Зборник Матице српске за природне науке / Matica Srpska J. Nat. Sci. Novi Sad, № 132, 87—100, 2017

UDC 633.11:581.134-034.721
https://doi.org/10.2298/ZMSPN1732087M

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THE CONCENTRATION RATIO OF ALKALINE EARTH ELEMENTS CALCIUM, BARIUM AND STRONTIUM IN GRAINS OF DIPLOID, TETRAPLOID AND HEXAPLOID WHEAT

ABSTRACT: Even though calcium (Ca), strontium (Sr) and barium (Ba) belong to the same group of the periodic table of elements, and thus have similar chemical features, their importance for plants differs greatly. Since plants do not have the ability to completely discriminate between essential (e.g. Ca) and non-essential elements (e.g. Sr and Ba), they readily take all of them up from soil solution, which is reflected in the ratios of concentrations of those elements in plant tissues, and it influences their nutritive characteristics. The ability of plant species and genotypes to take up and accumulate chemical elements in their different tissues is related to their genetic background. However, differences in chemical composition are the least reflected in their reproductive parts. Hence, the aim of this study was to evaluate ratios of concentrations of Ca, Sr and Ba in the whole grain of diploid and tetraploid wheat – ancestors of common wheat, as well as in hexaploid commercial cultivars, grown in the field, at the same location, over a period of three years.

The investigated genotypes accumulated Ca, Sr and Ba at different levels, which is reflected in the ratio of their concentrations in the grain. The lowest ratio was established between Ba and Sr, followed by Ca and Ba, while the highest ratio was between Ca and Sr. Moreover, the results have shown that the year of study, genotype and the combination highly significantly affected the ratio of the concentration Ca:Sr, Ca:Ba, and Ba:Sr.

KEYWORDS: barium, calcium, concentration ratio, grain, ploidy levels, strontium, wheat

INTRODUCTION

The alkaline earth metals, belonging to the group II A of the periodic table of elements, include beryllium (Be), magnesium (Mg), calcium (Ca),

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strontium (Sr), barium (Ba), and radium (Ra). They are widely distributed, in varying concentrations, in all parts of the biosphere (Kabata-Pendias, 2000). A common feature of alkaline earth metals is that their degree of oxidation is +2. Two electrons in the highest quantum state are characteristic of the electronic configuration of the alkaline earth metals. Moreover, compounds of these elements, except for Ba, have mainly ionic character. The similarity in physical and chemical properties of Ca, Ba and Sr is important in some physiological processes of plants.

Ca, Ba and Sr are not equally distributed in plants. Whereas Sr and Ba are regarded as trace elements, Ca belongs to macronutrients. Their ecological importance is also different. Contamination of the environment with Ba (Suwa *et al*., 2008) and Sr (^{90}Sr) (ATSDR, 2014) jeopardizes the living world, which is not the case with Ca. Nevertheless, Ba and Sr can take over the role of Ca in some physiological processes in plants (Vanselow, 1966 a,b), but most probably only non-specific ones. They can precipitate in the form of oxalates in some plant species (Fink, 1991; Wyttenbach *et al*., 1995), their mobility in plants is poor (Marschner, 1995; Kastori *et al*., 2007), and they have similar geochemical behavior.

Plant species differ in their ability to take up, accumulate, translocate and use mineral elements (Mengel, 1982). Differences exist also between genotypes, lines and individual parts of the whole plant within a species or variety (Sarić, 1981; Clark, 1983). The ratio between concentrations of alkaline earth metals differs not only between different plant species, but also between different genotypes of the same species (Young and Rasmusson, 1966), and also between different organs and tissues within each individual plant (Watmough, 2014). The ratio between Ca and Sr in edible plant parts is particularly important having in mind the potential risk of Sr (and its ^{90}Sr isotope) entering the food chain, and the importance of Ca as essential macronutrient. In this context, and considering also the importance of wheat as food and feed, the aim of this research was to assess ratios between concentrations of alkaline earth elements Ca, Ba and Sr in the whole grain of wheat genotypes of different levels of ploidy (diploid, tetraploid and hexaploid), grown under the same agro-ecological conditions. The results of this research may contribute to the creation of genotypes with more favorable ratio between these elements in wheat grain.

MATERIALS AND METHODS

Six diploid genotypes of wheat with different genome formula (BB, AA or DD), five tetraploids (BBAA) and nine hexaploids (BBAADD) were used in the experiment. Among the diploid wheat, four were wild and one (*Triticum monococcum* subsp. *monococcum*) was primitive cultivated wheat. Among the tetraploid wheat included in the experiment, three genotypes were wild einkorn while two were cultivated. All hexaploids were cultivated genotypes. The names of the cultivars are given in Table 1.

The wheat genotypes were planted in the experimental field of the Institute of Field and Vegetable Crops, Novi Sad, in 2011, 2012 and 2013, on Calcic, Gleyic Chernozem, well-provided with total nitrogen and rich in available phosphorus and potassium. Wheat genotypes were sown in a randomized complete block design, in three replications. Surface of field plots was 2.5 m^2. The soil of the experimental area was fertilized with 50 kg N ha^{-1}, and 50 kg P_2O_5 ha^{-1}. Top-dressing was conducted once, with 50 kg N ha^{-1}.

Table 1. Genotypes of *Aegilops* and *Triticum* species (classified according to van Slageren, 1994) included in the experiments.

No	Species and subspecies	Genome(s)	Name	Source/Origin
1	*Aegilops speltoides* subsp. *speltoids* 1	BB		IPK*
2	*Aegilops speltoides* subsp. *speltoids* 2	BB		IPK
3	Triticum urartu	AA		IPK
4	*Triticum monococcum* subsp. *Aegilopoides*	AA	Wild einkorn	IFVC, SRB**
5	*Triticum monococcum* subsp. *Monococcum*	AA	Cultivated einkorn	IFVC, SRB
6	*Aegilops tauschii* subsp. *Tauschii*	DD	Goat grass	IPK
7	*Triticum turgidum* subsp. *Dicoccoides* (IPK)	BBAA	Wild emmer	IPK
8	*Triticum turgidum* subsp. *Dicoccoides* (IFVC)	BBAA	Wild emmer	IFVC, SRB
9	*Triticum turgidum* subsp. *dicoccon*	BBAA	Cultivated emmer	IFVC, SRB
10	*Triticum turgidum* subsp. *turgidum*	BBAA	Ri vet wheat	IPK
11	*Triticum turgidum* subsp. *Durum* (cv. *Durumko*)	BBAA	Durum wheat	IFVC, SRB
12	*Triticum aestivum* subsp. *spelta* (cv. *Nirvana*)	BBAADD	Spelt wheat	IFVC, SRB
13	*Triticum aestivum* (cv. *Panonnia*)	BBAADD	Common wheat	IFVC, SRB
14	*Triticum aestivum (*cv. *Bankut* 1205)	BBAADD	Common wheat	HUN
15	*Triticum aestivum* (cv. *Bezostaja 1*)	BBAADD	Common wheat	RUS
16	*Triticum aestivum* (cv. *Siete Cerros*)	BBAADD	Common wheat	MEX
17	*Triticum aestivum* (cv. *Florida*)	BBAADD	Common wheat	USA
18	*Triticum aestivum* (cv. *Renan*)	BBAADD	Common wheat	FRA
19	*Triticum aestivum* (cv. *Condor*)	BBAADD	Common wheat	AUT
20	*Triticum aestivum* (cv. *Bolal*)	BBAADD	Common wheat	TUR

* IPK – Genebank Gatersleben of the Leibniz Institute of Plant Genetics and Crop Plant Research, Gatersleben, Germany; ** IFVC, SRB – Institute of Field and Vegetable Crops, Novi Sad, Serbia; HUN – Hungary; RUS – Russia; MEX – Mexico; USA – United State of America; FRA – France; AUT – Australia; TUR – Turkey.

Genotypes included in the experiment were harvested at crop maturity and all hulled genotypes were manually de-hulled. After digestion of grain whole meal in a mixture of 10 mL HNO_3 (65%) and 2 mL of H_2O_2 (30%), the concentration of Ca, Ba and Sr were determined by inductively coupled plasma emission spectroscopy.

The data were subjected to a combined analysis of variance, treating environment as the main plot and the species as the sub-plot, and the differences among genotypes and environments were determined using the Tukey test. Standard deviations, analysis of variance, Pearson's linear correlation coefficients among all the traits were obtained by Infostat (Di Rienzo *et al*., 2016). Principal coordinates analysis (PCO) was used to find the eigenvalues and eigenvectors of a matrix containing the distances between all data points (Davis, 1986) applying Euclidean correlation.

RESULTS AND DISCUSSION

Concentration ratios Ca:Sr, Ca:Ba and Ba:Sr in the whole grain of *Aegilops* and *Triticum* species varied significantly between different genomes but also between different years (Table 2). However, the differences were more pronounced between genomes than within them. Significant differences were recorded with respect to all three ratios between *Triticum* species, but not within *Aegilops* (Table 2). The ratio Ba:Sr was affected the most by the year (Table 2). The ratio between concentrations of alkaline earth metals and the other elements in particular plant species, genotypes, organs, tissues, and cell organelles depends, besides genetics, on many ecological factors, as well as on physical and chemical features of particular ions. The most important ecological factor is the concentration of elements in the root zone, although in this respect opinions vary. According to White (2001), the accumulation of Ca, Sr, and Ba in shoots is often linear in relation to their concentration in the nutrient solution, and the ratio Ca:Ba:Sr in the shoot is the same as in the nutrient solution in which the root is embedded. During the transport of Ca, Sr, and Ba towards the shoot there is no competition or interaction between these cations, in spite of the fact that there is competition between them during their uptake into root cells. Russell and Squire (1958) found that the absorption of Sr in the presence of Ca declined and translocation of Sr in plants insufficiently supplied with Ca was lower probably due to binding of Sr on the root surface or close to it.

Combined analyses of variance showed that the year of study, genotype, and the combination highly significantly affected the three examined ratios (Table 3). When the analysis was done with respect to the genomes, the result was the same (highly significant differences) with the exception of Ca:Sr which was significant (Table 4). Standard deviation and coefficient of variation were quite variable within and between genotypes and years (Table 5). The ratio Ca:Sr was the smallest in genotype 13 (ranging from 121 to 263) and the highest in genotype 7 (423–612); the ratio Ca:Ba was the smallest in genotype 2 (74–124) and the highest in genotype 10 (174–535); the ratio Ba:Sr was the lowest in genotype 15 (0.64–2.23) and the highest in genotype 2 (1.78–3.41). Coefficient of variation was also pretty variable and ranged from 1.9 for ratio Ca:Sr in genotype 19 to over 52 for ratio Ca:Ba in genotypes 6, 10 and 18 (Table 5). With respect

Table 2. Concentration ratios: Ca:Sr, Ca:Ba, and Ba:Sr in the whole grain of *Aegilops* and *Triticum* species over the period of 3 years.

	Ca:Sr	Ca:Ba	Ba:Sr
Genotype no.*			
1	262.6^{i}	97.2^{i}	2.9^{a}
2	258.4^{i}	97.5^{i}	2.8^{ab}
3	374.3^{e}	273.3^{c}	1.4^{j}
4	439.3^{cd}	211.8^{de}	2.2^{ef}
5	440.1b^{cd}	167.1^{fg}	2.7^{abc}
6	469.3^{b}	239.9^{d}	2.4^{cde}
7	524.1^{a}	223.4^{de}	2.4d^{ef}
8	309.8^{g}	194.2^{ef}	1.6^{j}
9	502.7^{a}	349.0^{d}	1.5^{j}
10	459.4^{bc}	308.3^{b}	1.9^{hi}
11	458.4^{bc}	222.0^{de}	2.1^{fgh}
12	340.3^{f}	149.7^{gh}	2.3^{efg}
13	206.7^{j}	91.2^{i}	2.3^{efg}
14	279.4^{hi}	122.1^{hi}	2.3^{defg}
15	332.1^{fg}	223.4^{de}	1.6^{j}
16	303.8^{gh}	122.8^{hi}	2.6^{bgd}
17	258.3^{i}	138.0^{gh}	2.1^{gh}
18	268.3^{i}	210.1^{de}	1.6^{ij}
19	416.9^{d}	311.1^{b}	1.4^{j}
20	303.8^{dh}	144.5^{gh}	2.2^{efgh}
Genome			
BB	260.5^{c}	217.4^{a}	2.8^{a}
AA	469.3^{a}	97.3^{c}	2.1^{bc}
DD	417.9^{b}	239.9^{a}	2.4^{b}
BBAA	450.9^{ab}	259.4^{a}	1.9^{c}
BBAADD	301.1^{c}	168.1^{b}	2.1^{bc}
Year			
2011	345.2^{b}	183.1^{b}	2.1^{b}
2012	373.8^{a}	235.9^{a}	1.8^{c}
2013	362.3^{ab}	165.5^{b}	2.4^{a}

*Genotypes of *Aegilops* and *Triticum* species examined in the experiments are given in Table 1.
Average ratios were obtained from three independent measurements and significance of differences between the average ratios was assessed by Tukey's test; different letters indicate a significant difference at 5% probability level.

to genomes and experimental years, in each ratio of concentrations, all examined ranges had overlaps (Table 5).

Table 3. Combined analysis of variance (ANOVA) of concentration ratios: Ca:Sr, Ca:Ba, and Ba:Sr in the whole grain of *Aegilops* and *Triticum* species over the period of 3 years.

	DF	Ca:Sr		Ca:Ba		Ba:Sr	
		SS	(%)[a]	SS	(%)[a]	SS	(%)[a]
Year (Y)	2	24810[b]	1	161043[b]	9	10.41[b]	11
Genotype (G)	19	1561592[b]	73	990100[b]	54	34.25[b]	36
Y x G	38	505355[b]	24	654806[b]	35	46.31[b]	49
Error	120	35145	2	42541	2	3.39	4
Total	179	2126902		18448191		94.36	

[a] % explained and calculated from ANOVA as factor SS (sum of squares)/total SS.
[b] Significant at P <0.01.

Table 4. Combined analysis of variance (ANOVA) of concentration ratios: Ca:Sr, Ca:Ba, and Ba:Sr in the whole grain of 20 genotypes and 5 genomes over the period of 3 years.

	DF	Ca:Sr		Ca:Ba		Ba:Sr	
		MS	F	MS	F	SS	F
Year (Y)	2	12405**	4.3	80522**	25.7	5.21**	24.4
Genome (Gen)	4	257316*	88.8	112091**	35.7	3.15**	14.7
Y x Gen	8	13214**	4.6	28261**	9.0	2.21**	10.3
Gen/Gen>G	15	35489**	12.2	36116**	11.5	1.44**	6.7
Error	150	2899		3140		0.21	

* Significant at P < 0.05; ** Significant at P < 0.01

Pearson's correlation coefficients for ratios of concentrations of examined elements were significant between all genomes for Sr/Ca:Sr, Sr/Ca:Ba, Ba/Ba:Sr, and Ca:Sr/Ca:Ba (Table 6). Antagonism between Ca, Sr, and Ba was investigated in the middle of the last century by Epstein and Leggett (1954) and later by Kabata-Pendias (2000). It is generally accepted that the Ca:Sr ratio does not change significantly during their uptake (Blum *et al.*, 2002). In eight woody species Watmough (2014) found that the ratios Ca:Sr and Ca:Ba were different in shoots with respect to the soil. In ten pasture species, the ratio Sr:Ca depended on plant species but also on soil features (Veresoglou *et al.*, 1996). In wheat, the ratio Sr:Ca to a small and Ba:Ca to a higher extent depended on their ratios in the soil extract (Smith, 1971a). On the bases of these results, it can be concluded that ratios of concentrations of Ca, Sr, and Ba in the nutrient medium under certain conditions may affect their ratios in shoots. Therefore, studies of genotypic

Table 5. Range, standard deviation and coefficient of variation of concentration ratios: Ca:Sr, Ca:Ba, and Ba:Sr in the whole grain of *Aegilops* and *Triticum* species over the period of 3 years.

		Ca:Sr			Ca:Ba			Ba:Sr		
	N	range	SD	CV	range	SD	CV	range	SD	CV
Genotype no.*										
1	3	251–268	8.0	3.1	77–132	24.6	25.3	1.91–3.48	0.69	24.0
2	3	221–321	44.6	17.3	74–124	20.4	22.0	1.78–3.41	0.71	25.7
3	3	292–417	58.2	15.6	202–322	51.0	18.7	1.29–1.45	0.07	4.7
4	3	321–568	101.2	23.0	188–240	21.49	10.2	1.59–3.09	0.67	30.9
5	3	403–502	44.3	10.1	142–192	20.7	12.4	2.41–2.96	0.23	8.5
6	3	425–525	41.5	8.9	124–415	101.2	52.5	1.27–3.69	0.99	40.4
7	3	423–612	77.5	14.8	215–236	9.5	4.2	2.01–2.84	0.35	14.7
8	3	224–405	74.0	23.9	159–238	33.0	17.0	1.41–1.71	0.12	7.73
9	3	428–600	72.3	14.4	259–442	74.9	21.5	0.97–1.89	0.41	26.6
10	3	429–500	29.9	6.5	174–535	152.1	52.2	0.84–2.87	0.83	43.8
11	3	407–510	41.9	9.1	190–278	39.9	18.0	1.84–2.34	0.21	9.7
12	3	213–438	94.1	27.7	136–163	11.2	7.5	1.56–2.94	0.56	24.9
13	3	121–263	61.4	29.7	81–108	11.8	12.9	1.43–3.23	0.74	32.3
14	3	269–292	9.5	3.4	113–128	6.9	5.6	2.09–2.61	0.22	9.4
15	3	318–346	11.5	3.5	152–305	62.9	28.1	1.09–2.09	0.41	25.71
16	3	281–318	16.4	5.4	98–164	29.3	23.9	1.94–2.94	0.45	17.6
17	3	251–273	10.2	3.9	106–200	44.2	32.0	1.25–2.57	0.57	27.9
18	3	230–334	46.9	17.5	108–363	110.2	52.4	0.64–2.23	0.72	43.6
19	3	409–428	7.7	1.9	197–490	128	41.1	0.87–2.08	0.50	32.5
20	3	211–375	68.5	22.5	125–168	17.6	12.2	1.26–2.67	0.64	29.7
Genome										
BB	6	221–321	32.1	12.3	74–132	22.6	23.3	1.78–3.48	0.71	24.9
AA	9	292–569	78.3	18.8	142–322	55.3	25.4	1.29–3.09	0.66	32.1
DD	3	425–525	41.5	8.9	124–415	101.2	52.5	1.27–3.69	0.99	40.4
BBAA	15	224–612	97.4	21.6	159–535	101.6	39.2	0.84–2.87	0.55	29.2
BBAADD	27	121–438	73.3	24.3	81–490	90.1	53.6	0.64–3.24	0.66	32.0
Year										
2011	20	121–525	101.6	29.5	83–443	95.3	52.0	0.97–3.41	0.67	31.4
2012	20	211–612	126.8	33.9	108–535	117.4	49.8	0.64–3.09	0.69	38.0
2013	20	221–536	89.7	24.8	74–322	67.6	40.8	1.29–3.69	0.65	27.1

* Genotypes of *Aegilops* and *Triticum* species examined in the experiments are given in Table 1

differences with respect to ratios between concentrations of these elements have to be conducted under the identical soil and other agro-ecological conditions, and the experiment described here was done in line with this recommendation.

Table 6. The Pearson's correlation coefficient (*r*) for concentration of Ca, Sr, and Ba and their ratios in the whole grain of *Aegilops* and *Triticum* genomes over the period of 3 years. Genotypes of *Aegilops* and *Triticum* species examined in the experiments are given in Table 1.

Elements	Genome				
	BB	AA	DD	BBAA	BBDD
Ca/Sr	0.853**	0.521**	0.955**	0.158	0.290**
Ca/Ba	-0.446	0.513**	-0.707*	0.286	0.280*
Ca/Ca:Sr	-0.353	-0.047	-0.819**	0.296*	0.369**
Ca/Ca:Ba	0.398	0.014	0.923**	-0.379*	-0.285**
Ca/Ba:Sr	0.870**	0.539**	0.923**	0.284	0.253*
Sr/Ba	-0.254	0.410*	-0.608	0.526**	0.527**
Sr/Ca:Sr	-0.781**	-0.832**	-0.946**	-0.838**	-0.692**
Sr/Ca:Ba	0.816**	0.857**	0.996**	0.837**	0.826**
Sr/Ba:Sr	0.677**	0.133	0.839**	-0.306*	-0.224*
Ba/Ca:Sr	-0.103	-0.182	0.517	-0.372*	-0.358**
Ba/Ca:Ba	0.077	0.181	-0.574	0.367*	0.321**
Ba/Ba:Sr	-0.825**	-0.439*	-0.919**	-0.792**	-0.751**
Ca:Sr/Ca:Ba	-0.990**	-0.926**	-0.970**	-0.887**	-0.897**
Ca:Sr/Ba:Sr	-0.179	0.152	-0.713*	0.445**	0.422**
Ca:Ba/Ba:Sr	0.218	-0.169	0.801**	-0.436**	-0.326**

* significance level alpha=0.05; ** significance level alpha=0.01

The intensity of transport from the root and redistribution of elements from vegetative parts to the fruit may significantly determine their ratios in generative parts. Indexes of translocation of Sr and Br were found to be the lowest out of examined microelements (Ni, Cu, Zn, Mo, Sr, and Ba) in five plant species, including wheat, and it was not significantly influenced by the increase in their concentration available to plants (Kastori *et al.*, 2007). According to Smith (1971a) Sr, Ba, and Ra are less mobile in wheat in comparison to Ca, and a significant part of Ba and Ra is bound in stems. Russell and Squire (1958) found that redistribution of Sr in barley is very low. Also, low concentration of Ca, Sr, and Ba in generative parts and grain of wheat may be explained by their low mobility (translocation) in plants.

Distribution of examined alkaline earth metals in plant organs is variable, and this is reflected in the ratios of their concentrations in the other plant species as well. For example, concentration of Sr in rapeseed was the highest in chaff, of Ba in stems, and the lowest concentration of both elements was in seed. The ratio of concentrations Sr:Ba in stems was 9.7, in chaff 14.4, and in seeds 8.9 (Kastori *et al*., 2003). According to Watmough (2014) in eight woody species the highest molar ratios Ca:Sr, Ca:Ba, and Sr:Ba were found in leaves, and the lowest in stems. Sr and Ba accumulate in the endosperm of Brazil nut and their ratio to Ca was found to be 20 times higher than in stem tissues (Smith, 1971b).

Regression analysis of concentration ratios Ca:Sr against Ca:Ba was in 2011 and 2013 highly significant, whereas concentration ration of Ca:Ba against Ba:Sr was significant in all experimental years. On the contrary, concentration ratio of Ca:Sr against Ba:Sr was not significant (Figure 1). It is clear that concentrations of individual elements are reflected in the analyses of their ratios. Significant differences with respect to the concentrations of particular alkaline earth elements were recorded between the genotypes of the same species. Young and Rasmusson (1966) found significant differences in the accumulation of Ca and Sr between genotypes of barley: those genotypes which accumulated higher amounts of Sr accumulated Ca as well. Barley genotypes differed significantly with respect to Sr:Ca ratio in the shoots. Significant differences were recorded with respect to the concentration of Ba (Denčić *et al*., 2015), Sr (Kastori *et al*., 2017) and Ca in the whole wheat grain. All three elements accumulated most in the grain of *Aegilops speltoides.*

Principal coordinate analysis of ratios of concentrations Ca:Ba, Ba:Sr, and Ca:Sr during three years allowed grouping of genotypes according to their genome into distinct groups (Figure 2) and these results are further supported by discriminant analysis (Figure 3). Therefore, the results described here underline the significance of the genetic background with respect to the ability to accumulate Ca, Ba, and Sr in the wheat and *Aegilops* grain. These findings are important since they can be used in the breeding programs to obtain wheat grains of better nutritional quality.

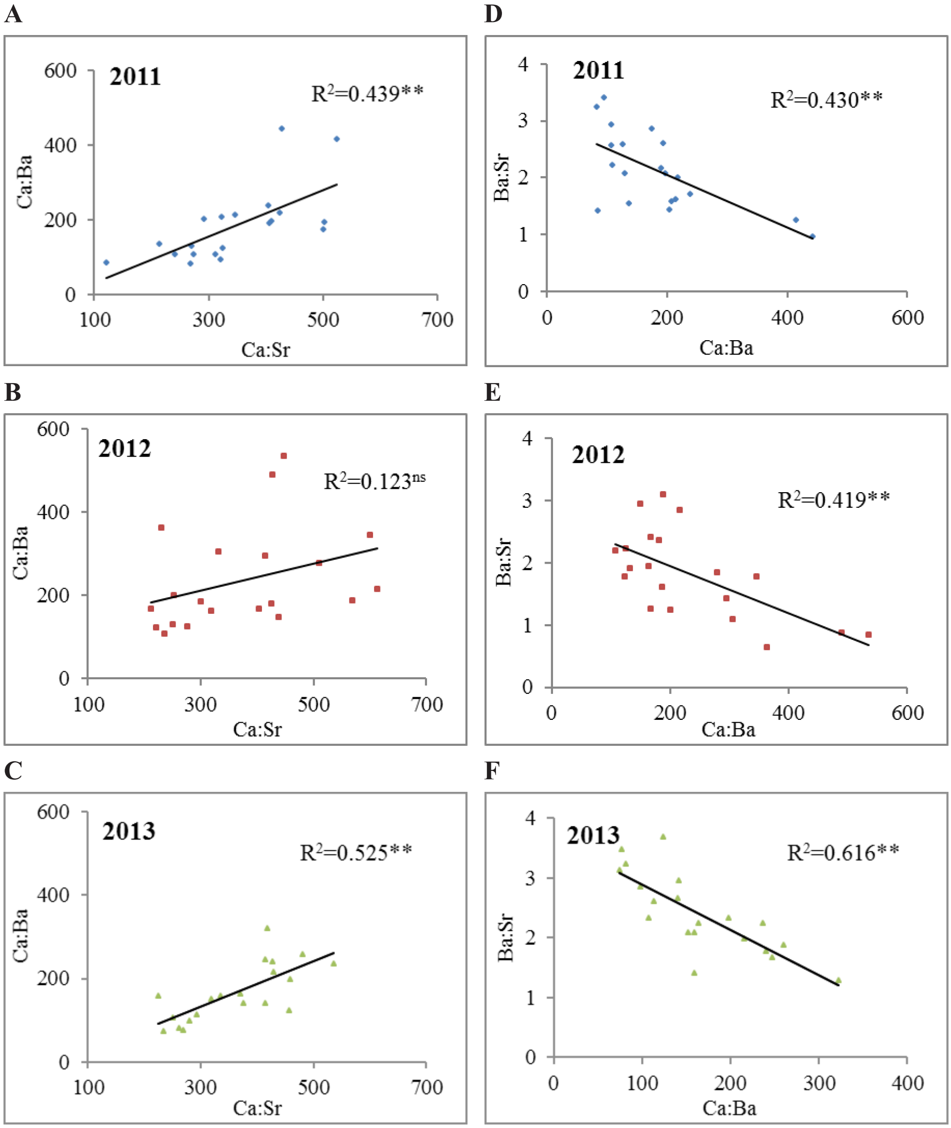

Figure 1. Pearson's liner correlation coefficients among ratios of concentrations of Ca:Ba and Ca:Sr (**A, B, C**), and Ba:Sr and Ca:Ba (**D**, **E**, **F**) in the whole grain of *Aeglops* and *Triticum* species in three experimental years. Ratios between Ba:Sr and Ca:Sr were not statistically significant and therefore are not shown. Genotypes of *Aegilops* and *Triticum* species examined in the experiments are given in Table 1

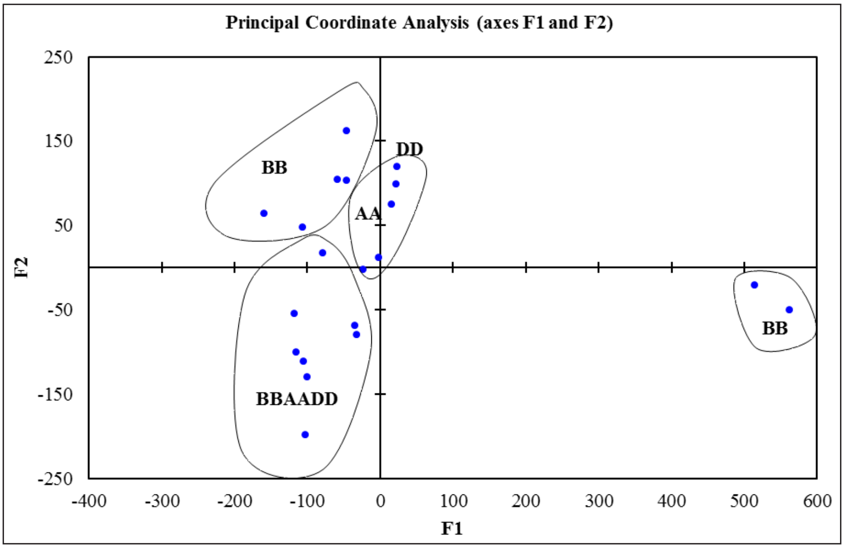

Figure 2. Principal coordinate analysis of concentration ratios: Ca:Sr, Ca:Ba and Ba:Sr in the whole grain of *Aegilops* and *Triticum* species over a 3-year period shows segregation groups with respect oto their respective genetic backgrounds. Genotypes of *Aegilops* and *Triticum* species examined in the experiments are given in Table 1

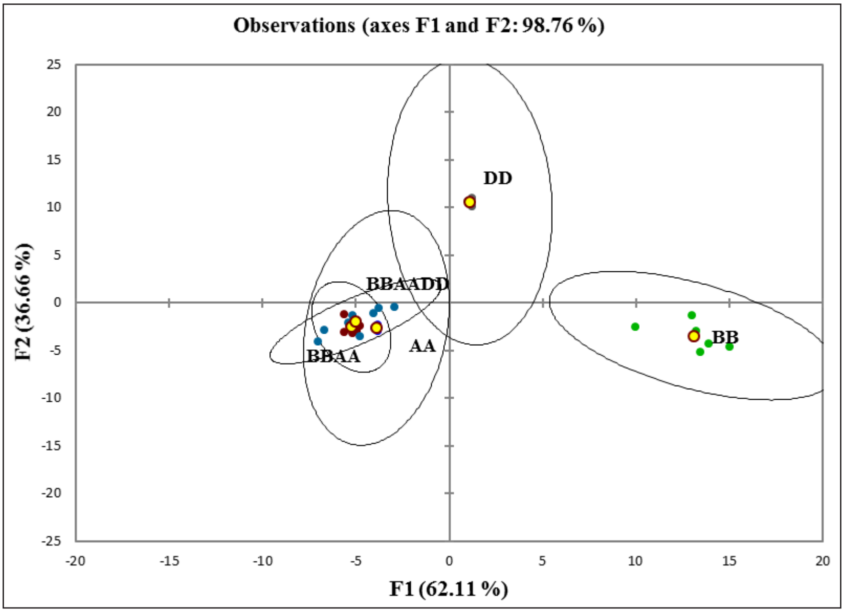

Figure 3. Discriminant analysis of concentration ratios: Ca:Sr, Ca:Ba, and Ba:Sr in the whole grain of *Aegilops* and *Triticum* species over a 3-year period shows segregation groups with respect to their respective genetic backgrounds. Genotypes of *Aegilops* and *Triticum* species examined in the experiments are given in Table 1

CONCLUSION

Examined alkaline earth metals have different physiological and ecological significance. Calcium is a necessary element for all living things, while strontium, under certain circumstances, is considered as an ecological hazard. Therefore, the knowledge of their concentrations and ratios of their concentrations in wheat grain, beside scientific, has practical significance as well. Diploid, tetraploid, and hexaploid wheats accumulated Ca, Sr, and Ba at different levels. Overall ratios of their concentrations in the grain were the lowest for Ba:Sr, than for Ca:Ba, and the highest for Ca:Sr. Besides genotype, the year of study, and also the combination of genotype and the year of study highly significantly affected the ratios of concentration Ca:Sr, Ca:Ba, and Ba:Sr.

ACKNOWLEDGEMENT

The authors express their gratitude to Prof. Dr. Kádar Imre, from the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, for his help in chemical analysis.

REFERENCES

ATSDR (2014): Agency for toxic substances and disease registry, public health statement, strontium CAS#: 7440-24-6, Available from: <www.atsdr.ede.Gov/>

Blum JD, Klaue A, Nezat CA, Driscott CT, Johnson CE, Sicama TG, Eagar C, Fahey TJ, Likens GE (2002): Mycorrhizal weathering of apatite as an important calcium source in base poor forest ecosystems. *Nature* 417: 729–731.

Clark RB (1983): Plant genotype differences in the uptake, translocation and use of mineral elements required for plant growth. *Plant Soil* 72: 175–196.

Davis JC (1986): *Statistics and data analysis in geology*. New York: John Wiley & Sons,.

Denčić S, Kastori R, Kádár I, Maksimović I, Putnik-Delić M, Momčilović V (2015): Barium concentration in grain of *Aegilops* and *Trtiticum* species. Novi Sad: *Matica Srpska J. Nat. Sci.* 129: 27–34.

Di Rienzo JA, Casanoves F, Balzarini MG, Gonzalez L, Tablada M, Robledo CW (2016): InfoStat version. InfoStat Group, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Argentina, Available from: <http://www.infostat.com.ar>.

Epstein E, Leggett J (1954): The absorption of alkaline earth cations by barley roots: kinetics and mechanism. *Am. J. Bot.* 41: 785–791.

Fink S (1991): Comparative microscopical studies on the patterns of calcium oxalate distribution in the needles of various conifer species. *Bot. Acta* 104: 306–315.

Kabata-Pendias A (2000): *Trace elements in soil and plants*. 3rd edition CRS Press, Boca Raton London New York Washington D.C.

Kastori R, Kádár I, Sekulić PĐ, Zeremski-Škorić TM (2003): Effect of Mo, Zn, Sr and Ba loads on these elements' uptake and oil content and fatty acid composition of rapeseed. Novi Sad: *Matica Srpska Proc. Nat. Sci.* 105: 5–14.

Kastori, R, Kádár, I, Maksimović, I (2007): Translocation of heavy metals and Sr and Ba from vegetative parts to seeds of some crops. *Proceedings of the 14th Symposium on Analytical and Environmental Problems*. SAB Szakbizottsága Analitikai és Környezetvédelmi Munkabizottsága, Szeged, Hungary, 121–125.
Kastori R, Maksimović I, Denčić S, Kádár I, Putnik-Delić M, Momčilović V (2017): Strontium accumulation in whole grain of *Aegilops* and *Triticum* species. *J. Plant. Nutr. Soil Sci*. 180: 212–219.
Marschner H (1995): *Mineral nutrition of higher plants*. 2nd Edition, Academic Press, London.
Mengel K (1982): Response of various crop species and cultivars to mineral nutrition and fertilizer application. In: *Genetic specificity of Mineral Nutrition of Plants*. Belgrade: Serb. Acad. Sci. Arts, 22: 233–245.
Russell RS, Squire HM (1958): The absorption and distribution of strontium in plants I. Preliminary studies in water culture. *J. Exp. Bot.* 9: 262–276.
Sarić M (1981): Genetic specificity in relation to plant mineral nutrition. *J. Plant Nutr*. 3: 743–766.
Smith KA (1971a): The comparative uptake and translocation by plants of calcium, strontium, barium and radium. *Plant Soil* 34: 369.
Smith KA (1971b): The comparative uptake and translocation by plants of calcium, strontium, barium and radium II. *Triticum vulgare* (wheat). *Plant Soil* 34: 643–651.
Suwa R, Jayachandran K, Nguyen NT, Boulenouar A, Fujita K, Saneoka H (2008): Barium toxicity effects in soybean plants. *Arch. Environ. Contam. Toxicol*. 55: 539–403.
Van Slageren MWSJ (1994): *Wild wheats: A monograph of Aegilops L. and Amblyopyrum (Jaub. et Spach) Eig (Poaceae): a revision of all taxa closely related to wheat, excluding wild Triticum species, with notes on other genera in the tribe Triticeae, especially Triticum*. Wageningen: Wageningen Agricultural University Papers, The Netherlands, 94–97.
Vanselow AP (1966a): Barium. In: Chapman, HD (eds.), *Diagnostic criteria for plants and Soils. Division of agricultural sciences*, Berkeley: University of California, 24–32.
Vanselow AP (1966b): Strontium. In: Chapman HD (eds.), *Diagnostic criteria for plants and soils. Division of agricultural sciences*, Berkeley: University of California, 433–443.
Veresoglou DS, Barhayiannis N, Matsi T, Anagostopoulos C, Zalidis GC (1996): Shoot Sr concentrations in relation to shoot Ca concentrations and to soil properties. *Plant Soil* 178: 95–100.
Watmough SA (2014): Calcium, strontium and barium biogeochemistry in a forested catchment and insight into elemental discrimination. *Biogeochemistry* 118: 357–369.
White PJ (2001): The pathways of calcium movement to the xylem. *J. Exp. Bot.* 52: 891–899.
Wyttenbach A, Bajo S, Bucher J, Furrer V, Schleppi P, Tubler L (1995): The concentration of Ca, Sr, Ba and Mg in successive needle age classes of Norway spruce (*Picea abies* (L.) Karst.), *Trees* 10: 31–39.
Young WI, Rasmusson DC (1966): Variety differences in strontium and calcium accumulation in seedlings of barley. *Agron. J.* 58: 181–483.

ОДНОС КОНЦЕНТРАЦИЈЕ ЗЕМНОАЛКАЛНИХ МЕТАЛА КАЛЦИЈУМА, БАРИЈУМА И СТРОНЦИЈУМА У ЗРНУ ДИПЛОИДНЕ, ТЕТРАПЛОИДНЕ И ХЕКСАПЛОИДНЕ ПШЕНИЦЕ

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РЕЗИМЕ: Калцијум (Ca), стронцијум (Sr) и баријум (Ba) припадају истој групи елемената Периодног система и имају сличне хемијске особине. Међутим, њихове улоге у биљном организму веома се разликују. Обзиром да биљке немају способност да у потпуности разликују есенцијалне (Ca) од неесенцијалних елемената (Sr и Ba), оне их све усвајају из земљишног раствора, а то се одражава у различитом односу концентрација ових елемената у биљном ткиву и утиче на њихове нутритивне особине. Способност врста и генотипова да усвајају и акумулирају хемијске елементе у различитим ткивима, зависи од њихове генетике. И поред тога, разлике у хемијском саставу огледају се у њиховој репродуктивној улози. Циљ истраживања био је да се одреде односи концентрација Ca, Sr и Ba у целом зрну диплоидне и тетраплоидне пшенице – претка данашње пшенице, као и хексаплоидних комерцијалних врста, гајених на истом пољу и локалитету током три године.

Испитивани генотипови су акумулирали Ca, Sr и Ba у различитим количинама, што се одразило на однос њихових концентрација у зрну. Најнижи однос установљен је између Ba и Sr, затим Ca и Ba, а највећи између Ca и Sr. Такође, резултати су показали да година испитивања, генотип и комбинација значајно утичу на однос концентрације Ca:Sr, Ca:Ba и Ba:Sr.

КЉУЧНЕ РЕЧИ: баријум, калцијум, однос концентрације, нивои плоидности, пшеница, стронцијум