



Simultaneous Determination of Cyclitols and Sugars Following a Comprehensive Investigation of 40 Plants

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Abstract

Due to the important features of widely unexplored cyclitols, a comprehensive qualitative and quantitative study is needed. Moreover, measuring the possible available amounts of identified components in plant material represents a stringent need, due to their importance in phytomedicine and their use in food. The purpose of this study was to realize an extended investigation mainly of cyclitols, but of sugars and sugar alcohols as well, from natural sources. Thus, 17 target compounds (7 cyclitols and 2 sugar alcohols and 8 sugars) extracted from medicinal and edible plants are reported. All detected components were simultaneously separated in just one chromatographic run, using a single GC column. A number of 52 sources coming from 40 species were studied. Thus, we report 37 new sources of cyclitols. Moreover, almost for all cyclitols, the richest source was not investigated previously. Therefore, the obtained results can represent a valuable material for food, pharmaceutical, medical, or cosmetic industry interested in the use of cyclitols.

Keywords Cyclitols · Sugars and sugars alcohols · Relevant natural sources

Introduction

Carbohydrates represent a complex class of organic compounds naturally occurring in plant material. The main sources of energy for normal human body functions, especially brain functions, are actually the carbohydrates (Muir et al. 2009). Cyclic polyols (cyclitols) are secondary metabolites that are produced in plant and have an essential contribution

in plant self-defense against hostile environmental conditions like water and salt stress. Their biological activity as anti-diabetic, anti-inflammatory, or anti-cancer agents was already described by several groups of researchers (Rengarajan et al. 2015; Singh et al. 2001; Sivakumar and Subramanian 2009). Cyclitols also secure the good cell functioning, being responsible for signal transduction, biogenesis and cell wall formation, phosphate storage, and osmoregulation (Egamberdieva et al. 2012). Many other important pharmaceutical properties of cyclitols were described. For example, myo-inositol was reported as efficacious in treating panic attacks, premenstrual dysphoria, or depression obsessive-compulsive disorders (Carlomagno et al. 2011). Protective effect of D-pinitol, utilized in the treatment of hypertension, rheumatoid arthritis, and cardiovascular and neurological disorders, was described as well (Zheng et al. 2017). Moreover, D-chiro-inositol and myo-inositol are demonstrated to be efficacious in improving ovary functionality by increasing the ovulation rate in women affected by polycystic ovary syndrome (Monastra et al. 2017).

Sugars are synthesized in plants and in the body, they are absorbed immediately or stored in the form of glycogen (Murphy and Johnson 2003). Frequently, foods are supplemented with sugars during preparation process, to enhance sensorial quality, to preserve the edibles for longer time or to

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favor the fermentation substrate. Nevertheless, sugar overconsumption became a big concern (Millar et al. 2014). Many studies reported diabetic problems, dental diseases, attention-deficit combined with hyperactivity disorders (ADHD), and obesity entailed by huge intake of sugars ingested by children from chocolates, candies, and even from basic everyday foods (Feig 2010; Gross et al. 2004; Kim and Chang 2011; Peres et al. 2016). Conversely, the use of sugars alcohols (sorbitol or mannitol) as sweeteners became an alternative to reduce the uses of classical sugars (Grabitske and Slavin 2008). In contrast to classical sugars, which were intensively restricted, the acceptable daily intake (ADI) for sugar alcohols has been fixed by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) as “Not specified.” Sugar alcohols are accepted as well in UE, Japan, and USA (Japan Ministry of Health, Labour and Welfare (2007); Regulation (EC) no. 1333/2008 of the European Parliament and of the Council on food additives, 2018; United States Food and Drug Administration: 21CFR 2018). However, sugar alcohols’ excess can lead to stomach disturbances (Ruskone-Fourmestraux et al. 2003).

Currently, several analytical methods are available for quantification of sugars and cyclitols (Al-Suod et al. 2017, 2018a, Al-Suod et al. 2019). High-performance liquid chromatography (HPLC) with different detectors was used for the analysis of this type of compounds (Filip et al. 2016; Márquez-Sillero et al. 2013; Shanmugavelan et al. 2013). Therefore, HPLC allows for rapid and simultaneous analysis and due to the large number of publications, it seems that it has been reported to be the most utilized analysis technique for this specific application. Capillary electrophoresis (CE) has the ability for fast analysis of sugars like fructose, glucose, and sucrose (Dominguez et al. 2016), but there is no application for assorted sugars, sugar alcohols, or cyclitols. Another simple option suitable for determination of sugar class is high-performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD). As in case of HPLC and CE, a derivatization step is not required, but experimental results proved that the technique is providing poor resolution for some components like sucrose (Pico et al. 2015). Three different cyclitols extracted from alfalfa plant were identified using matrix-assisted laser desorption/ionization with time-of-flight mass spectrometry (MALDI-TOF-MS); however, the technique is useful and sensitive for identification, but not suitable for quantification (Al-Suod et al. 2018b).

Liquid chromatography–mass spectrometry (LC-MS) proved to be suitable in analyzing sugars, sugar alcohols, and cyclitols (Dewangan et al. 2014; Ghfar et al. 2015). LC-MS can detect low concentrations, below ppm level. However, the required instrumentation is not cheap, matrix effects can appear, and a laborious sample pretreatment is necessary. Gas chromatography coupled with mass spectrometry (GC-MS) is one of the most sensitive and powerful tool

suitable for the analysis of this type of components. GC-MS affords high sensitivity and resolution at below ppm levels for both sugars and cyclitols. In contrast with LC-MS, for GC-MS, a derivatization step is required. This fact may have the inconvenient to be time consuming and to involve reagent usage, and also to the apparition of some potential unwanted contamination and/or composition modification of the sample. Nevertheless, the advantages of derivatization consist in both volatilization of target components by binding them to silyl groups and also in serving as a purification step, once other non-volatile existing components are not going to be included into the analysis. Moreover, the silyl groups’ intercalation can lead to a more favorable ion fragmentation pattern used for structure investigations (Ligor et al. 2018). A major advantage of GC-MS compared to LC-MS is the high reproducibility of generated mass spectra using EI (electron impact). The EI ionization process used in GC-MS is a hard ionization that produces very reproducible mass spectra from one instrument to another (Ligor et al. 2018).

Sugars, sugar alcohols, and cyclitols are found in plant material. The knowledge of the relevant sources is a crucial step that allows for the plant selection for a convenient industrial exploitation (Al-Suod et al. 2018a; Ratiu et al. 2018). Sugar alcohols are typically produced by conversion of fructose and glucose using bacteria and yeasts (Ghoreishi and Shahrestani 2009). Their isolation from natural sources was reported as well. For example, in China, mannitol isolation from seaweed is very common (Deis and Kearsley 2012). In contrast with sugars and sugar alcohols, relevant sources of cyclitols still remained uninvestigated. The strength of our study consists in reporting 52 important sources of cyclitols, which include 40 species of plants, most of them part of everyday diet. Because our target compounds are present in different amounts in the various morphological parts of plant, different parts (leaves, stems, flowers, roots, seeds or pods) were analyzed. A total number of 7 cyclitols, 2 sugar alcohols, and 8 sugars were identified and quantified. An important achievement worth to be highlighted is that all the mentioned components were analyzed at the same time, on the same GC column. To the best of our knowledge, 37 from 52 investigated sources were not reported so far.

Material and Methods

Plant Material and Chemicals Involved

Most of these plants were purchased from the special herbal stores or grocery stores. Some of them were cultivated in Poland. The full list including plant species analyzed, purchasing manufacturer, and origin country is presented in Table 1.

Chemicals D-pinitol, myo-inositol, scyllo-inositol, D-chiro-inositol, ononitol, bornesitol, allo-inositol, D-glucose,

Table 1 The source and origin of plant species investigated

No	Plant species	Origin country	Manufacturer
1	<i>Allium ursinum</i>	Poland	Dary Naturity
2	<i>Sorbus aucuparia</i>		
3	<i>Trigonella foenum-graecum</i>		
4	<i>Carum carvi</i>	India	
5	<i>Myristica fragrans</i>		
6	<i>Laurus nobilis</i>	Turkey	
7	<i>Elettaria cardamomum</i>	Guatemala	
8	<i>Eugenia caryophyllus</i>	Brazil	
9	<i>Taraxacum officinale</i>	Poland	Kawon-Hurt
10	<i>Solidago virgaurea</i>		
11	<i>Sambucus nigra</i>		
12	<i>Rosa canina</i>	Poland	Herbapol
13	<i>Chamomilla recutita</i>		
14	<i>Salvia officinalis</i>		
15	<i>Vaccinium myrtillus</i>	Poland	Flos
16	<i>Calendulae anthodium</i>		
17	<i>Mentha piperita</i>		
18	<i>Hypericum perforatum</i>	Poland	Grocery stores
19	<i>Solanum tuberosum</i>		
20	<i>Anethum graveolens</i>		
21	<i>Beta vulgaris</i>	India	
22	<i>Petroselinum crispum</i>		
23	<i>Allium sativum</i>		
24	<i>Daucus carota subsp. sativus</i>	Jordan	
25	<i>Lactuca sativa</i>		
26	<i>Agaricus bisporus</i>		
27	<i>Curcuma longa</i>	Holland	
28	<i>Zingiber officinale</i>		
29	<i>Oryza sativa</i>		
30	<i>Capsicum annum</i>	Austria	
31	<i>Brassica oleracea</i> var. <i>acephala</i>		
32	<i>Brassica oleracea</i>		
33	<i>Allium cepa</i>	Spain	
34	<i>Ceratonia siliqua</i> L.		
35	<i>Ipomoea batatas</i>		
36	<i>Arachis hypogaea</i>	China	
37	<i>Phacelia tanacetifolia</i> ,	Poland ^a	Cultivated without the use of any treatments and collected in August 2017
38	<i>Medicago sativa</i> L.,		
39	<i>Camelina sativa</i> L.		
40	<i>Lupinus perennis</i>		

^a Bobrowniki, Kuyavian-Pomeranian Voivodeship

D-fructose, D-mannose, D-mannitol, lactose, D-sorbitol, and D-(+)-turanose with purity $\geq 95\%$ (used as standards) and trimethylsilylimidazole TMSI (used for derivatization) were all purchased from Sigma-Aldrich (St. Louis, MO, USA). Sucrose, xylose, galactose, (purity $\geq 98\%$), 96% ethanol, 70% ethanol, and pyridine were purchased from Avantor (Gliwice, Poland). Methanol (HPLC grade, ≥ 99.9) was obtained from Sigma-Aldrich (Steinheim, Germany). Ultra-pure water was obtained from a Milli-Q water system (Millipore,

Bedford, MS, USA). The columns used for SPE were CHROMABOND® C18 ec columns, purchased from Macherey-Nagel (Düren, Germany).

Sample Preparation

Accelerated solvent extraction (ASE) was carried out using a Dionex ASE 350 system (Thermo Scientific, Waltham, MA, USA) equipped with an auto-sampler carousel and a

collection tray that allowed for sequential extraction of up to 24 samples. Some plant material was purchased dried, while others required being dry in the laboratory. The drying was performed in the oven, at 30 °C, during 24 to 48 h, depending by plant material. The plant material was grinded using a laboratory mill, until a fine powder was obtained. The resulted powder was passed through a sieve with mesh size 1 mm. Consequently, particles with the dimension equal of less than 1 mm were used (Krakowska et al. 2018). For each plant included in the study, 1 g of grounded powder was placed in a 10 mL stainless steel extraction cell and extracted using water as a solvent. The extraction was performed at 50 °C, 10 MPa, for three cycles (18 min each), according to the methodology developed by Ruiz-Aceituno et al., which, as a result of a PLE optimization found this parameters to be the most suitable for inositol's extraction. SPE cartridges were used for both purification and pre-concentration step (Ruiz-Aceituno et al. 2014). CHROMABOND® C18 ec columns were employed to remove non-polar components. The solution obtained after extraction process was filtered through CA membrane (0.22 µm × 25 mm) and after that passed through a column of CHROMABOND® C18 ec, previously activated with 3 mL of methanol and equilibrated with 3 mL of water. In the next step, the water from purified solution was evaporated to dryness under a nitrogen gas flow, using a heating block thermostated at 40 °C. Finally, the dried sample was re-dissolved in 5 mL of pyridine. From this stock, 150 µL of pyridine solution was derivatized using 150 µL of TMSI at 80 °C for 150 min, and 1 µL of each sample was injected into the GC injection port. For quantification, derivatized standards with known concentration were injected. All the samples were analyzed in triplicate. The concentration ranges for each standard are mentioned in Table 2.

Gas-Chromatographic Analysis

GC-MS analyses were performed to identify and quantify sugars and cyclitols extracted from 40 species of plants. The analysis was carried out using an AutoSystem XL gas chromatograph coupled with mass spectrometer TurboMass (both from Perkin Elmer, Norwalk, CT, USA) using He at 1 mL/min as carrier gas. An RTX-5MS capillary column (30 m × 0.25 mm, 0.250 µm) (Restek, Bellefonte, PA, USA) was used. The oven temperature was programmed as follows: initial temperature of 90 °C was kept for 1 min, and then temperature was increased, at a rate of 10.0 °C/min, to 300 °C and maintained for 5 min at this temperature. Injector temperature was 260 °C, and injections were made in the split mode with a split flow 1:25. Mass spectrometer was operating as follows: ion source temperature 280 °C, ionization energy 70 eV (electron impact ionization), m/z scanning range 35–650 Da. The acquisition of chromatographic data was performed by means of

TurboMass (Perkin Elmer) and mass spectrum library NIST 2005 (Gaithersburg, USA).

Validation Parameters

All calibration data: average of the peak retention time (R_t), calibration equations using peaks area for GC-MS detection, linearity presented as a correlation coefficient (R^2) of the calibration curves, and limits of detection (LOD) and quantification (LOQ), precision (RSD) as a relative standard deviation estimated for peak areas are presented in Table 2.

The limit of detection ($LOD = 3 \times SD_{xy}/b$, where SD_{xy} is the standard deviation and b is the slope) and the limit of quantification ($LOQ = 10 \times SD_{xy}/b$) were calculated with acceptable precision and accuracy. LOD ranged from 0.10 to 44.91 ng·mL⁻¹ and LOQ from 0.31 to 136.08 ng·mL⁻¹. Using our method, we obtained LODs lower than other authors for some components and higher for others (Gomez-Gonzalez et al. 2010; Mechri et al. 2015). The accuracy was evaluated as a recovery at each concentration over 80–120% of the analyte range concentrations. The results showed that average recovery at different level of concentration ranged from 94.9 to 98.3%, and RSD was 2%. The calibration curve parameters have a very good linearity, with a correlation coefficient R^2 ranging between 0.9990 and 0.9997. The amount of each identified target was calculated using calibration curves created based on concentrations of standards presented in Table 2. Three repetitions were realized for each concentration, and the same protocol was followed for extract samples. Retention indexes were calculated using Kovats retention index equation and were established based on mixed alkane standards from C9 to C27.

Selected ion mode was used to calculate the concentrations of fructose and mannose, peaks which did not highlight clear separation from the base line in extract samples. We utilized the ion with m/z 437 to calculate the fructose amount and the ion with m/z 305 for mannose quantification.

Statistical Approaches

Statistical approaches: bar graphs of components were created using IBM SPSS Statistics, version 21; sunburst chart was created in Microsoft Excel 2016, and Microsoft Power Point 2010 was used to prepare the chromatogram figure.

Results and Discussion

General Remarks

All detected components were simultaneously separated in just one chromatographic run, using a single GC column. It was noticed that some components (like fructose and glucose)

Table 2 Parameters of calibration curves and concentration ranges of quantified compounds

Identified targets	RI	R _t (min)	<i>m/z</i>	Calibration Equation	R ²	RSD (%)	LOD ng/mL	LOQ ng/mL	Concentration ranges (μg/mL)
Xylose	1728	11.50	73, 204, 191, 217, 147	$y = 6E+08x + 77,534$	0.9994	0.32	3.34	10.12	0.25–10.00
	1735	11.57	73, 204, 191, 217, 147	$y = 3E+08x - 13,007$	0.9993	0.33	3.28	9.94	0.25–10.00
D-mannose	1832	12.60	73, 305 ^a , 147, 306, 103, 204, 217	$y = 3E+07x + 11,656$	0.9993	3.08	20.74	62.85	0.50–1000.00
D-fructose	1840	12.68	73, 217, 147, 68, 437 ^a , 75, 204	$y = 6E+06x - 5366$	0.9990	2.11	1.07	3.26	0.50–700.00
	1847	12.75	73, 217, 147, 68, 437 ^a , 75, 204	$y = 2E+06x - 1501$	0.9993	1.88	0.86	2.62	0.50–700.00
	1944	13.74	73, 204, 68, 147, 217, 437 ^a , 75	$y = 1E+08x + 59,765$	0.9995	1.12	0.27	0.82	0.50–700.00
D-Pinitol	1861	12.90	73, 147, 217, 260, 133, 191, 318	$y = 1E+09x - 3E+06$	0.9994	1.37	6.78	20.54	0.25–400.00
Galactose	1887	13.17	73, 204, 191, 147, 217, 205, 129, 192	$y = 3E+08x - 969,018$	0.9997	0.27	4.40	13.33	5.00–600.00
Allo-inositol	1902	13.32	73, 60, 102, 43, 71	$y = 8E+08x - 289,471$	0.9990	2.22	22.49	68.16	0.50–20.00
D-Glucose	1992	13.52	73, 204, 191, 147, 205, 217, 129,	$y = 2E+08x - 425,596$	0.9994	2.88	0.30	0.91	0.25–500.00
	2006	14.37	73, 204, 191, 147, 205, 217, 129,	$y = 1E+08x - 186,687$	0.9995	1.63	0.13	0.41	0.25–500.00
D-Mannitol	1959	13.90	73, 319, 205, 147, 217, 103, 117, 320	$y = 6E+08x + 210,769$	0.9994	1.42	44.91	136.08	0.25–500.00
D-Sorbitol	1966	13.97	73, 319, 147, 205, 217, 103, 320, 117	$y = 9E+08x - 2E+06$	0.9991	1.58	0.11	0.33	0.50–100.00
D-Chiro-inositol	1985	14.13	73, 147, 318, 217, 305, 191, 265, 319	$y = 2E+09x - 465,311$	0.9996	2.17	3.56	10.80	0.125–50.00
Ononitol	1988	14.19	73, 217, 147, 191, 133, 260, 318, 159, 305, 247, 218	$y = 1E+08x - 2E+06$	0.9992	0.19	25.13	76.16	12.50–500.00
Bornesitol	2035	14.65	73, 217, 147, 133, 159, 191, 305, 318	$y = 1E+08x - 230,968$	0.9966	0.10	5.75	17.44	2.00–250.00
Scyllo-inositol	2058	14.87	73, 318, 217, 147, 305, 191, 204, 319, 265	$y = 6E+08x - 205,566$	0.9997	0.69	4.05	12.27	0.50–100.00
Myo-inositol	2120	15.45	73, 217, 147, 305, 191, 318, 204, 129, 218, 265, 103, 206	$y = 1E+09x - 61,935$	0.9993	1.77	9.71	29.44	0.125–80.00
Sucrose	2686	20.17	73, 361, 217, 147, 103, 362, 129, 169, 271, 437	$y = 4E+08x - 359,784$	0.9996	3.52	0.10	0.31	0.50–700.00
Lactose	2730	20.47	204, 73, 191, 217, 205, 147, 129, 103, 206, 361	$y = 7E+08x - 2E+06$	0.9987	2.36	22.21	67.34	5.00–50.00
D-Turanose	2747	20.60	73, 361, 147, 217, 103, 129, 204, 362	$y = 2E+08x - 164,756$	0.9997	1.12	3.56	10.68	0.50–100

^a fragments used for quantification by extracted ion mod

appeared as different isomers, in the form of two or three peaks. The peaks of fructose (with retention times: 12.67, 12.75, and 13.73 min) are represented by α -furanose, β -furanose, and β -pyranose, while the two peaks of D-glucose (observed at 13.51 and 14.37 min) are equivalent to α -pyranose and β -pyranose, as our results confirm and other researchers mentioned before (Yang 2009). An example presenting a GC tracing of Goldenrod flowers (*Solidago virgaurea*) extract is presented in Fig. 1. From 17 targets detected in the presented work, 14 of them were present in this extract, while two peaks remained unidentified.

The most frequently appearing cyclitols were *myo*-inositol, *D*-pinitol, and bornesitol. From these three

compounds, we notice that usually, the highest quantities were registered for *D*-pinitol and *myo*-inositol. Talking about sugar alcohols, sorbitol seems to be present most often than mannitol in plant material. Mushroom is an excellent source of sorbitol, with 21.8 ± 1.9 mg/g of dried powder. This amount is more than three times higher than fructose determined in mushrooms. Moreover, in mushroom, all other occurring sugars have very low concentrations compared with sorbitol. The second important source of sorbitol is the parsley, both leaves (6.8 ± 0.07 mg/g of dried plant) and roots (7.4 ± 0.5 mg/g of dried plant). An important source of mannitol is Caraway seeds (4.4 ± 0.2 mg/g of dried powder).

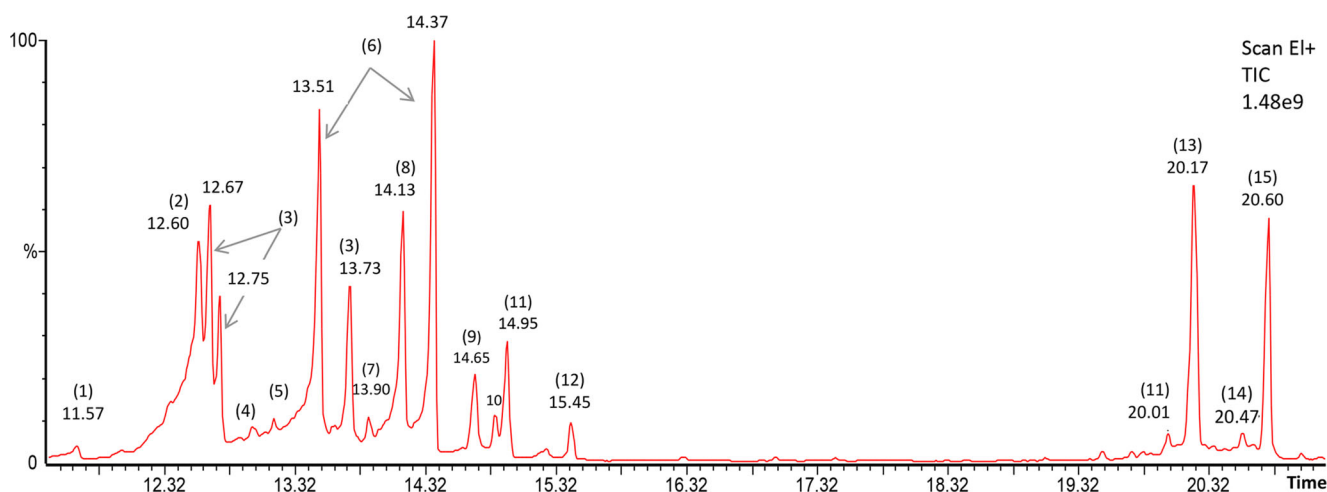


Fig. 1 GC-MS chromatogram presenting the occurrence of target components in Goldenrod flowers, where: 1—Xylose; 2—D-mannose; 3—D-fructose; 4—D-pinitol; 5—galactose; 6—D-glucose; 7—D-

mannitol; 8—Chiro-inositol; 9—Bornesitol; 10—Scyllo-inositol; 11—unknown; 12—Myo-inositol; 13—Sucrose; 14—Lactose; 15—D-turanose

A full list of investigated species is presented in Table 3, where the quantities of all sugars and cyclitols occurring in each sample can be also observed. The results are presented in mg/g of dried plant, together with standard deviation calculated for three different replicates.

Distribution of Cyclitols in Plants

Because our particular interest was to find the most relevant sources of cyclitols, during data processing, a remarkable observation caught our attention. It was generally observed that if plants are rich in cyclitols, they are usually rich in all of them. But, this fact will not facilitate too much the extraction possibility in case that some target compounds are needed to be isolated from all those present in the matrix. The valuable observation was that, there are some plants which are significantly rich in one compound in comparison with others present in the extract. Consequently, those plants that present this specific advantage can be used in industrial extraction. In Fig. 2, bar graphs highlighting 10 of the most relevant sources of each investigated cyclitol are presented. The darker bars represent the sources uninvestigated so far, while the lighter bars present the plants in which the cyclitols were previously found. For example, Mountain Ash fruits (*Sorbus aucuparia*) are an excellent source of *D-chiro*-inositol, containing 1.44 ± 0.07 mg/g of dried plant. The occurrence of all other cyclitols was less than 1 mg/g of dried plant. In comparison with all investigated plants, Mountain Ash fruits contain about 3.5 times more *D-chiro*-inositol than others. It is worth mentioning that cyclitol content in this plant was not investigated before. Due to this fact, and especially because of the important role of *D-chiro*-inositol, the fruits of this plant may be the

perfect candidates for extraction of this cyclitol at pharmaceutically or industry level.

Carob pods (*Ceratonia siliqua* L.) have proven to contain larger amounts of D-pinitol in comparison with other investigated species (about 25 times more). However, cyclitol content in carob pods was already investigated in other studies.

Regarding *myo*-inositol, cinnamon, lettuce leaves, and blueberry fruits proved to contain a quantity approximately double compared with other investigated plants. Not one of them was investigated before.

Allo-inositol is quite a rare cyclitol. Its curative properties seem not to be studied so far, maybe exactly for this reason. However, *allo*-inositol is one of the four possible isomers derived from *myo*-inositol [20]. *Allo*-inositol was detected in 14 samples from the 52 investigated. The richest sources of *allo*-inositol are blueberries, which contain 10.8 ± 0.2 mg/g of dried fruit. This fact could make them extremely suited for *allo*-inositol extraction. Moreover, the amount of other cyclitols present in blueberries is significantly lower than that of *allo*-inositol. Ononitol (4-O-methyl-*myo*-inositol), which belongs to the class of methyl *myo*-inositols, is another rare cyclitol. Ononitol is a cyclohexane-1,2,3,4,5-pentol substituted by a methoxy group at position 6. It was found in 14 samples and the highest amount has been found in blueberries as well (3.2 ± 0.5 mg/g of dried fruit). However, the occurrences of ononitol in other plants like wild garlic, garlic, kale, mint, or dill, even in smaller quantities, make them suitable for ononitol extraction, because they contain reduced quantities of cyclitols compared with the mentioned one.

Bornesitol is one of frequently appearing cyclitol in plants. An alternative name is D-1-O-methyl-*myo*-inositol; it is the methyl ether of D-*myo*-inositol. The highest quantity appeared in goldenrod flowers (2.6 ± 0.4 mg/g of

Table 3 The full list of investigated samples presenting quantities of cyclitols and sugars detected ($\text{mg} \cdot \text{g}^{-1}$ of dry weight of sample)

No	Plant name	Latin name	D-Pinitol (mg/g)	Allo-inositol (mg/g)	D-Chiro- inositol (mg/g)	Ononitol (mg/g)	Bornesitol (mg/g)	Scyllo-inositol (mg/g)	Myo-inositol (mg/g)	Xylose (mg/g)
1	Kale (leaves)	<i>Brassica oleracea</i> var. acephala	0.062 ± 0.0007	nd	0.0172 ± 0.0017	0.5063 ± 0.0091	nd	nd	0.3133 ± 0.0264	nd
2	Fenugreek (seeds)	<i>Trigonella foenum-graecum</i>	0.2199 ± 0.0014	nd	0.0059 ± 0.0002	nd	0.0783 ± 0.0117	nd	0.0399 ± 0.0028	nd
3	Alfalfa (seeds)	<i>Medicago sativa</i> L.	0.1383 ± 0.0073	nd	0.0081 ± 0.0004	0.4607 ± 0.0009	nd	0.0184 ± 0.0010	0.2265 ± 0.082	nd
4	Goldenrod (leaves)	<i>Solidago virgaurea</i>	0.0631 ± 0.0006	nd	0.0188 ± 0.0004	0.5614 ± 0.0011	nd	0.6908 ± 0.0277	0.0792 ± 0.0013	0.0116 ± 0.0006
5	Goldenrod (roots)	<i>Solidago virgaurea</i>	0.0727 ± 0.0011	nd	0.0457 ± 0.0008	0.5306 ± 0.0010	0.0767 ± 0.0048	0.0331 ± 0.0007	0.0575 ± 0.0009	0.4485 ± 0.0108
6	Goldenrod (stems)	<i>Solidago virgaurea</i>	0.0744 ± 0.0012	nd	0.1731 ± 0.0183	nd	0.1367 ± 0.0106	0.5183 ± 0.0281	0.3395 ± 0.0045	0.0627 ± 0.0037
7	Goldenrod (flowers)	<i>Solidago virgaurea</i>	0.0783 ± 0.0027	nd	0.4036 ± 0.0080	nd	2.5916 ± 0.3638	0.1950 ± 0.0088	0.1173 ± 0.0060	0.3998 ± 0.0090
8	Cardamom (seeds)	<i>Elettaria cardamomum</i>	0.0603 ± 0.0004	0.4929 ± 0.0019	0.0076 ± 0.0003	0.4433 ± 0.0040	nd	0.0148 ± 0.0005	0.0033 ± 0.0001	nd
9	Carob pods	<i>Ceratonia siliqua</i> L.	9.5013 ± 0.2843	1.4846 ± 0.0479	0.3201 ± 0.0142	nd	0.6983 ± 0.0515	0.0715 ± 0.0005	0.5903 ± 0.0419	0.2191 ± 0.0086
10	Sage (stems)	<i>Salvia officinalis</i>	0.0817 ± 0.0028	nd	0.1049 ± 0.0058	nd	0.0712 ± 0.0014	0.0157 ± 0.0001	0.5939 ± 0.0121	0.0689 ± 0.0014
11	Sage (leaves)	<i>Salvia officinalis</i>	0.2689 ± 0.0152	nd	0.0576 ± 0.0003	nd	0.1526 ± 0.0004	0.0303 ± 0.0048	0.5465 ± 0.0258	0.1328 ± 0.0012
12	Peanut (seeds)	<i>Arachis hypogaea</i>	0.1069 ± 0.0015	nd	0.0149 ± 0.0015	nd	nd	nd	0.0428 ± 0.0026	nd
13	Lupinus (seeds)	<i>Lupinus perennis</i>	0.1937 ± 0.0025	0.4310 ± 0.0002	0.0206 ± 0.0011	nd	0.0892 ± 0.0021	nd	0.1402 ± 0.0082	0.0374 ± 0.0013
14	Cabbage (Brussels sprout)	<i>Brassica oleracea</i>	0.0673 ± 0.0015	nd	0.0438 ± 0.0009	nd	0.1288 ± 0.0004	nd	0.3835 ± 0.0225	0.0224 ± 0.0028
15	Beetroot	<i>Beta vulgaris</i>	nd	nd	0.0895 ± 0.0036	nd	0.1246 ± 0.0121	nd	0.0582 ± 0.0001	0.0155 ± 0.0006
16	Parsley (roots)	<i>Petroselinum crispum</i>	0.4068 ± 0.0080	0.5114 ± 0.0023	0.0438 ± 0.0009	nd	0.2590 ± 0.0058	0.2256 ± 0.0279	0.0329 ± 0.0042	0.0444 ± 0.0012
17	Parsley (leaves)	<i>Petroselinum crispum</i>	0.0678 ± 0.0003	nd	0.0087 ± 0.0004	nd	0.1003 ± 0.0025	0.0486 ± 0.0029	0.2306 ± 0.0101	nd
18	Mint (roots)	<i>Mentha piperita</i>	0.0678 ± 0.0003	nd	0.0092 ± 0.0009	0.4349 ± 0.0004	0.0820 ± 0.0013	nd	0.1399 ± 0.0098	0.0120 ± 0.0003
19	Mint (leaves)	<i>Mentha piperita</i>	nd	nd	0.0058 ± 0.0005	0.5074 ± 0.0046	0.0749 ± 0.0016	nd	0.0442 ± 0.0004	0.0069 ± 0.0002
20	Ginger (root)	<i>Zingiber officinale</i>	0.0634 ± 0.0001	nd	0.0233 ± 0.0006	nd	0.0810 ± 0.0017	nd	0.0087 ± 0.0010	0.0043 ± 0.0002
21	Dill (leaves)	<i>Anethum graveolens</i>	nd	nd	nd	0.4177 ± 0.0411	0.0704 ± 0.0022	0.0134 ± 0.0003	0.0108 ± 0.0006	0.0122 ± 0.0003
22	Laurel (leaves)	<i>Laurus nobilis</i>	0.1474 ± 0.0107	nd	nd	nd	0.2247 ± 0.0071	0.1867 ± 0.0168	0.1267 ± 0.0061	0.2674 ± 0.0103
23	Chamomile (flowers)	<i>Chamomilla recutita</i>	0.0794 ± 0.0009	nd	0.4147 ± 0.0097	nd	0.3426 ± 0.0101	0.0394 ± 0.0006	0.5467 ± 0.0316	0.7373 ± 0.0283
24	Marigold (flowers)	<i>Calendulae anthodium</i>	0.0681 ± 0.0009	nd	0.0406 ± 0.0049	nd	0.2004 ± 0.0119	0.1048 ± 0.0183	0.0730 ± 0.0066	nd
25	St John's wood (flowers)	<i>Hypericum perforatum</i>	nd	nd	0.1458 ± 0.0032	nd	0.1346 ± 0.0029	0.0296 ± 0.0031	0.2301 ± 0.0057	0.0263 ± 0.0005
26	Camelina (seeds)	<i>Camelina sativa</i> L.	0.0820 ± 0.0005	nd	0.1999 ± 0.0082	nd	0.1132 ± 0.0192	nd	0.2132 ± 0.0026	0.0218 ± 0.0010
27	Tumeric (roots)	<i>Curcuma longa</i>	nd	nd	0.2354 ± 0.0036	nd	0.2958 ± 0.0171	0.0518 ± 0.0014	0.1489 ± 0.0182	0.1135 ± 0.0031
28	Wild rose (flowers)	<i>Rosa canina</i>	0.0634 ± 0.0003	nd	0.1536 ± 0.0049	nd	0.3318 ± 0.0092	0.0687 ± 0.0059	0.0763 ± 0.0068	0.0812 ± 0.0035
29	Cinnamon	<i>Myristica fragrans</i>	nd	1.3098 ± 0.0093	0.1051 ± 0.0022	nd	nd	1.5143 ± 0.0133	1.2087 ± 0.0247	0.0658 ± 0.0020
30	Dandelion (roots)	<i>Taraxacum officinale</i>	0.0657 ± 0.0006	nd	0.2363 ± 0.0060	nd	0.1168 ± 0.0016	nd	0.1243 ± 0.0008	nd
31	Elder (flower)	<i>Sambucus nigra</i>	0.0686 ± 0.0006	nd	nd	nd	nd	nd	0.2241 ± 0.0146	0.0202 ± 0.0019
32	Elder (fruit)	<i>Sambucus nigra</i>	0.1084 ± 0.0021	3.4908 ± 0.1723	0.1052 ± 0.0028	0.5850 ± 0.0047	0.0257 ± 0.0002	0.0241 ± 0.0011	0.2241 ± 0.0146	nd
33	Caraway (seeds)	<i>Carum carvi</i>	0.0641 ± 0.0008	nd	0.0229 ± 0.0010	nd	0.1417 ± 0.0054	0.5253 ± 0.0248	0.4148 ± 0.0147	0.1457 ± 0.0013
34	Mountain Ash (fruits)	<i>Sorbus aucuparia</i>	0.2146 ± 0.0084	0.5100 ± 0.0074	1.442 ± 0.07269	nd	0.8204 ± 0.0616	0.0271 ± 0.0003	0.0204 ± 0.0021	0.3075 ± 0.0064
35	Blueberry (fruit)	<i>Vaccinium myrtillus</i>	nd	10.8484 ± 0.2101	0.2031 ± 0.0134	3.2564 ± 0.5330	1.2610 ± 0.2179	nd	0.0198 ± 0.0005	0.9586 ± 0.1356
36	Wild garlic (leaves)	<i>Allium ursinum</i>	0.0766 ± 0.0003	nd	0.0320 ± 0.0018	0.8393 ± 0.0112	nd	0.0198 ± 0.0005	0.0322 ± 0.0013	nd
37	Potato	<i>Solanum tuberosum</i>	0.0714 ± 0.0010	nd	0.0282 ± 0.0009	nd	0.0705 ± 0.0070	nd	0.0141 ± 0.0015	nd
38	Garlic	<i>Allium sativum</i>	nd	0.4662 ± 0.0057	nd	0.4519 ± 0.0001	nd	nd	0.0270 ± 0.0008	nd
39	Carrot	<i>Allium sativum</i>	nd	nd	0.1667 ± 0.0198	nd	0.8926 ± 0.1891	0.8119 ± 0.0098	0.8001 ± 0.0097	0.0397 ± 0.0028

Table 3 (continued)

No	Plant name	Latin name	D-Pinitol (mg/g)	Allo-inositol (mg/g)	D-Chiro-inositol (mg/g)	Ononitol (mg/g)	Bornesitol (mg/g)	Scyllo-inositol (mg/g)	Myo-inositol (mg/g)	Xylose (mg/g)
<i>Daucus carota subsp. sativus</i>										
40	Rice	<i>Oryza sativa</i>	Nd	nd	0.0124 ± 0.0015	nd	nd	nd	0.0096 ± 0.0006	nd
<i>Capsicum annuum</i>										
41	Bell pepper		Nd	3.3429 ± 0.1132	0.1047 ± 0.0163	nd	1.1595 ± 0.1191	0.0525 ± 0.0055	0.5052 ± 0.0363	0.0867 ± 0.0009
42	White onion	<i>Allium cepa</i>	Nd	nd	0.2058 ± 0.0218	nd	0.7576 ± 0.0528	nd	0.6642 ± 0.0561	0.0647 ± 0.0018
43	Lettuce (leaves)	<i>Lactuca sativa</i>	Nd	nd	0.3564 ± 0.0288	nd	0.1658 ± 0.0066	0.0270 ± 0.0008	1.0685 ± 0.0060	0.0236 ± 0.0022
44	Lacy Phacelia (leaves)	<i>Phacelia tanacetifolia</i>	Nd	nd	0.0508 ± 0.0023	nd	nd	nd	0.4849 ± 0.0154	0.5205 ± 0.0257
45	Lacy Phacelia (stems)	<i>Phacelia tanacetifolia</i>	Nd	nd	nd	nd	0.1088 ± 0.0098	nd	0.1168 ± 0.0037	Nd
46	Lacy Phacelia (seeds)	<i>Phacelia tanacetifolia</i>	0.0809 ± 0.0018	0.7145 ± 0.0338	0.0143 ± 0.0014	nd	nd	nd	0.1441 ± 0.0143	1.2016 ± 0.1079
47	Lacy Phacelia (roots)	<i>Phacelia tanacetifolia</i>	0.0829 ± 0.0018	nd	0.0675 ± 0.0040	nd	nd	nd	0.1186 ± 0.0023	nd
48	Lacy Phacelia (flowers)	<i>Phacelia tanacetifolia</i>	nd	0.5234 ± 0.0003	0.0111 ± 0.0002	0.5424 ± 0.0105	0.4441 ± 0.0130	0.0251 ± 0.0007	0.6727 ± 0.0269	0.5344 ± 0.0130
<i>Eugenia caryophyllus</i>										
49	Clove (seeds)		nd	0.5704 ± 0.0083	0.0385 ± 0.0003	0.7028 ± 0.0041	0.0526 ± 0.0012	0.0157 ± 0.0014	0.7703 ± 0.0664	0.0242 ± 0.0011
50	Mushrooms	<i>Agaricus bisporus</i>	0.0650 ± 0.0003	0.4349 ± 0.0020	0.0082 ± 0.0003	nd	0.1488 ± 0.0025	0.0383 ± 0.0021	0.0062 ± 0.0002	nd
51	Sweet potato	<i>Ipomoea batatas</i>	0.1249 ± 0.0005	nd	0.0172 ± 0.0001	nd	0.2170 ± 0.0171	0.0429 ± 0.0033	0.3944 ± 0.0055	nd
52	Nutmeg	<i>Myristica fragrans</i>	nd	nd	0.0245 ± 0.0005	nd	nd	nd	0.0157 ± 0.0010	nd
No	D-Mannose (mg/g)	D-fructose (mg/g)	Galactose (mg/g)	D-Glucose (mg/g)	D-Mannitol (mg/g)	D-Sorbitol (mg/g)	Sucrose (mg/g)	D-Turanose (mg/g)		
1	0.7868 ± 0.0696	2.9736 ± 0.0463	0.0739 ± 0.0004	3.0011 ± 0.0907	nd	nd	5.8914 ± 0.3093	0.2845 ± 0.0393		
2	0.1531 ± 0.0025	1.5150 ± 0.0201	0.1755 ± 0.0140	0.5374 ± 0.0256	nd	nd	0.4104 ± 0.0022	nd		
3	0.6627 ± 0.0450	6.2599 ± 0.0362	0.2672 ± 0.0151	1.7428 ± 0.0322	nd	0.0765 ± 0.0036	2.6583 ± 0.1443	nd		
4	1.2775 ± 0.1234	3.8150 ± 0.0668	nd	1.8686 ± 0.0126	0.0587 ± 0.0026	0.0457 ± 0.0001	0.7524 ± 0.0339	0.1155 ± 0.0045		
5	6.0836 ± 0.0447	18.2228 ± 0.0215	0.2195 ± 0.0047	13.0037 ± 0.1364	0.1535 ± 0.0159	0.0466 ± 0.0003	0.0566 ± 0.0008	nd		
6	9.3568 ± 0.7209	19.9954 ± 0.1761	0.3355 ± 0.0153	25.4623 ± 0.2250	0.0098 ± 0.0002	nd	3.5208 ± 0.0648	0.3428 ± 0.0660		
7	16.1199 ± 1.4638	32.7434 ± 0.6030	0.3047 ± 0.0359	20.8340 ± 0.2505	0.0911 ± 0.0027	nd	3.0859 ± 0.0589	3.9422 ± 0.1292		
8	0.2649 ± 0.0539	1.2622 ± 0.0191	0.0759 ± 0.0009	0.6712 ± 0.0097	nd	0.0454 ± 0.0003	0.4913 ± 0.0150	nd		
9	63.3391 ± 1.3750	146.7573 ± 5.9660	0.4268 ± 0.0163	99.5461 ± 1.7317	0.0571 ± 0.0085	0.2139 ± 0.0090	71.9673 ± 2.0525	2.5436 ± 0.0634		
10	3.0070 ± 0.2891	10.7912 ± 0.0233	0.5334 ± 0.0420	18.6547 ± 0.4189	0.0105 ± 0.0004	nd	0.3381 ± 0.0140	0.1740 ± 0.0055		
11	20.9077 ± 1.7880	34.6748 ± 0.7398	0.2323 ± 0.0185	35.6071 ± 1.0253	0.0371 ± 0.0057	nd	0.9704 ± 0.0057	0.0673 ± 0.0030		
12	0.9882 ± 0.2047	3.6292 ± 0.0486	nd	4.2258 ± 0.1723	nd	0.0555 ± 0.0006	13.7586 ± 1.2956	nd		
13	0.2787 ± 0.0049	2.8526 ± 0.1180	0.2265 ± 0.0014	0.8972 ± 0.0201	0.0055 ± 0.0003	0.0551 ± 0.0005	5.9282 ± 0.3318	nd		
14	6.9678 ± 0.2374	13.4292 ± 0.3797	0.1089 ± 0.0010	11.8713 ± 0.2153	0.0034 ± 0.0007	nd	12.2889 ± 0.7653	nd		
15	12.0836 ± 0.2346	40.7323 ± 1.0685	nd	36.0690 ± 0.3231	0.0595 ± 0.0044	nd	33.6771 ± 0.7984	nd		
16	nd	181.6682 ± 1.7731	0.1504 ± 0.0014	74.2455 ± 4.0437	3.9789 ± 0.1595	7.4468 ± 0.5332	nd	nd		
17	0.0867 ± 0.0046	0.6980 ± 0.0102	0.1051 ± 0.0026	2.5560 ± 0.0530	nd	6.8052 ± 0.0693	5.2512 ± 0.1142	0.0787 ± 0.0013		

Table 3 (continued)

No	D-Mannose (mg/g)	D-fructose (mg/g)	Galactose (mg/g)	D-Glucose (mg/g)	D-Mannitol (mg/g)	D-Sorbitol (mg/g)	Sucrose (mg/g)	D-Turanose (mg/g)
18	0.1916 ± 0.0056	1.8562 ± 0.0932	0.0949 ± 0.0062	0.9936 ± 0.0256	0.0095 ± 0.0006	nd	0.0811 ± 0.0038	nd
19	0.0633 ± 0.0017	0.5502 ± 0.0269	nd	0.5099 ± 0.0123	nd	nd	nd	nd
20	4.4320 ± 0.0477	10.3710 ± 0.2690	0.0847 ± 0.0006	8.4005 ± 0.3665	nd	nd	3.1364 ± 0.1014	0.0338 ± 0.0038
21	0.1795 ± 0.0010	0.2331 ± 0.0176	nd	0.1842 ± 0.0015	0.0328 ± 0.0007	nd	0.1239 ± 0.0014	nd
22	15.0748 ± 0.3771	30.6618 ± 2.009	0.2142 ± 0.0035	50.8214 ± 0.8410	nd	0.2836 ± 0.0140	1.2915 ± 0.0178	0.2252 ± 0.0032
23	4.8154 ± 0.1461	12.1585 ± 0.8096	0.1820 ± 0.0040	6.8159 ± 0.3383	0.2643 ± 0.0483	0.1747 ± 0.0180	0.5086 ± 0.0187	nd
24	8.6916 ± 0.4583	14.7293 ± 0.3881	0.0851 ± 0.0012	3.6527 ± 0.0191	0.0054 ± 0.0005	0.0574 ± 0.0006	0.9540 ± 0.0564	nd
25	26.2787 ± 0.5115	51.4721 ± 3.8912	1.1841 ± 0.2329	44.2591 ± 1.1647	0.0166 ± 0.0003	0.0601 ± 0.0009	0.5563 ± 0.0847	0.1300 ± 0.0025
26	6.9478 ± 0.3566	17.2839 ± 0.3609	0.2477 ± 0.0027	22.3306 ± 0.2162	0.0085 ± 0.0002	0.0842 ± 0.0046	9.4948 ± 0.0336	0.2276 ± 0.0044
27	30.9856 ± 3.7216	73.7770 ± 1.0433	0.5548 ± 0.0281	97.9177 ± 1.5720	0.0506 ± 0.0031	nd	2.6509 ± 0.2291	1.7781 ± 0.1872
28	58.4171 ± 1.7122	120.1218 ± 3.5841	1.1653 ± 0.1625	85.2748 ± 1.8763	0.0112 ± 0.0007	nd	4.3355 ± 0.4798	nd
29	11.4774 ± 0.5362	28.9615 ± 0.3873	0.7149 ± 0.0680	17.1903 ± 0.1852	0.1677 ± 0.0294	0.0524 ± 0.0002	0.2592 ± 0.0300	nd
30	10.9186 ± 0.155	23.9225 ± 0.6879	0.0723 ± 0.0006	5.9636 ± 0.0689	0.0124 ± 0.0014	0.0629 ± 0.0006	3.0775 ± 0.0306	nd
31	4.8776 ± 0.3823	12.8028 ± 0.1067	0.4191 ± 0.0050	7.2398 ± 0.2565	0.0371 ± 0.0002	0.1225 ± 0.0044	0.1244 ± 0.0032	nd
32	85.1081 ± 0.9410	191.5491 ± 1.2768	0.2965 ± 0.0104	112.4918 ± 2.9271	0.1168 ± 0.0052	0.0851 ± 0.0016	0.2513 ± 0.0136	0.8291 ± 0.0044
33	6.1670 ± 0.1257	13.5955 ± 0.9536	0.1133 ± 0.0020	10.211 ± 0.2456	4.4100 ± 0.2179	0.1892 ± 0.0213	10.3299 ± 0.3069	0.2129 ± 0.0096
34	74.5537 ± 5.2038	163.1526 ± 3.2386	0.1409 ± 0.0044	93.5631 ± 4.9944	3.6056 ± 0.1532	6.6416 ± 0.0561	0.8271 ± 0.1368	nd
35	200.4024 ± 4.2635	368.4669 ± 7.8145	10.391 ± 1.6889	330.5328 ± 3.0433	0.0622 ± 0.0015	0.1339 ± 0.0113	0.4039 ± 0.0024	1.6558 ± 0.0616
36	7.4923 ± 0.3170	16.2169 ± 0.4551	0.1253 ± 0.0090	6.4914 ± 0.0717	0.0046 ± 0.0001	0.0666 ± 0.0049	7.8124 ± 0.3334	nd
37	4.0618 ± 0.0134	14.7810 ± 0.6108	0.1204 ± 0.0027	10.4845 ± 0.3395	0.0242 ± 0.0005	0.0652 ± 0.0007	1.3745 ± 0.1677	0.0524 ± 0.0086
38	0.3562 ± 0.0471	0.8564 ± 0.0040	nd	0.3210 ± 0.0047	nd	0.0471 ± 0.0001	1.0989 ± 0.0436	nd
39	167.7875 ± 5.7559	364.7827 ± 5.7585	8.1743 ± 1.2885	335.8920 ± 5.2615	0.2588 ± 0.0016	0.3570 ± 0.0052	1.0158 ± 0.0240	0.1732 ± 0.0026
40	1.3183 ± 0.1512	2.8004 ± 0.0040	0.0674 ± 0.0003	3.2124 ± 0.0395	> LOD	nd	0.0287 ± 0.0008	nd
41	152.9202 ± 5.6524	362.9527 ± 8.1853	5.9939 ± 0.5313	204.5401 ± 2.3887	0.0604 ± 0.0193	0.1975 ± 0.0096	1.0608 ± 0.0577	nd
42	179.0332 ± 4.5774	233.4356 ± 1.3271	14.7869 ± 0.4093	320.7173 ± 3.0621	0.6285 ± 0.0778	0.1149 ± 0.0032	0.3665 ± 0.0032	nd
43	27.0540 ± 2.5557	37.2735 ± 0.7991	nd	74.597 ± 1.3348	0.0839 ± 0.0014	0.1134 ± 0.0055	0.7114 ± 0.0421	0.9879 ± 0.0991
44	2.2868 ± 0.2013	11.8184 ± 0.9508	0.0955 ± 0.0016	14.661 ± 0.4688	0.1592 ± 0.0110	nd	0.3348 ± 0.0258	nd
45	1.9168 ± 0.2748	5.7824 ± 0.1780	0.1078 ± 0.0119	1.7017 ± 0.0422	> LOQ	nd	0.6387 ± 0.0267	nd
46	0.6876 ± 0.1208	9.5678 ± 0.1079	0.2825 ± 0.0077	3.7541 ± 0.1474	0.2440 ± 0.0254	0.1271 ± 0.0032	10.6774 ± 1.4893	nd
47	5.7605 ± 0.3138	17.6323 ± 0.6962	0.1526 ± 0.0074	12.176 ± 0.37734	0.0096 ± 0.0025	nd	6.7975 ± 0.1255	nd
48	3.1867 ± 0.4776	9.5954 ± 0.1537	0.1480 ± 0.0011	2.8476 ± 0.0713	0.1248 ± 0.0133	0.0640 ± 0.0007	2.7634 ± 0.2659	nd
49	2.3367 ± 0.0262	4.6273 ± 0.1988	0.2304 ± 0.0258	9.5097 ± 0.1947	nd	0.0572 ± 0.0007	0.1977 ± 0.0315	0.0633 ± 0.0003
50	nd	6.0989 ± 0.1185	nd	1.4875 ± 0.0711	nd	21.8031 ± 1.8892	0.0612 ± 0.0043	nd
51	23.8275 ± 0.9121	70.7282 ± 1.5825	0.7238 ± 0.0646	41.000 ± 0.4110	0.4945 ± 0.0777	0.1349 ± 0.0047	164.5098 ± 0.5523	3.4126 ± 0.1296
52	1.2216 ± 0.0603	2.2013 ± 0.0479	0.0698 ± 0.0005	7.9257 ± 0.1356	nd	nd	0.5206 ± 0.0791	0.0724 ± 0.0026

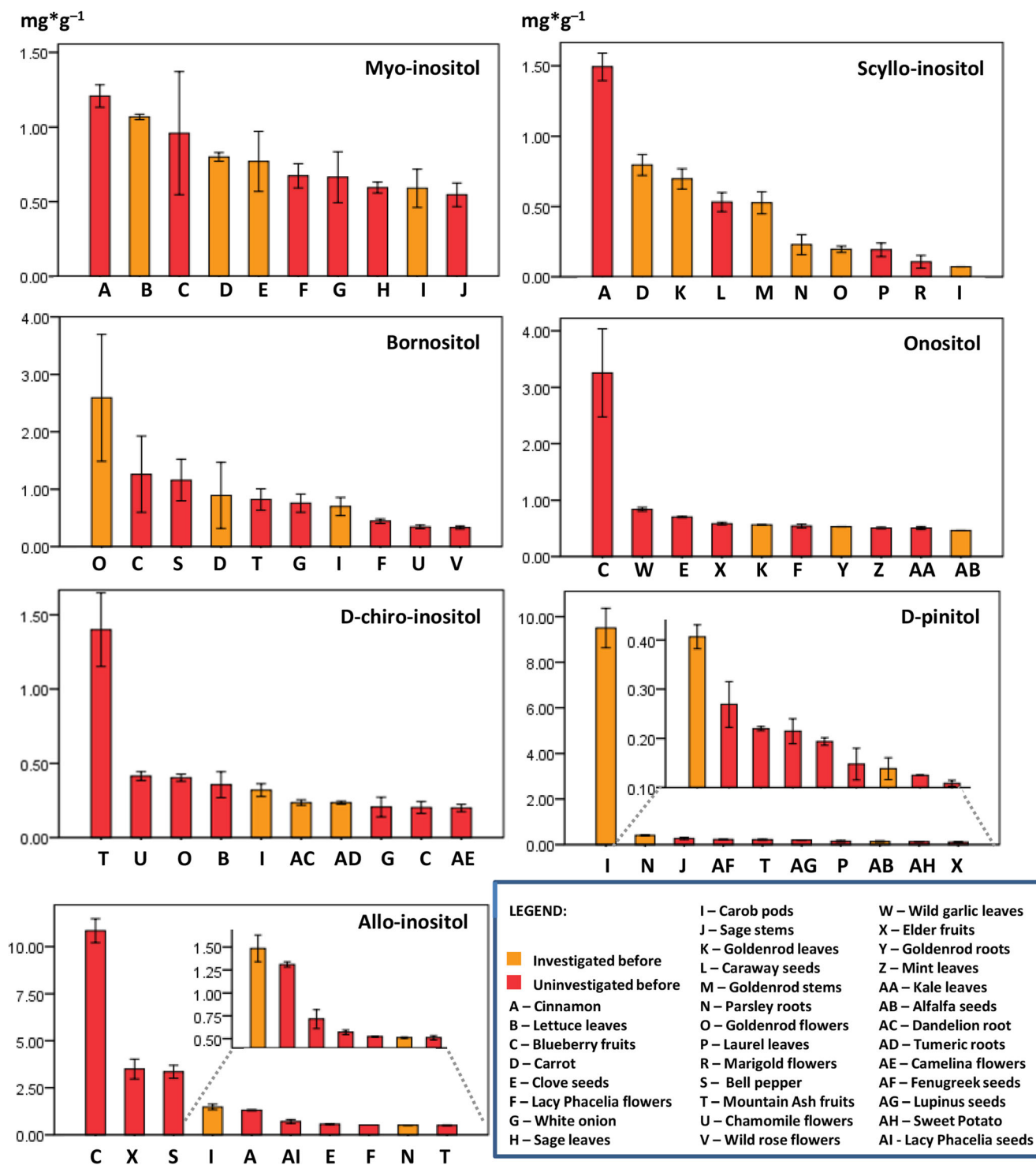


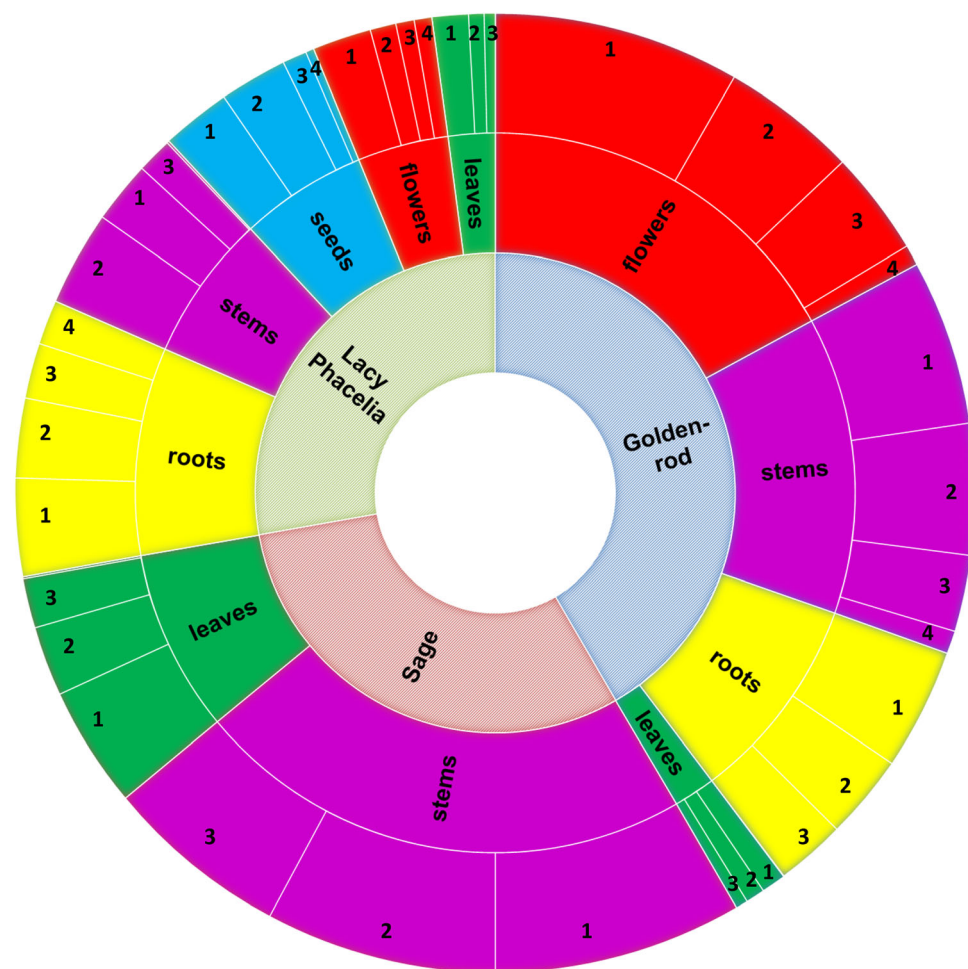
Fig. 2 The richest 10 sources of cyclitols detected in investigated samples

dried plant), where bornesitol was investigated previously, but in a mixture including all aerial parts together. Our detailed analysis of all goldenrod parts confirms that the highest quantity can be found in flowers. *Scyllo*-inositol was found in 30 of the 52 samples, and the most relevant amount was found in cinnamon (1.5 ± 0.01), a source from where it was not investigated before.

Distribution of Sugars in Different Morphological Parts of the Plant

In case of plants for which different morphological parts were investigated in the study, another two important observations came to our attention: firstly, the amount of sugars is significantly different from a certain part of the investigated plant to

Fig. 3 Sunburst chart representing variation in sugars concentration in different parts of plants, where 1 = fructose, 2 = glucose, 3 = mannose, 4 = sucrose



another one, and secondly, the smallest quantities were always detected in leaves. This fact is highlighted in Fig. 3, where a sunburst chart representing variation of sugar concentrations found in different parts of plants was used to support this statement. Three plants with comparable detected quantities

of sugars were chosen, but this assumption is believed to be valid for all cases.

The explanation of this phenomenon is that in plant material, sugars are produced in the leaves during photosynthesis. Because they play an important role in plant nutrition, they are

Table 4 Top 10 most important sources of cyclitols investigated

	D-Pinitol ^a	Allo- inositol ^a	Chiro- inositol ^a	Ononitol ^a	Bornesitol ^a	Scyllo- inositol ^a	Myo- inositol ^a	Total amount ^a
Blueberry fruits	0	10.84	0.203	3.256	1.261	0	0.958	16.518
Carob pods	9.501	1.484	0.320	0	0.698	0.071	0.590	12.664
Bell pepper	0	3.342	0.104	0	1.159	0.052	0.505	5.162
Elder fruits	0.108	3.490	0.105	0.585	0.025	0.024	0.224	4.561
Cinnamon	0	1.309	0.105	0	0	1.514	1.208	4.136
Goldenrod flowers	0.078	0	0.403	0	2.592	0.195	0.117	3.385
Mountain Ash fruits	0.214	0.510	1.444	0	0.820	0.027	0.020	3.035
Carrot	0	0	0.166	0	0.890	0.811	0.800	2.667
Lacy Phacelia flowers	0	0.523	0.011	0.542	0.444	0.025	0.672	2.217
Clove seeds	0	0.570	0.038	0.702	0.052	0.015	0.770	2.147

^a The quantities are presented are expressed in mg*g⁻¹ of dry weight of sample; each value represent the mean of three replicates

transported to the whole parts of plant by a vascular tissue called phloem. Within phloem, sugars are transported from high osmotic concentration and high-water-pressure areas, to regions with low osmotic concentration and low water pressure. Thus, the sugars are produced in the leaves, which act like sources, and transported to the roots, which act as sinks. Sometimes, even stems can act as sinks. During flowering period, the phloem transports important part of dissolved sugars to help in the development of flowers and future fruits and seeds (Noiraud et al. 2001).

Dissimilarities highlighted in sugars and cyclitol distribution can be produced as well by other factors, such as climate influence, precipitations, type of soil, cultivation area, etc. All these aspects can strongly influence the occurrence of sugars and cyclitol quantity in plant material (Ratiu et al. 2018).

Top 10 Relevant Plants Suitable for Cyclitol's Extraction

Cyclitols are the basis, the novelty, and the very justification for the present work. Given the complexity and large amount of data presented previously in the figures and tables, a simplified table showing the top ten sources with the highest concentration of the cyclitols is presented in Table 4. From this ten sources, seven of them, namely, Blueberry fruits, Mountain Ash fruits, Bell pepper, Elder fruits, Cinnamon, Goldenrod flowers, and Lacy Phacelia flowers, were not investigated so far for cyclitol's extraction.

Conclusions

The study of sugars and cyclitol distribution in plants in terms of recovery from various plants, in order to enrich the range of relevant natural sources used nowadays for their extraction, could lead to high-value economic benefits, besides the medical advantages. It is worth mentioning that cyclitols possess a crucial role as curative agents and most of their natural sources remained unexplored before now. Moreover, sugars alcohols (sorbitol and manitol) are the perfect candidates to be used in food industry instead of classical sugars. Consequently, the results highlighted in the present study can represent valuable information for food, pharmaceutical, medical, or cosmetic industry interested to involve the cyclitols in the manufacture of food supplements, medicines, or cosmetics.

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Compliance with Ethical Standards

Conflict of Interest Ileana Andreea Ratiu declares that she has no conflict of interest. Hossam Al-Suod declares that he has no conflict of interest. Magdalena Ligor declares that she has no conflict of interest. Tomasz Ligor declares that he has no conflict of interest. Aneta Krakowska declares that she has no conflict of interest. Ryszard Górecki declares that he has no conflict of interest. Bogusław Buszewski declares that he has no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent Not applicable.

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