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Physico-chemical Properties of Inulin Produced from Jerusalem Artichoke Tubers on Bench and Pilot Plant Scale

[1]Azza A. Abou-Arab, [2]Hala.A.Talaat, [1]Ferial. M. Abu-Salem

[1]Department of Food Technology, National Research Centre, Dokki, Cairo, Egypt.
[2]Department of Chemical Engineering and Pilot Plant, National Research Centre, Dokki, Cairo, Egypt.

Abstract: Phyisco-chemical properties of inulin produced from Jerusalem artichoke tubers were studied. Inulin was light gray powder, natural taste, pH 6.0, soluble in water and low viscosity in solution. Water oil absorption index of inulin powder considered a good indicator for excellent oil absorption. Foam capacity (FC) and (FS) stability have been studied, at 120 min under pH 6.0, the foams of inulin in their maximum stabilities on bench or pilot plant scale, respectively. Emulsion capacity has been investigated and should high value at pH 6.0. The produced inulin has the following ingredients. The reducing sugars (4.90 – 5.21%), total carbohydrates (94.27-96.18%) and inulin content (90.97 & 89.47%). Inulin contains a high level of micro-elements: Zn, Fe and Mn, macro-elements: K, Ca, Na and P. Functional groups of inulin were known by FT-IR Spectrum. Qualitative and quantitative analysis of trace elements in the inulin powder by X-ray Fluorescence were studied.

Key words: Inulin; Jerusalem artichoke tubers; pilot plant production; physico-chemical properties; function properties; instrumental analysis

INTRODUCTION

Inulin is natural food ingredients commonly found in varying percentages in dietary foods more than 36,000 plant species as plant storage carbohydrates contain inulin such wheat, onion, bananas, garlic, asparagus and chicory (Carpita et al., 1989). Although today, chicory is the major crop used for the industrial production of inulin, Jerusalem artichoke tubers with 14-19 % inulin can be a valuable source of inulin too (Van et al., 1995), it contains 11 – 20% of carbohydrates where 70-90 % are represented as inulin and inulids (Rosa et al., 1986). The inulin powder typically contains 6-10% sugars represented as glucose, fructose and sucrose (Berghofer and Reiter, 1997). On the other hand, (Yamazaki et al., 1989) reported that inulin is a polysaccharide consists of 80 % fructose and 20 % glucose.

Inulin is a linear polymer of D- fructose joined by ß (2 → 1) linkages and terminated with a D- glucose molecule linked to fructose α (2 → 1) bond, as in sucrose (Modler et al., 1993). Inulin, a non-digestible oligosaccharide, can preferentially stimulate the growth and activity of one or a limited number of desired bacteria in the colon, and thus improves host health (Gibson and Roberfroid. 1995). And more, positive effects on blood glucose attenuation, lipid homeostasis and mineral bioavailability (Niness, 1999).

The inulin properties from Jerusalem artichoke tubers were total carbohydrates content on dry matter 99.51 % min., inulin (dry matter) 90.0 % min., free sugars 10 % max., ash (dry matter) 0.5 % max. and moisture 3.5 %. Inulin is mostly often commercialized as a powder product. It's color varying from white to grey depending on the purification degree. This powder does not have smell and practically no flavor (Fuchs, 1993).

From a technological point of view inulin is very suitable for drinks, because of it's moderately water solubility. (Franck, 1999). In addition, most inulin products used as "bulking agents" are found in a variety of products, including chewing gums, confectioneries, baking mixes, meat products (Berghofer and Reiter, 1997).

Several methods for inulin extraction from Jerusalem artichoke have been developed. A pretreatment step involving boiling water-extracting for 10-15 min of the ground tubers had been used (Laurenzo et al., 1999). Precipitation by alcohol is efficient and widely used laboratory; however, it was deemed uneconomical and unsuitable on an industrial scale (Luque- Garcia and Luque de Castro, 2003).

The industrial production process has been applied through diffusion in hot water followed by refining using exchanger technology then concentrating using evaporation and spray drying. (Franck, 2002).

Corresponding Author: Azza A. Abou-Arab, Department of Food Technology, National Research Centre, Dokki, Cairo, Egypt.
E-mail: drazza_nrc@yaoo.com

The objective of the present study is the production of some sweeteners (inulin) from untraditional sources of low calorie, such as Jerusalem artichoke tubers for diabetic and weight loss purpose with studying the physico-chemical properties of inulin produced on bench and pilot plant- scale. The physical properties estimated were pH value, appearance, flavor, taste, sweetness, solubility, color and viscosity. The function properties estimated were water and oil absorption, foam capacity (FC) and stability (FS), oil emulsion capacity (EC) and stability (ES), as well as instrumental analysis of inulin (Infrared spectroscopy (IR) and X-ray Fluorescence).

MATERIALS AND METHODS

Materials:

Jerusalem artichoke tubers *(Helianthus tuberosus)*, that harvested in October 2009 were provided from the Experimental Station, Agricultural Research Centre, El-Kanater El-Khayria, Egypt. Inulin was isolated from the tubers of Jerusalem artichoke in the Laboratory of Food Science and Technology, Food Technology Department, Food Technology and Nutrition Division, National Research Centre (NRC) and has been processed to produce the sweeteners (inulin) on pilot plant scale in Chemical Engineering and Pilot Plant, Department Engineering Research Division, NRC.

1- The raw material used in experiments is the Jerusalem artichoke tubers (gerasole or *Helianthus tuberosusi*) with chemical composition expressed by g/100g dry weight: inulin (12.05-12.48), Total carbohydrates (16.75-17.79), Total soluble sugar (13.34-13.75), Total non-soluble sugar (3.41-3.78), Reduced sugar (0.181-0.185), Non reduced sugar (13.13-13.82), N2 content (1.44-1.49), Phosphorus content (0.400-0.478) mg/kg, Potassium content (0.139-0.152) mg/kg, Ash (5.31), Lipid (0.10), Fibers (4.99).

2-Standard solutions of metals lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), cobalt (Co), zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), potassium (K), calcium (Ca) and sodium (Na) were provided by (Merck, Darmstadt, Germany).

3- Phenol & 3, 5 dinitrosalicylic acid (DNS), ammonium molybdate and ascorbic acid were obtained from Sigma Chemical Co. (St. Louis, MO).

4- corn oil was purchased from local market.

5-Coconut activated carbon: granules 2 mm diameter, surface area 1500 m^3/g, bulb density 500gm/lit, moisture content 3-5% max., pH 6-8, nodine absorption 1060 mg/g, hardness 99% and ash content 2%.

Methods:

Preparation of Jerusalem Artichoke Tubers:

The samples of Jerusalem artichoke tubers were washed with tap water to remove dust and other undesirable materials. The cleaned tubers peeled and cut into slices. In order to avoid enzymatic browning, the slices were dipped in boiling water acidified with ascorbic acid (0.1% w/w) and boiling 2-3 min if a very light powder is required, then, the slices was kept in polyethylene bags and stored in freezer at -10 ºC until used (Tchone et al., 2005).

Extraction of inulin on Bench- Scale:

About one kilogram from Jerusalem artichoke tubers was transferred into a Warring blender and blended with five-fold excess of hot water (70 ºC). The blended mixture was allowed to stand for 60 min. at 70 ºC with constant stirring. The suspension was filtered and residue was re-extracted using the same steps (Ezz El-Arab et al., 2003). The filtrates from the two extractions have been cooled and the liquor was saved for subsequent analysis. The filtrate was treated with active charcoal to adsorb the mono- and disaccharides. Then the filtrate has been dried by spray- drying

Preparation of Tubers by Washing and Cleaning:

Weight of raw tubers = 1000 gm; Weight loss = 240 gm

1st Stage of Extraction:

By using 5 liters water (70ºC) and adding it to the blended tubers and continuous mixing for one hour; Weight of residue after the first extraction = 334.7 gm; Extract volume after the first extraction = 4770 ml and the suspension is filtered and the residue is directed to the second stage.

2nd Stage of Extraction:

By using 5 liter water (70^{o}C) and adding it to the residue produced from the 1st stage and continuous mixing for one hour; Weight of residue after the second extraction = 265.1 gm; Extract volume after the second extraction = 4600 ml and concentration of inulin the extract = 64.6 gm/lit.

The filtrates produced from the two stages have been collected and treated by percolating through activated charcoal to adsorb mono and disaccharides then dried with freeze –dryer (Dura Dry, USA) to produce about 150 gm inulin powder /kg Jerusalem artichoke tubers.

**** Extraction of Inulin on Pilot Plant Scale:***

Inulin was extracted from the tubers of Jerusalem artichoke (Franck, 2002). The technology had been carried out to produce two products. The first product is the extracted inulin from Jerusalem artichoke tubers through diffusion in hot water followed by refining using ion exchanger's technology and concentration using evaporation and spray drying. The standard inulin could be transferred to high performance inulin by adding one step further operation before spray drying to remove degree of polymerization (DP's).

The pilot plant experiments for Inulin extraction have been performed according to the block flow sheet shown in Fig (1) using the following equipment:

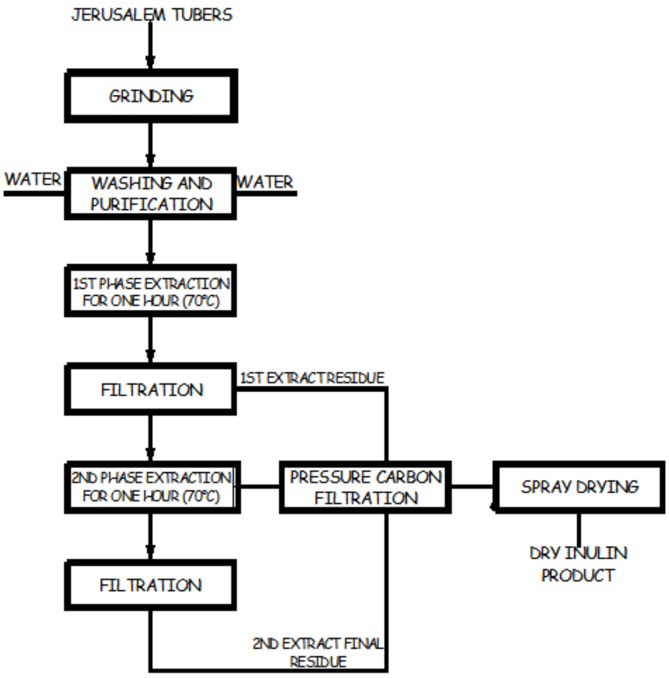

Fig. 1: Block Flow Sheet For Pilot Plant Production Process of Inulun From Jerusalem Artichhoke Tubers

1- Reactor:

Reactor volume is 250 liter lined with epoxy with a stirrer (100 rpm) and provided with steam jacket and a thermostat to maintain the temperature constant during the extraction process.

2- Notch-Filter:

The filter used to separate the residues from the filtrate is 50 cm diam with orifices 5mm covered with 2 layers cloth as filter medium.

3- Pressure carbon filters:

The carbon adsorption process has been performed through carbon adsorption stages in a filtration system containing the following components:-

- Tank with volume 1 m^3 made of steel lined with epoxy.

-Two pressure filters with two dish ends, 45 cm diam and 120 cm height provided with inner distributor and nozzles for filtrate percolation. Each filter is filled internally with 1 m height activated carbon bed with the prementioned specifications.

- Two pumps (1 m^3/hr) (one operating and one standby) to transfer the filtrate produced by filtering the extracted suspension to the activated carbon adsorption process.

4-Rota-Vapor:

The solution has been concentrated by Rota vapor apparatus. The Rota Vapor is provided with the following components: (feed flask capacity 20 liters, temperature up to 90°; 2 receiver flasks each 5 liters and condensers, vacuum up to 600 torr).

5-Spray Dryer:

The spray dryer converts the mixture from solid and liquid to dry particles with different sizes with respect to operating parameters via liquid evaporation with hot air at different temperatures. The spray dryer used to produce dry inulin from the filtrate obtained from pressure carbon filters has the following specifications (Feeding tank 100 lit, Water tank 7 lit, Inlet temp. 200 – 350 ºC, Outlet temp. 90 – 120 ºC) provided with control panel to control the operating system automatically.

Analytical methods:

Physical analysis:

Determination of pH value: The pH values of inulin sample were measured using pH meter (model Cyber Scan 500) as according to the procedure of (Kotula et al., 1976) Appearance, flavor, taste and sweetness: The inulin samples were determined according to (Berghofe et al., 1993). Solubility: Inulin solubilities was determined (Leite, 2004) by using 5 gm sample per 100 ml of water at temperature about 25 ºC. Determination of color: The color was measured by using a Hunter Lab. Model D25 color and color difference Meter (Hunter, 1958). This color assessment system is based on the Hunter L*-, a*- and b*- coordinates. L*- representing lightness and darkness, + a*- redness, - a*- greenness, + b*- yellowness and - b*- blueness with white Tile of Hunter Lab color standard: (L= 92.56, a= -0.87 and b= -0.15). Determination of Viscosity: using the Brookfield rotational viscometer, using No.4 spindle at 20 rpm. (Model DV III programmable Rheometer U.S.A) at 27.5 ºC and at different shear rates (Hayta et al., 2002).

Chemical analysis:

Moisture, protein, fat, ash and fiber were determined according to the methods described in the AOAC (2000). Total carbohydrates: were determined by the phenolsulphoric acid method of Dubois et al., (1956). Reducing sugars: were estimated by 3, 5- dinitrosalicylic acid (DNS) method using D-fructose (Mw= 180.16) as standard (Miller, 1959). The inulin content: was measured with the difference between total carbohydrates and reducing sugars (Lingyun et al., 2007). Minerals: Determination of micro-elements: copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), lead (Pb), cadmium (Cd), chromium (Cr), cobalt (Co) were carried out according to AOAC methods (2000). A Perkin-Elmer (2380) atomic absorption spectrophotometer. Macro-elements: The flame photometer was applied for potassium (K), calcium (Ca) and sodium (Na) determination according to the methods described by Pearson (1976). While spectrophotometric method was used for determination of the phosphorus (P) content of the tested samples using ammonium molybdate as outlined in the AOAC (2000).

Functional properties:

Water and oil absorption: were determined according to the method of Adebowale et al. (2005). The results calculated as gram water or corn oil (d= 0.9 g/ml) absorbed by 100 g dry sample.

Foam capacity (FC) and stability (FS):

were determined according to the method of Makri et al. (2005). Foam capacity (FC) was measured in terms of volume increase on whipping expressed as percentage of original volume of the liquid. Foam stability (FS) was expressed as percentage of foam volume remaining, in relation to initial foam volume at room temperature (25 ± 2°C) after 5, 15, 30, 50, 60and 120 min.

$$\text{Foaming capacity (\%)} = \frac{\text{Vol. after homogenization- Vol. before homogenization} \times 100}{\text{Vol. before homogenization}}$$

$$\text{Foam stability (\%)} = \frac{\text{Foam volume after time (t)} \times 100}{\text{Initial foam volume}}$$

Oil emulsion capacity (EC) and stability (ES):

Oil emulsifying capacity (EC) was evaluated in 100 ml of 1% (w/v) aqueous dispersion of each sample at pH values of 4.0, 5.0, 6.0, and 7.0 by titrating with corn oil to the break point of the emulsion (Naczk et al., 1985). Emulsifying capacity (EC) was expressed as ml oil emulsified by 1 g dry sample. The emulsion stability (ES) was recorded (25 ± 2°C) in term of the intervals of 25 min, 1, 2, 3, 24 and 48 h (Dipak and Kumar, 1986).

Instrumental analysis:

Infrared Spectroscopy (IR):

Fourier – transform infrared (FT-IR) spectra were obtained on a Nicolet Company, USA. The instrument was operated at the following conditions: Infrared spectrum, Nexus 670, FTIR spectrophotometer, the range: 4000-400 cm^{-1}., at a resolution of 4 cm^{-1}. The samples (2 mg) were pressed into pellets of potassium bromide (KBr) (200 mg), FT-IR. Spectrophotometer available at the Central Services Lab. of Infrared analysis Lab., (NRC) was used for analysis. The functional groups were identified (Dyer, 1965).

X- Ray Fluorescence:

The X- ray Fluorescence pattern was obtained in an AXIOS WD- XRF, sequential Spectrometer (P analytical, 2005). Experiments were carried out in the Central Services Lab. of X -ray Fluorescence analysis (NRC). The pressed powder samples were prepared through mixing fine powder sample with binding wax then pressing automatically. The yielded disk spacemen was used in qualitative and quantitative analysis of trace element (Kalnick, 1986).

Statistical analysis:

Data were subjected to statistical analysis using computerized analysis of variance and Duncan's multiple range test procedures (SAS, 1998). Mean values of three replicates of each test were recorded

RESULTS AND DISCUSSION

The mass balance results obtained from the investigations for inulin production from Jerusalem artichoke tuber which had been carried out according to the pre-mentioned methods are illustrated in Table (1) for bench scale and pilot scale experiments.

Purification by activated carbon has been performed then drying with spray drier produced about 660 gm inulin powders.

Table 1: Mass balance for bench and pilot plant production of Inulin from Jerusalem artichoke tubers (JAT)

	Bench	Pilot plant (I)	Pilot plant (II)
Weight of JAT, kg	1	15	10
Moisture content, % (Fresh JAT)	70.72	70.72	70.72
Moisture content, % (after boiling)	86.87	86.87	86.87
Weight of tubers before first extraction , kg		12.468	9.552
Weight of tubers before second extraction , kg		10.385	7.925
Volume of liquor product, lit	9.37	125	84
Weight of inulun powder, gm	150	992	660

Physical analysis:

Inulin produced from Bench and Pilot plant- scale tests has been examined for potential food use; examination for Jerusalem artichoke inulin shows similar physico-chemical properties of both scales except pH value Table (2).

Color of inulin sample obtained of both produced types is light grey and looked like a powder is light grey. It has a neutral taste, without any off –flavor or aftertaste and important properties of use in foodstuffs. It is moderately soluble in water inulin is insoluble in cold less sweetness than sugar (sucrose). The pH ranges 6.70 – 6.99. The solubility of inulin is one of the most water and swells in it. This it appropriate for applications in the food industry. Fat and carbohydrate replacement with Jerusalem artichoke inulin could offer the advantage of not compromising taste and texture. Similar results reported (Molina et al., 2005) and (Fuchs, 1993) who showed that the inulin is a powder, varying its color from white to grey depending on the purification degree.

Table 2: Some physical properties of inulin powder produced from Jerusalem artichoke tubers on Bench- scale and Pilot-plant scale.

Items	Physical properties of inulin powder	
	Bench- scale	Pilot-plant scale
Color	Light grey	Light grey
Taste	Neutral	Neutral
Flavor	No off flavor	No off flavor
Sweetness (v. sucrose= 100 %)	None	None
pH value	6.70	6.99
Solubility (at 25 ºC)	Moderately	Moderately

Results in Table (3) indicate that the color values of inulin produced from Bench- scale were better than those for inulin produced from Pilot plant-scale, as shown by a higher value for (L) and slightly yellow, especially the acidified spray-dried powder. The acidification results in a clear positive effect, the powders are brighter and slightly yellow (Berghofer and Reiter, 1997) tuber produced by spray-drying was substantially improved by heating the whole tubers prior to maceration. This serves to inactivate polyphenol oxidase, responsible for the undesirable brown color development (Modler et al., 1993).

Table 3: Hunter color values of inulin powder produced from Jerusalem artichoke tubers on bench- scale and pilot-plant scale

Items	L*	a*	b*
Bench- scale	83.6	0.12	4.50
Pilot-plant scale	69.74	0.11	7.50

L* is the lightness
a* is the red-green color component
b* is the yellow-blue color component

The rheological properties and apparent viscosity of the pastes were measured using Brookfield and at different shear rates. The results given in Table (4) and Fig (2) indicated that in both inulin production scales the viscosity decreased with increase in temperature and shear rate. Heating may rupture the molecular entanglement and bonds, stabilizing the molecular structure and resulting in a decrease in viscosity (Hayta et al., 2002). High heating temperature (greater than 80 ºC) causes some degree of hydrolysis of dissolved inulin molecules leading to lower volumetric gel index. A low degree of hydrolysis of inulin and critical concentration of inulin are important for gel formation (Senol and Esra, 1998). Fig (2) shows the flow properties of inulin prepared at different temperatures. Data revealed that all the pastes examined are characterized a non-Newtonian behaviour. Franck (1993) reported that the relationship between viscosity and shear rate can be used to classify foods into Newtonian, non-Newtonian, pseudoplastic, and rheoplasitic.

Table 4: Dependence of the apparent viscosity (in centipoises) of inulin powder produced from Jerusalem artichoke tubers on Bench- scale and Pilot-plant scale.

Shear rate (S^{-1})	Temp. ºC	Bench- scale		Pilot-plant scale	
		Shear stress (N/m^2)	**Viscosity (centipoises)**	**Shear stress (N/m^2)**	**Viscosity (centipoises)**
65.1	70	25.5	37.5	34.5	42.5
74.4	80	23.5	36.4	30.5	40.5
83.7	90	23.2	28.6	28.5	40.5
93.0	100	22.2	23.0	26.6	30.5

Pastes were prepared at concentration of 10 %, 1p=0.1 p.s

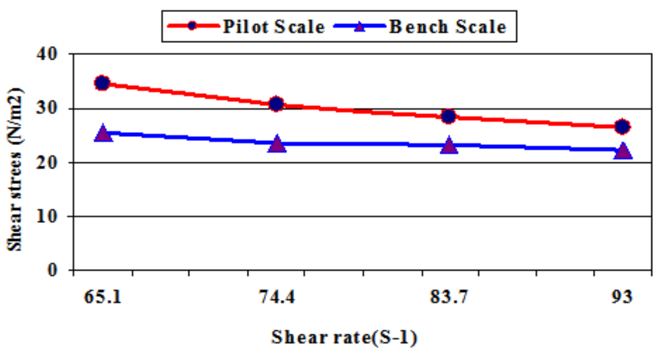

Fig. 2: Flow properties of inulin produced from jerusalem artichoke tubers on Plant-scale and Bench-scale

Inulin produces low viscosity in solution and has excellent texture modifying characteristics, especially with its synergy with gums. Because inulin is low in viscosity (15-35 cP in a 15% solution), it can easily be added to functional beverages without drastically altering the finished viscosity (Licari, 2006). The non-gelling and reduced viscosity property of the inulin applicable to the present invention is to some extent directly related to the molecule size and thus the molecular weight of the particular polysaccharides. Inulin is a mixture of fructose polymers of varying chain lengths ranging from 2 to 60 monomers with a molecular weight of less than 11,000 and with a typical molecular weight of about 5,000 (Barta and Patkai, 2007).

Chemical analysis:

The chemical composition of inulin produced on both scales is presented in Table (5) such as moisture, reducing sugars, total carbohydrates and inulin. Similar trends were observed by (Niness, 1999). who reported that the inulin properties from Jerusalem artichoke tubers were total carbohydrate content on dry matter 99.51 % min., inulin (dry matter) 90.0 % min., free sugar 10 % max., ash (dry matter) 0.5 % max. and lower moisture which was 3.5 %.

Table 5: Some chemical analysis of inulin powder % (on dry weight) produced on Bench- scale and Pilot-plant scale from Jerusalem artichoke tubers

Items	Bench- scale	Pilot-plant scale
Moisture	$5.89^{a} \pm 0.01$	$5.05^{b} \pm 0.01$
Ash	$0.48^{b} \pm 0.01$	$0.61^{a} \pm 0.01$
Protein	$0.55^{b} \pm 0.01$	$0.70^{a} \pm 0.01$
Fat	$0.25^{b} \pm 0.01$	$0.41^{a} \pm 0.01$
Fiber	$0.06^{b} \pm 0.01$	$0.80^{a} \pm 0.01$
Reducing sugars	$5.21^{a} \pm 0.01$	$4.90^{b} \pm 0.01$
Total carbohydrates	$96.18^{a} \pm 0.01$	$94.27^{b} \pm 0.01$
Inulin content	$90.97^{a} \pm 0.01$	$89.47^{b} \pm 0.01$

-All values are means of triplicate determinations ± standard deviation (SD).
-Means with the same letter within a raw are not significantly different (P<0.05)

The chemical analysis concerning mineral contents. Micro-elements (zn, Cu, Mn and Fe) and Macro-elements (K, Na, Mg, Ca and P) are illustrated in Table (6). Similar trends were observed by (Coussement, 1999) who found that the Jerusalem artichoke tuber contains a high level of potassium, phosphorus and calcium. The differences of mineral contents may be due to the plant species, methods for inulin extraction and different drying methods. Niness (1999) who found that the inulin content of 400 mg/kg sodium on dry matter while, the heavy metals each (Pb & Cd) ≤ 0.01 mg/kg on dry matter.

Table 6. Mineral contents (mg/ kg dry matter) of inulin powder produced on Bench- scale and Pilot-plant scale from Jerusalem artichoke tubers

Items	Bench- scale	Pilot-plant scale
	Micro-elements	
Zinc (Zn)	$170.20^{b} \pm 0.01$	$431.66^{a} \pm 0.01$
Copper (Cu)	$20.31^{a} \pm 0.01$	$13.85^{b} \pm 0.01$
Manganese (Mn)	$17.60^{a} \pm 0.01$	$5.27^{b} \pm 0.01$
Iron (Fe)	$124.30^{a} \pm 0.01$	$104.41^{b} \pm 0.01$
Cadmium (Cd)	Nd	Nd
Lead (Pb)	Nd	Nd
Nickel (Ni)	Nd	Nd
Cobalt (Co)	Nd	Nd
	Macro- elements	
Potassium (K)	$1041.09^{b} \pm 0.01$	$1340^{a}.12 \pm 0.02$
Sodium (Na)	$417.17^{a} \pm 0.01$	$300.31^{b} \pm 0.01$
Magnesium (Mg)	$56.36^{b} \pm 0.01$	$58.47^{a} \pm 0.02$
Calcium (Ca)	$437.62^{a} \pm 0.01$	$380.19^{b} \pm 0.01$
Phosphorus (P)	$159.06^{a} \pm 0.01$	$112.53^{b} \pm 0.01$

-All values are means of triplicate determinations ± standard deviation (SD).
-Means with the same letter within a raw are not significantly different (P<0.05).
Nd: non detected

Functional properties of inulin powder:

Water and oil absorption:

Low water oil index WOAI of inulin powder produced is considered a good indicator of excellent oil absorption and poor water absorption. The results shown in Table (7) indicated that the inulin powder had bind fat. Thus, the inulin powder from Jerusalem artichoke could be an added to meat applications to improve the texture of meat based products, reinforce firmness, improve sliceability and enhance mouthfeel, while keeping stable at all temperatures and pHs (Wu and Lee, 2000).

Table 7: Water and oil absorption (g/100g dry sample) and water oil absorption index (WOAI) of inulin powder produced on Bench- scale and Pilot-plant scale from Jerusalem artichoke tubers

Items	Bench- scale	Pilot-plant scale
Water absorption %	52.34 [b] ± 0.01	60.44 [a] ± 0.01
Oil absorption %	145.36 [a] ± 0.01	137.96 [b] ± 0.01
WOAI g water/g oil	0.36 [b] ± 0.001	0.44 [a] ± 0.001

-All values are means of triplicate determinations ± standard deviation (SD).
-Means with the same letter within a raw are not significantly different (P<0.05)

Foam capacity (FC) and foam stability (FS):

From data of (FC) and (FS) Table (8), it is obvious that, pH 4.0 lead to significantly (P<0.05) more foam capacity compared with others pH values in inulin produced. Foam stability had significantly (P<0.05) decreased as time of foam stability increased under all pH values. At 120 min under pH 6.0, the foams of inulin were in their maximum stabilities (42%) and (25%) on Bench-scale or Pilot plant scale, respectively.

Table 8: Foam capacity (FC) and stability (FS) of inulin powder produced on bench- scale or pilot-plant scale from Jerusalem artichoke tubers under different pH values

Sample	pH values	FC (%)	FS (Foam value %)					
			5 min	15 min	30 min	50 min	60 min	120 min
Bench-scale	4.0	173 [a]±1.15	52.0 [e]±1.73	50.0 [d]± 0.57	43.0 [d]± 1.15	32.0 [c]± 1.15	28.0 [a]± 1.75	25.0 [bc]± 0.57
	5.0	110 [e]± 1.15	85.0 [c]± 1.15	83.0 [b]± 1.73	63.0 [c]± 1.15	31.0 [c]± 1.15	25.0 [c]± 1.15	22.0 [c]±1.15
	6.0	130 [c]±1.15	90.0 [ab]±1.15	86.0 [b]±1.15	79.0 [a]±1.15	72.0 [a]±1.15	53.0 [a]±1.73	42.0 [a]±1.15
	7.0	94 [g]±1.73	87.0 [bc]±1.15	78.0 [c]±1.73	70.0 [b]±1.73	44.0 [b]±2.02	36.0 [b]±1.15	27.0 [b]±1.73
Pilot-plant-scale	4.0	155 [b]±1.15	40.0 [f]±1.15	40.0 [f]±1.73	39.0 [d]±1.73	32.0 [c]±1.73	25.0 [c]±1.15	13.0 [e]±1.15
	5.0	105 [f]±1.15	92.0 [a]±1.73	90.0 [a]±1.15	64.0 [c]±1.15	46.0 [b]±1.15	33.0 [b]±1.15	22.0 [c]±1.15
	6.0	121 [d]±1.15	65.0 [d]±1.73	45.0 [e]± 0.57	41.0 [d]±1.73	25.0 [d]±1.15	25.0 [c]±1.15	25.0 [bc]± 0.57
	7.0	87 [h]±1.15	38.0 [f]±1.73	28.0 [g]±1.15	25.0 [e]±1.15	18.0 [e]± 0.57	17.0 [d]±1.15	17.0 [d]±1.15

-All values are means of triplicate determinations ± standard deviation (SD).
- Means with the same letter within a column are not significantly different (P<0.05).

Emulsion capacity (EC) and emulsion stability (ES):

As shown in Table (9), (EC) was significantly (P<0.05) increased as pH values increased in inulin produced. Also, Bench-scale inulin emulsion capacity was significantly (P<0.05) higher compared to that produced in Pilot-plant scale under all pH values. Additionally, At 48 hrs, percentage of aqueous phase separated of inulin produced were significantly (P<0.05) decreased on pH 6.0 (89 % - 100%) comparing to pH 4.0 (100% - 106%), pH 5.0 (108% - 110%) and pH 7.0 (120 % - 131%), indicating that emulsion stability of inulin is high at pH 6.0 and lower at pH 7.0 where, percentage of aqueous phase separated were significantly (P<0.05) higher comparing to other pHs Table (9).

Table 9: Emulsion capacity (EC) and stability (ES) of inulin powder produced on bench-scale or pilot-plant scale from Jerusalem artichoke tubers under different pH values

Sample	pH values	EC (ml oil/sample)	ES. (% aqu. Phase separated after time, hrs.)					
			0.25 hrs	1.0 hrs	2.0 hrs	3.0 hrs	24.0 hrs	48.0 hrs
Bench-scale	4.0	48.5 [a]±0.11	86.0 [b] ±1.73	90.0 [c] ±1.15	95.0[c] ±1.73	100.0 [c]±1.15	100.0 [c]±1. 73	100.0 [d] ±1.15
	5.0	58.3 [f]±0.11	90.0 [b]±1.15	92.0 [bc]±1.73	108.0 [a]±1.15	108.0 [ab]±1.73	108.0 [b]±0.57	108.0 [c] ±1.15
	6.0	77.3 [d]±0.11	40.0 [e]±1.15	48.0 [e] ±1.73	48.0[e]±1.15	89.0 [d]±1.15	89.0 [d] ±1.73	89.0 [e] ±0.66
	7.0	98.9 [b]±0.05	47.0 [d] ±1.73	47.0 [e]±1.73	47.0 [e]±0.57	105.0 [b]±1.73	131.0[a] ±1.15	131.0 [a] ±1.15
Pilot-plant-scale	4.0	51.3 [g]±0.11	90.0 [b]±1.15	96.0 [ab]±1.15	100.0 [b] ±1.15	106.0 [ab] ±0.57	106.0 [b]±0.57	106.0 [c]±1.15
	5.0	63.0 [e]±1.15	95.0 [a] ±1.15	98.0 [a] ±1.73	106.0 [a] ±0.57	110.0 [a] ±1.15	110.0 [b] ±1.73	110.0 [c] ±1.15
	6.0	82.8 [c]±0.11	38.0 [e] ±1.15	38.0 [f] ±0.57	40.0 [f]±1.15	96.0 [c]±1.15	100.0 [c] ±1.73	100.0 [d] ±1.73
	7.0	103.5 [a]±0.11	58.0 [c] ±1.73	56.3 [d] ±2.02	58.0 [d] ±1.73	58.0 [e]±1.15	100.0 [c] ±1.15	120.0 [b]±1.15

-All values are means of triplicate determinations ± standard deviation (SD).
- Means with the same letter within a column are not significantly different (P<0.05)

Instrumental analysis:
FT-IR Spectrum for inulin:

In recent years, and according to the advanced technique of analysis, Infrared Spectroscopy can now take the form of characterizing the molecules as containing or lacking certain functional groups which acting as their finger prints. Through comparison with known spectrums, identification of compounds based on this functional group could be easily achieved. The functional groups of the samples were identified (Dyer, 1965).

With respect to the inulin powder produced on both scales, the obtained spectrum within Wave numbers 400 up to 4000 cm^{-1} was given in Figs (3 & 4) and Table (10). The identified wave numbers can be classified functional groups.

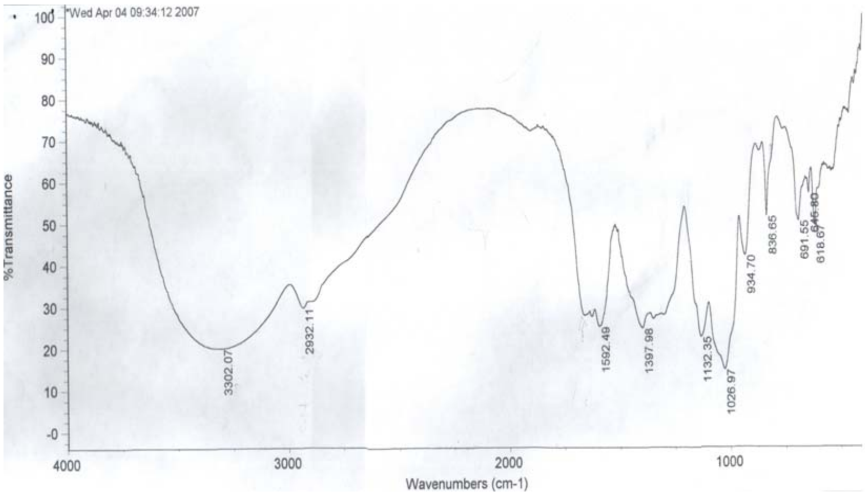

Fig. 3: FT-IR Spectrum for inulin from Jerusalem artichoke tuber production on Pilot- plant scale

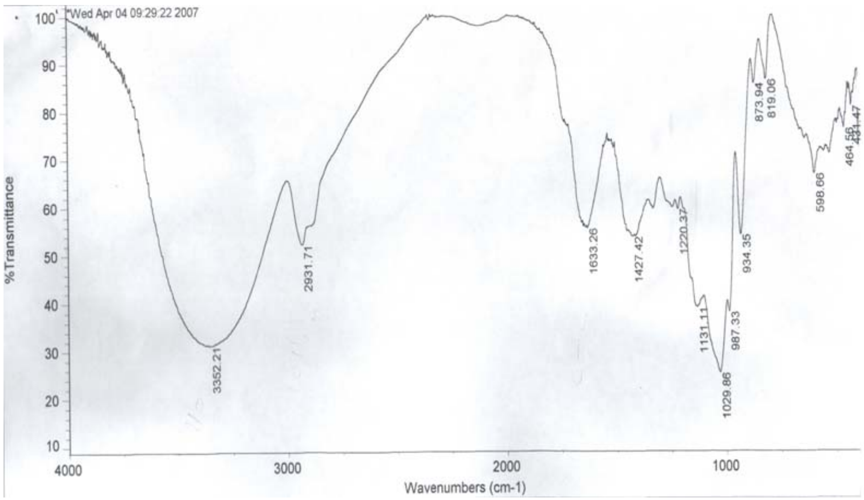

Fig. 4: FT-IR Spectrum for inulin from Jerusalem artichoke tuber production on Bench-scale

The following functional groups could be known in terms of (%) Transmittance and Wave numbers (cm^{-1}) as follows of Bench and Pilot plant-scales respectively:

IR (KBr) UMax/ cm^{-1}: 3302 – 3360, (OH stretching): 2931 – 2932, (CH stretching) 1592 – 1631, (C=C) 1397 - 1421 (OH stretching).

A similar trend was obtained (Wu and Lee, 2000), who found that the FT-IR Spectrum for artichoke inulin was essentially identical showing OH stretch (3353 cm^{-1}) for inulin.

Also, (Pitarresi et al., 2007) reported that the FT-IR (KBr) Spectrum showed a broad band centered at 3300 cm^{-1} (UMax OH) and a strong band at 1732 cm^{-1} (UMax Coo).

Grube er al. (2002) found that the FT-IR Spectra of inulin's, in the carbohydrate region 900-1200 cm^{1}, shows overlapping broad band with maximum at ~1030 cm^{1} and stronger absorption at ~940 cm^{1}. The differences in both spectra could be caused by different structure and glucose, sucrose and mannan influence.

Table 10: Wave numbers (cm-1) and (%) Transmittance of the infrared spectrum of the inulin powder produced from Jerusalem artichoke tubers on Bench- scale and Pilot-plant scale

Pilot-plant scale		Bench- scale	
Wave numbers (cm-1)	(%) Transmittance	Wave numbers (cm-1)	(%) Transmittance
1032.46	6.57	1026.97	14.567
3360.26	9.097	3302.07	19.859
2931.24	25.323	1132.35	22.382
1421.43	27.704	1397.98	24.638
934.77	28.272	1592.49	25.017
1631.45	28.962	2932.11	29.574
1220.22	34.618	934.7	41.908
598.62	41.611	618.67	49.21
464.82	55.155	691.55	50.201
873.9	66.916	836.65	51.362
819.12	68.151	645.8	6.682

X-ray Fluorescence:

Qualitative and quantitative analysis of trace elements in the inulin powder product used by X-ray Fluorescence is given in Table (11). The data proved that the highest levels of the elements, group in the inulin were K_2O followed by Na_2O, Cl and SO_3 and the lowest levels were Al_2O_3, Fe_2O_3, M_gO and SrO.

Contains trace elements such as sodium (Na), aluminum (Al), silicon (Si), sulphur (S), calcium (Ca), potassium(K), sulphur oxide (SO), chlorine (Cl), oxygen (O) and phosphorus (P).

Table 11: Qualitative and quantitative analysis of trace elements of the inulin powder produced from Jerusalem artichoke tubers on Bench- scale and Pilot- plant scale used by X-ray Fluorescence

Oxides	Formula	(Wt %)	
		Bench- scale	Pilot-plant scale
Silicon oxide	SiO2	0.09	0.35
Aluminum oxide	Al3O3	0.06	0.04
Iron oxide	Fe2O3	0.07	0.07
Magnesium oxide	MgO	0.06	0.07
Calcium oxide	CaO	0.48	0.41
Sodium oxide	Na2O	0.78	0.8
Potassium oxide	K2O	19.64	18.58
Phosphorus pentoxide	P2O5	0.5	0.1
Sulphur trioxide	SO3	0.6	1.56
Chlorine	Cl	0.7	1.07
Strontium oxide	SrO	0.002	0.003
Zinc oxide	ZnO	0.1	0.105
Rubidium oxide	Rb2O	0.04	0.048
Cupper oxide	CuO	-	-
Nickel oxide	NiO	-	-

(-): Not detectable

It could be concluded that the chemical properties and instrumental analysis of inulin produced from Jerusalem artichoke tubers make it suitable for applications in the food industry because it has unusual nutritional characteristics, rich source of carbohydrates and can be used to replace sugar, fat and flour. It is also a good source for some macro elements such as K, Na, Mg, Ca &P.

Cost Indicators for Inulin Production:

For production capacity 10 tons/day Jerusalem artichoke tubers (JAT) and similar raw materials during the year (16 hours / day – 300 days / year). The produced inulin is estimated to be 66 kg/day (198 ton/year).

The process of JAT storages is explained in details to avail the raw material quantity allover the year (Harris, 2007)

According to the preliminary process design and cost indicators for erecting such plant. Table (12) presents the capital cost, operating cost and production cost / ton which could be estimated as $ 4.7.

Table 12: Estimated cost for the inulin production To produce 198 ton per year from 3000 ton JAT raw material

Capital Cost I. Equipment Cost	Item US $	Operating Cost $/year Elec.	Chem.	Labour	Mainte	Other	Operating($/year)	Total cost annual ($/year)	Deprec. ($/year)	Total
Grinder	200000	2500								
Washer/Reactor	100000	7500								
Extractor (2)	100000	7500								
Basket Centrifuge	150000	10000								
Pressure Carbon Filtration	50000	600								
Fermentor										
Incubator										
Spray Dryer	130000	20000								
Sub Total	730000	4800	650000	928000	90000	838000	10000	15000	928000	
II. Piping (10 % of A)	73000									
III. Electricity (8 % of A)	58400									
IV Control (5 % of A)	36500									
V Site Preparation (5% of A)	36500									
Grand Total	934400									

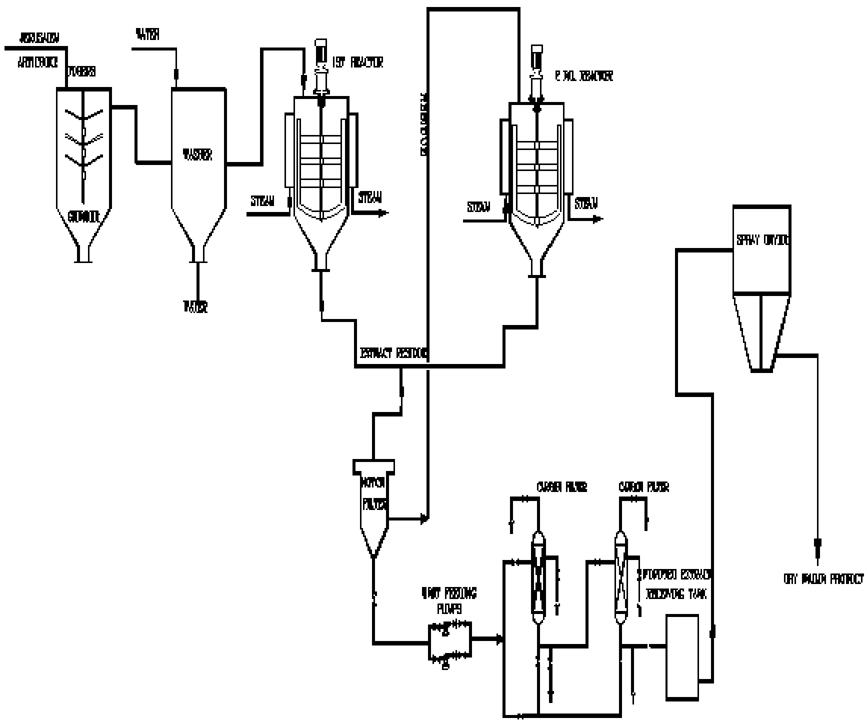

Fig. 5: Process flow diagram for inulin from Jerusalem artichoke tubers.

REFERENCES

Adebowale, K.O., B.I. Olu-Owolabi, E.K. Olawumi and O.S. Lawal, 2005. Functional properties of native, physically and chemically modified breadfruit (*Artocarpus artillis*) starch. Ind. Crops Prod., 21: 343-351.

A.O.A.C, 2000. Official Methods of Analysis of the Association of Official Analytical Chemists 17 th Ed. Published by the Association of Official Analytical Chemists. USA.

Barta, J and G. Patka, 2007. Chemical composition and storability of Jerusalem artichoke tubers. Acta Alimentaria, 36:(2): 257-267.

Berghofer, E., A. Cramer, U. Schmidt and M. Veigl, 1993. Pilot-scale production of inulin from chicory roots and its use in foodstuffs. Inulin and Inulin Containing Crops. A. Fuchs (Ed.) Elsevier Science Publishers B.V. p: 77-84.

Berghofer, E and E. Reiter,, 1997. Production and functional properties of Jerusalem artichoke powder. Proceedings of the Sixth seminar on inulin Braunchweig Germany Editors: A Fuch,s, S. Schittennem, L. Press. Nov. 14-15. (1996).

Carpita, N.C., J. Kanabus and T.L. Housley, 1989. Linkage structure of fructans and fructan oligomers from Triticum aestivum and Festuca arundinacea leaves. J. Plant Physiol., 134: 162-168.

Coussement, P.A., 1999. Inulin and oligofructose: safe intakes and legal status. J Nutr, 129(7 Suppl): 1412S-7S.

Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers and F. Smith, 1956. Colorimetric Method for Determination of Sugars and Related Substances, 28(3): 350-356.

Dipak, K.D and K.D. Mukherjee, 1986. Functional properties of rapeseed protein products with varying phytic acid contents. J. Agric. Food Chem, 34: 775.

Dyer, J.R, 1965. Applications of Absorption Spectroscopy of Organic Compounds. PP. 22- 39. Prentice-Hall, INC., Englewood Cliffs, N.J.

Ezz El- Arab, A., L. Hussein and Z. Zdunczyk, 2003. Purification and characterization of fructooligosaccharides from garlic, Tartoufa and chicory and their effects on blood lipids, colonic bacterial enzyme and bone mineralization. Proc. The 1 st International Conf. "Food for Better Health", NRC, 18-20, Cairo, Egypt.

Franck, A., 1993. Rafticreaming: The new process allowing to turn fat into dietary fiber. FIE Conference Proceedings 1992, pp: 193-197. Maarssen: Expoconsult Publishers.

Franck, A., 1999. Prebiotic sweeteners blends. Food Marketing and Technology, 13: 22-24.

Franck, A., 2002. Technological functionality of inulin and oligofructose. Br. J. Nutr. 87: S287- S291.

Fuchs, A., 1993. Inulin and Inulin-containing Crops, Studies in Plant Science, Elsevier Science. Publishers.

Gibson, G.R and M.B. Roberfroid, 1995. Dietary modulation of the human colonic microbiota: introducing the concept of prebiotics. J. of Nutr, 125: 1401-1412.

Grube, M., D.U. Bekers and E. Kaminska, 2002. Infrared spectra of some fructans. Spectroscopy, 16(3-4): 289-296.

Hayta, M., M. Alpaslan and A. Baysar, 2002. Effect of drying methods on functional properties of tarhana: a wheat flour-yogurt mixture. J. Food Sci, 67: 740-44.

Hunter, R.S., 1958. Photoelectric color difference meter. J. O. Pt. Soc. Am. 48 (12), 985, C. F. "Quality Control for the Food Industry", Vol. 1, 1970. Third Edition, P. 31, Kramer, A. and Twigg, B. A. Eds. AVI Publishing Company INC, USA.

Kalnick, D.J., 1986. Advances in X- ray Analysis, 29: 451-460.

Kotula, A.W., G. Twigg and E.P. Young, 1976. Evaluation of beef patties containing protein, during 12-month frozen storage. J. of Food Sci., 41: 1142-1147.

Laurenzo, K.S., J.L. Navia and S. David, 1999. Preparation of inulin products US. Patent no. S, 968: 365.

Leite, J.T.C., 2004. Proceedings of the 14 th International Drying symposium. Säo Paulo, Brazil, 22-25 August, Vol. B, pp: 868-875.

Licari, J.J., 2006. Dietary fiber delivery system. Issued: January 3, 2006. US. Patent no. 6: 982,093.

Lingyun, W., W. Jianhua, Z. Xiaodong, T. Da. Yalin. C. Chenggang and F. Tianhua, 2007. Studies on the extracting technical conditions of inulin from Jerusalem artichoke tuber. J. Food Eng, 79(3): 1087-1093.

Luque- Garcia, J.L and M. Luque de Castro, 2003. Ultrasound: a powerful tool for leaching. Trends in Anal., Chem, 22(1): 41-47.

Makri, E., E. Popalamproum and G. Doxastakis, 2005. Study of functional properties of seed storage proteins from indigenous European Legume crops (Lupin pea, broad bean) in admixture with polysaccharides. Food Hydrocolloids, 19: 583-594.

Miller, G.L., 1959. Use of dinitrosalicylic acid reagent for determination of reducing sugar. Anal., Chem, 31: 420-428.

Modler, H.W., J.D. Jones and G. Mazza,1993. Observations on long-term storage and processing of Jerusalem artichoke tubers (*Helianthus tuberosus*). Food Chem, 48: 279-284.

Molina, D.L., M.D.N. Martinez, F.R. Melgarejo, A.N.P. Hiner, S. Chazarra and J.N.P. Lopez, 2005. Molecular properties and prebiotic effect of inulin obtained from artichoke (*Cynara scolymus* L.).

Naczk, M., L.L. Diosady and L.J. Rubin, 1985. Functional properties of canola meals produced by a two-phase solvent extraction system. J. Food Sci, 50(6): 1683-1688.

Niness, K.P., 1999. "Nutitional and Health Benefits of Inulin and Oligofructose".Orafti Active Food Ingredients, Malvern, PA 19355, American Society for Nutritional Science. J of Nutr, 129: 1402S-1406S.

Pearson, D., 1976. The Chemical Analysis of Food. 7 th ed. Churchill Livingstone, Edinburg London AND New York. pp: S75.

Pitarresi, G., G. Tripodo, G. Cavallaro, F.S. Palumbo and G. Giammon, 2007. Inulin- iron complexes: A potential treatment of iron deficiency anemia. European J. Pharmaceutics and Bio pharmaceutics. xxx: xxx-xxx.

Rosa, M.F., A.M. Vieira and M.L. Bartolomen, 1986. Production of high concentration of ethanol from mash, juice and pulp of Jerusalem artichoke tubers by *Kluyveromyces fragilis*. Enzyme Microb. Technol, 8: 673-676.

SAS, 1998. "SAS. /STAT user's Guide Release 6.03 edition". SAS Institute Inc., Cary, Nc, USA.

Senol, L. and I. Esra, 1998. Rheological characterization of some traditional Turkish soups. J. Food Engin, 35: 251-256.

Tchone, M., G. Barweld and C. Meier, 2005. "Polyphenoloxidase in Jerusalem artichoke (*Helianthus tuberosus L*)". Br. Food J., 107(9): 693-701.

Van, L.J., J. Cummings, N. Delzenne, H. Hoebergs and G. Smith, 1995. On the of inulin and oligofructose as natural ingredients in the Western diets. Critical Review in Food Sci. and Nutr, 35: S25- S52.

Wu, X.Y and P.I. Lee, 2000. Preparation and characterization of inulin ester microspheres as drug carriers. J. Appl. Polym. Sci, 77: 833-840.

Yamazaki, H., H.W. Modler, I.D. Jones and J.I. Elliot, 1989. Process for preparing flour from Jerusalem artichoke tubers. U.S. Patent 487.