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ORIGINAL PAPER

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RELATIONSHIP BETWEEN HARVESTING TIME AND CARBOHYDRATE CONTENT OF JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) TUBERS

Judita Černiauskienė[1]✉, Jurgita Kulaitienė[1], Elvyra Jarienė[1], Honorata Danilčenko[1], Sandra Žaldarienė[1], Maria Jeznach[2]

[1] Faculty of Agronomy, Institute of Agriculture and Food Sciences, Aleksandras Stulginskis University, Kaunas, Studentų 11, Akademija, LT – 53356, Lithuania

[2] Faculty of Human Nutrition and Consumer Sciences, Warsaw University of Life Sciences, SGGW

ABSTRACT

The aim of this 3-year study was to determine the influence of harvest time on dry matter, total dietary fibre, fractional composition of dietary fibre (acid detergent fibre (ADF) and neutral detergent fibre (NDF)), water-soluble carbohydrates (WSCs) and inulin content in tubers of different cultivars of Jerusalem artichoke (*Helianthus tuberosus* L.): 'Rubik', 'Albik' and 'Sauliai'. The tubers were harvested in spring (March and April) and autumn (October and November). Our study shows that the largest amount of WSC to exist in 'Rubik' tubers harvested especially during October. In contrast, the largest amount of total dietary fibres and their fractions (NDF and ADF) accumulated in 'Albik' tubers during the spring harvest month (April). The largest amount of inulin was obtained from 'Sauliai' tubers harvested in October. Based on our results, it is advisable to use the 'Sauliai' tubers from the harvest time during October to obtain the largest amount of inulin.

Key words: dietary fibre, inulin, water-soluble carbohydrates, Jerusalem artichoke tubers

INTRODUCTION

The Jerusalem artichoke (*Helianthus tuberosus*), native to eastern North America, is a member of the sunflower family. The tuber of this species is one of the best sources of dietary fibres (DFs) and particularly contains high levels of oligofructose inulin, which is a soluble non-starch polysaccharide [Somda et al. 1999, Saxholt et al. 2008]. In addition, they are an extremely good source of minerals and electrolytes, particularly potassium, iron and copper.

DF is a group of food components that resist hydrolysis by human digestive enzymes and is necessary for promoting good health [AACC Report 2001]. DF plays an important role in the prevention and treatment of diabetes, obesity, atherosclerosis, heart diseases, colon cancer and colorectal cancer [Slavin 1987, Wang et al. 2002, Ferguson and Harris 2003, Figuerola et al. 2005]. DF is not only used for its nutritional properties but also for its functional and technological properties. Thus, to supplement the daily diet, DF should be incorporated into frequently consumed foods.

DF is generally understood to mean vegetable polysaccharides and lignins that retain their resistance when exposed to the influence of digestive enzymes in

✉ judita.cerniauskiene@asu.lt

the human gastrointestinal tract [AACC Report 2001]. DF consists of substances used in cell construction such as cellulose, hemicellulose, lignins and pectins, as well as resins and waxes [Prosky 1999].

Hemicellulose and pectin were found to have a remarkable capability for binding metal ions. The same proved to be true for cellulose and lignin, although to a smaller extent, because their origins notably affect the metal-binding properties of the two fractions [Nawirska 2005].

As the chemical structure of DFs differs from one fraction to another, the nutritional implications of DF similarly differ. Soluble DF fractions (pectin, gum and some of the hemicelluloses) undergo bacterial fermentation in the gastrointestinal tract and influence the metabolism of carbohydrates and fats. Insoluble DF fractions (cellulose, lignin and hemicellulose) shorten the gastrointestinal transit time and thus prevent constipation, and they exert an inhibiting effect on the development of many rectal forms of cancer by favourably stimulating the growth of intestinal microflora and preventing that of putrefactive bacteria [Bingham et al. 2003].

The Jerusalem artichoke (*Helianthus tuberosu* L.) constitutes one of the most interesting potential sources of fructose. The biggest interest through its high sugars content especially inulin, its productivity and the possibilities for its easy cultivation [Chekroun et al. 1994]. Inulin is used in the food industry as a soluble DF and fat or sugar replacement [Barclay et al. 2010]. Inulin is also known as a prebiotic and is able to stimulate health-promoting bacterial growth in the human colon [Gibson 1998, Roberfroid et al. 1998]. However, for all the applications mentioned above, products obtained from Jerusalem artichoke tubers, including inulin, as well as the flour obtained from processed tubers are useful within the biotechnology and food industry. Jerusalem artichoke is an abundant, inexpensive and renewable raw material.

The possibility of harvesting and offering tubers to consumers, depending on seasonal yield, would further enhance the potential use of Jerusalem artichoke. By the investigation of Liu et al. [2015] results showed that each factor as genotype, year and their interactions strongly influenced total soluble sugar, starch, cellulose, hemicellulose, and lignin content of Jerusalem artichoke.

Inulin is used as a raw material for health products, sweeteners, bio-ethanol and animal feed. In Thailand, this plant is becoming a commercial crop for the production of foods and health foods. Tubers generally contain mainly carbohydrates at between 20% and 32% of dry matter (DM), of which 54–75% is water-soluble inulin. The amount of inulin varies according to species, cultivars, production conditions, physiological ages and other factors [De Leenheer 1996, Cieslik et al. 2005, Saengthongpinit and Sajjaanantakul 2005].

Increased knowledge of Jerusalem artichoke as a raw material can be used to promote the consumption of this vegetable in the human diet and provide consumers with a larger selection of vegetables for human consumption. The present study aimed to determine the suitable harvest time and cultivar of Jerusalem artichoke tubers for providing the highest carbohydrate content as well as dietary fibre fractions, inulin and water-soluble carbohydrates (WSCs) to increase the value of food in the human daily diet.

MATERIAL AND METHODS

The study material comprised Jerusalem artichoke (*Helianthus tuberosus* L.) cultivars 'Sauliai', 'Albik' and 'Rubik', originating from a field experiment conducted during 2012–2014 at an organic farm in south eastern Lithuania. Field experiments on three Jerusalem artichoke cvs. 'Albik', 'Rubik', 'Sauliai' were carried out at the organic farm in South Lithuania in years 2012–2014. The characteristics of these Jerusalem artichoke cultivars have been previously described [Krivorotova and Sereikaite 2013]. Composite soil samples were taken with a sampling auger from randomly selected points of each treatment replicate from the topsoil layer 0–20 cm depth before Jerusalem artichoke planting (in November, 2011). The soil of the experimental field was Calc(ar)I, an Epihypogleyic Luvisol LV g- p- w- cc (IUSS Working Group WRB, 2007) with a texture of silty light loam on heavy loam (tab. 1). Soil agrochemical characteristics were maintained at a similar level during the whole study period.

An additive fertilisation before planting and during the growing season was not used. Tubers of Jerusalem artichoke cultivar 'Sauliai', 'Albik' and 'Rubik' were planted during the third week of April by hand using a spacing of 70 × 30 cm. The size of the original field was 40 m^2 (4 m × 10 m) compared to that of the experiment fields of 18 m^2 (3 m × 6 m) in three repetitions.

Table 1. Characteristics of soil conditions

pH	Humus content (%)	P (mg kg^{-1})	K_2O (mg kg^{-1})
7.4	1.81	75.63	65.98

The beginning of the spring harvesting of the Jerusalem artichoke occurs in March and April, whereas the end of the harvesting occurs at the end autumn in October and November. Samples of all the tested varieties of tubers (5 kg) were collected in the 4th week of each month. The tuber sample for chemical analyses was a mass of 1 kg. Chemical analyses were performed in four replications.

Preparation of plant material. After the harvest, the Jerusalem artichoke tubers were washed, sliced and dried at 60°C in a thermostat (Termaks, Norway). Dried slices of tubers were milled using a grinder (Ultra Centrifugal Mill ZM 200, Retsch, Germany) to produce flour samples, which were kept in an air-tight container at 12–18°C until the laboratory analysis. The samples were evaluated in triplicate for each analysis.

Methods of sample preparation and chemical analyses. The studies were conducted at the laboratories of the Lithuanian Research Centre of Agriculture and Forestry, Agriculture and Food Sciences Institute of the Agronomy Faculty of Aleksandras Stulginskis University.

The DM content of the Jerusalem artichoke tubers was determined by drying each sample to a constant weight at 105°C [LST ISO 751:2000]. The DF content was determined by an enzyme-gravimetric method according to Prosky et al. [1985; 1988]. Samples were also subjected to fibre component analyses for acid detergent fibre (ADF) (cellulose and lignin) and neutral detergent fibre (NDF) (cellulose, hemicellulose and lignin) using the fractionation method of Van Soest [Faithfull 2002]. ADF extraction was performed with an ANKOM220 Fibre Analyser (ANKOM Technology Method 08-16-06) using F57 filter bags (25-µm porosity). NDF was analysed with sodium sulphite, and the results are presented as ash-free. The WSCs were determined using the anthrone method [Yemm and Willis 1954].

Inulin was extracted from the artichoke tuber according to method described by Saengkanuk et al. [2011]. Inulin was extracted from tuber samples using the accelerated solvent extraction method before subsequent hydrolysis in an acid condition. The hydrolysates were then analysed for fructose using spectrophotometry. The spectrophotometric method used is based on oxidation of fructose by periodate and the evaluation of the remaining periodate by measuring the absorbance of the triiodide complex formed at 350 nm, upon addition of potassium iodide. The optimum conditions for the detection of fructose were 0.1 mmol l^{-1} periodate and 1.5 mmol l^{-1} potassium iodide at pH 6.0.

The experimental data were statistically processed by the dispersion analysis method [analysis of variance (ANOVA)] in the statistical software STATISTICA 7.0 (StatSoft, USA). Dispersion analysis was applied to evaluate the chemical composition of Jerusalem artichoke (*Helianthus tuberosus* L.) tubers. The two-way analysis Tukey test ($p < 0.05$) was used to estimate the statistical reliability of the mean differences.

RESULTS AND DISCUSSION

DM is one of the most important chemical content quality indicators of Jerusalem artichoke (*Helianthus tuberosus* L.) tubers. DM in plants determines their yield quality and depends on the cultivar characteristics and meteorological conditions. DM ensures the quality and output of the recycled products. Depending on the type and cultivar, the amount of DM in Jerusalem artichoke tubers can fluctuate from 8.5% to 23.8% [Bach et al. 2012, Krivorotova and Sereikaite 2014]. In the present study, DM varied from 16.63% to 25.78 % (tab. 2). A significantly higher amount of DM was found in the tubers of 'Albik' than in the other two varieties (25.78% and 24.04%, respectively) during the November and March harvest times (tab. 2).

Table 2. Amount of dry matter in tubers of Jerusalem artichoke cultivars depending on the harvesting month (%)

Cultivar	Harvest month			
	October	November	March	April
'Sauliai'	20.23 ±1.01[b,c]*	21.23 ±0.55[b]	21.47 ±0.57[b]	20.25 ±0.99[b,c]
'Albik'	21.51 ±0.77[b]	25.78 ±1.67[a]	24.04 ±0.91[a]	21.31 ±0.25[b]
'Rubik'	16.63 ±0.84[d]	20.59 ±0.99[b,c]	21.27 ±0.84[b]	18.50 ±0.61[c,d]

Means followed by the same letter are not significantly different at P ≤ 0.05

Table 3. Total dietary fibre content in Jerusalem artichoke tubers depending on the harvesting month (% DM)

Cultivar	Harvest month			
	October	November	March	April
'Sauliai'	14.13 ±0.21*[e]	14.00 ±0.12[e]	16.13 ±0.12[c]	16.80 ±0.10[b]
'Albik'	15.30 ±0.30[d]	14.68 ±0.15[d,e]	16.93 ±0.06[b]	17.83 ±0.25[a]
'Rubik'	14.00 ±0.17[e]	13.73 ±0.21[e]	15.30 ±0.26[d]	15.97 ±0.15[c]

Means followed by the same letter are not significantly different at P ≤ 0.05

Table 4. Fractional composition of dietary fibre in Jerusalem artichoke tubers depending on the harvesting month (% DM)

Cultivar	Harvest month			
	October	November	March	April
		NDF		
'Sauliai'	6.24 ±0.95[c,d]*	6.00 ±0.83[d]	6.04 ±0.84[d]	12.80 ±0.96[a]
'Albik'	6.18 ±1.01[c,d]	6.86 ±0.88[b,c,d]	6.26 ±0.57[c,d]	14.20 ±0.99[a]
'Rubik'	7.88 ±0.82[bc]	8.32 ±0.91[b]	5.84 ±0.77[d]	10.46 ±1.01[b]
		ADF		
'Sauliai'	6.52 ±1.13[d,e]	5.66 ±0.88[e]	6.16 ±0.54[d,e]	12.50 ±0.99[b]
'Albik'	6.24 ±0.77[d,e]	4.98 ±1.01[e]	5.52 ±0.82[e]	14.70 ±0.91[a]
'Rubik'	9.44 ±0.84[c]	9.12 ±0.96[c]	7.12 ±0.95[d,e]	9.83 ±1.03[c]

Means followed by the same letter are not significantly different at P ≤ 0.05

McLaurin et al. [1999] found that the DM content of Jerusalem artichoke tubers changes depending on the aboveground part of the plant. The highest amount of DM accumulates in tubers during the autumn period when the aboveground plant parts begin to wither. During the spring period, the DM amount could decrease by up to 30% in tubers, depending on the formation of roots and the formation density of the stolon.

By researchers the genetic differences and year conditions are responsible for the DF and carbohydrates accumulation [Liu et al. 2015]. The content of DF comprising soluble carbohydrates in Jerusalem artichoke tubers has previously been investigated in unpeeled tubers and was found to depend on harvest time, variety and postharvest conditions [Kocsis et al. 2007, Slimestad et al. 2010].

Our results showed that contents of total DF differed significantly among tubers of all Jerusalem artichoke cultivars. The analyses showed a tendency to increase the amount of DF, particularly in tubers harvested during spring. The highest amounts of DF were estimated to occur in the tubers of cultivar 'Albik' harvested in April (tab. 3).

Analysis of the results of other researchers showed that the amount of DF depends on the genetic characteristics of the cultivar of Jerusalem artichoke tubers [Berghofer and Reiter 1997, Piskier 2009]. Our experimental results showed that the amount of DF in tubers fluctuates depending on the cultivar; however, essential differences were estimated depending on the harvesting time. The largest amount of DF accumulated in tubers was found to be 15%, which was found during overwintering in the soil. According to Florkiewicz et al. [2007], tubers harvested after winter storage in the soil contained approximately 20% more fibre than tubers harvested during autumn. A similar finding was reported by Praznik et al. [1998] found that higher levels of dietary fibre in overwintering tubers in the soil was likely the result of an increase in respiratory activity and tuber production of the substances used to construct the cell walls and polyphenolic compounds.

Our study showed that the largest amount of fibre accumulated in tubers depended on the growth period. The slight increase of fibre content may take place in the period leading to crop maturity. Maximal DM and DF content rates are reached at the end of the harvest period in April. The changes in the fibre fractional composition in Jerusalem artichoke tubers of cultivars 'Rubik', 'Sauliai' and 'Albik' were estimated at the harvesting times during spring and autumn. Our research showed that the amount of NDF in the tubers of all cultivars over harvest time ranged from 5.84% to 14.20% of DM (tab. 4). The amount of NDF was approximately twofold higher in tubers harvested in April than in other months, especially in 'Sauliai', 'Albik'.

The content of ADF in the tubers of Jerusalem artichoke cultivars also showed significant differences at different harvesting times. The content of ADF varied between 4.98% and 14.70%. Jerusalem artichoke tubers of all cultivars contained the significantly highest amount of ADF during the April harvesting time, and among these cultivars, 'Albik' tubers contained the significantly highest content of ADF at 14.70% DM (tab. 3).

The content of WSC in the developing tubers is generally high; however, the variation in WSC is mainly based on the genetic predisposition of different varieties [Kocsis et al. 2007; Liu et al. 2015]. By Liu et al. [2015] soluble sugar content of Jerusalem artichoke tuber in different genotypes have been varied between 30.7 and 68.0%. They declared that the smallest content determinated in the tubers form the plants were removed after a growth cycle of six months (from April to October), when the assimilates in above-ground still kept allocating to tubers when harvested. By Chekroun et al. [1994] the tubers of Jerusalem artichoke remaining in the ground during the winter season lose a significant fraction of their carbohydrates. The loss results from a biological mechanism necessary for tuber subsistence.

According to the data obtained in the present work, the lowest amounts of WSC were consistently accumulated in the tubers of 'Sauliai' (tab. 5), whereas tubers of cultivars 'Albik' and 'Rubik' consistently possessed the highest amounts of WSC at 24.30% and 29.60% of DM, respectively. The maximum level of WSC was identified in 'Albik' and 'Rubik' tubers during October.

The contents of inulin and sugars in Jerusalem artichoke tubers has previously been investigated in unpeeled tubers and was found to depend on harvest time, variety and postharvest conditions [Kocsis et al. 2007, Slimestad et al. 2010]. The inulin content of Jerusalem artichoke tubers depends on the climate, growing conditions and harvesting maturity [Saengthongpinit and Sajjaanantakul 2005]. In Austria, alterations in the frost period were found for early, moderately early and late varieties. The average amount of inulin decreased by approximately 1.5–2-fold [Modler et al. 1993, Kocsis et al. 2007].

Our results show that the amount of inulin in tubers fluctuated from 21.23% to 45.23% of DM. The results of the present research showed that there were differences between the amount of inulin, depending on the cultivar of Jerusalem artichoke and the harvesting time. 'Rubik' and 'Albik' tubers accumulated the lowest amounts of inulin during October at 21.23% and 26.60% of DM, respectively, whereas 'Sauliai' accumulated the highest amount at 45.23% DM during this period (tab. 5). The tubers usually

Table 5. Amount of water-soluble carbohydrates in Jerusalem artichoke tubers depending on the harvesting month (% DM)

Cultivar	Harvest month			
	October	November	March	April
'Sauliai'	10.50 ±1.01^{f}*	6.71 ±0.99^{g}	4.87 ±1.54^{g}	6.58 ±1.31^{g}
'Albik'	24.30 ±0.51^{b}	15.25 ±0.74^{d,e}	17.10 ±0.55^{c,d}	14.70 ±0.87^{d,e}
'Rubik'	29.60 ±0.55^{a}	20.10 ±0.76^{c}	11.90 ±1.01^{e,f}	14.00 ±0.63^{d,e}

Means followed by the same letter are not significantly different at P ≤ 0.05

Table 6. Amount of inulin in Jerusalem artichoke tubers depending on the harvesting month (% DM)

Cultivar	Harvest month			
	October	November	March	April
'Sauliai'	45.23 ±0.15a*	41.47 ±0.55^{d}	43.93 ±0.21^{b}	39.00 ±0.17e
'Albik'	26.60 ±0.40^{h}	30.53 ±0.45^{g}	38.50 ±0.87^{e}	33.07 ±0.35^{f}
'Rubik'	21.23 ±0.29^{i}	28.84 ±0.06^{g}	42.37 ±0.47^{c}	38.33 ±0.51^{e}

Means followed by the same letter are not significantly different at P ≤ 0.05

showed intensive growth during in September, whereas during October, growth slowed and they started to accumulate reserve materials. During November, tubers started the process of polymerisation of materials and also intensified the accumulation of inulin after reaching full maturity. Therefore, mature tubers of Jerusalem artichoke contained approximately 11.7% inulin and 6.3% sugars [Taper and Roberfroid 2002].

Inulin was found to depend on the harvest time and cultivar of Jerusalem artichoke. Our research data show that the larger amount of inulin occurred during early spring rather than during autumn (tab. 6). Except the tubers of 'Sauliai' cultivar have been accumulated the essential biggest amount of inulin in October comparing with other harvesting months. The inulin content was significantly different during the spring period from 33.07% to 43.93%. Especially in March, Jerusalem artichoke tubers contained the highest inulin concentrations (up to 20%). This could be due to the effect of weather conditions such as a warm autumn and late winter.

Other studies found that the content of sugars, flavour and nutritional value of tubers decline markedly when the growing season begins. The cause of the decrease in inulin was mainly due to its conversion to sucrose, and at the same time, the formation of inulin with a lower degree of polymerisation [Morten et al. 2012]. The present research obtained the same result, with the amount of inulin showing a strong decline. The existing literature indicates that Jerusalem artichoke tubers contain a large amount of sucrose and are therefore not suitable for diabetic products; therefore, tubers harvested during autumn would be the best choice for minimising sucrose levels. Moreover, tubers harvested during autumn could be used in biotechnology for high-fructose syrup production because of the high fructose/glucose ratio [Krivorotova and Sereikaite 2014].

CONCLUSION

Our study shows the largest amount of WSC to exist in 'Rubik' tubers harvested especially during October. Contrary to the amount of WSC, the largest amount of total DFs and their fractions (NDF and ADF) accumulated in Jerusalem artichoke tubers of cultivar 'Albik' during the spring harvest months in

April. According our research, to obtain the largest amount of inulin, it is advisable to use the 'Sauliai' tubers from the harvest time during October.

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