ACTA Acta Sci. Pol. Hortorum Cultus, 16(3) 2017, 97–107
www.acta.media.pl ISSN 1644-0692 DOI: 10.24326/asphc.2017.3.10

ORIGINAL PAPER

Accepted: 13.01.2017

THE DISTRIBUTION OF BIOACTIVE COMPOUNDS IN THE TUBERS OF ORGANICALLY GROWN JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) DURING THE GROWING PERIOD

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ABSTRACT

This study aim to evaluate the distribution of bioactive compounds in the tubers of organically grown Jerusalem artichoke (JA) during the growing season in 2012–2014. Field experiments on the three JA cultivars: Albik, Rubik and Sauliai, were carried out at the organic farm in South Lithuania. The tubers were uprooted at the end of each month of the growing period (8 times) in March–June (spring period) and August–November (autumn period) and were analysed for the contents of dry matter, carbohydrates, phenolic compounds, leuco-anthocyanins, catechins.

The significantly highest dry matter content in JA tubers was determined in March of 2014 after they had been exposed to sub-zero temperatures in the soil during the winter, while the amount of phenolic compounds – at the beginning of the spring growing period. The significantly highest content of inulin in October of 2014 was accumulated in the tubers of cv. Sauliai (46.08%), carbohydrates – in Albik tubers in September of 2014 (44.23%), when the formation of new tubers began. Significantly higher amounts of catechins were determined in the second half of the growing period. Cultivar and organogenesis stage had a significant impact on the content of leuco-anthocyanins in JA tubers. Substantial differences in the content of leuco-anthocyanins among the tested cultivars were determined at the end of the growing season.

Key words: tubers, anthocyanins, inulin, catechins, phenolic compounds, carbohydrates

INTRODUCTION

Jerusalem artichoke (JA) tubers are very different from those of other root crops, in particular due to the main carbohydrate fructose and its polymers, namely, inulin and other oligosaccharides [Brkljača et al. 2014]. JA is a non-traditional crop with a wide range of applications not only in the food, fodder, pharmaceutical and machinery industries, but also in dealing with environmental problems due to their nutritional, functional, health-promoting and industrial properties [Hafez 2013].

Recently, increasingly more attention has been given to the research on natural products and plants

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which accumulate higher amounts of biochemical compounds. Most of these compounds have nutritional and pharmacological importance which influences tuber quality and taste of JA. It has been found that the compounds present in the stems and leaves of JA provide tubers with antioxidant, antibacterial, antifungicidal and anticarcinogenic properties, which are determined by such compounds as coumarins, unsaturated fatty acids, polyacetylenes, phenols, sesquiterpenes. Antioxidant properties of JA are associated with the phenolic compounds present in tubers [Chen et al. 2013].

Chemical composition of JA tubers depends on the cultivation technology, and most importantly, on the nutrition level [Baker et al. 1990, Cieslik 1998]. Chemical composition of tubers is also highly dependent on the soil type, its productivity, genetic potential of a variety, and growth stage [Meijer and Mathijssen 1991, Mclaurin et al. 1999, Sawicka and Kalembasa 2013], which are largely linked to their maturity [Saengthobpinit and Sajjaanantakul 2005, Rodrigues et al. 2007].

JA tubers contain 20.4–31.9% of dry matter, of which the main components constituting 13–20% are monosaccharides, disaccharides, polysaccharides and the dominant one is inulin [Barta and Patkai 2007]. According to the data of Canadian scientists, the content of carbohydrates in fresh JA tubers was 13.8–20.7%, and during later yield the content of glucose increased and that of fructose decreased [Taper and Roberfroid 2002]. Of the total carbohydrates present in tubers, fructooligosaccharides accounted for 30–54%, and the rest were saccharides, which were mainly sucrose and small amounts of fructose. Pan et al. [2009] indicated that the content of fructooligosaccharides in tubers varied from 20 to 40 mg g^{-1} and kestose and nystose were the main fructooligosaccharides.

Inulin and oligofructose are naturally occurring resistant carbohydrates that have a variety of uses as functional food ingredients. As a prebiotic, inulin has been associated with enhancing the gastrointestinal system and immune system. In addition to their role as prebiotics that selectively stimulate the growth of beneficial bacteria in the intestines, these inulin-type fructans act as dietary fibre in the digestive system and is applicated as a sugar substitute and fat replacer [Taper and Roberfroid 2002, Zhong et al. 2009].

During the growing period, biochemical composition, including the content of inulin, varies in JA tubers: its highest content was found in the autumn. Therefore, JA tubers harvested in this season are most suitable for inulin extraction. Spring harvest is the most suitable for the production of fructose-glucose syrup without enzymatic hydrolysis of inulin [Zubr 1988, Kays and Kultur 2005]. The JA tubers overwintered in the soil could be used in food industry because the shorter chains of inulin are more bifidogenic [Krivorotova and Sereikaite 2013].

Polyphenols are one of the most important functional components found in plant-derived foods, where they are present mostly in bound form. Pro-health properties of phenolic compounds are demonstrated by their anticarcinogenic and antimutagenic activity, as well as cardiovascular protective effect, associated mainly with decreased cholesterol concentration in plasma and prevention of arteriosclerosis [Dixon and Paiva 1995, Duthie et al. 2000, Zhong et al. 2009, Gupta and Verma 2011]. The bioactive compounds of JA have been extensively studied and this plant has been found to be a rich source of polyphenolics [Kapusta et al. 2013]. Several studies on phenolic compounds in sunflower (*Helianthus annuus* L.) have been reported as well [Tchone et al. 2006, Yuan et al. 2012]. Lattanzio et al. [2009] demonstrated that the leaves of JA contained high concentrations of phenolics; however, still little is known about the phenolic composition of JA tubers.

Catechins, which belong to the flavonoids, are organic compounds characterized by strong antioxidant properties. Flavonoids are plant pigments of phenolic compounds. The oxidation of anthocyanins and flavonoids during the technological processing of raw JA tubers produces sediments, flakes and dregs that deteriorate the commercial appearance of the products. These processes are the result of interaction between proteins and specific types of flavonoids. The retaining of polyphenols in tuber tissues and a high oxidase activity are the main reasons for the browning of tubers and by chopping, cutting or heat treating the integrity of tissues is broken [Gupta and Verma 2011, Yuan et al. 2012].

Detailed knowledge about the biochemical composition in tubers at optimal harvesting time enables correct decisions with regard to their application in food or feed products.

Part of the results of this experiment was published [Krivorotova and Sereikaite 2013]. This article presents a more detailed analysis of the findings obtained during the experimental period in years 2012–2014.

The aim of this study was to evaluate the distribution of bioactive compounds in the tubers of organically grown Jerusalem artichoke (*Helianthus tuberosus* L.) during the growing period.

MATERIALS AND METHODS

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]. The soil of the experimental site according to the FAO–UNESCO soil classification is Haplic Dystric Arenosol. 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 agrochemical characteristics were as follows soil pH_{KCl} 6.7–7.5, P 44.44–102.08 kg ha^{-1}, K 53.95–81.34 kg ha^{-1}. Soil agrochemical characteristics were maintained at a similar level during the whole study period. In the experimental area the soil was ditch-drained and the relief was artificially levelled. Planting: the tubers were spaced 70 cm apart in each row, with rows 30 cm apart. The treatments were laid out in randomized experimental design with 4 replications. The tubers of Jerusalem artichoke were uprooted at the end of each month of the growing season (8 times) in March–June (spring period) and August–November (autumn period). A 5 kg sample of tubers was collected from each replicate. The tuber samples were washed with tap water, weighed and air-dried for 24 hours to reduce the water content. All samples were oven-dried at 70–80°C for 24 hours. The dried material was ground on a GRINDOMIX GM 200 knife-mill. The obtained powder was packed in air-tight containers prior to use. The content of dry matter (DM) was determined by drying samples to a constant weight at a temperature of 1050C [LST EN 12145:2001].

Carbohydrates. Carbohydrates in Jerusalem artichoke tubers were quantified by the dinitrosalicylic acid method [Lindsay 1973].

Inulin. Sugars in the sample are removed by extraction with ethanol. Inulin extracted with water in extraction balance. The aqueous extract is clarified, and finally treated with hydrochloric acid. Fructose by hydrolysis received is determined photometrically. Inulin is calculated as fructose, is determined by the ratio of solution A to solution of B (fructose standard solution). Fresh plant material briefly recorded at 90–100°C and then dried in an oven at 65–75°C [Naumann and Bassler 1976].

Phenolic compounds. The total content of phenolic compounds was determined using the spectrophotometrically. An analytical reaction was a positive reaction of Berlin blue solution, which was obtained from a mixture of iron and potassium hexacyanoferrate ($K_3Fe(CN)_6$). The content of phenolic compounds was calculated based on the light absorbance of the obtained solution at the wavelength 720 nm. The solutions of gallic acid were used as a reference. The plant samples were homogenized in acidulated 96% ethanol solution (20 : 1), the homogenate was centrifuged at 4500 rpm for 30 min [Gupta and Verma 2011]. The optical density of the solutions was measured using a spectrophotometer "SF–2000" (ZAO OKB Spectr).

Leuco-anthocyanins. The leuco-anthocyanins were quantified spectrophotometrically in acidulated 96% ethanol at 520 nm using a spectrophotometer "Shimadzu UV3600" (Shimadzu, Japan) [Krivencov 1982, Chupahina and Maslennikov 2004].

Catechins. To quantify catechins, the samples were ground to a homogeneous state in acidulated 96% ethanol solution (20 : 1), the homogenate was centrifuged at 5000 rpm for 10 min. One ml of the extract was added to the tubes with 4 ml vanillyl reagent and hydrochloric acid (2.5 ml 5% alcoholic solution of vanillyl with 47.5 ml conc. HCl). Measurements were performed with a spectrophotometer "Shimadzu UV3600" (Shimadzu, Japan) at 520 nm [Krivencov 1982, Chupahina and Maslennikov 2004].

Table 1. The weather conditions during the growing period in 2012–2014

Months	Years	Air temperature (°C)	The standard rate of climate*	Rainfall (mm)	The standard rate of climate*
March	2012	–2.2	–1.2	7.1	7.5
	2013	2.7	2.5	7.0	8.0
	2014	4.3	4.0	12.1	12.5
April	2012	0.8	1.0	23.5	23.9
	2013	8.2	8.5	36.3	29.0
	2014	7.6	7.2	76.3	26.0
May	2012	12.7	12.0	12.9	12.5
	2013	11.8	11.0	28.5	29.0
	2014	15.5	16.0	2.3	4.2
June	2012	12.5	12.6	57.4	55.0
	2013	16.9	17.0	5.0	58.3
	2014	15.7	16.0	56.6	57.3
July	2012	22.2	22.5	74.7	35.6
	2013	16.3	17.0	31.2	31.2
	2014	20.3	20.5	13.4	18.2
August	2012	18.3	18.9	60.0	48.2
	2013	16.3	17.0	15.7	32.5
	2014	15.0	15.9	48.5	36.3
September	2012	13.6	14.0	7.5	9.6
	2013	14.2	14.0	6.5	7.3
	2014	11.5	11.3	14.5	14.8
October	2012	10.1	10.0	51.5	25.3
	2013	7.8	8.0	7.2	8.9
	2014	2.9	3.0	23.4	18.9
November	2012	5.8	5.9	47.5	25.3
	2013	3.1	3.0	0.8	1.2
	2014	4.6	4.5	22	1.3

* The standard climate normal (SCN) is a 30 year average from 1981 to 2010

The weather conditions during the tubers growing period in 2012–2014 were compared with the standard climate normal (SCN) of 30 years (1981–2010) data (the weather data were obtained from the Varena Meteorological Station, Lithuania). The air temperature and distribution of rainfall during the experimental years varied. In March–November of 2012–2014 during the Jerusalem artichoke tubers growing the vegetative season was average regarding air temperature, while in, July, August, October, November of 2012 and in April, November of 2014 was extremely wet, but in June, August of 2013 was extremely dry comparing with average rainfall (tab. 1).

Statistical analysis

The data were statistically processed using one-way ANOVA and management module of the integrated system STATISTICA. The standard deviation and the least significant difference at a 95% significance level were estimated using the Fisher's LSD test ($P < 0.05$).

RESULTS

The great differences in dry matter content in the tubers in the tested varieties correlated with the harvesting date. From the beginning of intensive growth in spring period and development of the tubers, the dry matter content was redistributed to other plant parts. In April, May and late June downward trend of dry matter content was found in all tested JA cvs tubers.

The highest dry matter content in tubers was observed in March of 2014 when the spring growing period started and when average regarding rainfall and air temperature: in Sauliai – 26.31%, in Rubik's – 25.26% and in Albik – 24.87% (tab. 2).

In late August in all experiment years, after new autumn tubers had developed, the highest dry matter content compares with others cvs was determined in cv. Albik (19.69–23.19%) (tab. 2). After the tubers had reached full maturity and the plants started to decay, the positive tendency of accumulation of dry matter content was established in all tested cvs. Independing the meteorological conditions in the end of vegetative period (in November) the highest amount of dry matter was accumulated in the tubers of Albik cv. (tab. 2).

Such trend remained during the rest of the tuber development stages.

In this study the changes of quantity of inulin in JA tubers of the cvs Rubik, Sauliai and Albik are presented at various periods of plant life cycle. Our research showed that the quantity of inulin in the tubers of the three tested cvs was decreasing from the beginning of March till the vegetative end of spring tubers (in June). The significantly highest concentration of inulin 30.92% and 32.08% in the tubers of Rubik and Albik respectively was in November, while in Sauliai – in October (46.08%) in 2014. The tubers were growing intensively during the X organogenesis stage (in September), while during the XI organogenesis stage (in October) the growth stopped but intense accumulation of reserve materials started (tab. 3).

Table 2. The distribution of DM content in Jerusalem artichoke tubers during the growing period (%)

Years	Cultivars	Harvesting month							
		March	April	May	June	August	September	October	November
2012	Sauliai	25.89ab	20.48ac	11.60d	6.50c	20.20a	25.12ab	23.53a	22.93a
	Albik	22.12b	21.61ab	12.43bd	7.13d	23.19a	23.71ac	22.60c	26.50c
	Rubik	24.95a	19.82a	13.56d	11.58d	18.80bc	20.93bc	21.30a	23.02a
2013	Sauliai	24.90ab	19.74ac	11.61d	7.50c	16.39a	20.34ab	21.90a	21.18a
	Albik	24.11b	21.35ab	13.56bd	11.26d	21.62a	21.53ac	27.48c	24.34c
	Rubik	23.29a	18.10a	14.68d	11.13d	16.36bc	16.69bc	20.57a	21.62a
2014	Sauliai	26.31ab	20.84ac	12.92d	9.08c	17.64a	22.81ab	19.68a	18.79a
	Albik	24.87b	25.73ab	14.59bd	12.40d	19.69a	15.81ac	25.64c	25.12c
	Rubik	25.26a	21.86a	15.77d	15.39d	16.95bc	16.68bc	20.15a	21.62a

The same letters in the row show no significant differences between the means ($p < 0.05$)

Table 3. The distribution of inulin content in Jerusalem artichoke tubers during their growing period (% d.m.)

Years	Cultivars	Harvesting month							
		March	April	May	June	August	September	October	November
2012	Sauliai	31.53h	39.07g	18.05b	15.07a	23.62c	38.44g	45.08h	44.07g
	Albik	28.87a	22.66b	14.20e	6.60c	18.99b	12.38d	26.60b	31.00a
	Rubik	22.60h	28.94g	27.50e	10.20a	16.16c	14.90b	21.38d	29.92e
2013	Sauliai	30.53h	38.07g	17.05b	14.07a	22.62c	37.44g	44.08h	43.07g
	Albik	27.87a	31.66b	13.20e	5.60c	17.99b	11.38d	25.60b	32.00a
	Rubik	21.60h	27.94g	26.50e	11.20a	15.16c	13.90b	20.38d	28.92e
2014	Sauliai	32.53h	40.07g	19.05b	16.07a	24.62c	39.44g	46.08h	45.07g
	Albik	29.87a	23.66b	15.20e	7.60c	19.99b	13.38d	27.60b	32.08a
	Rubik	23.60h	29.94g	28.50e	9.20a	17.16c	15.90b	22.38d	30.92e

The same letters in the row show no significant differences between the means ($p < 0.05$)

Table 4. The distribution of phenolic compounds contents in Jerusalem artichoke tubers during their growing period (mg 100 g^{-1} d.m.)

Years	Cultivars	Harvesting month							
		March	April	May	June	August	September	October	November
2012	Sauliai	9.2cd	9.99d	6.57bc	3.53ab	6.38bc	3.72ab	3.13b	3.03ab
	Albik	11.05b	11.22b	16.39c	11.18b	9.24ab	5.12a	2.05a	1.69a
	Rubik	16.69c	6.95c	16.28d	7.03c	15.64d	3.10b	1.58a	1.55a
2013	Sauliai	9.35cd	10.09e	6.32a	2.98ab	5.88bc	3.69ab	3.03a	3.00a
	Albik	11.00d	11.02d	16.26e	10.78d	8.65c	4.56b	1.62a	1.09a
	Rubik	15.55e	6.08c	15.89e	6.59c	14.64d	2.45b	1.08a	1.32a
2014	Sauliai	10.02cd	10.56d	7.00bc	3.55ab	6.66bc	3.92ab	3.33b	3.34ab
	Albik	11.22d	11.69d	17.22e	11.63d	9.68c	5.65b	2.32a	1.85a
	Rubik	17.58e	7.28c	16.99e	8.03c	15.99d	3.56b	2.11a	1.98a

The same letters in the row show no significant differences between the means ($p < 0.05$)

During the XII organogenesis stage (in November), the tubers started the polymerisation of materials as well as intense accumulation of inulin. The tubers reached full maturity and it was established that the highest amount of inulin was accumulated in Sauliai cv. tubers. According Taper and Roberfroid [2002] at this stage, the tubers of Jerusalem artichoke contained approximately 11.7% inulin and 6.3% sugar.

In the tubers of all tested cultivars the total phenolics concentration varied during the whole growing period. At the beginning of the spring period the content of phenolic compounds in tubers was higher than in the autumn growing period. The highest concentrations of phenolic compounds were estimated in 2014 in March in the tuber of Rubik cv. (17.58 mg 100 g^{-1}) and in May in the tubers of Albik cv. (17.22 mg 100 g^{-1}) (tab. 4).

When the plants started to accumulate the nutrients, a significant decrease in the content of phenolic compounds was estimated in all the 3 cultivars in June. At the beginning of autumn vegetative period (in August) in Sauliai and Rubik cvs tubers was estimated the increasing of total phenolic content while from the September until the end of November – the decreasing of them was identified in all tested cvs tubers. After the tubers had reached full maturity and the plants started to decay, the most significant reduction in the phenolics content 3.00 mg 100 g^{-1} (in Sauliai), 1,09 mg 100 g^{-1} (in Albik) and 1,32 mg 100 g^{-1} (in Rubik) was estimated in November of 2013 (tab. 4). Plants grown under stress conditions often produce and accumulate phenolic stress metabolites. During winter time monosaccharides glucose accumulates higher concentrations in the tubers, in that case early in the spring, the higher concentration of total phenolic accumulated in the tubers of all tested cultivars compared to November. Water deficiency is supposed to stimulate synthesis of phenolic stress metabolites in tubers. The period of March–May was drier than in August and November, and the higher amount of total phenol concentration of tubers was estimated. Similar results obtained and others researches [Terzić et al. 2012, Kapusta et al. 2013] and declared as well that these differences may be the result of genetic variation of tested cultivars.

In this study the changes in the carbohydrate composition in JA tubers of the cvs Rubik, Sauliai and Albik are presented at various periods of plant life cycle. The amount of carbohydrates in the tubers of all cultivars was gradually increasing from the end of May (tab. 5). When leaf growth is prevailing, sugar accumulation in the tubers declines and the texture of tubers becomes spongy. Significantly the highest content of carbohydrates (2014) in tubers accumulated for cv. Sauliai in June (36.99%), for Albik in September (44.23%), and for Rubik in August (40.00%), at an intensive new tuber growth stage. During the process of tuber maturing, the content of assimilates declines [Taper and Roberfroid 2002]. Carbohydrate content began to decline in September, except cv. Albik and kept declining until the end of the growing period in November.

Significantly higher content of catechins was determined in the second half of the growing period, thus it might be presumed that growth stage had the greatest impact on their content, which was 16 times greater than that at the beginning of the growing season. Organogenesis stage and cultivar of JA had a significant impact on the catechins accumulation and variation in the tubers. Significantly the highest content of catechins was determined in August in 2014 in the tubers of both Rubik (826.23 mg 100 g^{-1}) and Sauliai (442.59 mg 100 g^{-1}). A sudden increase in the quantity of catechins was determined in August with the beginning of new tuber growth (tab. 6).

Table 5. The distribution of carbohydrate contents in Jerusalem artichoke tubers during their growing period (% d.m.)

Years	Cultivars	Harvesting month							
		March	April	May	June	August	September	October	November
2012	Sauliai	4.87a	6.58b	4.23a	36.66f	32.89e	20.36d	10.51c	7.21b
	Albik	17.06c	14.71b	7.12a	18.44d	32.04f	43.33g	24.30e	17.62c
	Rubik	11.90a	14.04a	14.85ab	17.94b	38.87f	35.30e	29.64d	20.07c
2013	Sauliai	3.88a	5.65b	3.65a	37.60f	31.98e	19.63d	9.55c	6.66b
	Albik	16.11c	13.87b	6.00a	17.58c	32.00e	42.89f	24.01d	17.60c
	Rubik	10.99a	13.45a	13.99ab	16.99b	37.82e	34.22e	30.64d	19.00c
2014	Sauliai	5.23a	7.35a	4.89a	36.99e	33.45d	21.56c	10.89b	8.02a
	Albik	18.00b	15.32b	8.00a	19.0b	32.89d	44.23e	25.89c	18.89b
	Rubik	12.99a	15.40a	15.69ab	18.99b	40.00f	35.89e	28.66d	21.08c

The same letters in the row show no significant differences between the means ($p < 0.05$)

Table 6. The distribution of catechins content in Jerusalem artichoke tubers during the growing period (mg 100 g^{-1} d.m.)

Years	Cultivars	Harvesting month							
		March	April	May	June	August	September	October	November
2012	Sauliai	50.13a	68.08a	51.22a	65.56a	436.89b	212.91ab	365.5b	395.15b
	Albik	41.95a	71.39a	167.15b	155.34b	101.76ab	56.80a	40.58a	35.68a
	Rubik	170.25a	207.75a	284.82ab	286.14ab	814.23b	159.94a	126.38a	116.36a
2013	Sauliai	49.98a	67.26a	50.00a	63.23a	418.26b	199.03ab	326.26b	366.15b
	Albik	41.03a	65.65a	158.25b	145.26b	99.56ab	53.25a	35.26a	32.27a
	Rubik	167.65a	200.99a	268.26ab	265.14ab	798.89ab	149.89a	124.26a	110.36a
2014	Sauliai	52.36a	68.99a	53.56a	65.66a	442.59b	214.25ab	372.12b	400.25b
	Albik	43.95a	73.95a	169.32b	159.66b	110.67ab	60.08a	45.55a	38.56a
	Rubik	170.66a	215.56a	301.01ab	299.64ab	826.23b	165.94a	136.22a	124.63a

The same letters in the row show no significant differences between the means ($p < 0.05$)

Table 7. The distribution of leuco-anthocyanins content in Jerusalem artichoke tubers during their growing period (mg 100 g^{-1} d.m.)

Years	Cultivars	Harvesting month							
		March	April	May	June	August	September	October	November
2012	Sauliai	28.40a	9.04a	49.45c	56.57c	7.01a	19.02a	33.57b	35.64b
	Albik	42.04d	33.62c	21.27b	45.08d	13.14a	15.62b	51.56e	62.33f
	Rubik	10.62a	34.25b	47.68c	34.26b	34.49b	14.19a	20.46ab	25.62ab
2013	Sauliai	26.13a	8.13a	48.55b	54.69b	6.18a	17.56b	28.59ab	32.49ab
	Albik	40.02c	29.18b	20.89b	44.77c	12.18a	14.18a	50.56d	61.63e
	Rubik	10.12a	34.18a	46.89e	32.66d	32.29d	13.29b	18.26c	24.26c
2014	Sauliai	30.40a	10.14a	51.69c	61.21d	10.18a	19.99a	35.65b	36.56b
	Albik	43.32e	33.89d	21.89c	46.08a	14.52a	16.69b	53.65f	65.89g
	Rubik	11.65a	36.56cd	49.65a	33.89c	35.59cd	15.29b	21.18bc	26.62bc

The same letters in the row show no significant differences between the means ($p < 0.05$)

Comparison of the tested JA cultivars helped to determine significant differences in the content of leuco-anthocyanins. With the intensive growth of tubers, depending on the weather conditions, during May–June a significant increase in the content of leuco-anthocyanins was determined (tab. 7).

The highest content of leuco-anthocyanins (61.21 mg 100 g^{-1}) was determined in June in the tubers of Sauliai as well in the tubers of Albik and Rubik the highest content of leuco-anthocyanins (21.89 mg 100 g^{-1} and 49.6 mg 100 g^{-1}) was found in May in 2014 when new tubers were forming (tab. 7). From the beginning of September until the end of JA tubers vegetative period amount of leuco-anthocyanins has a tendency increasing.

DISCUSSION

The pattern of dry matter accumulation varies among JA clones due to differences in growth characteristics, photoperiodic requirements, time of planting, location and other factors [Barta and Patkai 2007]. The great differences in dry matter content in the tubers in the tested varieties correlated with the harvesting date. The reduction is due to several factors: the different soil moisture content and the different high transpiration during physiological tuber development; tuber number and diameter are important for dry matter accumulation [Rodrigues et al. 2007]. The lack of soil moisture reduces tuber and dry matter yield [Barta and Patkai 2007, Danilcenko et al. 2009]. Maturity, growth habit, mineral and moisture affect dry matter content in tubers.

JA contains a relatively large total dry matter content (20%), of which polymer – fructose – inulin accounts for 80% [Saengthobpinit and Sajjaanantakul 2005]. Growing and climate conditions as well as tuber maturity influence oligosaccharide concentration in JA tubers. In the conditions of high air temperature and low humidity tubers of JA accumulate less dry matter and inulin [Zubr 1988]. During the growing season, inulin is accumulated at greater quantities in stems and leaves compared to tubers [Zubr 1988]. The mature tubers produce complex organic compounds, thus the content of inulin increases. After the tubers reach maturity, the process of hydrolysis becomes more intensive, thus the content of these compounds decreases [Krishnappa 1989, Barta and Patkai 2007].

Phenolic compounds are widespread in the plant world and play a significant role in the lives of plants. They are involved in the processes of photosynthesis and respiration, affect the processes of growth and development, can serve as an energy material of plant cells and are also involved in redox processes of cells, as components of the phenol oxidase systems [Gupta and Verma 2011, Yuan et al. 2012]. Phenolic compounds are characterized by an antioxidant activity, which binds free radicals, removes radioactive materials (Sr, Co) from human organism, suppresses inflammations and regulate the intestine activity. The quantity of bioactive phenolic compounds and their accumulation properties depend on various factors such as JA cultivar, growth and tuber storage conditions. These compounds act as chemical signals in cellular, extracellular as well as extra organismic levels of plants, for instance, in allelopathic interaction among plants, fungi and microorganisms [Andersen and Markham 2006]. Kaluzewicz et al. [2009] indicated that the stages of organogenesis and the cultivar of JA had a significant influence on the change in the phenolics content. According to Duthie et al. [2000], Kapusta et al. [2013], the total phenolics content in JA tubers is 25.20 mg 100 g^{-1} d.m. The effects of light on the accumulation of phenolic compounds in plant tissues may be explained by providing energy for carbon assimilation thus providing carbon resources for biosynthesis. High temperature during cultivation may generally promote the phenolic content of the plants. During tissue differentiation and organ development the phenolic profiles often undergo remarkable changes indicating that their metabolism is integrated into programs of growth and development [Steyn et al. 2002]. It could be conducted that in March–June when the tubers growing process is very intensive, depending on cultivar, above mentioned factors could effect on the different accumulation of total phenolic amount.

In wintering plants, the content of polysaccharides and disaccharides decreases. Of these, monosaccharides are formed, which increase the osmotic potential, resistance to cold, energy potential of plants. During the hardening process, the plant cell accumulates saccharides which increase the concentration of the cell juice, and thus reduce the water potential. Saccharide accumulation affects stabilisation of cell structures [Taper and Roberfroid 2002, Tungland 2003, Rodrigues et al. 2007, Danilcenko et al. 2008]. There is evidence that accumulation of particular soluble saccharides in the cells during the adaptation period may be of great significance to preservation of viable tissue at low temperatures. Anderson and Markham [2006] determined that glucose and sucrose as well as other signalling molecules, i.e. phytohormones, regulate physiological, metabolic and developmental processes of the majority of the plants.

Catechins and leuco-anthocyanins are important groups of polyphenols, which strengthen the capillaries, kills germs, have astringent properties as well as capacity to neutralise radicals and slow down the oxidation process [Tchone et al. 2006]. It has been reported that the body mass index (BMI) correlates with the amount of malondialdehyde and thiobarbituric acid-reactive substances in the blood [Steyn et al. 2002]. In our study, anthocyanin group, namely, catechins were dominant in JA tubers and have various physiologic effects. At beginning of June the concentration of catechins exhibits values increase up to August in the tubers of Sauliai and Rubik after that it was established suddenly the exhibits values of up weight dropping sharply up to September and later until the end of vegetative period the significant variations not have been observed.

Carbohydrate availability is a prerequisite for catechins accumulation. Our research showed that significantly the highest content of carbohydrates could affects the more active synthesis of catechins in August in the tubers of all tested JA cultivars.

Leuco-anthocyanins is a highly unstable group of flavonoids whose chemical properties are closest to those of polyphenols – catechins. It has been observed that in most cases leuco-anthocyanins “behave” as anthocyanins as well they are good “helpers” for the formation of vitamin P complex [Lattanzio et al. 2009, Pan et al. 2009]. An experiment with JA tubers revealed that the highest amount of leuco-anthocyanins was produced under optimum water supply. Naturally, not only the genetics are expected to determine the chemical composition as other aspects – extrinsic factors: environmental conditions, cooler temperatures growing conditions – and the intrinsic factor: the cultivar [Steyn et al. 2002]. Our research showed that the great differences in leuco-anthocyanins content in the tubers in the tested varieties correlated with the organogenesis stage (harvesting date) and the JA cultivar had a significant impact on the content of leuco-anthocyanins in tubers.

CONCLUSIONS

Significantly the highest dry matter content in all tested Jerusalem artichoke cvs tubers was determined in March of 2014 after they had been exposed to subzero temperatures in the soil during the winter. The significantly highest content of inulin in November of 2014 was accumulated in the tubers of cvs Rubik and Albik, while in October in Sauliai. The total phenolics content accumulated more at the beginning of the spring growing period compared with that at the end of it in November. Significantly more content of carbohydrates accumulated when the formation of new tubers began in August, whereas accumulated more amounts of catechins in tubers were determined in the beginning of the second half of the growing period. Substantial differences in the content of leuco-anthocyanins among the tested cultivars were determined at the end of the growing period.

In summary, it can be maintained that the autumn-harvested tubers of the cv. Sauliai are best source for inulin and fructooligosacharides as natural ingredient for novel food preparation. The spring-harvested tubers of the cvs Sauliai, Rubik and Albik are most suitable for processing into flour, juice, extract, chips or other dry products because they contain the highest concentrations of dry matter, total phenolics concentration, carbohydrates at that time.

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