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CHEMICAL PROPERTIES AND INSTRUMENTAL ANALYSIS OF JERUSALEM ARTICHOKE FLOUR PRODUCED BY DIFFERENT DRYING METHODS

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ABSTRACT

Chemical composition of Jerusalem artichoke tubers collected from Egypt contained moisture, fat, reducing sugars, protein, total carbohydrates, fiber and ash at levels of 70.72, 0.42, 3.98, 7.25, 18.89, 3.81 and 2.52 % on dry weight basis, respectively. The tubers a good source rich source of K (4377.0 mg/kg) and contained moderate levels of P (790.30), Ca (424.12), Mg (168.19), and Na (32.10 mg/kg). However, Zn (11.97), Fe (11.15), and Cu (7.9 mg/kg) were detected at lower levels. In most cases compounds of the plant increased with drying process. Flour made from the tuber of the plant produced by different drying methods (sun, oven and microwave drying) in most cases chemical composition not affected among the three methods of drying, i.e. sun-drying method (at 40 °C/72 hr, 50 °C/50 hr and 60 °C/36 hr), oven- drying method (at 40 °C/12 hr, 50 °C/9 hr and 60 °C/7 hr), and microwave method (at a medium power level 60 °C/7 min). Functional groups of Jerusalem artichoke flour were known were in terms of (%) Transmittance and wave numbers (cm^{-1}) by FT-IR- Spectrum. Qualitative and quantitive analysis of trace elements in the Jerusalem artichoke flour by X-ray Fluorescence were studied. Trace elements detected as oxides were, K, Ca, P, and S. So we can storage the plant as flour by using any of dried methods in this study and the flour made from Jerusalem artichokes can be used as a low-calorie, bulking agent in pasta, baked goods and other processed foods.

Keywords: Jerusalem artichoke tubers, Flour, Drying methods, Chemical analysis, Instrumental analysis.

INTRODUCTION

The old vegetable plant Jerusalem artichoke (*Helianthus tuberosus*) has been paid attention during the last years because the high values as a function food plant. The tuber of this plant is a rich source from fructooligosaccharides (mainly inulin). These are sweet tasting compounds that have shown decreasing effect on blood glucose, cholesterol and triglycerides (Seljasen and Slimested, 2005).

A Jerusalem artichoke tuber contains 11-20 % carbohydrates and that is why it constitutes a good material for distillery industry, 70-90 % of these carbohydrates are inulin. (Azies *et al.*, 1999 and Niness, 1999). The dry matter of Jerusalem artichoke tubers consists of about of 60 – 80 % fructose, 8-12 % protein, 4-6 % fiber and 4 – 6 % ash rich in potassium (Yamazaki *et al.*, 1989). Because of lack of appropriate enzymes human beings are not able to digest polyfructans such as inulin, but different studies showed a positive influence of Jerusalem artichoke or their products on digestion and physical constitution in its entirety and note oligo-and polyfructansreach the colon practically quantitatively(Angeli, 1991).Oligofructans and inulin are therefore "prebiotics", which are non-digestible foods or food components which stimulate the growth and/or activity of one or more bacterial culture in the colon and thus improve the health of human beings (Coussement, 1995), but still they are grown only on small scale. The low caloric value of the tuber compounds, the high fiber content, and the beneficial influence on human health make Jerusalem artichoke very interesting for human nutrition (Modler *etal.*, 1993 and Coussement, 1995).

Consequently from the tubers of Jerusalem artichoke food of very high nutritional value can be produced (dried products; crystallized inulin; purified fructose syrup or natural concentrate, rich in inulin or fructose, containing all natural components of the plant) (Barta and Patkai, 2007).

The Jerusalem artichoke tubers do not contain bitter taste compounds and therefore might be suitable for the production of powder from whole tubers. The composition of tubers and the content of fructooligosaccharides and inulin in the powders depends on varieties of Jerusalem artichoke, harvest time and climate conditions. (Roberfroid, 1999).

Powders of the whole tubers of Jerusalem artichoke with high amounts of fructooligosaccharides and inulin as well as total carbohydrates (18.5 %), saccharose 10 -13% and that of reducing sugars 3.5 - 5%. Calcium content of the samples amount to 0.457 g/100g an average *(Yamazaki et al.,* 1989 and Praznik *et al.,* 2002) may be applied as substitute of cereal flour in bakery products.

A major problem in the commercialization of Jerusalem artichoke tuber products is that the fresh tubers are available for only about three or four months a year, so year-round production would require storage of the tubers. The usual methods of storing the tubers are mechanical refrigeration and freezing, but these are expensive in terms of capital investment and the requirement of space and transport (Berghofer and Reiter, 1997).

The dehydration technique is probably the oldest and the most important method of food preservation practiced by humans. The removal of moisture prevents the growth and reproduction of microorganisms which cause decay, and minimizes many of the moisture-mediated deteriorative reactions (Mujumdar, 1995).During the dehydration many changes take place; structural and physico-chemical modifications affect the final product quality (Taner *et al.*, 2003).The choice of dehydration method was based on quality and economic factor, and that the major losses of nutritional value in dehydration and storage of dried foods (Berghofer and Reiter, 1997).

During drying, Jayaraman *et al.*, (1990) observed irreversible cellular rupture and migration, resulting in loss of integrity and hence, a dense structure of collapsed, greatly shrunken capillaries with reduced hydrophilic properties, as reflected by the inability to imbibe sufficient water to rehydrate fully.

Dehydration of tuber slices would permit to avoid the high costs of storage as well as the preservation of fructans and other tuber compounds for commercial use. Such as a Jerusalem artichoke powder should have substantially the same content of chemical compounds as the tuber dry matter and unlike the tubers the powder would be readily available to consumers throughout the year. But still there is no rapid and economic method for drying larger amounts of tubers (Berghofer and Reiter, 1997). All these facts seemed good enough reasons to develop a rapid and economic method for processing a larger amount of tubers in order to avoid the high costs of storage and to preserve all the valuable chemical compounds of the tubers for commercial use.

Flour made from Jerusalem artichokes can be used as a low-calorie, bulking agent in pasta, baked goods and other processed foods. Jerusalem artichokes ,which have only 1.25 calorie per gram, are composed of about 65 % carbohydrate, 8 - 10 % protein and under 1 % fat. Jerusalem artichokes flour does not contain starch, and it is a good source of calcium, iron, potassium and other nutrients. The pale-brown, fine-mesh flour is dried from whole tubers (Bartta and Patkai, 1999).

In recent years, and according to the advanced technique of analysis Infrared Spectroscopy can now take the form of characterizating the molecules as containing or lacking certain functional groups which acting as their finger prints. Through comparison which spectrums, identification of compounds based on this functional group could be easily achieved (Pomeranz and Melon, 1994).

X-ray Fluorescence Spectrometry (XRFS) is a method of elemental analysis that assesses the presence and concentration of various elements by measurement of secondary X-radiation from the sample that has been excited by an X-ray source. Classically elements from the heaviest down to atomic number 9 (Fluorescence) can be determined at levels of a few mg/kg (ppm). Newer developments with wavelength dispersive spectrometers (WDXRF) allow the determination some of the ultralow atomic number elements (Skoog *et al.*, 2005).

Literature of the effect of different drying methods (sun-drying, oven-drying and microwave-drying) on the chemical properties and instrumentals analysis of Jerusalem artichoke flour is very rarely, scantly, and needs more studies, so the objective of the present study was to provide the effect of different drying methods (sun-drying, oven-drying and microwave-drying) at different temperatures on the chemical properties such as (moisture, protein, ash, fat, fiber, total carbohydrates, reducing sugars, inulin content and minerals). As well as instrumentals analysis by (Infrared spectroscopy) determination of the functional groups and trace elements by (X-ray Fluorescence).

MATERIALS AND METHODS

Materials:

1-The Jerusalem artichoke tubers (*Helianthus tuberosus*) that harvested in October, 2007 were provided from the Experimental Station, Agricultural Research Centre, El- Kanater El-Khayria, Egypt.

2- Standard solution of metals, those 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). The standards were prepared from the individual

1000 mg/L (Merck).Working standards were prepared from the previous solutions.

3- Ascorbic acid, phenol, ammonium molybdate and 3, 5 dinitrosalicylic acids were obtained from Sigma Chemical Co. (St. Louis, MO).

Methods:

All of the tested samples of Jerusalem artichoke tubers were prepared to be dried and converted to flour (powder) as follows: 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 have to be brought into contact with hot water immediately. The water can be acidified with ascorbic acid (0.1 % w/w) if a very light powder is required and boiling water for 2 - 3 min. The slices were dried on perforated trays by using the three different drying methods and temperatures as follows (Tchone *et al.,* 2005):

a) Control: Jerusalem artichoke tubers without the hot water acidified with ascorbic acid (0.1 % w/w) then dried by oven at 40 °C/12 hr.

b) Sun-drying: under conditions as shown in table (1), where one layer of Jerusalem artichoke slices was placed on stainless steel trays and dried at three different temperatures: 40 °C/72 hr, 50 °C/50 hr and 60 °C/36 hr (Modler *et al.,* 1993 and Soliman 2007).

c) Air oven-drying: The Jerusalem artichoke tuber slices were placed on stainless steel trays in one layer and then placed on oven and dried at three different temperatures: 40 °C/12 hr, 50 °C/9 hr and 60 °C/7 hr, the trays were removed when the weight of Jerusalem artichoke slices were being constant.

d) Microwave-drying: Microwave oven used in the present study, (Samsung,Model MF245), with oven cavity dimensions of 419 x 245 x 428 mm and operation frequency of 2.450 MHz, with a power source of: 230 V-50 Hz was used. The nominal microwave power out put was 600 W, at a medium power level (60 %), air temperature 60 °C /7 min.

The dried slices were milled in cereals mechanical mill to pass through 100 mesh screen sieve. The recovered powder was kept in polyethylene bags and stored at 4 ± 1°C in a refrigerator until used.

Table (1): Sun-drying conditions of Jerusalem artichoke tubers

Drying conditions	Temperatures /°C		
	40 °C/72 hr.	50°C/50 hr.	60°C/36 hr.
Temperature inside the dryer	40 °C	50°C	60 °C
Total time for drying	72 hr.	50 hr.	36 hr.
Ambient air temperature	19.4 °C	12.5 °C	26 °C
Relative humidity	57 %	66 %	56 %
Relative humidity inside the dryer	10 %	8 %	10 %
Global solar radiation	845 W/m^2	930 W/m^2	822 W/m^2
Initial moisture content	88 %	88 %	88 %
Final moisture content	5 %	5 %	5 %

Analytical methods:

Chemical analysis:

-Moisture, ash, fiber, protein and fat were determined according to the methods described in the A.O.A.C. (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, Fluka) 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, with flame atomization (air-acetylene) 60-20, equipped with a 10 cm burner and a deuterium lamp for background correction, was used for the flame atomic absorption measurement of the metals. Maximum absorbance was obtained by adjusting the cathode lamps at specific slit width and definite wave length as recommended by the method as follows: 0.7, 324.8 nm (Cu); 0.2, 248.3 nm (Fe); 0.7, 213.9 nm (Zn); 0.2, 279.5 nm (Mn); 0.7, 283.3 nm (Pb); 0.7, 228.8 nm (Cd); 0.7, 357.9 nm (Cr) and 0.2, 240.7 nm (Co), respectively.

The flame photometer was applied for macro-elements: 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 A.O.A.C (2000).

The recovery of micro and macro-elements were studying by adding known amounts of standard solution to samples. The amounts added were selected, so that they would be close to the amounts naturally found in the tubers under investigation. The recoveries were ranged between 91-98 %. All of the obtained results were corrected according to the recovery percentage. All glassware, before use were washed with distilled water, soaked in nitric acid (30 %), then rinsed in redistilled water and air-dried. The glassware kept in clean place, to avoid contamination.

Instrumental analysis:

Infrared Spectroscopy (FT- IR):

Fourier–transform infrared (FT-IR) spectra were obtained on a NICLET. 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., National Research Centre, Cairo, was used for analysis. The functional groups were identified according to Dyer (1965).

X- Ray Fluorescence:

The X- ray Fluorescence a pattem 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, National Research Centre, Cairo; the pressed powder samples were prepared through mixing of the fine powder of the sample with binding wax then pressed in automatic. The yielded disk spacemen was used in qualitative and quantitative analysis of trace elements (Kalnicky, 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 was recorded.

RESULTS AND DISCUSSION

Chemical analysis:

Chemical analysis of the Jerusalem artichoke tubers:

Chemical composition of the Jerusalem artichoke tubers depends on their varieties, harvest time and climate conditions (Roberfroid, 1999). Data presented in (Table 2) show that the dry matter of Jerusalem artichoke tubers contained high moisture content (70.72 %), fat (0.42 %), reducing sugars (3.98 %), protein (7.25 %), total carbohydrates (18.89 %), fiber (3.81 %) and ash (2.52 %) rich in K (4377.0 mg/kg), followed by P (790.30 mg/kg). On the other hand, low levels of Zn (11.97), Fe (11.15), Cu (7.90), and Mn (0.33) mg/kg. It was surprising that, toxic metals, i.e. Pb and Cd were detected in the tubers. The presences of Pb and Cd in different samples are certainly due to irrigation with contaminated water, as well as the addition of some fertilizers and herbicides. In addition, it was reported that the contamination of plants with Pb depends on several factors, e.g. traffic densities and distance from the root (Bosque *et al.,* 1990). Lead accumulated in plants is more pronounced at locations close to the emission source of Pb vapour and fine particles. On the other hand, heavy metal contents of plant depend on the plant species and climatic factors (Sovljanski *et al.*, 1990; Barta and Patkai, 2007) results also showed that Co, Cr, and Ni were not detected in the tuber samples in the present study.

Chemical composition of the Jerusalem artichoke tubers were also studied by Yamazaki *et al.,* (1989) and Berghofer and Reiter (1997). They found that Jerusalem artichoke tubers consists of (7 - 12 %) protein, (3.7 - 6.0 %) fiber, (4.0 - 8.0 %) ash rich in potassium, moisture level (75.80 -77.0 %) and the level of glucose and fructose (4.1 -4.3 %), respectively. Also, Barta and Patkai (2007); Yildiz and Kincal (2007) showed that the total carbohydrates (18.5 % - 19.8 %), (7 - 14 %) sucrose and (3.0 – 6.0 %) reducing sugar and inulin (16 - 20 g/100g). Besides, Cielik and Baranowski (1997) reported that the Jerusalem artichoke tubers consists of water 78.9 %; fat 0.41 %; carbohydrate 15.8 %; ash 1.74 % and inulin 14 %. They added that the higher amounts of potassium were 478 mg/100 g; calcium 10 mg/100 g; iron 3.7 mg/100 g and phosphorus 78 mg/100 g. While, (Duke, 1978) reported that the Jerusalem artichoke tuber contain phosphorus is about 65 mg/100 g; calcium, 23 mg/100 g; iron 3.4 mg/100 g; potassium 634 mg/100 g and magnesium 17 mg/100 g.

Table (2): Chemical analysis and mineral contents of Jerusalem artichoke tubers (on dry weight basis)

Constituents	Levels
Gross components (%)	
Moisture	70.72
Ash	2.52
Fiber	3.81
Protein	7.25
Fat	0.42
Total carbohydrates	18.89
Reducing sugars	3.98
Inulin content	13.95
Minerals (mg/kg)	
Potassium (K)	4377.00
Calcium (Ca)	242.12
Phosphorous (P)	790.30
Magnesium (Mg)	168.19
Sodium (Na)	32.10
Iron (Fe)	11.15
Copper (Cu)	7.90
Zinc (Zn)	11.97
Lead (Pb)	3.37
Cadmium (Cd)	0.58
Manganese (Mn)	0.33
Cobalt (Co)	nd
Chromium (Cr)	nd
Nickel (Ni)	nd

Chemical analysis of the Jerusalem artichoke flour:

Jerusalem artichoke flour produced by different methods (sun, oven and microwave drying) was studied to determine their chemical composition (Table 3). Moisture content in the flour was slightly decreased as temperature increased from 40°C to 50°C in different drying methods. However, it was significantly ($P<0.05$) decreased at 60°C comparing to other drying temperature. Data also showed that the content of moisture in flour samples dried by sun, oven and microwave at different temperature and time under study were ranged between (11.65 to 14.09 %), (8.89 to 13.59 %) and (12.18 %), respectively. These results indicate that the moisture content in oven-dried flour at 60°C/7 hr. was far lower than those given by other drying methods. On the other hand, the highest moisture content was detected in the flour dried by sun at 40°C/72 hr. Regarding to ash, data at the same table indicate that flour dried by sun at60°C/36 hr. was significantly ($P<0.05$) decreased (4.07 %) than either flour dried by sun at 40°C/72 hr (4.66 %) or at 50°C/50 hr (4.92 %). While, ash was not significant affect by oven drying method, which ranged between 3.97 to 4.46 %. Concerning microwave dried flour at 60°C/7 min, data showed that ash content was 4.70 %.

Table (3) indicated also, that fiber content affected significantly ($P<0.05$) by different drying methods in this study. The values of fiber in the flour dried by sun, oven and microwave ranged from (4.83 to 6.38 %), (4.31

to 5.88 %) and (4.11 %), in this order. The highest mean value of fiber (6.38 %) found in sun-dried flour at 50°C/50 hr., while the lowest value recorded in microwave flour at 60°C/7 min.

Table (3): Chemical analysis of Jerusalem artichoke flour produced by different drying methods

Components	JAF (control)	% on dry weight basis (Mean ± SE)						
		Sun-drying			Oven-drying			Microwave-drying 60°C/7 min medium power level (60%)
		40°C/72 hr	50°C/50 hr	60°C/36 hr	40°C/12hr	50°C/9 hr	60°C/7hr	
Moisture	13.58[ab] ± 0.02	14.09[a] ± 0.45	13.71[a] ± 0.01	11.65[c] ± 0.01	13.59[ab] ± 0.02	12.94[b] ±0.44	8.89[d] ± 0.03	12.18[c] ± 0.02
Ash	3.71[d] ± 0.72	4.66[ab] ± 0.13	4.92[a] ± 0.23	4.07[c] ± 0.26	3.97[c] ± 0.11	4.26[bc] ± 0.16	4.46[abc] ±0.05	4.70[ab] ± 0.10
Fiber	5.43[d] ± 0.01	4.83[e] ± 0.01	6.38[a] ± 0.02	5.67[c] ± 0.01	5.44[d] ± 0.01	4.31[f] ± 0.02	5.88[b] ± 0.01	4.11[g] ± 0.01
Protein	8.89[d] ± 0.02	8.32[f] ±0.01	9.11[c] ± 0.02	9.50[a] ± 0.02	8.90[d] ± 0.01	7.41[g] ±0.02	8.42[e] ± 0.01	9.38[b] ±0.01
Fat	0.68[e] ± 0.02	0.73[cde] ± 0.01	0.67[e] ± 0.01	0.76[bc] ± 0.10	0.69[e] ± 0.03	0.74[cd] ± 0.01	0.83[a] ± 0.01	0.86[a] ± 0.01
Total carbohydrates	70.65[d] ± 0.01	70.75[c] ± 0.01	68.83[f] ± 0.01	70.35[e] ± 0.10	70.65[d] ± 0.01	72.34[b] ± 0.01	73.54[a] ± 0.01	68.81[f] ± 0.01
Reducing sugars	5.92[a] ± 0.01	5.22[d] ± 0.01	5.38[c] ±0.01	5.70[b] ± 0.10	5.91[a] ± 0.01	5.78[b] ± 0.01	5.11[e] ± 0.01	5.98[a] ± 0.01
Inulin Content	64.73[d] ± 0.01	65.53[c] ± 0.01	63.45[e] ± 0.01	64.65[d] ± 0.10	64.74[d] ± 0.01	66.56[b] ± 0.01	68.43[a] ± 0.01	62.83[f] ± 0.01

Means with the same letter are not significantly different (P<0.05).
Control: drying without ascorbic acid at 40 °C/12 hr.

Protein also affected significantly (P<0.05) in the flour due to drying methods (Table 3). The content of protein was ranged between (8.32 to 9.50 %), (7.41 to 8.90 %) and (9.38 %) with sun, oven and microwave drying methods, respectively.

Data in (Table 3) indicated also, that fat content affected significantly (P<0.05) by the previous drying methods. Fat content increased as temperature degree increased. However, the highest content of fat observed with the flour dried by microwave at 60°C/7 min (0.86 %). The other flour produced by sun and oven drying gave fat content ranged from (0.67 to 0.76 %) and (0.69 to 0.83 %), in this order.

Total carbohydrates, reducing sugars and inulin contents were slightly affected by the previous drying methods (Table 3). Sun, oven and microwave flour contained total carbohydrates ranged from (68.83 to 70.75 %), (70.65 to 73.54 %) and (68.81 %); reducing sugars were (5.22 to 5.70 %), (5.11 to 5.91 %) and (5.98 %); inulin were (63.45 to 65.53 %), (64.74 to 68.43 %) and (62.83 %), respectively.

Table (4) revealed the mean of collected data at different temperature and time in the three dried methods under investigation. Data showed that no significant (P<0.05) effect on moisture and ash of the flour dried by the three different methods. Also, no significant differences (P<0.05) observed in fiber, fat and reducing sugars contents in the dried flour by sun- or oven method. Microwave dried flour was significantly (P<0.05) decreased in each of fiber, total carbohydrates and inulin contents. However, it was significantly (P<0.05) increased in each fat and reducing sugars compared to other two methods.

Table (4): Effect of different drying methods on the chemical composition of Jerusalem artichoke flour

Compounds %	JAF (control)	% on dry weight basis (Mean ± SE))		
		Sun-drying	Oven-drying	Microwave- drying
Moisture	13.58^a ± 0.41	13.15^a ± 0.40	11.80^a ± 0.74	12.18^a ± 0.01
Ash	3.71^b ± 0.11	4.55^a ± 0.16	4.23^a ± 0.13	4.70^a ± 0.05
Fiber	5.43^a ± 0.21	5.62^a ± 0.22	5.21^a ± 0.23	4.11^b ± 0.01
Protein	8.89^a ± 0.16	8.97^a ± 0.17	8.24^b ± 0.21	9.38^a ± 0.01
Fat	0.68^b ± 0.01	0.72^b ± 0.01	0.75^b ± 0.02	0.86^a ± 0.01
Total carbohydrates	70.65^a ± 0.70	69.97^b ± 0.69	72.17^a ± 0.41	68.81^c ± 0.01
Reducing sugars	5.92^a ± 0.01	5.43^b ± 0.07	5.60^b ± 0.12	5.98^a ± 0.01
Inulin content	64.73^b ± 0.30	64.54^b ± 0.30	66.57^a ± 0.53	62.83^c ± 0.01

Means with the same letter are not significantly different (P<0.05).
Control: drying without ascorbic acid at 40 °C/12 hr

Similar results obtained by Duke (1978) who reported that the flour made from Jerusalem artichoke tuber is composed of about 65 -72% carbohydrates, 8 - 10 % protein, under 1 % fat, 7 % fiber, and 10 % water. On the other hand, (Roberfroid, 1999) reported that Jerusalem artichoke powders contained 71.0- 77.2 % soluble carbohydrates, 12.3 - 18.9 % insoluble fiber, 5.5 - 8.6% protein, 4.8 - 5.9 % ash and 0.5 - 1.6 % lipids. Regarding to (Praznik *et al.*, 2002), they found that the Jerusalem artichoke powder contained 5.01 % water, 0.91 % lipid, 4.3 % ash, 6.6 - 8.5 % proteins, 72.1 - 78.4 % soluble carbohydrates and 51.72 - 71.10 % inulin.

Mineral contents in the different flour under investigation are shown in (Table 5). Results reveal that in most cases the concentration of minerals increased as the temperature of drying increased due to decreasing the moisture content. Major elements such as K, Ca, P, Mg and Na levels in the flour produced by different methods in this study were determined. Data showed that oven-dried flour contained K (4397 - 4402), Ca (241.41 - 252.61), P (789.15 - 793.23), Mg (161.83 - 166.87) and Na (32.71 - 38.31 mg/kg) at highest levels followed by microwave dried flour, and then sun dried flour (Table 5). Heavy metal contents were also determined. Results proved that microwave dried flour contained the highest levels of Fe (42.54), Cu (20.84) and Zn (45.18 mg/kg)) followed by oven and sun dried flour. Regarding to toxic metals such as Pb and Cd, data showed that the lowest levels of them was detected in microwave dried flour, which recorded 0.65 and 0.62 mg/kg with Pb and Cd, respectively. It was surprising that a Pb and Cd content was high in the flour dried by sun and oven methods.

Table (5): Mineral contents (mg/ kg) of Jerusalem artichoke flour (JAF) treated with ascorbic acid and dried by different method

Treatments	Temp. °C	Mean concentration (mg/kg) ± SE													
		K	Ca	P	Mg	Na	Fe	Cu	Zn	Pb	Cd	Mn	Co	Cr	Ni
JAF (control)	40°C/12 hrs	4380^{c} ± 0.73	230.11^{g} ± 0.01	781.25^{b} ± 0.02	160.22^{e} ± 0.01	30.15^{g} ± 0.01	10.01^{f} ± 0.01	7.67^{f} ± 0.01	11.30^{h} ± 0.01	3.28^{f} ± 0.01	0.56^{e} ± 0.01	0.31^{h} ± 0.01	0.79	nd	nd
Sun-drying	40 °C/72 hrs	4276^{e} ±1.15	233.21^{f} ± 0.06	776.15^{c} ± 0.01	158.31^{f} ± 0.01	32.71^{f} ± 0.01	19.14^{e} ± 0.01	10.22^{d} ± 0.02	30.95^{f} ± 0.01	5.26^{d} ± 0.01	0.08^{g} ± 0.01	1.60^{b} ± 0.02	nd	nd	nd
	50°C/50 hrs	4223^{f} ±1.73	238.30^{e} ± 0.01	771.22^{d} ± 0.01	157.72^{g} ± 0.01	35.29^{e} ± 0.01	20.68^{d} ± 0.01	10.73^{d} ± 0.01	40.19^{d} ± 0.01	6.37^{c} ± 0.01	0.49^{f} ± 0.01	1.43^{c} ± 0.01	nd	nd	d
	60°C/36 hrs	4197^{g} ±1.15	241.38^{d} ± 0.01	749.31^{e} ± 0.01	154.79^{h} ± 0.01	38.31^{c} ± 0.01	28.04^{c} ± 0.01	12.09^{b} ± 0.01	41.26^{c} ± 0.02	7.54^{b} ± 0.06	0.82^{b} ± 0.02	0.84^{f} ± 0.01	nd	nd	nd
Oven-drying	40°C/12 hrs	4393^{b} ±1.15	243.17^{c} ± 0.01	789.15^{a} ± 0.01	161.83^{d} ± 0.01	37.21^{d} ± 0.01	18.72^{e} ± 0.01	9.38^{e} ± 0.01	22.69^{g} ±0.01	4.61^{e} ± 0.01	0.71^{c} ± 0.01	1.18^{e} ± 0.01	nd	nd	nd
	50°C/9 hrs	4397^{b} ± 0.57	241.41^{d} ± 0.01	791.21^{a} ± 0.01	164.71^{b} ± 0.01	38.18^{c} ± 0.01	39.02^{b} ± 0.01	11.37^{c} ± 0.01	33.26^{e} ± 0.01	9.87^{a} ± 0.01	0.91^{a} ±0.01	0.69^{g} ± 0.01	1.11	nd	nd
	60°C/7 hrs	4402^{a} ± 1.15	252.61^{a} ± 0.01	793.23^{a} ± 0.01	166.87^{a} ± 0.01	41.11^{b} ± 0.02	39.00^{b} ± 0.15	12.09^{b} ± 0.01	51.03^{a} ± 0.01	4.65^{e} ± 0.32	0.89^{a} ± 0.01	1.85^{a} ± 0.01	nd	nd	nd
Microwave-drying	60°C/7 min. medium power level (60%)	4371^{d} ±1.15	250.64^{b} ± 0.01	697.18^{f} ± 0.02	162.50^{c} ± 0.01	64.96^{a} ± 0.01	42.54^{a} ± 0.01	20.84^{a} ± 0.01	45.18^{b} ± 0.01	0.65^{g} ± 0.01	0.62^{d} ± 0.01	1.35^{d} ± 0.01	nd	nd	nd

Control: drying without ascorbic acid at 40 °C/12 hr.

nd: not detectable

Jerusalem artichoke flour contained high levels of some heavy metals such as Cu, Mn, Zn and Fe. These metals are the natural essential components of enzymes and coenzymes and are important for growth and respiration. Jerusalem artichokes flour it is a good source of calcium, iron, potassium and other nutrients (Duke, 1978).

Instrumental analysis:

FT-IR Spectrum for Jerusalem artichoke flour:

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.

With respect to the Jerusalem artichoke flour dried by different drying methods, the obtained spectrum within Wave numbers 400 up to 4000 cm^{-1} was given in Figs. (1 - 4) and table (6). The identified wave numbers can be classified functional groups. The following functional groups could be known in terms of (%) Transmittance and Wave numbers (cm^{-1}) as follows:

* Jerusalem artichoke flour without acidification (control):

IR (KBr) UMax/ cm^{-1}: 3342 (OH stretching); 2927 (CH stretching); 1631 (C=C); 1413 (CH bending).

* Jerusalem artichoke flour dried by sun at 50 °C/50 hr:

IR (KBr) UMax/ cm^{-1}: 3352 (OH stretching); 2931 (CH stretching); 1633 (C=C); 1427 (CH bending).

* Jerusalem artichoke flour dried by oven at 50 °C/9hr:

IR (KBr) UMax/ cm^{-1}: 3360 (OH stretching); 2931 (CH stretching); 1631 (C=C); 1421 (CH bending).

* Jerusalem artichoke flour dried by microwave at 60°C/7 min:

IR (KBr) UMax/ cm^{-1}: 3352 (OH stretching); 2930 (CH stretching); 1631 (C=C); 1422 (CH bending).

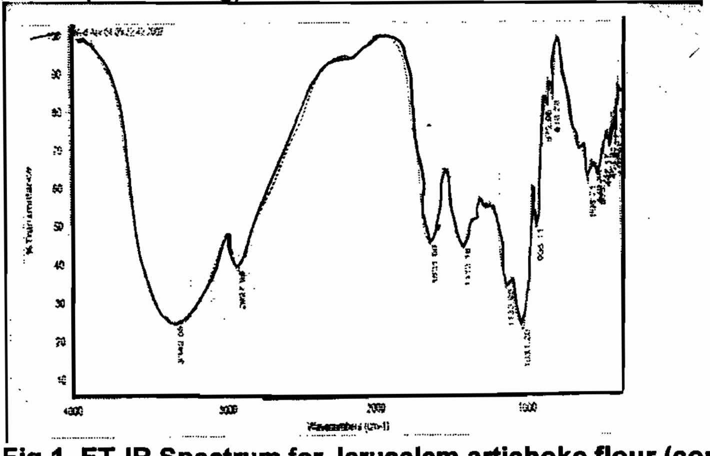

Fig.1. FT-IR Spectrum for Jerusalem artichoke flour (control)

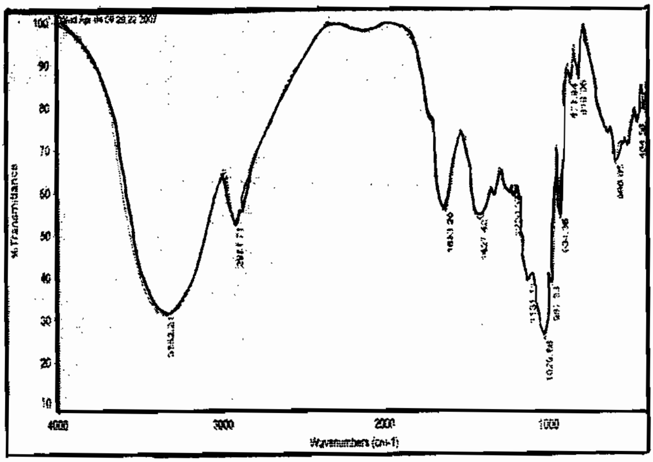

Fig. 2. FT-IR Spectrum from Jerusalem artichoke flour drying by sun-drying at 50 °C/50 hr

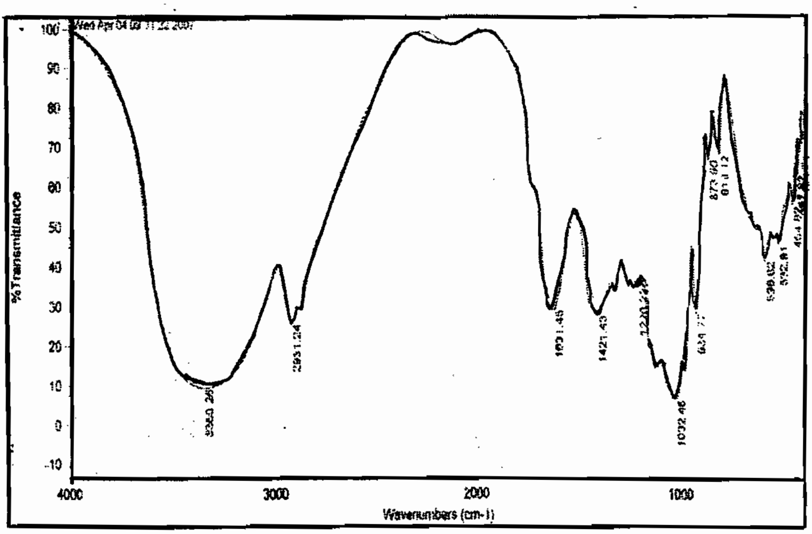

Fig.3. FT-IR Spectrum for Jerusalem artichoke flour drying oven at 50 °C/9 hr

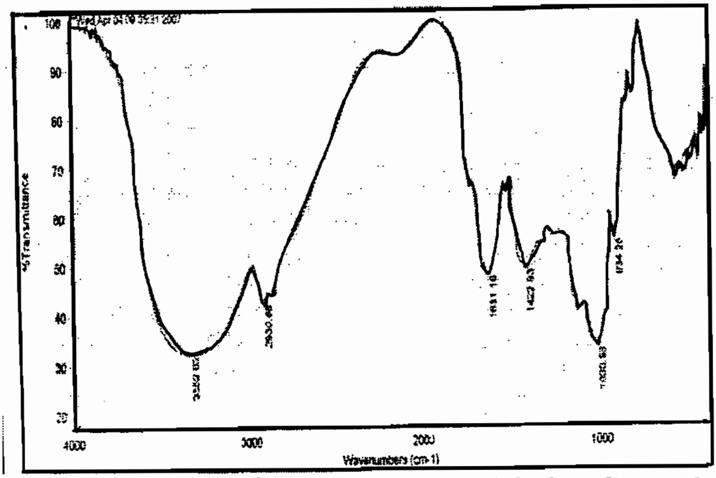

Fig. 4. FT-IR Spectrum for Jerusalem artichoke flour drying by microwave oven

Similar trends was obtained by (Wu and Lee, 2000), who found that the FT-IR spectrum for Jerusalem artichoke flour was essentially identical, showing OH stretch (3353 cm^{-1}) bonds of inulin. Also, Pitarriesi *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).

Table (6): Wave numbers (cm^{-1}) and (%) Transmittance of the Infrared Spectrum (IR) of Jerusalem artichoke flour (JAF) dried by different drying methods

Treatments	Temperatures (°C)	Wave numbers (cm^{-1})	(%) Transmittance
JAF (control)	40°C/12 hr	3342	23
		2927	37
		1631	44
		1413	43
Sun-drying	50° C/50 hr	3352	43
		2931	51
		1633	55
		1427	53
Oven-drying	50°C/9 hr	3360	9
		2931	25
		1633	28
		1427	27
Microwave- drying	60°C/7min. medium power level (60%)	335	31
		2930	42
		1631	47
		1422	48

Control: drying without ascorbic acid at 40 °C/12 hr.

X-ray Fluorescence:

Qualitative and quantitative analysis of trace elements in the flour from Jerusalem artichoke tubers using a different drying method by X-ray Fluorescence given in Table (7). The data proved that the highest mean values of SiO_2, Al_3O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O were detected in Jerusalem artichoke flour, dried by oven at 50° C/9hr, which recorded 0.11, 0.03, 0.11, 0.11,1.04, 0.03 and 3.73 %, respectively. However, the lowest levels detected in microwave dried samples, except K_2O. The levels of trace elements in these methods were SiO_2 (0.05), Al_3O_3 (0.01), Fe_2O_3 (0.04), MgO (0.06), CaO (0.52) and Na_2O (0.02 %). Regarding to P_2O_5, SO_3, Cl, SrO and NiO, data showed that microwave dried samples contained the highest values, which recorded 2.26, 0.39, 0.15, 0.09 and 0.009 %, respectively. On the other hand, the lowest values detected in sun dried samples, which recorded 0.38, 0.13, 0.07, 0.007 and 0.008 % with K_2O, P_2O_5, SO_3, Cl, SrO and NiO, in this order.

Subsequently, the given sample of Jerusalem artichoke flour drying by different methods contains trace elements such as potassium (K), calcium (Ca), phosphorus (P), and Sulphur (S).

Table (7): Qualitative and quantitative analysis of trace elements of Jerusalem artichoke flour (JAF) dried by different drying methods used by X-ray Fluorescenc

Oxides	Trace elements (Wt %)				
	Formula	Control	Sun-drying at 50 °C/50 hrs	Oven-drying at 50 °C/9 hrs	Microwave-drying 60°C/ 7min. medium power level (60%).
Silicon oxide	SiO_2	0.14	0.06	0.11	0.05
Aluminum oxide	Al_3O_3	0.03	0.02	0.03	0.01
Iron oxide	Fe_2O_3	0.08	0.07	0.11	0.04
Magnesium oxide	MgO	0.07	0.06	0.11	0.06
Calcium oxide	CaO	0.42	0.55	1.04	0.52
Sodium oxide	Na_2O	0.01	0.02	0.03	0.02
Potassium oxide	K_2O	2.82	1.86	3.730	2.26
Phosphorus pentoxide	P_2O_5	0.41	0.38	0.71	2.26
Sulphur trioxide	SO_3	0.15	0.13	0.30	0.39
Chlorine	Cl	0.13	0.07	0.14	0.15
Strontium oxide	SrO	0.003	0.007	0.012	0.09
Zinc oxide	ZnO	0.007	0.091	0.017	0.006
Rubidium oxide	Rb_2O	0.004	-	-	0.008
Cupper oxide	CuO	0.006	-	-	0.003
Nickel oxide	NiO	0.006	0.008	-	0.009

Control: drying without ascorbic acid at 40 °C/12 hr.
(-): Not detectable

It could be concluded that Jerusalem artichoke tubers contained moisture, fat, reducing sugars, protein, total carbohydrates, fiber and ash at levels of 70.72, 0.42, 3.98, 7.25, 18.89, 3.81 and 2.52 % on dry weight basis, respectively. Also, the tuber of this plant is a good rich source of K and contained moderate levels of P, Ca, Mg and Na. However, the plant contained low levels of Zn, Fe and Cu. In most cases compounds of the plant increased with drying process. Flour made from Jerusalem artichoke tubers, in most cases not affected among the three methods of drying. So we can storage the plant as flour by using any of dried methods in this investigation

and the flour made from Jerusalem artichokes can be used as a low-calorie, bulking agent in pasta, baked goods and other processed foods.

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الخواص الكيميائية ووسائل التحليل لدقيق الطرطوفة المنـتج بواسـطة طـرق التجفيف المختلفة

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تم دراسة التركيب الكيميائى لدرنات نبـات الطرطوفـة وتـشمل الرطوبـة والـدهن والسكريات المختزلة والبروتين والكربوهيدرات الكلية والألياف والرماد. فأشـارت النتـائج الـى أحتوائها على٧٢و٧٠ , ٤٢و٠ , ٩٨و٣, ٢٥و٧ ، ٨٩و١٨، ٨١و٣ ،٥٢و٢ % على التوالى علـى أساس الوزن الجاف.
كما وجد أن درنات نبات الطرطوفة مصدر غنى بالبوتاسوم (٤٣٧٧ مللجم/كجم) كما تحتوى على مستويات متوسطة من الفوسفور (٣٠و٧٩٠ مللجم/كجم) وكالـسيوم (١٢و٢٤٢ مللجـم/كجـم) وماغنيسيوم (١٩و١٦٨ مللجم/كجم) وصوديوم (١٠و٣٢ مللجم/كجم) .بينما تحتوى على مستويات منخفضة من الزنك (٩٧و١١ مللجم/كجـم) والحديـد (١٥و١١ مللجـم/كجـم) والنحـاس (٩و٧ مللجم/كجم).
كما لوحظ أن فى معظم الحالات أن التركيب الكيميائى للدقيق المنتج من درنـات نبـات الطرطوفة لم يتأثر بطرق التجفيف الثلاثة النجفيف الشمسى (٤٠ م°/٧٢ ساعة، ٥٠ م°/٥٠ ساعة، ٦٠ م°/٣٦ ساعة) والتجفيف فى الفرن(٤٠ م°/١٢ ساعة، ٥٠ م°/ ٩ ساعات، ٦٠ م°/٧ سـاعات) والتجفيف فى الميكروويف(٦٠ م°/٧ دقائق) على مستوى طاقة متوسطة (٦٠ %).
ولظهرت نتائج اختبار الأشعة تحت الحمراء أنه قد تم تحديد المجاميع الوظيفية لأنـواع الدقيق المختلفة. كما تم اجراء تحليل كمى ونوعى للعناصر النادرة فى دقيق الطرطوفة بواسـطة جهاز الأشعة السينية حيث وجد أنها تحتوى على أكاسيد عناصر البوتاسيوم والكالسيوم والفوسفور والصوديوم.
ولذلك فانه يمكن تخزين درنات الطرطوفة فى صورة دقيق بواسطة استخدام أى طريقة من طرق التجفيف فى هذه الدراسة وكذلك يمكن استخدام هذا الدقيق فى منتجـات المخابزكـدقيق مـنخفض السعرات وفى بعض الأغذية الأخرى.