juice (Dimitrovski et al., 2016). This suggests that, despite its bland flavour, Jerusalem artichoke juice may hold potential as an added ingredient in existing juices that are developed to provide prebiotic and synbiotic properties. Overall, it appears that Jerusalem artichoke inulin can provide the best health benefits when fermented through bacteria, as this enhances the overall effects of the two substances.

4. The Canadian Market Potential for Jerusalem Artichoke-derived Food Products

In order to develop an understanding of the market potential for baked goods and beverages enhanced with Jerusalem artichoke inulin, it is important to analyze the current Canadian market. Important factors include the regulatory framework which may impact the marketability of certain products, consumer trends and preferences, and market penetration rate. These three factors will play a key role in identifying the potential customers in Canada who may be interested in these alternative food product options.

4.1 Regulatory Framework

The government of Canada has instituted regulations that affect product labels and packaging, particularly with respect to claims made about nutrition and health. Health Canada recognizes that the Jerusalem artichoke is a key source of inulin and highlights that claims made regarding inulin can only suggest that it: (a) provides a source of fibre, (b) helps maintain digestive health, (c) stimulates growth of beneficial bacteria, (d) acts as a prebiotic, and (e) provides relief of constipation or irregularity (Health Canada, 2013). The report does not indicate that inulin can contribute to mineral absorption, thus these claims cannot be made regarding inulin-enhanced food products. Additionally, though the report does not outline claims regarding the use of inulin as a fat or sugar substitute, the Canadian Food Inspection Agency determines these claims based on the content of these nutrients found in products (Canadian Food Inspection Agency, 2016b). Thus, food and beverages can use inulin as a sugar and fat substitute if the product meets the content requirements set by the government. As such, the subsequent analyses will not consider the mineral absorption characteristics of inulin, but will instead focus on factors that impact its role as a dietary fibre, prebiotic, and replacement for fat and/or sugar.

4.2 Consumer Trends

One of the most prominent trends that has affected Canadian consumers is a shift towards a healthier mindset. Canadians are now actively seeking out ways to improve their health through their consumption habits (Business Development Bank of Canada, 2013). This has given rise to an increase in demand for healthier food products, including functional foods (Zimmerman & Jenkins, 2016). Additionally, it is expected that growth in the baked goods industry will be driven by high-value baked goods that also provide health benefits (Agriculture and Agri-Food Canada, 2013). This presents an excellent opportunity for Jerusalem artichoke to be incorporated into baked goods, as it can drastically improve the health effects of goods such as cakes and breads. Jerusalem artichoke could become a value-added component that customers can associate with general health maintenance due to its prebiotic and dietary fibre characteristics. Moreover, the healthy mindset of Canadians has also influenced their perceptions of the juice industry. Canadian consumers are more skeptical of health claims made by juice companies due to the high sugar content of their products (Theodore, 2016). Theodore (2016) also suggests that consumers are choosing to avoid juices containing preservatives and sugars. Instead, customers are opting for healthier beverage alternatives, such as coconut water, that are increasingly available (Euromonitor International, 2016b). This suggests that a Jerusalem artichoke juice blend could be introduced to the market as a low-calorie alternative to juice. If blended with natural fruit juices with no added sugars, the Jerusalem artichoke juice could provide a drink that is similar to juice but healthier for consumers. Additionally, fermented milk beverages made from Jerusalem artichoke inulin could appeal to consumers who are seeking improvements to their gastrointestinal health. In fact, a recent report indicates that digestive health is becoming a more prominent concern for Canadian consumers, likely a result of the country’s aging population (Euromonitor International, 2016a). This has prompted a significant increase in consumer interest towards dietary fibre, which was deemed by Agriculture and Agri-Food Canada (2016) as the most sought ingredient in health products. Thus, the trend towards healthier lifestyles among Canadians presents a key opportunity for Jerusalem artichoke provide health benefits in baked goods and beverages.

Another important trend in the Canadian market is the increased interest in locally-produced and locally-sourced goods. A report published in 2015 regarding consumer lifestyles indicated that two-thirds of Canadian consumers valued products made in Canada (Euromonitor International, 2015). Consumers tend to have greater trust in locally-sourced and produced goods as they associate these factors with higher production standards (Faye, 2010). As Jerusalem artichoke is native to North America, it could potentially be entirely sourced and processed locally into value-added food and drink products. In order to appeal to customers, the Canadian origins of these products must then be highlighted, which Faye (2010) suggests is a key way to inspire and inform consumers about the benefits of food products. However, given that the Jerusalem artichoke is not currently used in large-scale production of inulin-rich substances, costs to produce either baked goods or beverages with this plant will initially be high. Local sourcing may also contribute to higher costs as compared to sourcing from a less expensive foreign market. Thus, Jerusalem artichoke-enriched products will likely be priced at a premium. The Business Development Bank of Canada (2013) reported that 30% of consumers would pay more to purchase a locally-produced product and 33% would pay more for a product that improves health. This suggests that, under optimistic conditions, roughly one-third of the Canadian population represents a potential market for these products.

4.3 Market Penetration Rate

The market penetration rate, for the purposes of this report, reflects the percentage of the total potential market that may become consumers of Jerusalem artichoke-enriched baked goods or beverages. As the Jerusalem artichoke is a relatively unknown source of dietary fibre and prebiotics, a strong marketing campaign is imperative to ensure that potential consumers are informed enough to make purchasing decisions. The marketing campaign must abide by the federal regulations regarding labelling and health claims while also capitalizing on key consumer trends. The ideal campaign will highlight the Jerusalem artichoke products as lower calorie sources of fibre and prebiotics. Additionally, it will brand the products as 100% Canadian-grown and processed, emphasizing the history of Jerusalem artichoke growth in Canada. However, a powerful marketing message may be unable to sway consumers who are familiar with existing products. For example, the juice industry in Canada has several competitors, each with unique brand portfolios (Euromonitor International, 2016b). As such, consumers may favor existing healthy alternatives over Jerusalem artichoke products. Without sufficient information and education, consumers will be unaware of the benefits of these products which will result in weak market penetration. For example, Health Canada (2012) reported that many Canadians may not be consuming inadequate levels of dietary fibre. Thus, unless consumers are aware of this problem and understand its implications for their health, they will be unlikely to seek out a potential solution. The marketing and advertising of Jerusalem artichoke products should emphasize the ability of inulin to provide an organic and healthy solution to dietary and digestive problems; a solution that simultaneously helps Canadian business and agriculture. Based on these factors, a market penetration rate of 60% can be assumed, to account for competitive forces, the lack of public knowledge surrounding of the Jerusalem artichoke, and potential shifts in consumer trends. This estimation is slightly optimistic but relies on the basis of a strong marketing campaign built on information and inspiration.

Figure 4. Potential Market Size for Jerusalem Artichoke Products

Total Population	36,286,425
Population 18 and Older	29,267,746
30% of Population 18 and Older	9,755,915
Total Potential Market (Adjusted for Market Penetration Rate)	5,853,549

Source: (Statistics Canada, 2016)

4.4 Potential Market Size

The potential market size for Jerusalem artichoke products can be determined by identifying the total population of Canada above the age of 18, calculating one-third of that number, and multiplying the result by a factor of 0.65, as seen in Figure 4. The total adult population of Canada is currently 29,267,746 individuals (Statistics Canada, 2016). For this report, individuals under the age of 18 were not included as that particular subsection of the population does not often have full control over purchase decisions regarding food products. As such, this segment of the population would not be a primary target market for Jerusalem artichoke products. Furthermore, no other generational cohort was eliminated as an unfit target market because all adult groups, including millennials and baby boomers, are interested in products that contribute to a healthy lifestyle (Business Development Bank of Canada, 2013). The remaining population of 29.2 million can be thus divided by three to obtain 9,755,915, which represents the third of the population that represents individuals who would pay higher prices for locally-produced and health-improving products. Finally, this number is multiplied to the market penetration and results in a total potential market size of 5,853,549 consumers. As previously mentioned, this estimation is optimistic as it represents roughly 16% of the total population. However, given that the number of adults suffering from high blood pressure and obesity each comprise roughly the same percentage of the population (Statistics Canada, 2014), it is possible that this estimation provides a relatively accurate image of the potential market for Jerusalem artichoke products.

4.5 Potential Price Points

Currently, there are no commercially available Jerusalem artichoke-enriched baked goods or beverages in Canada. Thus, in order to determine potential price points, similar products have been identified that can act as price guides for Jerusalem artichoke products. Two simple products were chosen to illustrate the market potential for baked goods and beverages enriched with Jerusalem artichoke inulin. Both of the selected products contain inulin, but from different plant sources. The first product is the Whole Grain Pecan Banana Muffin sold at Tim Hortons locations across Canada. The muffin contains inulin derived from the chicory root and is likely included in the recipe to supplement the dietary fibre effects of whole grains (Tim Hortons, 2015). These muffins are sold at a price of 1.49 CAD per unit, which is comparable to regular muffins that do not contain any inulin. The second product is Oogavé soda sold by the Rocky Mountain Soda Company in the United States and around the world. The company produces a variety of sodas that are sweetened using organic agave nectar, which also acts as the soda's inulin source (Rocky Mountain Soda Company, 2016). Soda bottles are sold in packs of 12 at a price of 18 USD, which means that one 355mL bottle of soda can be valued at approximately 2 CAD. Though these products do not reflect the premium price of a highly value-added product, they indicate the minimal price point at which inulin-enriched baked goods and beverages can be sold.

Using the aforementioned prices, market potential for Jerusalem artichoke-enriched baked goods and beverages can be determined. For baked goods, namely muffins, the market potential would be $CAD 8,721,788. For beverages, such as soda, the market potential would be $CAD 11,707,098. These values only indicate approximate market potential based on the factors considered in this report. They reflect the status of the current market and as a result are limited due to the lack of inulin-based consumer food products that are sold in North America.

4.6 Benefits for indigenous communities in Canada:

JA originally belongs to indigenous people in Canada and re-assessing of this valuable plant is important for engaging indigenous growers to contribute to the economic development of Canada's indigenous communities. Growing JA will encourage indigenous communities to use a better choice of sugar in their diet, improving their overall health and well-being.

5. Conclusion and Perspectives

This paper provides researchers with a preliminary analysis of the potential for Jerusalem artichoke application in baked goods and beverages. Jerusalem artichoke, though a prominent source of inulin, is widely underused for commercial purposes. Its prebiotic nature, dietary fibre effects, and fat and sugar replacement capabilities suggest that Jerusalem artichoke inulin could be widely used in consumer food products to reduce caloric content and fat content while maintaining the integrity of these products. For researchers in the field of food sciences and chemistry, this report provides a review of the structural components of Jerusalem artichoke inulin that enable it to impact digestive health. Additionally, this report enables researchers to understand the gaps in current literature. These gaps predominantly include determining the optimal large-scale extraction method for Jerusalem artichoke inulin and identifying the specific effects of Jerusalem artichoke inulin on mineral absorption and bone density development. However, additional research may also focus on developing new beverages of fermented Jerusalem artichoke juice that are tailored to suit the flavour preferences of specific consumers. Further research on the Jerusalem artichoke and its inulin content will ideally prompt the development of more efficient and cost-effective processes for extraction, fermentation, and addition to existing products. Beyond these implications for future research, this report has significant implications for the Canadian agriculture industry. As the prominence of digestive health issues rises in Canada, the agriculture industry should seize this opportunity to promote the development of naturally-derived prebiotic and dietary fibres (e.g. Jerusalem artichoke inulin). Currently, lack of production and lack of awareness contribute to the scarce use of Jerusalem artichoke. The government could combat these two issues while simultaneously promoting growth in agriculture and entrepreneurship. Similar to its campaigns on the benefits of milk, the government could develop an informational marketing campaign centred around the Canadian-grown Jerusalem artichoke. Recognizing the potential for this product in the Canadian market, as outlined in this paper, entrepreneurs may begin to develop new food products that rely solely on inulin to provide dietary fibre and prebiotic effects. Thus, as demand for Jerusalem artichoke rises, Canadian farmers will begin to cultivate the crop in greater quantities. Once awareness is developed in the market, it is likely that Jerusalem artichoke and its inulin will become popular additions to the increasingly healthy lifestyles of Canadian consumers.

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