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Nutritive value of spelt (*Triticum aestivum* spp. *spelta* L.) as influenced by the foliar application of copper, zinc and manganese

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Abstract

The research determined crop yield, content of mineral nutrients (Cu, Zn, Mn and Fe), protein and its composition in the grain of the spelt variety 'Schwabenkorn' as affected by the foliar application of micronutrients. A field experiment was carried out during 2011–2013 at the Research Station in Tomaszkowo (53°72 N, 20°42 E), Poland. Cu, Zn and Mn and microelements together (Cu + Zn + Mn) with mineral fertilisers were applied. Nitrogen (N) was applied to all the plots in a dose of 90 kg ha^{-1}, triple superphosphate in a dose corresponding to 30.2 kg ha^{-1} P, and potassium salt in a dose of 83.1 kg ha^{-1} K. Copper (1.0% solution of $CuSO_4 \times 5H_2O$), zinc (1.0% solution of $ZnSO_4 \times 7H_2O$) and manganese (0.5% solution of $MnSO_4 \times 5H_2O$) were foliar-applied as water solutions at the stem elongation stage. The mineral fertilisation, including micronutrients (individually or in combination), changed the contents of mineral nutrients, protein and the composition of its individual fractions in the grain. It was observed that the grain had high Cu, Mn and Fe content. The application of Mn, as well as micronutrients used in combination (Cu + Zn + Mn) as an addition to NPK fertilisation, increased the content of Fe, Zn and Mn in spelt grain. The application of Zn increased Fe and Zn content, while the application of Cu increased the content of Mn in grain. The total protein content in spelt ranged from 12.4% to 13.5%. Storage proteins proved to have the highest share in the total protein. Additional application of Cu, Zn and micronutrients in combination had a positive impact on the gliadins:glutenins ratio. Foliar application of Mn increased the content of ω, α/β, γ gliadins, and reduced that of low molecular weight glutenins. Foliar spraying with Cu reduced the content of α/β and ω gliadins. Supply of Zn decreased α/β content and increased the content of the high molecular weight glutenins fractions. The application of the micronutrients in combination reduced the content gliadin γ and increased the content of high molecular weight and low molecular weight glutenins. The cultivation year was a significantly differentiating factor for the grain yield, mineral nutrient content (Fe, Zn and Mn) and the content and composition of protein fractions (with the exception of high molecular weight glutenins).

Key words: gliadins, glutenins, micronutrients, protein composition, protein content, 'Schwabenkorn'.

Introduction

Spelt (*Triticum aestivum* spp. *spelta* L.) is one of the oldest wheat subspecies. Today, spelt is grown mainly on ecological farms in German-speaking countries and in Belgium, Italy, France and Central European countries (Akeret, 2005). This species has become interesting as a result of advantageous grain quality parameters, its use in production and the potential possibility to arouse consumer interest in new products with the addition of spelt flour. In many studies, the researchers presented the suitability of spelt grain and flour for bread making and the manufacturing of food products (Świeca et al., 2014). As regards nutrition, spelt grain is more valuable than bread wheat (Rachoń, Szumiło, 2009). It is richer in protein, which is characterized by its relatively high biological value (Branković et al., 2015). The technological parameters of spelt flour are close to those of bread wheat flour and, in many respects, much like those of hard wheat grain. Spelt grain usually contains more wet gluten, which is characterized by higher flowability, i.e. a weaker gluten structure (Schober et al., 2006; Pruska-Kędzior et al., 2008). Among the elements of production technology during the vegetation period, mineral fertilisation with NPK, as well as organic fertilisers, affects the content of gluten proteins in grain, differentiating the content of gliadins, especially ω, α/β, γ types and high molecular weight and low molecular weight glutenins (Konopka et al., 2007; Stępień, Wojtkowiak, 2013). The unique position of wheat among cereals can be attributed to gluten proteins (gliadins and glutenins). Their accumulation and interrelations affect such properties of dough as viscoelasticity and viscosity, as well as bread porosity. Dough rising and quality are affected by the composition of glutenins, especially HMW glutenins (Goesaert et al., 2005).

Differences in grain quality may result from the genetic properties of the variety, habitat conditions and agrotechnology applied (Podolska, 2008; Cazzato et al., 2013). Compared to bread wheat, spelt grain contains more iron, zinc, copper, magnesium, potassium, sodium and selenium (Ruibal-Mendieta et al., 2005). In plant production, the availability of nutrients is one of the most important factors affecting yield and grain quality. Besides mineral nitrogen, nutrients include the following microelements: copper, manganese and zinc. They perform important functions in plant metabolic processes, and their deficiencies disrupt biochemical processes.

The aim of this study was to determine the crop yield, the content of mineral nutrients (Cu, Zn, Mn, Fe), protein and its composition in the grain of the spelt variety 'Schwabenkorn' as affected by the foliar application of micronutrients.

Materials and methods

A field experiment was carried out during 2011–2013 at the Research Station in Tomaszkowo (53°72 N, 20°42 E), Poland. The experiment was set up using the random block method in three replications, on brown soil with the texture of light soil, *Haplic Cambisol* according to World Reference Base (WRB, 2014). The physical and chemical soil properties are presented in Table 1.

Table 1. Physical and chemical soil properties before the experiment (2011)

Measured parameters	Values
Soil type	*Haplic Cambisol*
Soil texture	loam
pH in KCl	5.99
Total organic C g kg^{-1} DM	9.98
Total N g kg^{-1} DM	0.95
P mg kg^{-1} DM	35.5
K mg kg^{-1} DM	26.51
Mg mg kg^{-1} DM	7.5
Mn mg kg^{-1} DM	192
Cu mg kg^{-1} DM	2.3
Zn mg kg^{-1} DM	7.8
Fe mg kg^{-1} DM	1500

DM – dry matter

Nitrogen (N) was applied to all the plots at a dose of 90 kg ha^{-1}, the amount was divided as follows: soil-applied 54 kg ha^{-1} N (46% urea) during the tillering stage (BBCH 21–22) and foliar-applied 36 kg ha^{-1} N – (10% urea solution) during the stem elongation stage (BBCH 30–31); triple superphosphate (46%) at a dose of 30.2 kg ha^{-1} P, and potassium salt (56%) at a dose of 83.1 kg ha^{-1} K, before sowing. The fertilisation treatments of the experiment are presented in Table 2.

Table 2. Scheme of the field experiment

Fertilisation treatments*	Micronutrients** kg ha^{-1}	Form of micronutrients
Control (NPK)	–	–
NPK + Cu	Cu (0.2)	1.0% solution of $CuSO_4 \times 5H_2O$
NPK + Zn	Zn (0.2)	1.0% solution of $ZnSO_4 \times 7H_2O$
NPK + Mn	Mn (0.2)	0.5% solution of $MnSO_4 \times 5H_2O$
NPK + Cu + Zn + Mn	Cu (0.2) Zn (0.2) Mn (0.2)	1.0% solution of $CuSO_4 \times 5H_2O$ 1.0% solution of $ZnSO_4 \times 7H_2O$ 0.5% solution of $MnSO_4 \times 5H_2O$

Note. * – in all treatments the same mineral NPK fertilisation (90 kg ha^{-1} N, 30.2 kg ha^{-1} P and 83.1 kg ha^{-1} K) was used; ** – micronutrients were foliar-applied at the stem elongation stage (BBCH 30–31).

The plot size was 6.25 m^2, the harvested plot area was 4.0 m^2, and winter triticale was a forecrop. Winter spelt variety 'Schwabenkorn' was sown at 5.50 million grains ha^{-1}, spacing between plant rows of 120 mm. Agrotechnical practices, included shallow ploughing, were performed as soon as the forecrop was harvested. Ploughing before sowing and harrowing was performed in order to bury crop residue before winter wheat sowing. A cultivating-sowing unit was used immediately before sowing in all treatments in order to mix fertilisers (mineral) and prepare the soil for sowing. Weeds were eliminated with herbicides: in 2011 – Mustang Forte 195 SE (a.i. florasulam 5 g dm^{-3}, aminopyralid 10 g dm^{-3}, 2.4 D 180 g dm^{-3}) 1.0 dm^{-3} ha^{-1} and Puma Universal 069 WG (a.i. fenoksaprop-P-etyl 69 g dm^{-3}) 1.2 dm^{-3} ha^{-1}; in 2012 – Atlantis 12 OD (a.i. jodosulfuron methyl sodium 2 g dm^{-3}, mesosulfuron methyl 10 g dm^{-3}) 0.45 dm^{-3} ha^{-1} + Sekator 125 OD (a.i. jodosulfuron methyl sodium 25 g dm^{-3}, amidosulfuron 100 g dm^{-3}) 0.15 dm^{-3} ha^{-1}, in spring after resumption of wheat vegetation (BBCH 21–29). No protection was provided against pests and diseases.

The weather conditions during the years of the study are shown in Table 3. In the experimental years, the precipitation during spelt sowing and germination was higher in September of the first year (2011) – by 21.8 and 10.6 mm compared to the multi-year average. October and November 2011 were characterized by much lower precipitation than the following year (by 39.0 and 31.1 mm) and also lower than the multi-year average (by 13.1 and 30.7 mm). In the experimental years, the monthly precipitation in December was lower, and in January it was higher than the multi-year average values. In March 2012 and 2013, the precipitation was lower than multi-year average values – by 8.8 and 14.8 mm. At the beginning of the vegetation period (April) in 2012, the precipitation (73.1 mm) was more than double the average rainfall sums of the multi-year average. In the experimental years (2011–2013), in May (beginning of coming into ear), the rainfall sums were much the same (51.7 and 54.5 mm). In June 2012 (end of the tillering phase), the rainfall was 40% higher than in 2013. In July (grain ripening stage), the precipitation in individual years was similar, although it considerably exceeded the multi-year average values (39% on average).

Table 3. Weather conditions in 2011–2013 and the multi-annual average of 1981–2010

Year	Month												
	09	10	11	12	01	02	03	04	05	06	07	08	September–August
	Temperature ºC												average
2011–2012	14.1	8.3	3.1	2.3	−1.7	−7.5	3.0	7.8	13.4	15.0	19.0	17.7	7.9
2012–2013	13.5	7.4	4.9	−3.5	−4.6	−1.1	−3.5	5.9	14.8	17.5	18.0	17.4	7.2
1981–2010	12.8	8.0	2.9	−0.9	−2.4	−1.7	1.8	7.7	13.5	16.1	18.7	17.9	7.9
	Rainfall mm												sum
2011–2012	67.5	29.5	14.1	25.8	61.8	27.7	24.1	73.1	51.7	103.2	121.0	45.1	644.6
2012–2013	45.7	68.5	45.2	11.8	44.1	22.6	18.1	28.5	54.5	61.2	121.9	37.6	559.7
1981–2010	56.9	42.6	44.8	38.2	36.4	24.2	32.9	33.3	58.5	80.4	74.2	59.4	581.8

Each year during the study period, the crop was harvested, ground and the samples were taken for chemical analysis. Spelt grain collected from the experimental field was first separated from spikes and was then dried and its yield was calculated in tonnes per hectare at 15% humidity. After grinding in a WŻ-1 type laboratory mill (Labortechnik, Germany), grain samples were subjected to hot mineralization in an HNO_3 and $HClO_4$ acid mixture (ratio 3:1). A sample of milled grain (5 g) was placed in a Kjeldahl flask and 30 ml acid mixture was added. The next day it was heated in a digester heater K-439 (Buchi Speed Digester, Switzerland) until total sample transparency, Cu, Zn, Mn and Fe content was determined using an atomic absorption spectrometer-flame technique with an apparatus Hitachi Z-8200 (Japan). Total nitrogen was determined using the Kjeldahl method and converted to protein content (N × 5.75). Quantitative and qualitative protein characteristics were determined through the RP-HPLC technique developed by Wieser et al. (1998). Albumins plus globulins were twice extracted with 1 mL of 0.4 mol L^{-1} of NaCl with 0.067 of mol L^{-1} $HKNaPO_4$ (pH 7.6); gliadins were extracted with 1 mL of 60% ethanol (three-fold extraction), and glutenins were twice extracted with 1 mL of 50% 1-propanol, 2 mol L^{-1} of urea, 0.05 mol L^{-1} of Tris-HCl (pH 7.5), 1% DTT (ditiotreitol), under nitrogen. The determination was carried out using a 1050 series apparatus Hewlett Packard (Palo Alto, USA) with the following parameters: a RP-18 Vydac 218TP54 column with 5 µm bead size and 300 A pore size, 250 × 4.6 mm; a Zorbax 300SB C18 pre-column, 4.6 × 12.5 mm; a column temperature of 45°C, a mobile phase flow rate of 1 mL min^{-1}, and an injection volume of 20 µL. A two-component gradient was used. Component A: 0 min 75%, 5 min 65%, 10 min 50%, 17 min 25%, 18 min 15% and 19 min 75%. The first component (A) was water with 0.1% of trifluoroacetic acid (TFA) and the second (B) was acetonitrile (ACN) with 0.1% of TFA. The absorbance spectra of eluted proteins were determined by a diode-array detector HP 1050 (Palo Alto, USA). Quantification of proteins was done by UV absorbance at 210 nm. The integration procedure was performed using software *HPLC 3D ChemStation*. The identification of gliadins was based on the second derivative of their UV spectra (Dziuba et al., 2007). Spectral parameters of individual peaks were compared using the ratio of tryptophan to tyrosine calculated using the protein sequence database Swiss-Prot/TrEMBL (http://www.expasy.org). The iden-tification of glutenin was performed using standards of high molecular weight (HMW) and low molecular weight (LMW) subunits isolated according to Wieser et al. (1998). A quantitative analysis of all protein fractions was carried out, based on a curve for a gliadin standard prepared on an intra-laboratory basis. The results were expressed in mAUs (milli-absorbance units). One-factor analysis of variance was used in statistical calculations, which was consistent with the mathematical model of the experiment configuration – the randomized blocks. Besides basic statistical parameters, the researchers determined statistically homogeneous groups using the Duncan's test, at a significance level of $\alpha = 0.05$. Moreover, they formulated correlation dependencies between the content of micronutrients in grain and grain yield, protein content and its fraction composition. A spread sheet *Excel* and statistical package *Statistica 10.0* were used to perform statistical computations and analyses.

Results and discussion

Grain yield of spelt (*Triticum aestivum* spp. *spelta* L.) variety 'Schwabenkorn' with the foliar application of Cu, Zn and Mn, individually or in combination, ranged from 5.63 to 5.98 t ha^{-1} (Table 4). This yield level was much like that obtained by Lacko-Bartošová et al. (2010). According to them, the average grain yield for the variety 'Schwabenkorn' was 5.54 t ha^{-1}. Andruszczak et al. (2011) observed that levels of crop chemicalization and rates of mineral fertilisation diversified the level of grain yield of variety 'Schwabenkorn'. In the current research, it was found that supplementing mineral fertilisation with micronutrients did not have a significant effect on the

Table 4. Grain yield, content of micronutrients in the grain of spelt variety ‘Schwabenkorn’ foliar-applied with micronutrients

Fertilisation treatments		Grain yield t ha^{-1}	Cu	Fe	Zn	Mn
			mg kg^{-1}			
Control (NPK)	average	5.47 a	3.65 a	58.1 d	33.4 c	41.8 d
	SD	0.379	0.111	1.652	0.216	0.726
NPK + Cu	average	5.98 a	3.37 b	59.0 d	30.5 d	46.4 a
	SD	0.463	0.038	0.650	0.606	0.450
NPK + Zn	average	5.63 a	3.71 a	70.5 a	40.5 a	40.4 e
	SD	0.607	0.068	1.500	1.185	0.879
NPK + Mn	average	5.73 a	3.26 b	62.3 c	35.1 b	45.1 b
	SD	0.608	0.060	0.656	0.333	1.076
NPK + Cu + Zn + Mn	average	5.88 a	3.04 c	64.5 b	35.8 b	43.0 c
	SD	0.564	0.078	1.214	0.823	0.879
			Years			
2012	average	4.00 b	3.40 a	63.7 a	33.7 b	42.9 b
	SD	0.729	0.380	4.232	4.484	3.292
2013	average	7.47 a	3.41 a	62.1 b	36.5 a	43.8 a
	SD	0.400	0.055	3.561	1.655	2.522

Note. Averages in columns (separately for micronutrients and years) followed by the same letter are insignificant ($\alpha < 0.05$); SD – standard deviation.

grain yield. A significantly higher (by 86.8%) grain yield was obtained in the second experimental year. This may have been caused by the different thermal conditions in the winter of 2012–2013 which helped the plants to pass through the stage of vernalisation.

Application of mineral fertilisers with micronutrients results in a higher yield and content of mineral components in grain (Narimani et al., 2010; Nadim et al., 2012). The nutritive value of spelt grain is high – the grain contains all necessary nutrients (Rachoń, Szumiło, 2009; Rachoń et al., 2015). Those authors found that, regardless of the micronutrients applied, the grain of spelt variety ‘Schwabenkorn’ contained more Cu, Mn and Fe compared to the finding of Kraska et al. (2013). The research carried out by Gomez-Becerra et al. (2010) and Kohajdová and Karovičová (2009) showed a higher content of Zn in spelt grain than in the current experiment (70 and 47 g kg^{-1}, respectively), while Fe concentration was lower (57–60 g kg^{-1}). Kraska et al. (2013) observed a strong dependence of micronutrient content in grain on the variety. Among eight spelt varieties evaluated by them, the variety ‘Schwabenkorn’ was richest in iron.

Supplementation of the basic mineral fertilisation NPK with Cu, Mn and micronutrients in combination (Cu + Zn + Mn) reduced Cu content in grain – by 7.7, 10.7 and 16.7 %, respectively. A statistically significant increase in iron concentration in grain partly resulted from a higher supply of Zn (by 21.3%), Mn (by 7.2%) and micronutrients (Cu + Zn + Mn) application (by 11.0%). Zinc content in grain increased by 21.3% after spraying (at the stem elongation stage) with a urea solution and $ZnSO_4 \times 7H_2O$, and after treatment with $MnSO_4 \times 5H_2O$ – by 5.1%. The application of micronutrients with mineral fertilisers increased Zn content by 7.2%. Adding Cu to NPK fertiliser reduced Zn content by 8.7%.

The application of nitrogen as urea, together with Cu or Mn, or in combination with all the micronutrients (Cu + Zn + Mn) increased Mn content by 11.0, 7.9 and 2.9 %, respectively. Foliar application of a 10% urea solution with Zn significantly reduced Mn content. In the second experimental year , Zn and Mn content increased by 8.3% and 2.1%, respectively, and iron content dropped by 2.5%. Lack of a clear effect of foliar application of microelements on the chemical composition of spelt grain may result from an ionic antagonism present in the plant.

Spelt grain is characterized by higher protein content than bread wheat grain (Kohajdová, Karovičová, 2008; Rachoń, Szumiło, 2009; Escarnot et al., 2012). According to Mikos and Podolska (2012) and Świeca et al. (2014), total protein content in spelt variety ‘Schwabenkorn’ grain varies within a wide range from 13.2% to 15.5%. High protein content in grain of that variety was observed in the research carried out by Lacko-Bartošová and Rédlová (2007) – 18.6%. According to Rachoń et al. (2015), the higher nitrogen fertilisation rate (140 kg ha^{-1} N compared to 70 kg ha^{-1} N) resulted in increased protein (by 1.6 percentage points). The tested fertilisation treatments had an ambiguous influence on the protein content levels reached (Table 5). Supplementing the basic fertilisation with micronutrients, applied either individually (Zn and Mn) or in combination (Cu + Zn + Mn) reduced the protein content in grain.

According to Schober et al. (2006), European spelt varieties were characterized by much the same protein content, less insoluble polymeric protein and more gliadins and soluble polymeric proteins compared to American varieties. Escarnot et al. (2012) indicate that, compared to bread wheat, spelt grain is characterized by a similar content of albumin and globulin fractions and higher content of gliadin fractions compared to glutenins. The gliadins:glutenins ratio is 3.5 (for spelt) and 2.0 (for common wheat), respectively. According to Pruska-Kędzior et al. (2008), among all cereal species under assessment grain spelt was the most valuable in term of its technological properties.

The protein fraction content in spelt grain differed depending on the applied micronutrients (Table 5). The highest albumin and globulin content (19987 mAUs) was observed after applying NPK with 0.2 kg ha^{-1} Cu (7.7% rise compared to mineral NPK fertilisation).

Table 5. The content and composition of proteins in the grain of spelt variety ‘Schwabenkorn’ foliar-applied with micronutrients

Fertilisation treatments		Content of protein %	Albumins and globulins	Gliadins	Glutenins	Gliadins:glutenins
			mAUs			
Control (NPK)	average	13.4 a	18554 b	45878 b	41849 c	1.10 b
	SD	0.058	20.0	150.0	211.9	0.006
NPK + Cu	average	13.5 a	19987 a	44704 b	42755 bc	1.05 c
	SD	0.144	123.4	285.6	163.4	0.006
NPK + Zn	average	12.4 c	18328 b	42052 c	43321 ab	0.97 e
	SD	0.029	195.1	154.9	365.8	0.009
NPK + Mn	average	13.1 b	18432 b	48530 a	38117 d	1.27 a
	SD	0.289	37.5	385.1	140.3	0.014
NPK + Cu + Zn + Mn	average	13.0 b	18216 b	43320 c	44257 a	0.98 d
	SD	0.116	26.5	117.7	281.4	0.004
			Years			
2012	average	13.4 a	19570 a	43341 b	45870 a	0.94 b
	SD	0.468	68.3	231.1	220.0	0.003
2013	average	12.8 a	17836 b	46453 a	38250 b	1.32 a
	SD	0.123	98.3	401.0	303.1	0.005

Note. Averages in columns (separately for micronutrients and years) followed by the same letter are insignificant ($\alpha < 0.05$); SD – standard deviation; mAUs – milli-absorbance units.

In general protein share, storage proteins (gliadins and glutenins) significantly prevail (from 81.4% to 82.8%) over enzymatic and structural proteins (albumins and globulins). This was confirmed in the research carried out by Świeca et al. (2014), where storage proteins constituted 71% to 72% in the grain of spelt variety ‘Schwabenkorn’. The gliadins:glutenins ratio ranged from 0.97 to 1.27, and fertiliser treatments also significantly differentiated it. Adding Mn to mineral fertilisers caused the highest accumulation of gliadins (48530) and a considerable reduction of glutenins (38117). This resulted in an increased ratio (1.27). According to Konopka et al. (2007), a high gliadins:glutenins ratio may indicate deterioration of protein technological properties. A higher gliadin share proves the potential predominance of protein sticky properties over its elastic properties. In the completed research, mineral fertilisation, including foliar spraying with Zn applied individualy and in combination (Cu + Zn + Mn), resulted in reduced content of gliadins and increased content of glutenins, while their advisable ratio (0.97 and 0.98) was maintained. Statistical analysis confirmed the impact of the experimental years on protein content and composition. In the first year of the study, the researchers observed higher content of albumins, globulins and glutenins, while the content of gliadins was lower.

Foliar application of nitrogen in combination with Cu, Zn and Mn, either individually or in combination differentiated the content of monomeric gliadins and polymeric glutenins (Table 6). Spraying with $MnSO_4 \times 5H_2O$ caused an increase in the content of gliadins – ω, α/β and γ, by 8.0, 6.0 and 5.3 %, respectively, compared to the treatment without micronutrient fertilisation. Foliar application of Cu significantly reduced the accumulation of ω and α/β gliadins (by 6.4% and 5.7%), and Zn reduced α/β and γ gliadins (by 6.1% and 11.8%).

Table 6. The protein fractions of gliadins and glutenins in the grain of spelt variety ‘Schwabenkorn’ foliar-applied with micronutrients

Fertilisation treatments		Gliadins (mAUs)			Glutenins (mAUs)	
		ω	α/β	γ	HMW	LMW
Control (NPK)	average	1895 b	25426 b	18557 b	11399 b	30451 b
	SD	9.29	124.86	23.64	66.34	219.91
NPK + Cu	average	1774 c	23967 c	18964 ab	11303 b	31452 ab
	SD	15.51	62.17	211.14	42.58	170.50
NPK + Zn	average	1815 bc	23864 c	16374 c	11988 a	31333 ab
	SD	32.53	209.10	70.47	51.74	380.31
NPK + Mn	average	2047 a	26944 a	19539 a	11213 b	26904 c
	SD	38.37	301.80	191.42	201.55	64.30
NPK + Cu + Zn + Mn	average	1872 bc	24742 b	16707 c	12062 a	32195 a
	SD	30.01	62.75	28.68	28.68	261.37
			Years			
2012	average	1672 b	22446 b	19249 a	11546 a	32345 a
	SD	66.07	285.25	78.11	155.45	301.50
2013	average	2089 a	27532 a	16807 b	11640 a	28589 b
	SD	43.15	49.87	225.20	58.12	77.52

Note. Averages in columns (separately for micronutrients and years) followed by the same letter are insignificant ($\alpha < 0.05$); SD – standard deviation; mAUs – milli-absorbance units; HMW – high molecular weight, LMW – low molecular weight.

As a result of spraying with micronutrients (Cu + Zn + Mn), the γ gliadin content dropped by 10% compared to NPK. Glutenin content levels (HMW and LMW) in spelt grain are primarily genetically conditioned (Wieser et al., 2009) and are differentiated by weather conditions and both mineral and organic fertilisation (Stępień, Wojtkowiak, 2013). In the completed research, the highest content of HMW glutenins (12062 mAUs) and LMW (32195 mAUs) was observed in the case of application of three micronutrients with nitrogen, as compared to mineral nitrogen fertilisation. As a result of fertilisation with Zn, HMW glutenins increased by 5.2%. Adding Mn to mineral fertilisation reduced the concentration of LMW glutenins by 11.6%. The content of ω and α/β gliadins was found to increase and that of γ gliadins and LMW glutenins was found to decrease in grain during the second year of the study. Based on the findings of the study the changes in the content and composition of the protein resulting from application of microelements were not uniform. Cu, Zn and Mn participate in many physiological processes vital for the plant. The difficulty in interpreting the effect of these microelements results from tha fact that it cannot be definitely stated which physiological effects evoked by these elements had an effect on the direction of the change. Weather conditions could also influence the quality of spelt grain during the vegetation period.

Correlation analysis proved a positive relationship between Mn content in grain and the volume of albumins and globulins ($r = 0.647$), the sum of gliadins ($r = 0.524$) and γ gliadins ($r = 0.695$), and a negative relationship with the content of HMW glutenins ($r = -0589$) (Table 7).

Table 7. Correlations between micronutrients, grain yield, content of protein, composition of protein in the grain of spelt variety ‘Schwabenkorn’ with the foliar application of micronutrients

		Cu	Mn	Fe	Zn
Grain yield		ns	ns	ns	ns
Content of protein		ns	ns	−0.659	ns
Albumins and globulins		ns	0.647	ns	0.739
Gliadins		ns	0.524	−0.591	ns
Glutenins		ns	ns	ns	ns
Gliadins:glutenins		ns	ns	ns	ns
Gliadins	ω	ns	ns	ns	ns
	α/β	ns	ns	ns	ns
	γ	ns	0.695	0.754	0.540
Glutenins	HMW	ns	−0.589	0.720	ns
	LMW	ns	ns	ns	ns

ns – not significant differences; HMW – high molecular weight, LMW – low molecular weight

A positive correlation was also observed between Fe content and γ gliadins ($r = 0.754$) and HMW glutenins ($r = 0.720$), and a negative correlation with sum of gliadins. Zn content in grain was positively correlated with the amount of albumins and globulins ($r = 0.739$) and γ gliadins ($r = 0.540$).

Conclusions

1. Supplementing NPK fertilisation with Mn and micronutrients used in combination (Cu + Zn + Mn) increased Fe, Zn and Mn content in spelt grain. Fertilisation with Zn increased Fe and Zn contents, and fertilisation with Cu increased the amount of Mn in grain.
2. Additional fertilisation with copper, zinc and micronutrients in combination had a positive impact on the gliadins:glutenins ratio.
3. As a result of foliar fertilisation with Mn, the content of ω, α/β, γ gliadins increased, and the content of low molecular weight (LMW) glutenins dropped. Foliar spraying with Cu decreased the content of α/β and ω gliadins in grain. Fertilisation with Zn reduced α/β content and increased the amount of high molecular weight (HMW) glutenin fractions. The application of micronutrients in combination (Cu + Zn + Mn) reduced the content of γ gliadins and increased the HMW and LMW glutenins content.

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Spelta (*Triticum aestivum* spp. *spelta* L.) kviečių maistinė vertė priklausomai nuo tręšimo per lapus variu, cinku ir magniu

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Santrauka

Tyrimo metu veislės ‘Schwabenkorn’ spelta kviečių grūduose buvo nustatytas grūdų derlius, mineralinių medžiagų (Cu, Zn, Mn bei Fe) kiekis, baltymai ir jų sudėtis, priklausomai nuo tręšimo mikroelementais per lapus. Lauko bandymas buvo vykdytas 2011–2013 m. Lenkijoje, Tomaszkowo bandymų stotyje (53°72 N, 20°42 E). Mikroelementai Cu, Zn ir Mn buvo naudojami kartu su mineralinėmis trąšomis (Cu + Zn + Mn). Visi laukeliai buvo tręšti 90 kg ha^{-1} azoto, trigubu superfosfatu – norma, atitinkančia 30,2 kg ha^{-1} P, ir kalio druska – norma, atitinkančia 83,1 kg ha^{-1} K. Varis (1,0 % tirpalas $CuSO_4 \times 5H_2O$), cinkas (1,0 % tirpalas $ZnSO_4 \times 7H_2O$) ir manganas (0,5% tirpalas $MnSO_4 \times 5H_2O$) buvo purškiami ant lapų kaip vandeniniai tirpalai stiebo ilgėjimo tarpsniu. Mineralinis tręšimas, taip pat ir mikroelementais (atskirai arba kartu), grūduose pakeitė mineralinių maisto medžiagų bei baltymų kiekį ir jų atskirų frakcijų sudėtį. Nustatyta, kad grūdai turėjo didelį kiekį Cu, Mn ir Fe. Tręšimas Mn, taip pat ir mikroelementais (Cu + Zn + Mn), kaip priedas prie NPK tręšimo, spelta grūduose padidino Fe, Zn ir Mn kiekį. Tręšimas Zn grūduose padidino Fe ir Zn kiekį, o Cu – Mn kiekį. Bendras baltymų kiekis spelta grūduose svyravo nuo 12,4 iki 13,5 %. Nustatyta, kad didžiausią dalį bendro baltymų kiekio sudaro atsarginiai baltymai. Papildomas tręšimas Cu ir Zn kartu su mikroelementais turėjo teigiamos įtakos gliadinų ir gluteninų santykiui. Tręšimas Mn per lapus padidino gliadinų ω, α/β bei γ kiekį ir sumažino mažo molekulinio svorio gluteninų kiekį. Tręšimas Cu per lapus sumažino gliadinų α/β ir ω kiekį. Tręšimas Zn sumažino gluteninų α/β kiekį ir padidino didelio molekulinio svorio gluteninų frakcijų kiekį. Tręšimas mikroelementų deriniu sumažino gliadino γ ir padidino didelio bei mažo molekulinio svorio gluteninų kiekį. Auginimo metai buvo svarbus veiksnys, lemiantis derliaus, mineralinių maisto medžiagų (Fe, Zn ir Mn) ir baltymų frakcijų kiekio bei sudėties (išskyrus didelio molekulinio svorio gliuteninus) skirtumus.

Reikšminiai žodžiai: baltymų kiekis, baltymų sudėtis, gliadinai, gluteninai, mikroelementai, ‘Schwabenkorn’.