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PROSPECTS OF INULIN FROM *Helianthus tuberosus* L. AS RAW MATERIAL FOR BIOPROCESSES - REVIEW

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Abstract

This review summarizes several important aspects for primary production and advanced processing of Helianthus tuberosus. At the same time, a series of use areas of inulin are pointed out, which also offer some prospects for maximizing the benefits and the economic potential of this resource. Inulin from Helianthus tuberosus has been studied from the point of view of agricultural production by addressing the cultivation, harvesting, storage and drying from the perspective of the inulin content, as well as from the point of view of the extraction and processing technologies for the economic use as food, food supplement or biomass, respectively as biofuel/bioethanol.

Key words: *inulin, Jerusalem artichoke, Helianthus tuberosus.*

INTRODUCTION

From a scientific point of view, there is a permanent search for new biological resources, which have the potential for maximum economic use and optimal ratio in terms of costs and efficiency of economic exploitation.

From our perspective, *Helianthus tuberosus* (taking into account, primarily inulin as the main component of its tubers) is one of those insufficiently exploited biological resources that can bring great benefits, given the possibility of being used as food - for humans and animals, as a source for pharmaceuticals and not at least as a source of biomass and biofuel.

Inulins are o type of polysaccharides found in various parts of plants as reserve carbohydrate (Roberfroid, 2005) usually as an alternative to starch. This class of fructans are involved also in biological processes of resistance to low temperatures (Niness, 1999). Considering their roles as energy reserve and as biological regulators in cold environment, inulins are found mainly in the bulbs, tubers, rhizomes and tuberous roots of the plants (Franck & De Leenheer, 2005).

Natural sources of fructans are many plants of mono and dicotyledonous families such as Liliaceae, Amaryllidaceae, Gramineae, and Compositae (more than 25,000 species) (Chi et al., 2011). Speaking specifically about inulins, this class of fructans is common and prevalent in Compositae family (Franck & De Leenheer, 2005).

The list of plants with a significant content of inulin (up to 22% of fresh weight), include among others: Onion (*Allium cepa*), Jerusalem artichoke (*Helianthus tuberosus*), Chicory (*Cichorium intybus*), Leek (*Allium ampeloprasum* L.), Garlic (*Allium sativum*), Globe Artichoke (*Cynara scolymus*, *Cynara cardunculus* var. *scolymus*), Banana, Rye (*Secale cereale*), Barley (*Hordeum vulgare*), Dandelion (*Taraxacum officinale*), Burdock (*Arctium lappa*), Camas (*Camassia* spp.), Murnong (*Microseris lanceolata*), Yacon (*Smallanthus sonchifolius*), Salsify (*Tragopogon porrifolius*), Agave (*Agave* spp.), Coneflower (*Echinacea* spp.), Elecampane (*Inula helenium*) (Franck & De Leenheer, 2005) and (Table 1) (Wouters, 2009).

Inulin was discovered by Rose Valentin in 1804 using boiling water extraction method on Elecampane (*Inula helenium*) prepared roots (Boeckner et al., 2001), it was detected by Julius Sachs in Jerusalem artichoke, Dahlia and Elecampane after ethanol precipitation (Franck & Levecke, 2012).

Contrary of most crops, which store carbon as starch, in *Helianthus tuberosus* L. carbon is stocked as inulin. Therefore, this have a definite consequence on the value and utility of the crop. A highly important attribute of inulin is its nutritional value, which is, however, under-exploited.

Table 1. Inulin content (percentage of fresh weight) in some edible plants (Stephen et al., 2006)

Source	Edible Part	Dry solids	Inulin
Onion	Bulb	6-12	2-6
Jerusalem artichoke	Tuber	19-25	14-19
Chicory	Root	20-25	15-20
Leek	Bulb	15-20[a]	3-10
Garlic	Bulb	40-45[a]	9-16
Artichoke	Leaves-heart	14-16	3-10
Banana	Fruit	24-26	0.3-0.7
Rye	Cereal	88-90	0.5-1.0[a]
Barley	Cereal	NA[b]	0.5-1.5[a]
Dandelion	Leaves	50-55[a]	12-15
Burdock	Root	21-25	3.5-4.0
Camas	Bulb	31-50	12-22
Murnong	Root	25-28	8-13
Yacon	Root	13-31	3-19
Salsify	Root	20-22	4-11

[a]Estimated.
[b]NA: data not available.
Source: From Van Loo, J., Coussement, P., De Leenheer, L., Hoebregs, H., and Smits, G., Crit. Rev. Food Sci. Nutr., 35, 525, 1995.

MATERIALS AND METHODS

We systematically searched ScienceDirect, Research Gate, DeepDyve Library, Academia, Wiley, NCBI, Google Schoolar and other databases for literature from 1980 to 2020 using the following search terms: "inulin", "*Helianthus tuberosus*" and "Jerusalem artichoke". From searches were selected 195 articles. Inclusion criteria were defined as: report on the obtaining, describing, analysing and use of inulin and *Helianthus tuberosus*; in English.

Papers were not considered if they presented literature review, if described clinical investigations, if reported only on the effects of inulin on the human body or specific diseases. Abstracts were reviewed to identify those relevant to the purpose of this review, for which the full papers were then obtained. In this way, 33 studies fulfilled the inclusion criteria for this review. Due to the range of largely different methodologies employed, it was not possible to apply a single quality assessment method to studies.

RESULTS AND DISCUSSIONS

Inulin

In nature, inulin is a mixture of polysaccharides composed of 20-30 fructose unit chains (linked by β-(2.1)-D-fructosyl-fructose bonds) of various lengths with a glucose molecule at the end of each fructose chain and produced by some plants. In garlic specifically it has a (2.1)-linked β-D-fructosyl backbone with (2.6)-linked β-D-fructosyl side chains (Chi et al., 2011) (Van Loo, 2012). A starting glucose moiety may be present, but not necessarily. Both GF_n and F_n compounds (where F is a fructosyl unit and G a glucosyl unit) are thus included under the same nomenclature (Stephen et al., 2006).

Because fructans are synthesized from sucrose by repeated fructosyl transfer from a fructosyl donor inulins, but not always, they have a terminal glucose unit. The enzyme generally considered to be involved in plant fructan synthesis is sucrose-sucrose fructosyl transferase (EC 2·4·1·99) which catalyses the transfer of a fructose molecule from one sucrose molecule to another, leading to glucosyl-1, 2 fructosyl-1, 2 fructose formation. Chain elongation is mediated by either 1F-or 6F fructan-fructan-fructosyl (EC 2·4·1·100) transferase leading to inulin (Kaur & Gupta, 2002).

One of the plants which has high content of inulin is Helianthus tuberosus, which is also exploited industrially, yet far from its economic potential.

Helianthus tuberosus L. inulin has only 20% of chains with a degree of polymerization longer than 10 (Franck & Levecke, 2012).

Helianthus tuberosus

Helianthus tuberosus L. is a flower plant of the family helianthus, native to cold areas, with large amount of inulin (14-19%) in its tubers. The extraction yield (98%) of inulin was obtained with dry *Helianthus tuberosus* L. powder (Yi et al., 2010) with medium-chain inulins (DP_{max}<40) (Van Loo, 2012).

The genus *Helianthus* L. include about 50 annual and perennial sunflower species (tribe *Heliantheae*). Jerusalem artichoke (*Helianthus tuberosus* L., syn. *H. serotinus* Tausch) and sunflower (*H. annuus* L.) are the only cultivated crops of this genus. *H. tuberosus* is a perennial plant species, distributed in all regions of the world including Romania, where it can be frequently found as a weed species of pastures and fallow or as ornamental plant. The tubers of *H. tuberosus* having high content of inulin, makes them interesting to produce sweeteners, low-caloric food products, supplements and beverages, and biomass and bioethanol (Radulovič & Dordevič, 2014).

Collections of *Helianthus tuberosus* L. cultivars have a tendency to be dispersed, resulting in duplication and naming confusions in identification of varieties. Two local cultivars originating in Romania are held by the University of Agricultural Sciences and Veterinary Medicine from Timișoara, Romania: "GURAHONT" ('ROM023-6150') and "SEBIS" ('ROM023-6151'), collected in 1989 (Kays & Nottingham, 2007).

Crop and growth

Helianthus tuberosus L. is cultivated in Europe and other parts of the world as a food crop and ornamental plant (Radulovič & Dordevič, 2014).

Because of specific responses of *Helianthus tuberosus* cultivars to planting dates for total dry mass, inulin content and inulin yield is pointed out the importance of choice for adaptation of *Helianthus tuberosus* L. varieties for the most convenient growing seasons which differ in temperature sums. Planting dates with warmer weather are beneficial as *Helianthus tuberosus* L. varieties grow better under these conditions producing and accumulating more inulin in tubers later growth phases. For a mean temperature sum of 2,965°C were obtained 70.9 g/plant as total dry weight, 67.0% of inulin content and 45.4 g/plant of inulin yield (Puangbut et al., 2012).

The collected data on total dry weight and inulin content of *Helianthus tuberosus* L. related to planting dates and temperature sums offer support for a definite choice of planting date for suitable processing of tubers as source of inulin for utilization as prebiotic and functional food (Puangbut et al., 2012).

Related to soil condition it is suggested to not cultivate *Helianthus tuberosus* L. in clay soil as the tubers are small and irregular and, hence, a lot of soil is attached to them (Wouters, 2009).

When *Helianthus tuberosus* start to germinate, sprouts emerge from the "seed" tuber. In six weeks, the number of sprouts reach a maximum (for ~9 per plant), and then decrease by ~30% by the end of the growing season. In the 4th week after planting, fully expanded leaves and small branches begin to be formed on the shoots. Leaf number increase, reaching a mean of ~500 leaves per plant in the 20th week after planting and then abruptly decline, by the end of November.

The number of branches develop gradually from the early phase of the growth, up to approximately 60 branches per plant by the end of the season, having greatest growth in branches per plant between 6th and 8th weeks. The first stolon emerges at the base of the plant preceding the 8th week after planting; in the 8th week there are approximately 16 stolons per plant.

The most rapid rise in number of tubers is between 14th (24 tubers) and 16th week (68 tubers) and with maximum in the 24th after planting (85.5 tubers per plant) (McLaurin et al., 1999).

Helianthus tuberosus L. shows a significantly high inulin content (14-19%) (Franck & Levecke, 2012); its inulin metabolism is very sensitive to cold.

Table 2. Content of soluble inulin and Dp_N of inulin in early varieties 'Bella', 'Bianka', also in Middle Early Varieties 'Topstar' and 'Gigant' (Kocsis et al., 2007)

Harvest time		'BELLA'		'BIANKA'		'TOPSTAR'		'GIGANT'	
weeks (*after planting*)	temp-sum [°C]	inulin [g/100 g]	Dp_N of inulin average	inulin [g/100 g]	Dp_N of inulin average	inulin [g/100 g]	Dp_N of inulin average	inulin [g/100 g]	Dp_N of inulin average
14	1733	53.5±0.4 a	11.6±0.8 ab	63.5±0.5 a	11.2±0.1 ad	57.5±0.6 ab	12.5±0.1 ac	61.9±0.1 a	13.2±0.1 ab
17	2138	55.2±0.6 a	11.9±0.2 ab	63.0±0.9 ab	12.2±0.1 ab	58.2±0.3 a	15.1±0.3 b	58.4±0.3 bcd	14.4±0.9 a
19	2444	54.8±0.8 a	13.2±0.1 b	62.5±0.2 ab	13.2±0.1 b	60.9±0.7 a	13.2±0.2 ab	57.7±0.7 c	13.1±0.8 ab
22	2823	54.2±0.9 a	10.5±0.3 a	58.3±0.3 b	13.1±0.4 b	56.3±0.9 abc	12.4±0.1 ac	59.6±0.5 d	13.4±0.7 ab
25	3053	49.2±0.3 b	9.9±0.3 a	47.7±0.8 c	10.5±0.9 a	55.0±0.6 abc	10.3±0.3 c	55.9±0.2 e	10.9±0.4 b
29	3282	44.4±0.5 c	6.7±0.9 c	43.4±0.2 d	8.6±0.1 c	50.6±0.4 bc	6.5±0.1 d	52.4±0.4 f	7.4±0.1 c
33	3328	32.8±0.4 d	5.3±0.3 c	45.2±0.7 cd	10.0±0.9 cd	49.7±0.8 c	5.5±0.1 d	41.3±0.3 g	7.7±0.2 c
44	3476	37.6±0.8 e	5.6±0.1 c	35.2±0.5 e	6.5±0.1 e	41.5±0.5 d	6.5±0.2 d	31.4±0.6 h	7.4±0.3 c
47	3578	30.8±0.4 d	5.5±0.2 c	35.3±0.6 e	6.3±0.2 e	39.5±0.4 d	6.8±0.4 d	30.0±0.2 h	7.7±0.2 c

Helianthus tuberosus L. inulin has 20% of chains with a DP >10 (Table 3) (Stephen et al., 2006).

Considering a test of 37 varieties of Helianthus tuberosus was found that fructose/glucose ratios of *Helianthus tuberosus* L. cultivars shows high ratio for 'MEDIUS', 'GRANDO' and 'FAUCHO' (Chekroun et al., 1996).

Table 3. Yield and inulin content of Dahlia, Jerusalem Artichoke, and Chicory (Stephen et al., 2006)

	Dhalia	J. Artichoke	Chicory
Roots or tubers (tons per ha)	25	35-60	25-75
DM[a] (%)	15-22	19-25	20-25
Inulin (%)	10-12	14-18	15-18
Inulin (tons per ha)	2.5-3.0	4.5-8.5	5-11
Mean DP[b]	13-20	6-10	10-14

[a]DM: dry matter.
[b]DP: degree of polymerization.

A high content (60-65% of dry mass DM) of inulin was found in early harvested cultivars ('BELLA' and 'BIANKA') and middle early cultivars ('TOPSTAR' and 'GIGANT') harvested 22-25 weeks after plantation. In late cultivars ('WALDSPINDEL', 'VIOLET DE RENNES', 'ROTE ZONENKUGEL') a similar amount was obtained (55-60% of DM) when harvested 29-33 weeks after planting.

There was a specific effect on maturing process as well as extreme cold period modifications which resulted in transformation of high polymer inulin to low polymer inulin as well as to sucrose. The highest yield for tubers of early cultivars was found to be at the end of September with 17.5 t/ha of DM and similar level of yield for middle late and late cultivars was achieved at the end of November/(Table 2) (Kocsis et al., 2007).

Table 4. Content of inulin in three varieties of *Jerusalem artichoke* tubers (g/100 g fresh weight) (Bach et al., 2012)

Harvest time (week)	'MARI'	'DRAGA'	'REMA'
30	9.6	10.7	11.9
38	9.8	10.6	12.0
46	10.3	10.2	11.3

The content of inulin was constant across the three harvest times for all varieties (Table 4); It is known that inulin degrades into polymers of shorter chain length during hibernation (Bach et al., 2012).

A decrease in the more polymerised fractions (degree of polymerisation, DP>10) with an increase in fructose and sucrose composition was observed for late harvested (20 weeks) tubers (Praznik & Beck, 1987). The inulin DP distribution profile from tubers (Figure 1), stored at 2 and 5°C, significantly changed with increased storage time and temperature. Sucrose and DP 3-10 fractions increased while DP>10 decreased, particularly after 4-6 weeks of storage. Storage of *Helianthus tuberosus* L. tubers at low temperature (4°C) for 34 days also increases the fructo-oligosaccharide content (Saengthongpinit & Sajjaanantakul, 2005).

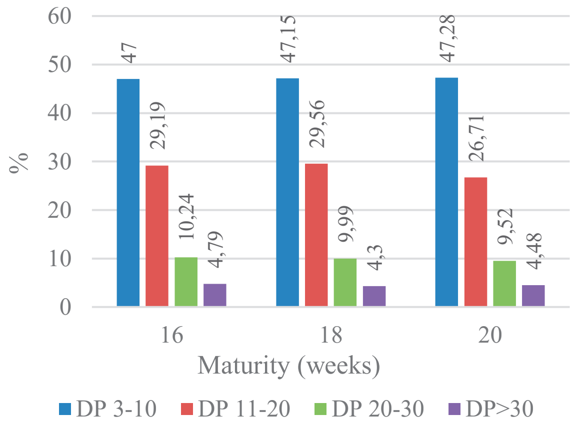

Figure 1. Relative percentage composition of inulin of *Helianthus tuberosus* L. tubers with different maturity (*DP - degree of polymerisation*)

Drying of J. artichoke tubers for storing, resulted in good performance with high quality product in terms of drying time (DT), effective moisture diffusivity (EMD), and rehydration ratio (RhR). Models developed by response surface methodology (RSM) and genetic algorithms (GA) displayed similar performances to predict the experimental results determined for each interested response; optimization procedure by RSM was conducted for all responses as a function of processing conditions. The EMD and RhR were maximized, since higher values of these responses means faster drying and better product quality, respectively. The DT response was minimized because a short process length is preferred due to economic considerations. As a result of the optimization procedures for these three drying characteristics, the following operating conditions were found to be optimal: power of 235 W; slice thickness of 5.95 mm; and NaCl concentration of 0.081 (Karacabey et al., 2016).

Stored at different relative humidity, powder products can be physically transformed (i.e. crystallisation) and because of this effect, the measurement and control of water content of inulin during storage and quality control requires correct analytical techniques for determination in order to prevent such negative effects. Given the above the inulin powder is the most reliable form for commercial inulin, having the advantage of facilitating packing, storage and transport (Ronkart et al., 2006).

Nutritional, pharmacological and medical value of inulin

Helianthus tuberosus L. tubers have been utilized as a subsistence crop at various times and in diverse places; from this plant some parts of the plant are not used in human diet. With issue about the rising occurrence of obesity and diabetes, the dietary intake of inulin-containing products derived from *Helianthus tuberosus*, should offer major health enhance. Generally, inulin is used for its consistency and sweetness for replacement of sugar and fat, to boost texture, taste and organoleptic qualities of the foods.

Tubers of *Helianthus tuberosus* are used in the human diet and above-ground parts and tubers are used as animal feed as well (Radulovič & Dordevič, 2014).

Inulin has large applications in various types of food products like confectionery, fruit preparations, milk desserts, yogurt and fresh cheese, baked goods, chocolate, ice cream and sauces (Chi et al., 2011).

The main sources of inulin and oligofructose that are used in the food industry are chicory and *Helianthus tuberosus* L.

Inulin provides various useful nutritional and pharmacological benefits to humans and animals (Table 5) (Franck & Levecke, 2012).

The use of inulin and by-products in the food industry are in constant development, and the main advantages and nutritional interests of these products are widely discussed and analysed in the literature.

Inulin and oligofructose are considered as functional food ingredients since they influence physiological and biochemical processes in human beings and animals, generating better health and reduction in the risk of many diseases (Kaur & Gupta, 2002).

Products obtained from *Helianthus tuberosus* have some pharmacological effects: (a) antioxidant effect of leaves n-butanol and ethyl acetate extracts also ethanol extracts of tubers, (b) anticancer effect of methanol extracts, (c) antidiabetic effect of tubers, (d) antifungal effect of crude extract or n-butanol fraction of leaves (Al-Snafi, 2018).

Table 5. Physiological properties of inulin (Franck & Levecke, 2012)

Strong evidence:
• Nondigestibility and low caloric value (1-1.5 kcal/g) • Suitable for diabetics • Soluble dietary fiber • Stool bulking effect: increase in stool weight and stool frequency, relief of constipation • Modulation of the gut flora composition, stimulating beneficial bacteria (Bifidobacteria) and repressing harmful ones (Clostridia): prebiotic/bifidogenic effect • Improvement of calcium (and magnesium) bioavailability
Promising evidence:
• Reduction of serum and liver triglycerides and serum insulin levels • Reduction of colon cancer risk (in animal models) • Modulation of immune response and resistance • Protection against intestinal disorders and infections • Improved well-being metabolism,

For extracts from *Helianthus tuberosus* have been reported a lot of biological activities as antimicrobial and cytotoxic properties; also folk medicine use preparations for the treatment of diabetes and rheumatism, for aiding digestion and preventing constipation, or as a diuretic. (Radulovič & Dordevič, 2014).

Experimental studies have shown fructans and inulin particularly benefits as bifidogenic agents, improving the immune system, lowering the activity of pathogenic bacteria in the intestine, relieving constipation, reducing the risk of osteoporosis by increasing mineral absorption (Kuntz et al., 2013), decreasing the risk of atherosclerosis by lowering the synthesis of triglycerides and fatty acids. Fructans modulate the hormonal level of insulin and glucagon, thereby regulating carbohydrate and lipid metabolism by lowering the blood glucose levels. Inulin and oligofructose also reduce the incidence of colon cancer (Kaur & Gupta, 2002).

Because of the β-(2→1) configuration of the fructosyl-fructose osidic linkages, inulin resist digestion in the upper gastrointestinal tract but are fermented in the colon. For these phenomenon, they are definitely part of the dietary fibre complex (Roberfroid, 2005).

Other parts of *Helianthus tuberosus,* especially the leaves show antipyretic, analgesic, anti-inflammatory effects and for this reason leaves are used as folk medicine in China for the treatment of fractures, skin wound, swelling and pain (Yuan et al., 2013).

Moreover, the stalks and leaves of this plant were also found to possess various biological activities including antimicrobial, antifungal and anticancer activities. Sesquiterpene lactones were presented as the major active component of the aerial parts of *Helianthus tuberosus* and cytotoxic activities of these compounds were subsequently tested against the MCF-7, A549 and HeLa cancer cells lines. The results showed that sesquiterpene lactones exhibited persistent cytotoxicity against all three cancer cell lines and flavones showed selective inhibitory action against HeLa cell lines (Yuan et al., 2013).

Inulin processing

Microwave-assisted extraction (MAE) has been studied as a potential alternative to traditional solid-liquid extraction for the isolation of inulin yield. MAE shows considerably higher and better extraction yield than traditional method under optimum conditions. Use of aqueous phase leads to rapid energy transfer between polar molecules. The parameters were optimised using RSM and the optimum values for solid: liquid ratio, microwave power, temperature and time were found to be 1:40, 400 W, 90°C and 30 min (Table 6) (Kulathooran Ramalakshmi, 2014).

Table 6. Comparative analysis of MAE and conventional extracts (Kulathooran Ramalakshmi, 2014)

Exp. Set	Method of Extraction	Parameters	Inulin Yield, %
I	Conventional heat reflux method of extraction	Time (30 min) Temperature (at boiling) Solid: Liquid ratio (1:40)	51.20 ± 0.14a
II	Microwave-assisted extraction (MAE)	Time (30 min) Temperature (90°C) Power (400 W) Solid: Liquid ratio (1:40)	63.00 ± 0.04b

Values are Means ± SD of triplicates.

The analysis of microwave power and extraction time on the inulin yield and extraction efficiency shows the highest yield (39.61 and 36.38%) of purified inulin observed with (700 W/5 min & 450 W/14 min) respectively, with no significant differences between them ($P<0.05$). Regarding the extraction an efficiency (EF), the highest EF

(94.34%) achieved with 700 W/5 min, followed by 450 W/8 min (86.62%) and 350 W/14 min (80.64%). There were reported that the highest EF of inulin was recorded at 80˚C/90 min. using conventional heat reflux method (Gaafar et al., 2010). The high temperatures in closed vessels extraction by MAE resulted in higher extraction performance. While the surface tension and solvent viscosity will decline as temperature increases, consequently the efficiency of the inulin extraction will rise (S. ch. Abood & Alabadi, 2020).

For concentration of the solution the precipitation process can be optimized by measuring the soluble solids concentration in the precipitated inulin. The best centrifuge velocity and time values, would be keeping the concentrated solution at a temperature of -24 °C followed by centrifugation at a velocity of 10,000 rpm for a time interval of 15 min (Leite et al., 2007).

Inulin from *Helianthus tuberosus* is used to obtain ethanol, fructose, single cell oil production (SCO) and ultra-high fructose syrup (Chi et al., 2011).

Helianthus tuberosus L. is suitable for biorefinery applications due to high biomass production and limited cultivation requirements. For economic profit, the products of highest economical value from the crop have to be defined for a biorefinery utilization of the crop (Johansson et al., 2015).

Inulin is a better material for high concentration ethanol production than starch, cellulose and xylan. In order to go through this bioprocess two phases are needed, in the first one an enzyme, the exo-inulinase, catalyses removal of the terminal fructose group from the non-reducing end of the inulin molecule in one step, producing fructose and glucose units, which can be easily converted into ethanol by S. cerevisiae in the second step (Chi et al., 2011).

Fructose can also be obtained by acid hydrolysis of inulin, but fructose is easily degraded at low pH and the process gives rise to colouring of the inulin hydrolysate and by-product formation in the form of difructose anhydrides. An easier, direct, cheap and quicker alternative could be enzymatic hydrolysis of inulin. This method includes microbial sources, which secrete high amount of inulinase and can produce fructose from inulin by a single step catalysed reaction with yields up to 95% of fructose (Chi et al., 2011).

For SCO *Rhodotorula mucilaginosa* TJY15a was isolated from surface of marine fish and it could accumulate 47.9% (w/w) oil from hydrolysate during batch cultivation, whereas 52.9% (w/w) of lipid was obtained during the fed-batch cultivation (Li et al., 2010a).

In order to know if inulin and extract of *Helianthus tuberosus* L. tubers can be used as the substrates for single oil cell production by *R. mucilaginosa* TJY15a, inulin and extract of *Helianthus tuberosus* L. tubers were hydrolysed by the recombinant exo-inulinase produced by the recombinant *P. pastoris* X-33 Then, the hydrolysates of inulin and extract of *Helianthus tuberosus* L. tubers were used as the substrates for SCO production by *R. mucilaginosa* TJY15a. It was found that *R. mucilaginosa* TJY15a could accumulate 48.8% (w/w) oil from hydrolysate of inulin and its cell dry weight reached 14.8 g/l during the batch cultivation while it could accumulate 48.6% (w/w) oil and 52.2% (w/w) oil from hydrolysate of extract of *Helianthus tuberosus* L. tubers and its cell dry weight reached 14.4 g/l and 19.5 g/l during the batch and fed-batch cultivations, respectively. Over 87.6% of the fatty acids from the yeast strain TJY15a cultivated in the hydrolysate of extract of *Helianthus tuberosus* L. tubers was C16:0, C18:1 and C18:2, especially C18:1 (54.7%) (Zhao et al., 2010a). Therefore, the results show that hydrolysates of inulin and extract of *Helianthus tuberosus* L. tubers were good materials for single cell oil production (Chi et al., 2011).

There have been revived interests in edible films made of renewable and natural resources. Compared to other traditional edible films, *Helianthus tuberosus* L. derived edible films have several advantages in free of animal disease and heavy metals, environment friendly and low cost. The most important feature of inulin in film forming is its hygroscopic property and capability to maintain water (Li et al., 2013).

An important factor in design and scale-up bioprocesses which involve use of inulin and *Helianthus tuberosus* extracts is the rheological characteristics of the material. So, there were conducted studies on solutions of inulin.

Extracted solution concentration process has resulted in a concentrated inulin solution with 28 °Brix of soluble solids concentration. This material presented a rheological behaviour of a highly pseudoplastic fluid, with high resistance to flow at low pressure rates followed by a breakdown of the structure when the pressure rate increases, originating low apparent viscosity values and a tendency to linear behaviour. The rheological behaviour of the inulin-concentrated solution with 28°Brix of soluble solids can be defined by Power Law, Herschel-Buckley, Casson or Cross rheological equations. The apparent viscosity of the inulin-concentrated solution increases when temperature increases between 25 and 53°C, corresponding, according to the Arrhenius equation. For a measuring temperature of 60°C, the apparent viscosity is higher, possibly as a result of of the hydrolysis of high molecular weight components. The inulin solutions prepared at the concentrations of 12.5, 16 and 19.5°Brix presented a pseudoplastic behaviour, which can be represented by the Power Law model. The consistency index of the Power Law equation heightened with the rise of the measurement temperature and the soluble solids concentration. The effect of temperature on the consistency index can be described by the Arrhenius equation, with high activation energy values, showing a strong relation between the consistency index and the temperature (Toneli et al., 2008).

CONCLUSIONS

The *Helianthus tuberosus* L. is adapted to both high and low technology and inputs, but as a crop plant, the *Helianthus tuberosus* L. has stagnated behind the traditional crop plants. The global production of *Helianthus tuberosus* is not monitored by the Food and Agriculture Organization in its annual statistics of agricultural crops. However, the necessity for inulin is rising, mainly within the food industry. Also, the need to reduce the effects of global climate change have pushed high interest in alternative fuels and energy sources, including biofuels. *Helianthus tuberosus* L. is one of the appropriate plants which yield large quantities of biomass, is fast growing, needs relatively few inputs in terms of pesticides, fertilizer, and water, and can be grown on marginal land; therefore, it is an useful crop for obtaining biofuel, and in particular bioethanol. We consider that, in addition to the development of *Helianthus tuberosus* cultures, the development of *Helianthus tuberosus* processing technology in accordance with the economic potential will be an important future area.

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