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Elemental composition of seeds of representatives of the genus *Turbinicarpus* (Backeb.) Buxb. et Backeb.

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Abstract: The article presents data on the elemental composition of seeds of species of the genus *Turbinicarpus*. The study of the content of chemical elements in seeds makes it possible to explain their species-specificity, which can be used as one of the systematic characteristics of the studied group of plants.

Keywords: Chemical elements, scanning electron microscopy

Introduction

Electron microscopy with electron probe chemical analysis makes it possible to find out the elemental composition of seeds of the studied species and to carry out their quantitative analysis. In works Sorokopudov (Sorokopudov *et al.*, 2012) and Tokhtar (Tokhtar *et al.*, 2012) differences in the percentage of individual chemical elements in different parts of fruits and seeds were found. Belopukhov (Belopukhov *et al.*, 2012) divided chemical elements into groups depending on their percentage in plants, which also makes it possible to use this as a systematic trait.

Turbinicarpus (Backeb.) Buxb. et Backeb is a genus of Mexican cacti which, according to Hunt *et al.* (Hunt *et al.*, 2006) includes 16 species and 21 subspecies; however, the number of species and subspecies varies among authors (Anderson, 2001; Donati and Zanovello, 2005). *Turbinicarpus* extends in the northeastern region of the Republic of Mexico (in the Sonoran and Highland Mexican provinces of the Holarctic Kingdom (northeastern regions of Mexico, in particular, the states of San Luis Potosi, Guanajuato, Nuevo Leon, Queretaro, Hidalgo, Coahuila, Tamaulipas, and Sac). Due to illegal harvesting, changes in soil use, and overgrazing, all species of the genus, except for *T. horripilus*, are listed in NOM-059-SEMARNAT 2010. In addition, all species of this genus are included

in Appendix I of CITES (Hunt *et al.*, 2016) and the Red List of the International Union for Conservation of Nature (Duarte *et al.*, 2015).

Turbinicarpus have a spherical or slightly flattened stem that varies in color from grayish to brown (Figure 1). The height and diameter of representatives of this genus vary from 1.5 cm to 12–14 cm. The ribs are divided into tubercles. The tubercles are pronounced, rounded, located in a spiral. The spines are usually in the form of papery, hair-like, or feathery structures. Areolae are covered with white hairs. Plants have a turnip root, which accumulates not only moisture but also nutrients, it penetrates very deeply into the substrate and becomes thinner to the lower part. The flower is sessile, 0.7–3.8 cm long. The color of the perianth varies by species and subspecies and can be white, yellow, red, pink, or purple. Numerous stamens grow together with the perianth. Ripe fruits are 0.4–1.8 cm long, berry-like, and fleshy. Seeds are 1–1.5 mm long, black or red (Mario, 2004).



Figure 1. *T. schmidickeanus* subsp. *klinkerianus* (Backeb. & W. Jacobsen) Glass & R. A. Foster and *T. alonsoi* Glass & S. Arias.

Thus, the study of all aspects of the growth of this plant will lead to a more specific plan for conservation and restoration in habitats and botanical gardens. One of these aspects is the study of the structure and composition of seeds. The study aims to establish the elemental composition of seeds of the genus *Turbinicarpus*.

Materials and methods

The objects of the study were seeds of 43 species of the genus *Turbinicarpus*. These are seeds of own reproduction of the Central Botanical Garden of the National Academy of Sciences of Belarus, as well as attracted seed material. The studies were carried out by scanning electron microscopy with electron probe chemical analysis using a JSM-5610 LV scanning electron microscope with an EDX JED-2201 chemical analysis system.

Results and discussion

The study established the mass fractions (%) of the following chemical elements: Na, P, Cl, S, Si, Al, Ca, Mg, K (Table 1).

Table 1. Weight fraction (%) of chemical elements in seeds *Turbinicarpus*

Species (adopted names)	Na	Mg	Al	Si	P	S	Cl	K	Ca
<i>T. schmiedickeanus</i> subsp. <i>klinkerianus</i> (Backeb. & W. Jacobsen) Glass & R. A. Foster	0.65	1.29	0.84	0.59	0.08	0.62	0.99	8.40	1.55
<i>T. klinkerianus</i> "lilinkeuiduus"	0.59	0.63	0.95	0.87	0.2	0.56	0.33	5.39	3.77
<i>T. lophophoroides</i> (Werderm.) Buxb. & Backeb.	0.24	1.5	1.11	0.29	0.47	0.58	0.31	6.75	2.51
<i>T. lophophoroides</i> f. <i>roseiflorus</i>	0.55	3.34	0.71	3.68	0.34	0.37	0.45	10.12	2.82
<i>T. pseudomacrochele</i> subsp. <i>lausseri</i> (Diers & G. Frank) Glass	–	0.65	0.78	0.31	0.23	0.19	0.08	7.48	2.36
<i>T. schmiedickeanus</i> subsp. <i>andersonii</i> Mosco	1.01	0.82	0.81	0.4	0.01	0.20	0.06	2.2	2.62
<i>T. schmiedickeanus</i> subsp. <i>flaviflorus</i> (G. Frank & A.B. Lau) Glass & R. A. Foster	0.62	0.35	0.18	0.39	0.15	0.23	0.47	4.35	1.91
<i>T. graminispinus</i> Matusz.	–	2.7	2.6	0.38	–	0.33	0.01	3.03	5.86
<i>T. hoferi</i> Lüthy & A. B. Lau	0.44	0.90	0.19	0.34	0.23	0.15	0.11	2.95	2.56
<i>T. jauernigii</i> G. Frank	0.41	1.29	0.80	0.51	0.44	0.45	0.21	4.82	2.77
<i>T. pseudopectinatus</i> v. <i>albiflorus</i>	–	0.54	0.78	1.25	0.19	0.42	2.31	6.25	2.04

Species (adopted names)	Na	Mg	Al	Si	P	S	Cl	K	Ca
<i>T. pseudopectinatus</i> <i>v. rubriflorus</i>	1.99	0.40	1.82	0.80	0.10	0.48	0.54	3.63	2.76
<i>T. valdezianus</i> (Møller) Glass & R. A. Foster	0.37	0.07	1.91	2.32	0.05	0.80	0.36	10.3	2.88
<i>T. valdezianus v. albiflorus</i>	0.12	0.36	2.34	0.62	–	0.64	0.62	15.16	2.72
<i>T. zaragozae</i> (Glass & R. A. Foster) Glass & Hofer	2.67	0.49	1.34	2.88	0.38	0.27	0.34	4.62	6.36
<i>T. schmiedickeanus subsp.</i> <i>bonatzii</i> (G. Frank) Panar.	–	0.74	2.24	1.59	0.37	–	0.31	6.57	1.50
<i>T. schwarzii</i> (Shurly) Backeb.	0.10	3.20	0.88	–	0.03	0.04	0.19	9.96	1.50
<i>T. schwarzii v. rubriflorus</i> Gerhart Frank	0.17	1.24	0.70	0.63	0.05	0.37	0.22	5.53	2.05
<i>T. spacellatus</i>	0.38	0.53	0.78	1.45	0.43	0.45	0.42	2.97	7.43
<i>T. × mombergeri</i> Riha	0.93	0.6	0.93	1.46	0.27	0.23	0.78	5.64	2.29
<i>T. gielsdorffianus</i> (Werderm.) John & Riha	0.38	0.8	0.84	0.15	0.11	0.29	0.22	3.96	2.64
<i>T. schmiedickeanus subsp.</i> <i>gracilis</i> (Glass & R. A. Foster) Glass.	0.18	0.39	1.68	0.58	0.38	0.16	0.17	5.86	3.71
<i>T. saueri subsp.</i> <i>knuthianus</i> (Boed.) Lüthy	0.11	0.77	1.86	0.64	0.68	0.22	0.79	5.26	1.54
<i>T. pseudomacrochele subsp.</i> <i>minimus</i> (G. Frank) Lüthy & A. Hofer	0.32	0.73	1.07	2.7	0.57	0.28	0.14	2.67	1.13
<i>T. krainzianus v. lausseri</i>	0.33	0.19	1.48	1.22	0.16	0.35	0.28	4.71	0.96
<i>T. schmiedickeanus subsp.</i> <i>macrochele</i> (Werderm.) N. P. Taylor	0.91	0.79	0.54	0.17	0.23	0.39	0.64	5.19	1.14
<i>T. macrochele v. kupackii</i>	0.46	0.86	0.58	0.59	0.28	0.16	0.42	6.37	1.69
<i>T. macrochele v. frailensis</i>	1.1	0.38	0.76	0.69	0.10	0.12	0.13	5.81	1.47
<i>T. polaskii</i> Backeb.	2.1	1.5	0.85	0.24	0.87	0.47	0.51	9.48	1.79
<i>T. pseudomacrochele</i> (Backeb.) Buxb. & Backeb.	0.06	0.65	0.84	1.31	0.46	0.29	0.47	4.58	1.52
<i>T. pseudomacrochele</i> <i>v. alenae</i>	0.05	0.66	0.63	1.02	0.18	0.03	0.14	5.67	1.39

Species (adopted names)	Na	Mg	Al	Si	P	S	Cl	K	Ca
<i>T. schmiedickeanus subsp. dickisoniae</i> (Glass & R. A. Foster) N. P. Taylor	1.13	0.99	1.83	0.83	–	0.48	–	4.79	1.65
<i>T. swobodae</i> Diers & Esteves	0.99	1.41	2.43	1.19	–	0.26	1.10	3.47	9.33
<i>T. saueri subsp. ysabelae</i> (Schlange) Lüthy.	0.34	0.59	1.41	0.24	0.08	0.26	–	6.64	1.86
<i>T. saueri</i> (Boed.) John & Riha	2.38	1.57	0.97	0.85	0.12	–	–	6.69	2.54
<i>T. saueri subsp. gonzalezii</i>	0.99	0.63	0.97	0.73	0.26	0.21	–	5.21	1.34
<i>T. beguinii v. senilis f. nobile</i>	3.87	1.62	2.05	1.99	0.62	0.05	0.05	6.74	6.66
<i>T. mandragora</i> (Frič ex A. Berger) A. D. Zimmerman	2.88	1.09	2.78	0.68	–	0.20	1.14	6.68	4.27
<i>T. alonsoi</i> Glass & S. Arias	–	2.13	1.76	1.16	–	0.54	–	10.29	2.05
<i>T. laui</i> Glass & R. A. Foster	0.58	2.34	1.35	–	0.81	0.59	0.41	7.38	3.75
<i>T. roseiflorus</i> Backeb.	0.48	1.11	0.22	0.75	0.15	0.33	0.41	3.87	1.1
<i>T. dickisoniae</i> (Glass & R. A. Foster) Glass & A. Hofer	–	0.82	0.82	0.99	0.19	0.6	0.3	2.66	3.74
<i>T. pseudopectinatus</i> (Backeb.) Glass & R. A. Foster	1.04	0.16	0.65	0.58	0.22	0.57	0.59	4.31	1.05
<i>T. saueri subsp. nelissae</i>	1.62	1.71	0.27	1.21	0.39	0.7	0.12	7.93	2.2

These elements can be divided into two groups according to their content: 1st group – 2.5–15.2% (K, Ca) and 2nd group – 0.01–2.5% (Na, P, Cl, S, Si, Al, Mg). However, it is worth noting the exceptions in these groups. Thus, the weight fraction of Na in *T. beguinii v. senilis f. nobile* – 3.87%, *T. mandragora* – 2.88%, *T. zaragosae* – 2.67%; Mg in *T. schwarzii* – 3.2%; Al in *T. mandragora* – 2.78%; Si in *T. zaragosae* – 2.88%; Ca in *T. bonatzii* – 1.5%, *T. knuthianus* – 1.54%, *T. pseudopectinatus* – 1.05%, *T. polaskii* – 1.79%, *T. schmiedickeanus subsp. klinckerianus* – 0.42%, *T. schwarzii* – 1.5%. The highest content was shown by Ca (0.42–9.33%), K (2.66–15.16), Mg (0.7–3.2%), P (0.01–0.87%) – included in phytin – the main source of inorganic phosphate in seeds. Calcium in the composition of pectates is part of the cell walls of plants, its presence is important for the normal functioning of membranes, and it is an activator of enzymes also. Potassium is a calcium antagonist, is part of the enzymes involved in the formation of ATP in the process of oxidative phosphorylation, in addition, many enzymes involved in protein synthesis require the presence of potassium. Magnesium supports the structure of ribosomes by binding RNA and protein, is part of chlorophyll, and

is an activator of many enzymes. Phosphorus is involved in metabolism, cell division, reproduction, the transmission of hereditary properties, and other complex processes occurring in the plant.

The seeds are the units of plants with the most stable characteristics. Therefore, the chemical composition of the seeds can be one of the important characteristics of taxonomy. The activity of most enzymes depends on the content of activators and inhibitors in the cells, which are micro- and macroelements.

This study showed that even within the same genus, species have a different elemental composition of seeds, which indicates the species specificity of this indicator.

Thus, the seeds have a species-specific elemental composition, which can be used as one of the diagnostic features to establish the systematic position of plant seeds obtained from controversial sources.

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