ZINC ACCUMULATION IN WHOLE GRAIN OF DIPLOID, TETRAPLOID AND HEXAPLOID WHEAT

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Abstract

Zinc (Zn) is an essential element for all leaving organisms. Plants are the most important source of Zn for humans and animals; therefore its accumulation in edible plant parts is of great importance.

Plant species, but also genotypes and specific varieties differ with respect to accumulation of mineral elements. During three years, accumulation of Zn in the grain of A*egilops* and *Triticum* species, with different genomes (AA, BB, BBAA, BBAADD and DD), grown on calcareous, gleyic chernozem soil in temperate continental climate, was followed. Three-years average results allowed to establish the following order with respect to the concentration of Zn in the whole grain (mg kg^{-1} DW): BB (36.24) > AA (30.86) > DD (28.98) > BBAA (25.43) > BBAADD (17.97). The analysis of variance revealed a highly significant effect of genome and year as well as of the interaction between genome and year.

Introduction

Zinc is present in low concentrations in all parts of the biosphere. It is essential element for all living organisms. Metabolic role of Zn is based on its tendency to form tetrahedral complexes with O-, N-, and especially S-ligands. Therefore, Zn has functional (catalytic) and structural role in enzymatic reactions [1]. Zinc is associated with more than fifty metaloenzymes which are involved in different processes, including synthesis of nucleic acids, specific proteins like hormones and their receptors [2]. Hence, Zn has a very important role in metabolism, growth and differentiation of cells.

Zinc enters human and animal organisms predominantly through food. Since its extreme importance for metabolic processes, Zn content in food is very important as well. Wheat is one of the most significant sources of nutrients for people in many parts of the world. Among three most important small grain cops wheat is grown on the largest surfaces (around 221 millions of ha). It is followed by maize (around 185 millions of ha) and rice (around 161 millions of ha). Wheat is gown mostly for food – about 54% of production in developed countries and 85% in developing countries. After [3] nearly one half or human population takes in insufficient amounts of Zn. The lack of Zn in food and feed may cause many diseases. Therefore, the aim of this work was to examine concentration of Zn in the whole grain of different kinds of wheat, since plant species but also genotypes within them often differ greatly with respect to the accumulation of mineral elements [4].

Experimental

Concentration of Zn was assessed in the grains of 20 genotypes of different levels of ploidy and of different origin: six diploid genotypes of wheat with different genome formulas (BB, AA or DD), five tetraploids (BBAA) and nine hexaploids (BBAADD). The names of the cultivars are given in Table 1. The wheat genotypes were sown in 2011, 2012 and 2013, on calcareous, gleyic chernozem. The soil was well-provided with total nitrogen and Zn, and rich in available phosphorus and potassium. The genotypes were harvested at crop maturity and all hulled genotypes were manually de-hulled. After digestion of grain whole meal in the mixture of 10 mL HNO_3 (63%) and 2 mL of H_2O_2 (30%), the concentration of total Zn was determined by inductive coupled plasma emission spectrometer. Statistical analyses were done in Infostat, version 2016. More details about the experimental procedures are available in the paper [5].

Results and discussion

Plants belonging to family *Gramineae*, to which wheat belongs, are about average with respect to the accumulation of Zn. In wheat, Zn accumulates more in the grain than in the straw [6]. In the grains and seeds mineral elements, including Zn, are located predominantly in the protein [7]. High concentrations of Zn in the protein bodies of wheat scutelum (600 µg g^{-1} DW) were found by [8]. Protein bodies are characterized by high content of phytine. Zn binds firmly to phytic acid, building in this way protein-Zn-phytic acid complex which is resistant to hydrolysis, which reduces bioavailability of Zn for monogastric animals and men. In the regions where molar ratio phytate: Zn in food high, the danger of insufficient intake of Zn is much higher [3]. The grain of the majority of small grains is characterized by medium levels of Zn. In additions, the high phytine content in them reduces the concentration of absorbable Zn. Nevertheless, wheat grain, due to its high abundance in the diet, globally represents important source of Zn for men and animals alike.

[9] states that average concentrations of Zn in wheat grains in different countries are similar and they are about 22-33 mg Zn kg^{-1} of dry matter. However, inside one country large differences are present. [10] found significant differences in the Zn concentration in the grains of different wheat cultivars, and those differences were much higher in *T. durum* than in *T. aestivum* cultivars.

Concentration of Zn in the grain depends also on many ecological factors. [11] found that precipitations and soil type significantly affect concentration of Zn in wheat grains. Higher doses of phosphorus fertilizers reduce availability of P for plants. [12] concluded that concentration of Zn in wheat grain declined with application of phosphorus fertilizers.

During the three years long experiment, in *Aegilops* and *Triticum* species concentration of Zn in the whole grain, depending on the genotype and a year, ranged between 14.8 and 36.7 mg kg^{-1} DW (Tab. 1). Significant differences in the concentration of Zn were found between different species (Tab. 1; Tab. 3) and genomes (Tab. 2; Tab.4). In average, during three years, the highest concentration of Zn was found in the genome BB and the lowest in BBAADD. Contemporary hexaploid genotypes are also characterized by significant variations of the concentration of Zn in the whole grains (Fig. 1 and Fig. 2).

In our previous study we found that the concentration of tin [13], barium [14] and strontium [5] was also significantly the highest in the grains of *Aegilops speltoides* which is characterized by several times lower mass of 1000 grains (5.40 g) than the other examined genotypes. Mineral substances in wheat grains are concentrated in the peripheral part of the grain. Hence, the concentration of mineral substances in whole grains depends on the ratio of peripheral part and endosperm. The smaller the grain, the higher is the mass of the peripheral portion in the total mass of grain, which may contribute to higher concentrations of minerals in the grain as a whole. According to [15], there is a weak correlation between the mass of 1000 grains, and the concentrations of microelements, except in cultivars which differ significantly in the mass of 1000 grains, which is in line with our results. Further research is needed with the aim to find out whether only the small size of the grain or some other genetic characteristic besides the size of the grain contribute to much higher accumulation of Zn in the grains of *Aegilops speltoides* with respect to the other examined *Aegilops* and *Triticum* species.

Table 1. Concentration of Zn in the whole grain of *Aegilops* and *Triticum* species (mg kg^{-1} DW)

No	Species and subspecies	Genome	Year 2011	Year 2012	Year 2013	Average
1	Aegilops speltoides subsp. speltoids 1	BB	45.8	23.9	40.5	36.7^{a}
2	Aegilops speltoides subsp. speltoids 2	BB	36.5	29.3	41.6	35.8^{ab}
3	Triticum urartu	AA	28.7	30.0	25.4	28.0^{e}
4	Triticum monococcum subsp. egilopoides	AA	37.7	27.4	37.3	34.1^{bc}
5	Triticum monococcum subsp. monococcum	AA	39.7	20.7	31.0	30.5^{d}
6	Aegilops tauschii subsp. tauschii	DD	47.1	16.0	23.9	29.0^{de}
7	Triticum turgidum subsp. dicoccoides (IPK)	BBAA	24.8	18.4	27.4	23.5^{f}
8	Triticum turgidum subsp. dicoccoides (IFVC)	BBAA	37.8	26.9	22.8	29.2^{de}
9	Triticum turgidum subsp. dicoccon	BBAA	24.0	14.9	20.6	19.8^{ghi}
10	Triticum turgidum subsp. turgidum	BBAA	32.3	30.2	36.3	32.9^{c}
11	Triticum turgidum subsp. durum (cv.Durumko)	BBAA	25.2	21.7	18.3	21.7^{fg}
12	Triticum aestivum subsp. spelta (cv. Nirvana)	BBAADD	20.7	18.0	23.3	20.7^{gh}
13	Triticum aestivum (cv. Panonnia)	BBAADD	14.0	15.8	16.2	15.3^{kl}
14	Triticum aestivum (cv. Bankut 1205)	BBAADD	17.4	21.3	21.8	20.2^{ghi}
15	Triticum aestivum (cv. Bezostaja 1)	BBAADD	15.0	17.0	19.5	17.^{1jk}
16	Triticum aestivum (cv. Siete Cerros)	BBAADD	11.5	17.9	18.3	15.9^{kl}
17	Triticum aestivum (cv. Florida)	BBAADD	13.2	14.2	17.3	14.9^{l}
18	Triticum aestivum (cv. Renan)	BBAADD	19.0	12.4	23.7	18.4^{ij}
19	Triticum aestivum (cv. Condor)	BBAADD	15.3	22.4	21.8	19.8^{ghi}
20	Triticum aestivum (cv. Bolal)	BBAADD	11.7	22.2	24.8	19.5^{hi}
	Average		25.9^{a}	21.0^{b}	25.6^{a}	

Different letters indicate significant difference at P < 0.05 level.

Table 2. Concentration of Zn in the whole grain of five genomes over 3 years (mg kg^{-1} DW)

Genome	Year 2011	Year 2012	Year 2013	Average
AA	35.3	26.0	31.2	30.86^{b}
BB	41.1	26.6	41.1	36.24^{a}
BBAA	28.8	22.4	25.1	25.43^{c}
DD	47.1	16.0	23.9	28.98^{b}
BBAADD	15.3	17.9	20.7	17.97^{d}

Table 3. Analysis of variance of Zn concentrations of *Aegilops* and *Trtiticum* species

Source of variation	SS	df	MS	F	p-value
Year	886.24	2	443.12	285.71	<0.0001
Genotype	8825.58	19	464.5	299.5	<0.0001
Genotype*Year	4024.91	38	105.92	68.29	<0.0001
Error	186.11	120	1.55		

Table 4. Analysis of variance of Zn concentrations in five genomes

Source of variation	SS	df	MS	F	p-value
Year	886.24	2	443.12	41.86	<0.0001
Genome	7223.54	4	1805.88	170.59	<0.0001
Year*Genome	2623.15	8	327.89	30.97	<0.0001
Genome/Genome>Genotype	1602.05	15	106.8	10.09	<0.0001
Error	1587.88	150	10.59		

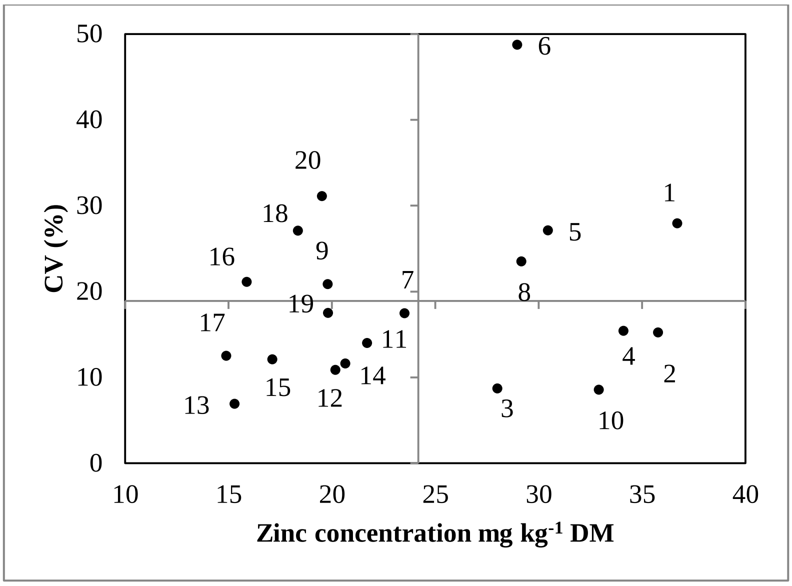

Figure 1. Coefficient of variation for zinc concentration in *Aegilops* and *Triticum* genotypes

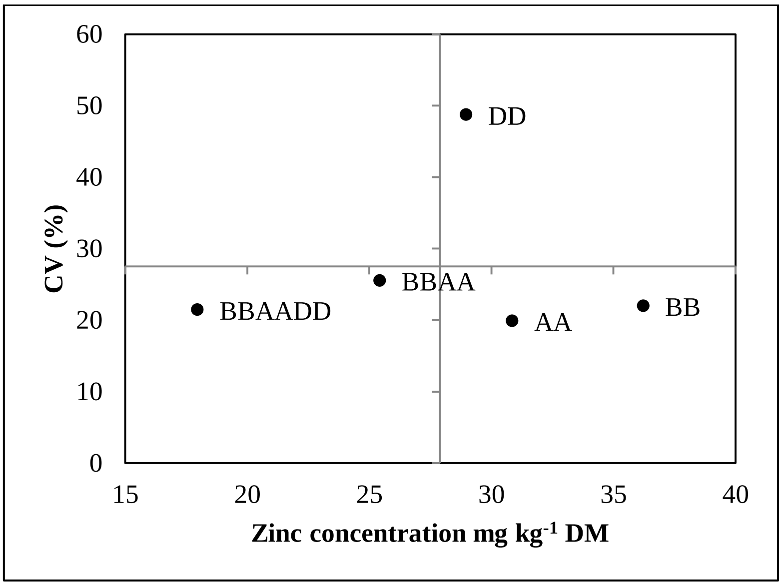

Figure 2. Coefficient of variation for zinc concentration in different genomes

Conclusion

Average concentration of Zn in the whole grains, in three-years period, ranged from 14.9 to 36.7 mg kg^{1} DW. Concentration of Zn differed significantly in different genomes (BB, AA, DD, BBAA, BBAADD). The highest concentration of Zn was found in wild diploid species *Aegilops speltoides*, which bares BB genome (36.24 mg kg^{-1} DW), and the lowest in hexaploid wheat, baring genome BBAADD (17.97 mg kg^{-1} DW). Concentration of Zn varied also between different experimental years. The results suggest that the grains of different *Triticum* and *Aegilops* genotypes, but also cultivars within them, due to differences in Zn concentrations, contribute to different levels to provision of humans and animals with Zn.

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