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EFFECT OF GENOTYPE AND FARMING SYSTEM ON CONCENTRATION OF MINERAL ELEMENTS IN ORGANICALLY AND CONVENTIONALLY GROWN CEREALS

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About half of the human population suffers from deficiency of mineral elements, mostly iron (Fe) and zinc (Zn). The purpose of the research was to compare the concentration of Fe and Zn in grain of 19 spring barley (in Hordeum vulgare *L.) genotypes and the concentration of Zn and manganese (Mn) in grain of 19 winter wheat (*Triticum aestivum *L.) genotypes grown in organic and conventional management systems during two growing seasons. The average concentration of Fe in barley ranged from 32.51–86.85 mg·kg^{-1} and was higher under conventional management (*$p < 0.001$*); the effect of genotype was significant (*$p = 0.014$*). The average concentration of Zn in barley ranged 16.79–48.51 mg·kg^{-1} and was significantly higher under the organic system (*$p < 0.001$*); in wheat it was 21.52–29.89 mg·kg^{-1} with no difference between the management systems; the effect of genotype was significant (*$p = 0.03$ *and* $p < 0.001$ *for barley and wheat, respectively). The average concentration of Mn in wheat ranged from 24.63–36.07 mg·kg^{-1} and was higher under the conventional system (*$p < 0.001$*); significant differences between genotypes were observed (*$p < 0.001$*). Barley and wheat genotypes with higher concentrations of the investigated elements were identified for use in breeding for improvement of grain quality. Zn concentration correlated negatively with grain yield and positively with grain protein concentration.*

Key words: *spring barley, winter wheat, iron, zinc, manganese.*

INTRODUCTION

The metals Mn, Fe, Cu, and Zn, and the non-metal Se are considered micronutrients or "trace elements" because of their very limited quantity needed by the human body. However, deficiency in any of these elements leads to undesirable pathological conditions. These metals are very essential for the enzymatic system regulating redox reactions. Mn is found in enzymes such as mitochondrial Mn superoxide dismutase, glutamine synthetase, and arginase, and it activates several hydrolases, transferases and carboxylases (Fraga, 2005). It is associated with bone development and with amino acid, lipid, and carbohydrate metabolism. Fe is found in Fe-heme proteins (e.g. hemoglobin, myoglobin, catalase, cytochromes); Fe-sulfur enzymes; proteins for Fe storage and transport, and other Fe-containing or Fe-activated proteins. Fe deficiency causes anemia (Fraga, 2005). Zn is involved in the activity of about 100 enzymes, e.g. RNA polymerase, carbonic anhydrase, Cu–Zn superoxide dismutase, and angiotensin I converting enzyme. Zn was found to support normal growth and development in pregnancy, childhood, and adolescence (Gibson, 2012). Zn deficiency is mainly associated with malnutrition, affecting the immune system, wound healing, the senses of taste and smell, and impairs DNA synthesis (Gibson, 2012).

The total concentration of mineral elements or ash in barley (*Hordeum vulgare* L.) ranges from 2 to 3% and in wheat (*Triticum aestivum* L.) from 1.2 to 3% (Obert *et al.,* 2004). This variation can be caused by genotype and environment (soil properties including pH, fertilizer application, meteorological etc. conditions). Nutritionally important microelements Fe, Zn and Mn are found in barley grain in relatively larger concentrations. The greatest part of mineral elements is found in outer layers of the grain, particularly in the embryo and aleurone layer (Akman and Kara, 2003; Newman and Newman, 2008; Gubatz and Shewry, 2011). Barley was found to have the highest levels of phosphorus, potassium, Zn, and the second highest content of Fe, following millet among soft and hard wheat, rye, maize, rice, oat, sorghum and millet (Villacres and Rivadeneira, 2005; Ragaee *et al.,* 2006). Great variability in trace elements was found in different wheat species and genotypes (Balint *et al.,* 2001).

According to data of several investigations, Fe concentration in cultivated barley grain ranges from 36–85 mg·kg^{-1} (Newman and Newman, 2008). Other source reports 94 mg·kg^{-1} Fe in covered barley, 72 mg·kg^{-1} in hulless barley and only 26 mg·kg^{-1} in pearled barley grain (Villacres and Rivadeneira, 2005). Ragaee *et al.* (2006) found 128 mg·kg^{-1} Fe in whole grain barley flour. In barley varieties originating from China, Fe concentration up to140 mg·kg^{-1} was shown and high variation of Fe concentration (11–329 mg·kg^{-1}) in wild barley populations from Israel (Yan *et al.,* 2012). Fe concentration in cultivated wheat ranges from 16–163 mg·kg^{-1} (Piironen *et al.,* 2009). Balint *et al*. (2001) found that the highest Fe concentration is in the tetraploid wheat; einkorn had higher Fe and Zn concentration than other wheat types, but the European winter and spring wheat were quite similar in trace element composition.

Concentration of Zn in covered barley grain in several sources was reported in the range 19–35 mg·kg^{-1} (Newman and Newman, 2008); Villacres and Rivadeneira (2005) recorded concentrations of 49 mg·kg^{-1} Zn in covered barley, 52 mg·kg^{-1} in hulless barley and 30 mg kg^{-1} in pearled barley and Ragaee *et al.* (2006) 74 mg·kg^{-1} Zn in whole grain barley flour. Yan *et al.* (2012) reported up to 99 mg·kg^{-1} Zn in Chinese barley varieties and a range of 66–493 mg·kg^{-1} in wild barley *Hordeum spontaneum*. Zn concentration in wheat ranges from 15–102 mg·kg^{-1} (Piironen *et al.,* 2009). Velu *et al.* (2012) reported 29–40 mg·kg^{-1} Zn in spring wheat; compared to 36–46 mg·kg^{-1} in various wheat types and species (Hussain *et al.,* 2010) and 23–43 mg·kg^{-1} in organically grown modern and historical spring wheat varieties (Murphy *et al.,* 2008).

Mn concentration in barley was reported in the range 9–24 mg·kg^{-1} (Villacres and Rivadeneira, 2005; Ragaee *et al.,* 2006; Newman and Newman, 2008). In wheat Mn concentration ranges from 10–90 mg·kg^{-1} (Piironen *et al.,* 2009); in organically grown modern and historical spring wheat varieties 39–62 mg·kg^{-1} of Mn was found (Murphy *et al.,* 2008).

Significant effect of genotype on concentration of mineral elements in cereals was reported in several investigations (Murphy *et al.,* 2008; Gao *et al.,* 2011; Velu *et al.,* 2012), however, a limited amount of genetic investigations have been conducted in regard to mineral element concentration, with the exception of P (Newman and Newman, 2008). A bacterial artificial chromosome (BAC) library has been constructed for cloning barley genes for high grain Zn concentration (Shi *et al.,* 2010). It was concluded by Martinez-Ballesta *et al.* (2010) that more precise studies are needed to improve the concentrations of essential microelements in plant foods.

Significantly higher concentrations of mineral nutrients were found in historical cultivars in comparison to the modern ones (Murphy *et al.,* 2008); this effect was explained mainly not by the dilution effect due to yield increase but by selection for low ash concentration in soft white wheat (*Triticum aestivum* L.) over time in order to ensure lighter color of white bread. This explanation is supported by lack of a negative correlation between concentration of some minerals (Fe and Zn) and grain yield, despite 11 and 25% reduction of Fe and Zn in modern cultivars, respectively. Also Kirchman *et al.* (2005) reported that the concentration of Fe, Mn, Zn and Cu had decreased significantly in wheat during a 30–40 year period; and mentioned decreased soil pH and amount of soluble nutrients as one of the possible reasons. A similar conclusion was raised by Hussain *et al.* (2010) who showed that spring wheat has higher Fe and Zn concentration than winter wheat, but for Mn no difference between both wheat types was found.

Significant effect of genotype × environment interaction on Fe and Zn concentration in wheat was described by Velu *et al.* (2012); soil type was shown to influence the concentration of mineral elements in grain (Gao *et al.,* 2011; Yan *et al.,* 2012).

Since the end of the last century, the market for organic products has grown. Organic farming is continuously becoming a widespread form of agriculture, and organic products are increasingly being requested by consumers. Many studies consistently report a lack of significant differences between organically and conventionally grown food in terms of safety and nutritional value, suggesting that crops and livestock products produced in both farming systems are comparable with regard to their nutrient concentration. Nevertheless, the results obtained are contradictory: some authors report no significant differences, yet many studies have shown different amounts of nutritionally important and health-promoting compounds in crops grown under organic and conventional management (Woese *et al.,* 1997; Worthington, 2001; Bourn and Prescott, 2002; Magkos *et al.,* 2003). Benbrook (2005) estimated that the concentration of biologically active compounds is, on average, 30% higher in organically grown plants in comparison to those grown conventionally.

In a review, Huber *et al.* (2011) found that the data on mineral concentration in organically and conventionally grown products were inconclusive. In a long-term study higher phosphorus concentration was found in organically produced horticultural crops than in conventionally produced ones (Herencia *et al.,* 2011). One of the major points of another review (Lairon, 2010) was that organic products generally contain more minerals than conventional products; for cereals two studies showed no effect of cropping system on mineral composition and a study with barley indicated a trend for higher levels of Ca, Cu and Zn in organically grown grain. Rembialkowska (2007) estimated that organic crops overall contain 21% more Fe and 29% more Mg than their conventional counterparts. Hussain *et al.* (2010) found higher levels of several minerals in organically grown wheat genotypes of various species and types as compared to other studies carried out in conventional systems. They claim that whole grain wheat flour from organic production can provide more than 70% of the daily intake of mineral elements, including Fe, Zn, Mn and others, and that the nutritional value can be further improved by using specific primitive wheat genotypes in breeding and performing selection under organic conditions.

The aim of this study was to compare the concentration of several mineral elements in organically and conventionally grown spring barley and winter wheat genotypes, and to estimate the effect of genotype, production system and their interaction.

MATERIALS AND METHODS

The field experiment was conducted during 2010 and 2011 in 5.0–6.5 m^2 plots with three replications and a random plot layout under organic and conventional management. The trials were arranged on sod-podzolic loamy sand (Latvian Soil Classification System, Kārkliņš, 2008); the soil properties are summarised in Table 1.

Spring barley. A total of 19 spring barley varieties and breeding lines differing in their plant morphological characteristics, origin and year of registration (Table 2) were grown in field trials at the State Priekuļi Plant Breeding Institute, hereafter Priekuļi (lat. 57°19′N, long. 25°20′E). In the conventional field, the precrop was potato. Mineral fertiliser at 80–83 $kg \cdot ha^{-1}$ N, 19.6–20.9 $kg \cdot ha^{-1}$ P_2O_5 and 62.3–69.7 $kg \cdot ha^{-1}$ K_2O and the herbicide Secator OD (100 $g \cdot L^{-1}$ amidosulfuron and 25 $g \cdot L^{-1}$ iodosulfuran) at 0.15 $L \cdot ha^{-1}$ and insecticide Karate Zeon 5 m.s. (50 $g \cdot L^{-1}$ lambda-cyhalothrin) at 0.15 $L \cdot ha^{-1}$ were applied. In the organic field, which was certified for organic farming, the precrop was pea for green manure; weed reduction was performed by harrowing at the beginning of the tillering stage.

The meteorological conditions were, in general, favourable for barley development in both years. The mean air temperature during the vegetation period surpassed the long-term average by 2.6 and 2.4 °C in 2010 and 2011, respectively, resulting in comparatively early maturity. In 2010, the amount of rainfall was 143% of the long-term average, which promoted lodging in the conventional field, whereas the precipitation was close to the average (93%) in 2011.

In 2010, in the conventional field, an unusually high infection level of Barley Yellow Dwarf Virus (BYDV) was ob-

Table 1

SOIL AGROCHEMICAL PROPERTIES IN BARLEY AND WHEAT ORGANIC (ORG) AND CONVENTIONAL (CONV) TESTING SITES DURING 2010–2011

Soil characteristics	Barley				Wheat			
	2010		2011		2010		2011	
	org	conv	org	conv	org	conv	org	conv
pH KCL	5.7	5.5	5.4	5.4	6.9	6.0	6.8	6.0
Humus content, %	2.8	2.6	2.1	3.0	2.9	2.4	3.0	2.6
K_2O, $mg \cdot kg^{-1}$	144	132	98	165	114	116	119	125
P_2O_5, $mg \cdot kg^{-1}$	111	100	116	187	167	200	156	189

Table 2

BARLEY AND WHEAT GENOTYPES INCLUDED IN THE STUDY

Genotype	Country of origin	Pedigree	Registration year and other information
Spring barley			
Idumeja	Latvia	Imula/Ida	2000, early maturity
Rubiola	Latvia	Rūja/Run8/458	2011, recommended for OF
Abava	Latvia	Mari/Elsa//Domen	1978
Rasa	Latvia	Frankengold/KM-R-54/72	1996
Vienna	Austria	n.a.	2007, registered for OF
Annabell	Germany	90014-DH/Krona	1999
Inari	Finland	JO-1263/Triumph	1994
PR-4814	Latvia	Danuta/L-3008//Rubiola	Breeding line selected under OF
PR-3605	Latvia	Rūja/Prestige/3/L-2233// Linus/Annabell	Breeding line
PR-4812	Latvia	Rubiola/L-3118	Breeding line selected under OF
PR-4407	Latvia	Roxane/Danuta//Idumeja	Breeding line
PR-4181	Latvia	Hydrogen/H-155	Breeding line
PR-4121	Latvia	Tunika/L-3118	Breeding line
Primus	Sweden	n.a.	Grown since 1901
Anni	Estonia	Lola/Lisa	1991
Dziugiai	Lithuania	n.a.	Grown since 1947
BZ14-12	Latvia	Anni/Dziugiai	Breeding line selected under OF
BZ14-99	Latvia	Anni/Dziugiai	Breeding line selected under OF
Irbe	Latvia	Filippa/CDC McGwire// Kristaps	2011, hulless barley
Winter wheat			
Olivin	UK	n.a.	2005
Edvins	Latvia	WHQ91058/OR908173	Under registration, early maturity
99-115	Latvia	Falke/Nadežnaja45/ Mir.808	Breeding line
96-58	Latvia	Veselanka/Nadzeja	Breeding line
Krista	Latvia	Mir. 808/Jubileinaja 50/Mir. 808	Recommended for OF
00-75	Latvia	Kolektivnaja/Nr.70/ Anatanka	Breeding line perspective for OF
Ada	Lithuania	Širvinta 1/Lut.290	2005
Fredis	Latvia	Donskaja polukarļikovaja/ Abe/Lowrin24	2009, early maturity
Bussard	Germany	n.a.	2001
00-154	Latvia	Veneda/Rothwell Perdix/Kaukazs	Perspective for OF
98-83	Latvia	Verbens/Kato/Raive	Breeding line
Skalmeje	Germany	n.a.	2006
Skagen	Denmark	n.a.	2011
00-93	Latvia	Krasnokolosaja/Banga	Breeding line
Leiffer	Germany	n.a.	2005
Zentos	Germany	n.a.	2001
SW Maxi	Germany	n.a.	2004
94-5	Latvia	Donskaja polukarļikovaja/ Movir10mut.1	Breeding line perspective for OF
00-182	Latvia	Banga/Bruta	Breeding line perspective for OF

n.a., not available
OF, organic farming

served (average score of 5.7, range of 2.3–8.3; scale from 0 to 9).

Winter wheat. Nineteen various genotypes (Table 1) were grown in field trials under organic and conventional management at the State Stende Cereal Breeding Institute, hereafter Stende (lat. 57°10′N, long. 22°33′E).

In conventional field mineral fertiliser at 140–150 kg·ha^{-1} N, 45–50 kg·ha^{-1} P_2O_5 and 90–95 kg·ha^{-1} K_2O and herbicide Tombo (50 g·kg^{-1} pirosulam, 25 g·kg^{-1} florasulam, and 50 g·kg^{-1} amonopiralid) at 0.18 kg·ha^{-1} were used. The organic field was managed according to organic standards. In both years the precrop was white mustard as a green manure in the conventional field and red clover in the organic field.

The meteorological conditions were not favourable for winter wheat overwintering during the autumn/winter period in both years. High infection of snow mould influenced negatively the winter wheat grain yield level. During the growing season the air temperature and soil moisture content were sufficient for wheat development.

For both cereals the grain yield was assessed by the direct method and recalculated to a 14% moisture content; the volumetric weight and content of crude protein, starch and β-glucans in the dry matter were determined using a Near-Infrared Transmittance grain analyser, Infratec 1241 (Foss, Hillerød, Denmark).

Measurement of mineral element concentration**.** The concentrations of iron (Fe), zinc (Zn) and manganese (Mn) were determined in the grain samples by atomic absorption method (LVS EN ISO6869:2002) and recalculated in dry matter.

Data analysis. A two-factor ANOVA with replications (year assumed as replication) and without replications was used for the statistical analysis. The phenotypic correlation coefficients were calculated between the values of mineral elements in both management systems and between mineral element content and several plant traits (i.e., grain yield, thousand grain weight, grain volume weight, crude protein, starch and β-glucan concentration in grain).

The broad-sense heritability was estimated from the variance components using the following formula:

$$h^2=100\times V_g/(V_g+V_{gs}/s+V_e/sr)$$

where V_g is the genotypic variance; V_{gs} is the variance of genotype × management system interaction; V_e is the error variance; r is the number of replications; and s is the number of management systems. The broad-sense heritability was estimated from the variance components using the following formula adapted from Holland *et al.* (2003).

RESULTS

Fe in spring barley. Fe concentration in barley samples ranged from 32.51 to 86.85 mg·kg^{-1} (Table 3). The effect of genotype on Fe concentration was significant in several cases (Table 4). The average Fe concentration over all envi-

Table 3

FE CONTENT IN GRAIN DRY MATTER OF SOME SPRING BARLEY GENOTYPES, mg·kg^{-1}, Priekuļi, 2010–2011

Genotype	Organic			Conventional			Overall average
	2010	2011	average	2010	2011	average	
Idumeja	54.87	55.88	55.38	54.73	76.78	65.76	60.57
Rubiola	68.53	67.56	68.05 (+)	57.03	81.72	69.38	68.71 (+)
Abava	54.80	53.23	54.02	47.78	76.04	61.91	57.96
Rasa	49.04	55.26	52.15	52.78	69.80	61.29	56.72
Vienna	55.70	56.62	56.16	52.70	73.34	63.02	59.59
Annabell	43.79	49.80	46.79	46.89	57.61	52.25	49.52
Primus	47.48	57.70	52.59	62.01	65.33	63.67	58.13
Anni	50.45	50.89	50.67	44.79	62.86	53.83	52.25
Dziugiai	46.59	54.82	50.70[b]	86.85	67.09	76.97[a]	63.84
Irbe	37.74	53.51	45.62	32.51	65.30	48.91	47.27
Average	*50.67*	*54.45*	*52.56[b]*	*54.50*	*66.62*	*60.56[a]*	*56.56*
min	*37.74*	*48.92*	*45.62*	*32.51*	*57.61*	*48.91*	*47.27*
max	*68.53*	*67.56*	*68.05*	*86.85*	*81.72*	*76.97*	*68.71*
$LSD_{0.05}$	-	-	8.53	-	-	n.s.	9.63*

a,b, mean values in respective row marked with different letter significantly different ($p < 0.05$) between management systems

(+), - mean values significantly above the average value of all genotypes in the respective column ($P < 0.05$)

* From two-factor ANOVA without replications; n.s. – differences not significant

Table 4

PARTITIONING OF SUM OF SQUARES AND SIGNIFICANCE OF FACTORS AFFECTING FE CONTENT IN BARLEY GRAIN

Data source	Partitioning of sum of squares, %				*p*-value			
	Genotype (G)	Management (M)	Year	G×M	Genotype	Management	Year	G×M
2 factor ANOVA with replications (year = replication)								
All data	25.8	17.2	-	10.7	n.s.	0.0006	-	n.s.
2 factor ANOVA without replications								
All data	25.8	38.9	-	-	0.014	<0.0001		-
Organic management	66.1	-	10.7	-	0.016	-	0.01	-
Conventional management	38.0	-	30.5	-	n.s.	-	0.0006	-
2010	53.9	4.2	-	-	n.s.	n.s.	-	-
2011	34.7	55.6	-	-	0.005	<0.0001	-	-

ronments significantly surpassed the average value for variety 'Rubiola'. This variety was the only one with a significantly higher Fe concentration than the average value of all tested genotypes under organic management and also in the year 2011. Relatively lower Fe concentration was found for 'Irbe' and 'Annabell', however, none of the genotypes had Fe concentration significantly below the average value.

The effect of environment (management system, year or combination of both) was found to be significant in all cases, with the exception of the year 2010 (Table 4). The average Fe of all genotypes was significantly higher under the conventional management system, compared to the organic one. However, when the data of individual genotypes is compared, the difference between management systems was significant only for 'Dziugiai', which reached the highest Fe concentration in the experiment in 2010. Significantly higher average Fe concentration was found in 2011 than in 2010 under both management systems.

Fe concentration correlated positively between organic environments in both years ($p = 0.05$) and between both managements in 2011 ($p = 0.01$); in other cases there was a positive trend. Broad sense heritability of Fe concentration in barley was 58%.

No consistent significant correlation between Fe concentration and grain yield and its quality parameters was found. Fe correlated positively with grain yield only in 2011 under the conventional management system ($p = 0.05$) and negatively with starch content in 2010 under conventional management ($p = 0.01$).

Zn in spring barley. Concentration of Zn in dry matter of barley samples was found in the range from 16.79 to 48.51 $mg \cdot kg^{-1}$ (Table 5). The effect of genotype on Zn content was significant only in the case when data of the four environments was processed in two-factor ANOVA without replications (Table 6). Average Zn concentration was significantly above the average of genotypes for breeding line PR-4121; it had the highest mean values under both management systems. None of the genotypes had average Zn significantly below the overall average; the lowest value was found for 'Annabell'.

Management system, conditions of growing year and combination of both influenced Zn content in barley grain significantly in all cases. Mean Zn content under organic management was significantly higher than that under the conventional system; the difference was significant for all genotypes except two that had relatively low Zn level. Simi-

Table 5

ZN CONTENT IN GRAIN DRY MATTER OF SPRING BARLEY GENOTYPES, $mg \cdot kg^{-1}$, Priekuļi, 2010–2011

Genotype	Organic			Conventional			Overall average
	2010	2011	average	2010	2011	average	
Idumeja	26.95	29.11	28.03^{a}	20.08	19.22	19.65^{b}	23.84
Rubiola	34.57	32.27	33.42^{a}	20.71	18.72	19.71^{b}	26.57
Abava	28.99	29.82	29.40^{a}	18.37	18.01	18.19^{b}	23.79
Rasa	27.98	32.03	30.00^{a}	21.05	19.40	20.23^{b}	25.12
Vienna	28.28	31.79	30.03^{a}	19.34	20.20	19.77^{b}	24.90
Annabell	24.56	29.25	26.91^{a}	17.73	20.38	19.05^{b}	22.98
Inari	28.05	31.42	29.73^{a}	16.99	21.12	19.06^{b}	24.39
PR-4814	31.05	31.13	31.09^{a}	17.15	23.42	20.29^{b}	25.69
PR-3605	31.18	32.92	32.05^{a}	17.93	23.67	20.80^{b}	26.42
PR-4812	35.45	33.84	34.65^{a}	20.26	22.52	21.39^{b}	28.02
PR-4407	25.20	25.50	25.35	21.60	22.43	22.02	23.69
PR-4181	26.03	38.48	32.26^{a}	18.06	16.79	17.42^{b}	24.84
PR-4121	31.06	48.51	39.79^{a}	22.37	26.51	24.44^{b}	32.11 (+)
Primus	32.86	41.02	36.94^{a}	23.97	23.88	23.93^{b}	30.43
Anni	31.88	32.60	32.24^{a}	19.77	24.33	22.05^{b}	27.14
Dziugiai	32.00	27.68	29.84^{a}	19.25	21.94	20.59^{b}	25.22
BZ14-12	31.05	36.93	33.99^{a}	17.88	25.12	21.50^{b}	27.75
BZ14-99	29.88	35.92	32.90^{a}	22.27	24.92	23.60^{b}	28.25
Irbe	29.33	21.44	25.38	19.22	29.14	24.18	24.78
Average	*29.81*	***32.72***	*31.26^{a}*	*19.68*	*22.20*	*20.94^{b}*	26.10
min	*24.56*	*21.44*	*25.35*	*16.99*	*16.79*	*17.42*	*22.98*
max	*35.45*	*48.51*	*39.79*	*23.97*	*29.14*	*24.44*	*32.11*
$LSD_{0.05}$			n.s.			n.s.	4.80*

a,b. mean values in respective row marked with different letter significantly different ($p < 0.05$) between management systems

(+), - mean values significantly above the average value of all genotypes in the respective column ($p < 0.05$)

Table 6

PARTITIONING OF SUM OF SQUARES AND SIGNIFICANCE OF FACTORS AFFECTING ZN CONTENT IN BARLEY GRAIN

Data source	Partitioning of sum of squares, %				*p*-value			
	Genotype (G)	Management (M)	Year	G×M	Genotype	Management	Year	G×M
2 factor ANOVA with replications (year = replication)								
All data	12.9	63.4	-	7.0	n.s.	<0.0001	-	n.s.
2 factor ANOVA without replications								
All data	12.9	67.7	-	-	0.03	<0.0001		-
Organic management	56.3	-	9.3	-	n.s.	-	0.04	-
Conventional management	48.5	-	19.6	-	n.s.	-	0.004	-
2010	11.7	81	-	-	n.s.	<0.0001	-	-
2011			-	-	n.s.	<0.0001	-	-

* environment (management and year combination)

larly to Fe also Zn content was significantly higher in 2011 in comparison to 2010 under both management systems.

There was a positive trend of correlation of Zn between the environments; however, none of the relationships were significant. Broad sense heritability for barley Zn content was 46%.

Zn content was correlated significantly (negatively) with grain yield under the conventional management in 2010 (p = 0.05), a negative trend was found also in the same management in 2011, while under organic management the trend was positive in both years. Zn concentration correlated positively with grain protein content (relationship significant in 2010 under both managements, p = 0.05), grain volume weight (significantly under organic management in 2010, p = 0.01), with TGW under organic management (significantly in 2011, p = 0.05), and negatively with grain starch content (significantly in 2010 under organic management, pP = 0.05).

No significant correlations between Zn and Fe contents in the respective environments were found, still the trends were contradictory.

Zn in winter wheat. Zn concentration in samples of wheat genotypes was found in the range 19.01–35.16 mg·kg^{-1} (Table 7). The effect of genotype on Zn concentration was significant, with the exception when data of the conventional management system was processed separately (Table 8). The overall average value significantly surpassed that of all genotypes for line 00-182; this line had Zn significantly above the average under organic management and in the year 2010 under both systems. Variety 'Fredis' had higher Zn concentration than average under organic management, and genotypes 00-75 and 'Leiffer' in 2010 and 2011, respectively. Zn concentration significantly below the overall average was found for variety 'Skagen'; line 99-115 had significantly lower value under organic management and in 2011.

No significant effect of management system on Zn content in wheat grain was found; the effect of year was significant for organic management, with a higher level in 2010.

Wheat Zn concentration correlated significantly positively between the environments in four out of six cases (p = 0.01) and broad sense heritability was 86%.

Wheat grain Zn concentration correlated negatively with grain yield under conventional management in 2010 (p = 0.01) and a negative trend was obtained in other environments as well. Positive relationship between Zn concentration and crude protein in grain was found (correlations significant under conventional management, p = 0.01).

Mn in winter wheat. The range of Mn concentration found in wheat samples was 14.60–44.09 mg·kg^{-1} (Table 9). Genotype had significant effect in 2-factor ANOVA without replications in all data combinations (Table 10). Overall

Table 7

ZN CONTENT IN GRAIN DRY MATTER OF SOME WINTER WHEAT GENOTYPES, mg·kg^{-1}, Stende, 2010–2011

Genotype	Organic			Conventional			Overall average
	2010	2011	average	2010	2011	average	
Olivin	25.36	28.62	26.99	27.45	27.78	27.62	27.30
Edvins	27.25	23.74	25.50	25.08	21.62	23.35	24.43
99-115	22.86	21.12	21.99 (-)	23.49	21.74	22.62	22.30
Krista	29.28	25.79	27.53	26.17	24.11	25.14	26.34
Ada	26.63	23.48	25.05	22.32	24.40	23.36	24.20
Fredis	32.76	27.29	30.03 (+)	27.69	26.93	27.31	28.67
Bussard	28.35	25.06	26.71	26.54	26.98	26.76	26.73
Skalmeje	22.14	23.55	22.84	19.81	26.10	22.96	22.90
Skagen	23.92	21.90	22.91	19.01	21.27	20.14	21.52 (-)
Leiffer	26.42	26.25	26.34	21.87	31.46	26.67	26.50
Zentos	24.55	23.00	23.78	22.64	26.85	24.75	24.26
SW Maxi	24.44	23.02	23.73	20.68	27.61	24.15	23.94
00-182	30.01	28.34	29.17 (+)	33.37	27.84	30.60	29.89 (+)
Average	*26.54*	*24.71*	*25.63*	*25.96*	*25.48*	*25.72*	*25.67*
min	*22.14*	*21.12*	*21.99*	*19.01*	*21.27*	*20.14*	*21.52*
max	*32.76*	*28.62*	*30.03*	*35.16*	*31.46*	*30.60*	*29.89*
$LSD_{0.05}$	-	-	3.12	-	-	n.s.	3.91*

(+), (-), mean values significantly above or below the average value of all genotypes in the respective column (p < 0.05)

*From two-factor ANOVA with replications; n.s. – differences not significant

Table 8

PARTITIONING OF SUM OF SQUARES AND SIGNIFICANCE OF FACTORS AFFECTING ZN CONTENT IN WHEAT GRAIN

Data source	Partitioning of sum of squares, %				*p*-value			
	Genotype (G)	Management (M)	Year	G×M	Genotype	Management	Year	G×M
2-factor ANOVA with replications (year = replication)								
All data	53.3	0.0	-	7.2	0.003	n.s.	-	n.s.
2-factor ANOVA without replications								
All data	53.3	4.8	-	-	<0.0001	n.s.		-
Organic management	70.3	-	13.2	-	0.002	-	0.001	-
Conventional management	55.5	-	0.5	-	n.s.	-	n.s.	-
2010	77.4	1	-	-	0.006	n.s.	-	-
2011	75.1	3.4	-	-	0.007	n.s.	-	-

Table 9

MN CONTENT IN GRAIN DRY MATTER OF SOME WINTER WHEAT GENOTYPES, mg·kg^{-1}, Stende, 2010–2011

Genotype	Organic			Conventional			Overall average
	2010	2011	average	2010	2011	average	
Olivin	29.21	26.55	27.88	31.74	30.58	31.16	29.52
Edvins	32.18	31.45	31.81	43.29	37.35	40.32	36.07 (+)
Krista	26.06	19.30	22.68^b	35.49	37.69	36.59^a	29.63
00-75	36.06	32.71	34.39 (+)	38.46	35.90	37.18	35.78 (+)
Ada	23.88	14.60	19.24^b (-)	33.93	26.31	30.12^a	24.68 (-)
Fredis	31.44	22.07	26.75^b	44.09	36.14	40.12^a	33.43
Bussard	27.36	19.57	23.47	38.08	27.15	32.61	28.04
Skalmeje	28.09	24.82	26.46	32.02	25.98	29.00	27.73
Skagen	31.74	28.23	29.98	36.21	34.10	35.16	32.57
Leiffer	35.66	18.29	26.98	38.41	27.20	32.80	29.89
Zentos	28.57	16.89	22.73	34.53	18.55	26.54 (-)	24.63(-)
SW Maxi	29.66	24.46	27.06	36.16	24.30	30.23	28.65
Average	*30.19*	*24.78*	*27.49^b*	*37.00*	*31.28*	*34.14^a*	*30.81*
min	*23.88*	*14.60*	*19.24*	*31.13*	*18.55*	*26.54*	*24.63*
max	*36.06*	*32.71*	*34.39*	*44.09*	*37.69*	*40.32*	*36.07*
LSD $_{0.05}$	-	-	6.22	-	-	6.87	4.63

a, b, mean values in respective row marked with different letter significantly different ($p < 0.05$) between management systems

(+), (-), - mean values significantly above or below the average value of all genotypes in the respective column ($p < 0.05$)

*From two-factor ANOVA without replications

mean values significantly surpassed the average for 'Edvins' and 00-75; the latter was superior also under organic management. Mean Mn concentration below average level was found for varieties 'Zentos' and 'Ada'.

Management system, year and combination of both affected Mn concentration in wheat significantly; higher average values were obtained under conventional management and in 2010. Among genotypes, differences between management systems were significant for only three of them ('Krista', 'Ada' and 'Fredis').

Mn concentration correlated positively between the environments (relationship significant in four out of six cases, $p = 0.05$); broad sense heritability was estimated at 70%.

No significant correlations between grain Mn concentration and yield were observed; no consistent correlations between Mn concentration and grain quality parameters including Zn concentration were found.

DISCUSSION

In recent years, there has been a growing interest in bioactive substances as components of our diet, which is related to their beneficial effects on human health. In several epidemiological studies, cereals were found to be the food group that contributed most to the intake of Fe, Mn and Zn (Rubio *et al.,* 2009; Winiarska-Mieczan and Kwiecień, 2011; Nishimuta *et al.,* 2012). For healthy individuals, the recommended dietary allowance (RDA) for Fe depends on age and gender, e.g. 8–11 mg per day for males and 10–15 mg per day for females. Doses larger than 20 mg may cause stomach upset, constipation and blackened stools. RDA for Zn is 12–15 mg per day. Doses larger than 25 mg may cause anaemia and copper deficiency. RDA for Mn is found to be 5 mg per day. Excess Mn may hinder Fe adsorption (Welch and Graham, 2004; Anonymous).

Hussain *et al.* (2010) reported that mean concentration of minerals from organically grown wheat grain flour provided more than 70% of the recommended daily intake for adults assuming 200 g wheat flour consumption per person (76, 78 and 90% for Fe, Zn and Mn, respectively). The average Fe concentration found by us in barley recalculated to a product would ensure 67–101% and the maximum concentration 120–180% of the RDA, if the consumption was 200 g per day. A similar calculation for average Zn concentration, which was very close for barley and wheat, resulted in 31–39% of RDA and the maximum Zn concentration found in barley would provide up to 71% of the necessary amount. The average Mn concentration found in wheat corresponds to 110 % and the maximum concentration is 157% of RDA. However, phosphorus and other minerals in cereal grain including Fe, Zn and Mn are present in the form of phytates; metals bound to phytic acid are unavailable or less available for monogastric animals and humans (Gubatz and Shewry, 2011). Therefore, not all of the mineral amount can be used by the human body and we cannot determine if the amount of investigated minerals in wheat and barley corresponds to

Table 10

PARTITIONING OF SUM OF SQUARES AND SIGNIFICANCE OF FACTORS AFFECTING MN CONTENT IN WHEAT GRAIN

Data source	Partitioning of sum of squares, %				*p*-value			
	Genotype (G)	Management (M)	Year	G×M	Genotype	Management	Year	G×M
2 factor ANOVA with replications (year = replication)								
All data	27.5	30.39	-	8.19	n.s.	.0001	-	n.s.
2 factor ANOVA without replications								
All data	27.5	51.7	-	-	<0.0001	<0.0001		-
Organic management	51.7		30.8	-	0.01	-	<0.0001	-
Conventional management	50.8	-	30.4	-	0.02	-	<0.0001	-
2010	33.2	54.7	-	-	0.02	<0.0001		-
2011	56.3	29.8	-	-	0.003	<0.0001	-	-

the dietary requirements. Still, cereals are not the only food ingredients providing essential minerals; vegetables, meat and other foodstuffs are rich with them as well.

Undoubtedly, cereal dietary value is not limited by the mineral content. Intake of protective substances (arabinoxylans, β-glucans, alkylresorcinols, tocols and phytosterols) contained in whole grains and their fractions contribute to a decreased risk of food-dependent diseases like coronary heart disease and insulin-dependent diabetes. Based on the current knowledge, it can be concluded that increasing the amount of whole grain products, including those from wheat and barley, in our diet can prevent the development of diet-dependent diseases (Bartłomiej *et al.,* 2012).

Fe and Zn concentrations found in barley were close to those reported by other authors (Newman and Newman, 2008) and the upper values can be considered as relatively high. For wheat the range of Zn and Mn was fairly low, compared to that reported in literature (Piironen *et al.,* 2009).

The highest mean contents of mineral elements were found in newly registered varieties and perspective breeding lines (barley 'Rubiola' and PR-4121, wheat 'Edvins', 00-75 and 00-182), which does not agree with the finding of Murphy *et al.* (2008) that the content of mineral elements has decreased over time due to breeding; however, historical barley varieties 'Dziugiai' and 'Primus' were the second richest with Fe and Zn, respectively, and comparatively low levels of both elements were observed in intensive barley 'Annabell' and low Zn and Mn was in relatively modern and intensive wheat varieties ('Skagen', 'Ada', 'Zentos'). Still, content of ash might be not so much influenced by selection in barley than in wheat, as it is not used in white bread production. The genotypes we identified to be superior for concentration of mineral elements can be used in breeding for improvement of nutritional quality. In barley, improvement of Fe concentration seems to be more feasible because of higher heritability, correlation between environments, and significance of genotype effect in more cases, when compared to Zn concentration in grain. In wheat, breeding for both investigated elements can be feasible. A potential to select for high Zn and Fe concentration in wheat was reported by Velu *et al.* (2012). To improve the bioavailability of mineral elements for humans and animals it can be useful to breed for low phytate content at the same time (Gubatz and Shewry, 2011). The broad sense heritabilities for concentration of mineral elements found by us were in the range from 46% for Zn in barley up to 86% for Zn in wheat. Similar results were obtained for Zn (h^2 = 78%) and Fe (h^2 = 88%) in spring wheat (Velu *et al.,* 2012).

The effect of management system on the content of mineral elements was significant, with the exception of Zn for wheat; however, the trends were different: higher Fe and Mn concentrations were found under the conventional system but Zn in barley was on average by 49% higher under the organic system and no difference was observed for wheat. Our findings partially agree with those of Ryan *et al.* (2004), who reported higher Zn concentration under organic management, higher Mn under conventional and only minor variation in Fe between both systems. In contrast, Mikulioniene and Balezentiene (2009) reported significantly lower Zn concentration in organic versus conventional management system in wheat and rye, however, only one variety per species was investigated. We found lower Mn concentration in organically grown wheat on average by 19% and Fe in organically grown barley on average 13%, in contrast results of Rembialkowska (2007) who estimated that organic crops overall contain 21% more Fe.

Higher Zn concentration under organic farming might be related to the higher antioxidative activity of organically grown products in comparison to conventional ones (Huber *et al.,* 2011). Although the ability of Zn to retard oxidative processes has been recognised for many years, the mechanisms of such action are still unclear. Future research on those mechanisms could potentially develop new antioxidant functions and uses for zinc (Powell, 2000).

No genotype × management system interaction was observed in our study, indicating that genotypes react similarly to both management systems. Significant genotype × environment interaction for wheat Zn and Fe concentration (Gao *et al.,* 2011; Velu *et al.,* 2012) and no genotype × year and genotype x location interaction for Fe concentration in organically grown spring wheat (Murphy *et al.,* 2011) was reported. To our knowledge no results on interaction between genotype and crop management system (organic and conventional) are published.

The effect of specific environmental conditions of the year on concentration of mineral elements was also found to be significant; for barley higher values occurred in 2011 under both management systems; in wheat, higher concentrations of Zn and Mn occurred in 2010. No significant differences in soil properties between both years were observed; however, the barley vegetation period in 2011 was dryer than in 2010, but the average yield level was higher in 2011 for both systems (2.9 and 3.7 $t \cdot ha^{-1}$, respectively). Higher Zn concentration in wheat was reported on sandy loam, compared to clay loam soils (Gao *et al.,* 2011).

We found no consistent correlations between concentrations of mineral elements and grain yield and its quality parameters, which is in agreement with Murphy *et al.* (2011). For Zn concentration we observed trends to correlate negatively with grain yield, especially under conventional management and positively with grain protein content in both cereals. According to results of Murphy *et al.* (2008), Fe and Zn were the only mineral elements of eight showing no negative relationship with grain yield; on the other hand, significant negative correlations between Fe and Zn concentration and grain yield have been found (Hussain *et al.,* 2010; Gao *et al.,* 2011). Our results agree with those of Gao *et al.* (2011), who observed a significant positive correlation between Zn and nitrogen (N) concentrations in grain.

We did not find previously observed positive correlation between Zn and Fe (Velu *et al.,* 2012) and Mg and Zn concentrations in spring wheat (Murphy *et al.,* 2011).

In conclusion, the results partially confirm higher Zn concentration in organically grown barley grain. However, the concentration of Fe in barley grain and Mn in wheat grain was lower under organic management than under conventional management. Barley and wheat genotypes with significantly higher than average concentrations of the investigated elements were identified and can be used in breeding for improvement of grain nutritional quality.

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GENOTIPA UN SAIMNIEKOŠANAS SISTĒMAS IETEKME UZ MINERĀLVIELU SATURU BIOLOĢISKI UN KONVENCIONĀLI AUDZĒTOS GRAUDAUGOS

Aptuveni puse no zemeslodes iedzīvotājiem cieš no minerālvielu, galvenokārt dzelzs (Fe) un cinka (Zn) trūkuma. Pētījuma mērķis bija salīdzināt Fe un Zn saturu 19 vasaras miežu (*Hordeum vulgare* L.) genotipos un Zn un mangāna (Mn) saturu 19 ziemas kviešu (*Triticum aestivum* L.) genotipos, kas divas sezonas audzēti bioloģiskajā un konvencionālajā saimniekošanas sistēmā. Vidējais Fe saturs miežu genotipu graudos bija robežās 32.51–86.85 mg·kg^{-1}, tas bija augstāks konvencionālajā sistēmā ($p < 0{,}001$), un genotipa efekts bija būtisks ($p = 0{,}014$). Vidējais Zn saturs miežos bija 16.79–48.51 mg·kg^{-1}, un tas bija būtiski augstāks bioloģiski audzētajos graudos ($p < 0{,}001$). Kviešos Zn atrasts 21.52–29.89 mg·kg^{-1} bez būtiskas starpības starp saimniekošanas sistēmām. Genotipa efekts uz Zn saturu graudos bija būtisks ($p = 0{,}03$ and $p < 0{,}001$ attiecīgi miežiem un kviešiem). Vidējais Mn saturs kviešu genotipu graudos konstatēts no 24.63 līdz 36.07 mg·kg^{-1}, un tas bija augstāks konvencionālajā saimniekošanas sistēmā ($p < 0{,}001$); starp genotipiem konstatētas būtiskas atšķirības ($p < 0{,}001$). Pētījuma rezultātā identificēti miežu un kviešu genotipi ar augstāku pētīto minerālvielu saturu izmantošanai selekcijā graudu kvalitātes uzlabošanai. Novērota negatīva Zn satura korelācija ar graudu ražu un pozitīva korelācija ar proteīna saturu graudos.