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ORIGINAL PAPER

EVALUATION OF IRON AND ZINC CONTENT IN GRAIN OF *AEGILOPS* L. × *TRITICUM AESTIVUM* L. HYBRID LINES

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Abstract

The aim of the study, carried out in 2012-2014, was to evaluate the content of iron and zinc in the grain of 15 hybrid lines of *Aegilops kotschyi* Boiss. and *Ae. variabilis* Eig. with *Triticum aestivum* L. and their parent forms. The content of micronutrients was analysed in grain samples from the plants with the highest 1,000 grain weight. The Fe and Zn content was determined by the ASA method. The study showed that the grain of the hybrid lines had a higher iron and zinc content (mean results from three years: 42.3 mg Fe kg^{-1} DW and 43.5 mg Zn kg^{-1} DW) than that of the parent wheat components (35.2 mg Fe kg^{-1} DW and 33.3 mg Zn kg^{-1} DW). The highest content of iron and zinc was found in the seeds of the wild parent species *Ae. kotschyi* Boiss (59.7 mg Fe kg^{-1} DW and 54.0 mg Zn kg^{-1} DW) and *Ae. variabilis* Eig. (61.9 mg Fe kg^{-1} DW and 49.1 mg Zn kg^{-1} DW). Among the hybrids of *Ae. variabilis* Eig. with *T. aestivum* L., the line *Ae. variabilis* Eig. × Rusałka stood out, with its grain containing on average 56.3 mg Fe kg^{-1} DW and 57.2 mg Zn kg^{-1} DW. Among the *Ae. kotschyi* Boiss × *T. aestivum* L. lines, the highest iron and zinc content was noted in the grain of *Ae. kotschyi* Boiss × Rusałka (51.9 mg Fe kg^{-1} DW and 51.3 mg Zn kg^{-1} DW), (*Ae. kotschyi* Boiss. × Rusałka) × Korweta (45.1 mg Fe kg^{-1} DW and 44.4 mg Zn kg), and [(*Ae. kotschyi* Boiss. × Rusałka) × Begra] × Piko (42.0 mg Fe kg^{-1} DW and 49.2 mg Zn kg^{-1} DW). The average iron content in the grain of the common wheat cultivars ranged from 32.3 mg kg^{-1} DW (cv. Piko) to 37.5 mg kg^{-1} DW (cv. Begra), and the zinc content ranged from 29.6 mg kg^{-1} DW (cv. Muza) to 36.7 mg kg^{-1} DW (cv. Turnia).

Keywords: *Aegilops kotschyi* Boiss., *Ae. variabilis* Eig., common wheat, hybrid lines, micronutrients, 1,000 grain weight.

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INTRODUCTION

Micronutrient deficiency is a global problem affecting about two billion people worldwide. Deficiencies of iron, zinc, iodine, folic acid and vitamin A are the most common (Bailey et al. 2015). Iron is a component of haem, which is in haemoglobin, myoglobin and in prosthetic groups of numerous enzymes. It participates in redox reactions (including cellular respiration and protection against oxidative stress). It enables oxygen transport in the body, affects intestinal micro-organisms, and reduces the risk of malaria and infection (Prentice et al. 2017). Iron deficiency in the body is manifested as reduced blood haemoglobin levels, causing anaemia (Papanikolaou, Pantopoulos 2017). Anaemia during pregnancy contributes to low birth weight and increases the risk of preterm birth and perinatal mortality. Even mild iron deficiencies can lead to cognitive deficits and delays in psychomotor development in children, and to reduced physical fitness and work productivity in adults (Finkelstein et al. 2017). Zinc, like iron, is essential for the normal growth and development of the human body. It is a component of many enzymes, including carbonic anhydrase, which influences the acid-alkaline balance in the body, and DNA and RNA polymerases, enzymes involved in gene replication and expression. Zinc ions protect the body against inflammatory processes by regulating the activity of certain apoptotic enzymes, mainly caspases; by inhibiting production of C-reactive protein and pro-inflammatory cytokines; and by blocking molecular adhesion on macrophages and monocytes. It reduces oxidative stress, which is the cause of many diseases, such as neurodegenerative diseases, atherosclerosis and diabetes. Zinc deficiency in the body causes immune, reproductive and nervous system disorders (Gapys et al. 2014).

Iron and zinc deficiency in the diet occurs mainly in developing countries, where most people use cereals as food. One third of crops in third-world countries are cereals. This area is affected by iron deficiency, and half of faces zinc deficiency (Cakmak 2008*a*,*b*, Peleg et al. 2008, Salim-Ur-Rehman et al. 2010).

Both Fe and Zn are present in small quantities in cereals. Biofortification is a method of plant production and breeding aimed at increasing their nutritional value. Genetic biofortification aims at breeding new cultivars of cereals with the genetic potential to accumulate high amounts of micronutrients in the grain (Das, Green 2013). Work on biofortification with iron is carried out on wheat, rice, millet, beans, peas and lentils. Commonly cultivated cultivars have relatively low iron concentrations, but some related wild species contain double or treble the concentration of this element (Prentice et al. 2017). Breeding wheat cultivars with improved efficiency of Fe and Zn uptake and transport to the grain increases plant productivity and can help to overcome Fe and Zn deficiencies (Cakmak et al. 2004). Wild relatives of wheat of the genus *Aegilops* contain two or three times more

Fe and Zn in the grain than common wheat does. *Aegilops* species with high micronutrient content in the grain have small kernels and produce poor yields (Prażak 1992). Previous research suggests that they can be used as a potential source of genes suitable for biofortification of common wheat (Chhuneja et al. 2006, Tiwari et al. 2008, 2009, 2010, Wang et al. 2011, Farkas et al. 2014, Zhang et al. 2014, Kumar et al. 2016). Genes increasing the efficiency of nitrogen and phosphorus utilisation have already been successfully introduced into wheat from related species (Subbarao et al. 2007). The case of iron and zinc may be similar. A fundamental condition for achieving the intended breeding effect is the use of wide crosses (Stefanowska et al. 1995, Pilch 2005, Kociuba, Kramek 2009). Earlier generations from interspecific crosses between wheat and *Ae. kotschyi* Boiss. had high content of Fe and Zn in the grain (Rawat et al. 2009, Prażak, Paczos-Grzęda 2013). According to Tiwari et al. (2010), substitution of chromosomes 2S and 7U of *Ae. kotschyi* Boiss. into wheat increases the Fe and Zn content in the grain.

The aim of the study was to evaluate the content of iron and zinc in the grain of F_{12-14}, BC_1F_{8-10}, and BC_2F_{7-9} hybrid lines obtained by crossing the species *Aegilops kotschyi* Boiss. and *Ae. variabilis* Eig. with common wheat *Triticum aestivum* L.

MATERIAL AND METHODS

The study material consisted of 15 hybrid lines of common wheat *Triticum aestivum* L. with *Aegilops variabilis* Eig. and *Ae. kotschyi* Boiss. and their parent components (Table 1). *Aegilops* species were obtained from the collection of the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Gatersleben, in Germany. The study was conducted in 2012-2014. The grain for the study came from a one-replicated field experiment set up at the Experimental Station of the Faculty of Agricultural Sciences in Zamość, University of Life Sciences in Lublin (50°42′36.7″ N, 23°12′47.3″ E). The experimental field was located on brown loess soil classified as good wheat complex, bonitation class II. The plants grew on separate plots with an area of 2 m^2, spaced at 20 x 10 cm. During the growing season, basic agrotechnical procedures were performed and NPK fertilizer was applied (60-90-90 kg ha^{-1}). Information on the weather conditions (Table 2) was obtained from the Meteorological Station in Zamość, Płoskie 1 (50°42′36.7″ N, 23°12′47.3″ E).

Each year the plants were harvested from the field at the fully ripe stage and the 1,000 grain weight was determined on 10 plants from each form. The iron and zinc content was analysed in grain samples from the plants with the highest 1,000 grain weight. The grains were ground, and the content of Zn and Fe was determined (following wet mineralisation in extra pure HNO_3) by atomic adsorption spectroscopy according to PN-EN ISO

Table 1

Derivation of hybrid lines and parental forms

No.	Forms	Symbol
1.	F_{12-14}* *Ae. variabilis* × Rusałka	VR
2.	F_{12-14} Rusałka × *Ae. variabilis*	RV
3.	F_{12-14} *Ae. kotschyi* × Rusałka	KR
4.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Begra	KRB
5.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Gama	KRG
6.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Korweta	KRKo
7.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Monopol	KRMo
8.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Muza	KRMu
9.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Piko	KRP
10.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Smuga	KRS
11.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Turnia	KRT
12.	BC_1F_{8-10} (*Ae. kotschyi* × Rusałka) × Zyta	KRZ
13.	BC_2F_{7-9} [(*Ae. kotschyi* × Rusałka) × Begra] × Piko	KRBP
14.	BC_2F_{7-9} [(*Ae. kotschyi* × Rusałka) × Begra] × Smuga	KRBS
15.	BC_2F_{7-9} [(*Ae. kotschyi* × Rusałka) × Begra] × Turnia	KRBT
16.	*Triticum aestivum* L. cv. Begra	Begra
17.	*Triticum aestivum* L. cv. Gama	Gama
18.	*Triticum aestivum* L. cv. Korweta	Korweta
19.	*Triticum aestivum* L. cv. Monopol	Monopol
20.	*Triticum aestivum* L. cv .Muza	Muza
21.	*Triticum aestivum* L. cv. Piko	Piko
22.	*Triticum aestivum* L. cv. Rusałka	Rusałka
23.	*Triticum aestivum* L. cv. Smuga	Smuga
24.	*Triticum aestivum* L. cv. Turnia	Turnia
25.	*Triticum aestivum* L. cv. Zyta	Zyta
26.	*Aegilops kotschyi* Boiss.	*Ae. kotschyi*
27.	*Aegilops variabilis* Eig.	*Ae. variabilis*

* generation since the last cross

Table 2

Rainfall and temperature according to the Meterological Station in Zamość, Płoskie 1

Year	Month				
	April	May	June	July	April-July
Rainfall (mm)					sum
2012	19.6	24.4	36.3	34.4	114.7
2013	15.6	35.6	85.6	63.4	200.2
2014	36.4	147.8	50.2	58.5	292.9
LYM	40.0	66.0	93.0	86.0	285.0
Temperature (°C)					mean
2012	12.0	18.4	20.0	24.8	18.8
2013	12.4	20.7	22.6	24.0	19.9
2014	15.0	18.5	20.8	25.2	19.9
LYM	6.9	13.4	15.9	17.1	13.3

LYM – long-term mean over 1979-1988

6869:2002. Iron and zinc were analysed each year in three laboratory samples from each hybrid and parent form. Statistical analysis of the results was performed. Significance of differences was determined by the Tukey test at $p = 0.05$.

RESULTS AND DISCUSSION

Wild species of *Aegilops*, which are a source of genes for wheat, are characterised by the grain with a high content of iron and zinc (Chhuneja et al. 2006, Tiwari et al. 2008, 2010, Rawat et al. 2009, Farkas et al. 2014).

The study conducted in 2012-2014 confirmed the high content of Fe and Zn in the grain of the wild parent species *Ae. kotschyi* Boiss. (average from three years: 59.7 mg Fe kg^{-1} DW and 54.0 mg Zn kg^{-1} DW) and *Ae. variabilis* Eig (average from three years: 61.9 mg Fe kg^{-1} DW and 49.1 mg Zn kg^{-1} DW) – Table 3. In a study by Kumar et al. (2016), the iron content in the grain of *Ae. kotschyi* Boiss. ranged from 52.10 to 56.81 mg kg^{-1} DW, and the zinc content ranged from 47.72 to 63.95 mg kg^{-1} DW. The iron content of the grain of *Ae. peregrina* (Hack.) Maire & Weller (synonym: *Ae. variabilis* Eig – Scott et al. 2014) ranged from 54.51 to 77.25 mg kg^{-1} DW, and that of zinc from 48.04 to 58.00 mg kg^{-1} DW.

The mean Fe content in the grain of the hybrid lines of wheat with *Ae. kotschyi* Boiss. and *Ae. variabilis* Eig. from the three years of the study was 42.3 mg kg^{-1} DW. The mean Zn content in the grain of the hybrid lines of wheat with *Ae. kotschyi* Boiss. and *Ae. variabilis* Eig. from the three years

Table 3

Weight of 1,000 grains and iron and zinc content in the grain of *Aegilops kotschyi* Boiss. and *Aegilops variabilis* Eig. with *Triticum aestivum* L. hybrid lines and their parental forms

Forms	Years											
	weight of 1,000 grains (g)				Fe mg kg^{-1} DW				Zn mg kg^{-1}DW			
	2012	2013	2014	2012-2014	2012	2013	2014	2012-2014	2012	2013	2014	2012-2014
VR	26.8	30.4	32.6	29.9	65.0	58.1	45.7	56.3	68.6	54.3	48.6	57.2
RV	32.6	31.0	34.8	32.8	56.2	50.8	43.4	50.1	59.0	55.5	44.5	53.0
KR	28.9	31.8	32.5	31.1	54.0	53.5	48.2	51.9	53.9	51.2	48.9	51.3
KRB	28.8	29.4	33.0	30.4	48.6	44.4	39.7	44.2	39.3	35.6	33.4	36.1
KRG	27.9	28.6	31.6	29.4	43.0	41.7	39.8	41.5	39.2	38.4	35.7	37.8
KRKo	31.7	37.6	40.1	36.5	50.5	46.1	38.8	45.1	50.3	46.0	36.9	44.4
KRMo	30.3	33.2	35.8	33.1	42.1	40.0	39.6	40.6	41.8	41.0	35.6	39.5
KRMu	32.3	34.4	39.6	35.4	37.1	34.7	34.2	35.3	37.8	36.4	34.8	36.3
KRP	31.8	36.8	36.2	34.9	41.1	40.7	36.7	39.5	45.7	41.0	40.3	42.3
KRS	30.9	35.4	38.8	35.0	32.1	32.9	31.9	32.3	42.1	35.3	31.7	36.4
KRT	32.3	34.8	39.5	35.5	39.8	36.2	36.4	38.3	51.4	40.8	35.5	42.6
KRZ	29.9	34.5	36.4	33.6	41.3	35.2	35.0	38.2	54.3	48.3	39.8	47.5
KRBP	28.8	30.2	33.8	30.9	45.3	40.9	38.5	42.0	57.6	49.6	40.4	49.2
KRBS	29.4	33.3	34.9	32.5	41.5	40.4	38.3	39.9	41.2	38.4	30.6	36.7
KRBT	31.5	34.6	38.5	34.9	40.9	39.2	38.6	39.6	49.8	40.9	36.6	42.4
Begra	34.8	33.2	38.9	35.6	38.3	37.7	36.6	37.5	35.5	34.3	32.8	34.2
Gama	31.9	32.7	33.3	32.6	37.5	34.6	28.1	34.4	38.4	31.3	29.4	33.0
Korweta	30.3	31.4	32.6	31.4	36.7	36.4	31.4	34.8	37.4	34.0	32.9	34.8
Monopol	30.6	33.5	33.8	32.6	38.6	37.3	32.4	36.1	38.6	35.8	31.6	35.3
Muza	31.4	31.2	34.2	32.3	37.2	36.1	34.4	35.9	31.3	29.6	28.0	29.6
Piko	27.6	31.3	31.9	30.3	36.9	31.1	28.9	32.3	32.2	31.4	25.6	29.7
Rusałka	39.5	40.9	44.1	41.5	36.2	36.8	34.4	35.8	33.5	30.1	29.7	31.1
Smuga	34.4	36.2	37.2	35.9	39.5	34.6	31.2	35.1	37.7	35.3	29.4	34.1
Turnia	33.3	34.7	39.9	32.0	38.6	35.6	30.3	34.8	39.8	37.7	32.6	36.7
Zyta	32.4	34.4	38.2	35.0	38.5	36.0	32.2	35.6	38.1	34.5	31.9	34.8
Ae .kot.	5.3	6.4	7.6	6.4	61.9	59.3	57.9	59.7	56.9	55.3	49.9	54.0
Ae. var.	12.2	15.1	16.3	14.5	64.4	60.9	60.3	61.9	52.2	48.6	46.4	49.1
Hybrids*	30.3	33.1	35.9	33.1	45.2	42.9	39.0	42.3	48.8	43.5	38.2	43.5
Wheats*	32.6	34.0	36.4	33.9	37.8	35.7	32.0	35.2	36.2	33.4	30.4	33.3
*Aegilops**	8.8	10.8	12.0	10.5	63.1	60.1	59.1	60.8	54.6	52.0	48.15	51.6
$LSD_{0.05}$	9.03	8.29	6.48	7.84	9.03	8.29	6.48	7.84	4.80	4.63	5.96	5.74

* mean

of the study was 43.5 mg kg^{-1} DW. For the hybrid lines of *Ae. kotschyi* Boiss. with common wheat, the Fe content ranged from 32.3 mg kg^{-1} DW (KRS) to 51.9 mg kg^{-1} DW (KR), while the zinc content ranged from 36.1 mg kg^{-1} DW (KRB) to 51.3 mg kg^{-1} DW (KR) – Table 3. For the hybrid lines of *Ae. variabilis* Eig. with common wheat, the Fe content was 50.1 mg kg^{-1} DW (RV) and 56.3 mg kg^{-1} DW (VR), while the zinc content was 53.0 mg kg^{-1} DW (RV) and 57.2 mg kg^{-1} DW (VR). In addition, for the three years of the study, the mean iron content higher than 40.0 mg kg^{-1} DW was noted in the grain of the KRB, KRG, KRKo, KRMo and KRBP lines, and the zinc content higher than 40.0 mg kg^{-1} DW appeared in KRKo, KRP, KRT, KRZ, KRBP and KRBT (Table 3). The hybrid lines showed great variation in the iron and zinc content in the grain (Figures 1-2).

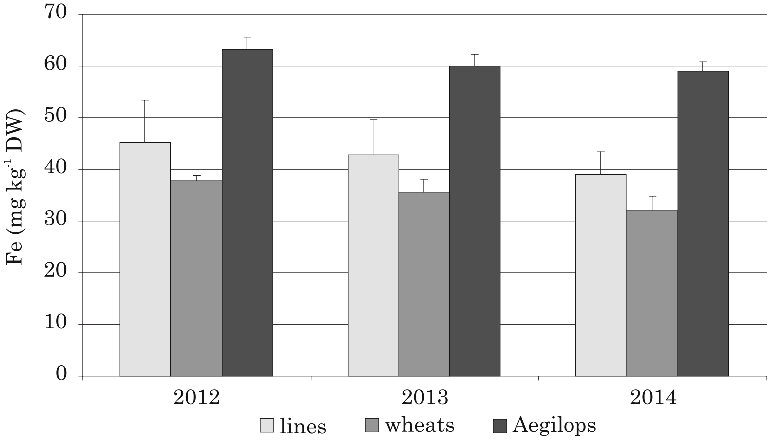

Fig. 1. Iron content in the grain of *Aegilops kotschyi* Boiss. and *Aegilops variabilis* Eig. with *Triticum aestivum* L. hybrid lines and their parental forms in 2012-2014 (mean ± SD)

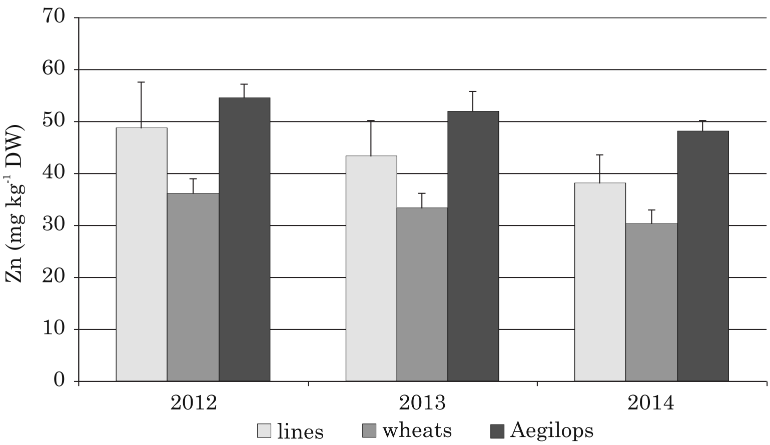

Fig. 2. Zinc content in the grain of *Aegilops kotschyi* Boiss. and *Aegilops variabilis* Eig. with *Triticum aestivum* L. hybrid lines and their parental forms in 2012-2014 (mean ± SD)

Analysis of earlier generations of common wheat hybrids with *Ae. kotschyi* Boiss. showed a high content of iron and zinc in the grain: 46.5-54.0 mg Fe kg^{-1} DW, 39.8-57.8 mg Zn kg^{-1} DW (PRAŻAK, PACZOS-GRZĘDA 2013). KUMAR et al. (2016) report that in $BC_{1-2}F_4$ hybrid lines of *Ae. kotschyi* Boiss. and *Ae. peregrina* (Hack.) Maire & Weller with wheat *Triticum aestivum* L., the iron content in the grain ranged from 32.01 to 37.55 mg kg^{-1} DW, and the zinc content ranged from 30.01 to 36.36 mg kg^{-1} DW. RAWAT et al. (2009) also reported a high Fe and Zn content in earlier generations from intergeneric crosses between wheat and *Aegilops kotschyi* Boiss.

In a study by WANG et al. (2011), the iron content in the grain of hybrid lines of *Ae. peregrina* (Hack.) Maire & Weller with wheat ranged from 42.3 to 43.8 mg kg^{-1} DW, while the zinc content ranged from 37.5 to 49.2 mg kg^{-1} DW. VELU et al. (2011) reported that **a** preliminary analysis of F_4/F_5 lines of *Aegilops taushii* Coss. with *Triticum dicoccon* (Schrank) Schübl. showed high variation in Zn (19-52 mg kg^{-1} DW) and Fe (23-52 mg kg^{-1} DW), with the mean content of 27.11 mg kg^{-1} DW for Zn and 30.52 mg kg^{-1} DW for Fe.

The wheat parent components of the hybrids were cultivars whose grain has good technological properties (SUBDA et al. 2002, WITKOWSKI et al. 2005, KOCIUBA, KRAMEK 2009). The three-year mean Fe content in the kernels of the wheat parent components was 35.2 mg kg^{-1} DW, and the mean Zn content was 32.3 mg kg^{-1} DW (Table 3). In a study by PRAŻAK and PACZOS-GRZĘDA (2013), the iron content in the grain of the cultivar Rusałka was 41.7 mg kg^{-1} DW and the zinc content was 23.6 mg kg^{-1} DW. WANG et al. (2011) report that the iron content in the grain ranged from 29.6 to 33.6 mg kg^{-1} DW and the zinc content from 20.5 to 30.5 mg kg^{-1} DW in the cultivar of common wheat Chinese Spring. In a study by RACHOŃ et al. (2012), the iron content in the grain of spring wheat cv. Torka averaged 37.7 mg kg^{-1} DW, while the zinc content was 32.5 mg kg^{-1} DW. KULCZYCKI and GROCHOLSKI (2004) reported that the iron content in cultivars of winter wheat *Triticum aestivum* L. ranged from 32.5 mg kg^{-1} DW (cv. Diamant) to 41.9 mg kg^{-1} DW (cv. Nutka), while the zinc content ranged from 20.8 mg kg^{-1} DW (cvs Diamant and Opus) to 29.0 mg kg^{-1} DW (cv. Nutka).

The kernels of hybrid lines were well filled, and their shape and colour were intermediate or similar to that of the kernels of the common wheat cultivars (Figures 3-5). The mean 1,000 grain weight of the hybrid lines from the three years of the study was only slightly lower (33.1 g) than that of the parent wheat cultivars (33.9 g). According to GŁOWACKA (2010), the 1,000 grain weight, together with the ear number per m^2 and grain number per ear, significantly affects yield. The larger, plumper and better filled the kernels, the higher the yield. In a study by PRAŻAK (1992), the 1,000 grain weight of the species *Ae. kotschyi* Boiss. and *Ae. variabilis* Eig. was 6.5 and 18.1 g, respectively. In the present study, it ranged from 5.3 to 7.6 g for *Ae. kotschyi* Boiss. and from 12.2 to 16.3 g for *Ae. variabilis* Eig. In a study by TYRKA and STEFANOWSKA (2001), the 1,000 grain weight of wheat hybrids with *Ae. ventricosa* Tausch. and *Ae. juvenalis* (Thell.) Eig. ranged from 21.6 to 52.1 g, while

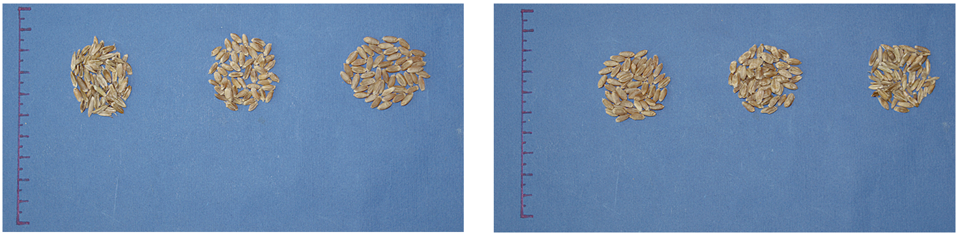

Fig. 3. Grains of hybrid lines and their parental components from the left:
Ae. variabilis, VR, Rusałka, Rusałka, RV, *Ae. variabilis* (rulers = 10 cm)

Fig. 4. Grains of hybrid lines and their parental components from the left:
I row from the top – KRG, KRKo, KRMo, KRMu, KRP,
II row from the top – KRS, KRT, KRT, KRZ,
III row from the top – *Ae. kotschyi*, Rusałka, Gama, Korweta, Monopol,
IV row from the top – Muza, Piko, Smuga, Turnia, Zyta (ruler = 10 cm)

Fig. 5. Grains of hybrid lines and their parental components from the left:
I row from the top – 1-4 KR, II row from the top – KRB, KRBP, KRBS, KRBT,
III row from the top – *Ae. kotschyi*, Rusałka, Begra, Piko, Smuga, Turnia (ruler = 10 cm)

that of the parent wheat cultivars ranged from 32.6 to 42.7 g. According to the authors, the hybrid plants showed a greater range of variation in 1,000 grain weight than the winter wheat cultivars.

The chemical composition of wheat grain is influenced by genetic factors and by the climate and cultivation conditions (Borkowska 2004). The atmospheric conditions in 2012-2014 were varied (Table 2). In 2012 and 2013, during the period from April to July, there were precipitation deficits of 60% and 30%, respectively, while in 2014 the total precipitation sum exceeded the long-term average by 3%. In all the years of the study, in the period from April to July, the average monthly air temperatures were higher than the long-term norm, on average by 5.5°C (2012) and 6.6°C (2013 and 2014). In our study, the highest 1,000 grain weight was noted in the hybrid lines in 2014 (35.9 g), when the precipitation sum was the highest of the three-year research period. In the previous years, with less rainfall, the 1,000 grain weight of the hybrids was lower (30.3 g in 2012 and 33.1 g in 2013). A similar effect was observed for the wheat cultivars and *Aegilops* species. Many experiments have demonstrated the dependence of yield structure elements on weather conditions during the growing period (Woźniak 2006, Brzozowska et al. 2008, Buraczyńska, Ceglarek 2008, Głowacka 2010).

The highest content of iron and zinc was noted in the grain of the hybrid lines in 2012 (45.2 mg Fe kg^{-1} DW and 48.8 mg Zn kg^{-1} DW) when the precipitation sum was the lowest of the three-year research period. In the next two years, when the precipitation sum was nearly 2-to 3-fold higher during the period from April to July, the iron content in the grain of the hybrid lines was lower by 5.1% (2013) and 13.7% (2014), and zinc content decreased by 10.8% (2013) and 21.7% (2014). A similar effect of atmospheric conditions was noted in the case of the parent components (Tables 2, 3).

CONCLUSIONS

1. The introgression of genes of *Ae. variabilis* Eig. and *Ae. kotschyi* Boiss. into the genotype of common wheat led to an increase in the content of iron and zinc in the grain of the hybrid lines of *Ae. variabilis* Eig. and *Ae. kotschyi* Boiss. with *T. aestivum* L. The lines obtained may become valuable starting material for breeding high-quality common wheat.

2. During the three-year study, atmospheric conditions were found to affect the content of iron and zinc in the grain and the 1,000 grain weight of the hybrid lines of *Ae. variabilis* Eig. and *Ae. kotschyi* Boiss. with *T. aestivum* L. When the precipitation sum in the period from April to July was higher, the average iron and zinc content in the grain of the hybrids decreased and the 1,000 grain weight increased.

3. Statistically significant differences were noted in the iron and zinc content and in 1,000 grain weight between the hybrid lines of *Ae. variabilis* Eig. and *Ae. kotschyi* Boiss. with common wheat and their parent forms. The hybrid plants were characterised by great variation in the iron and zinc content in the grain.

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