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The effect of environmental conditions on the content of selected micronutrients in spelt grain

Wpływ warunków środowiskowych na zawartość wybranych mikroelementów w ziarnie orkiszu

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Słowa kluczowe: nawożenie azotem i mikroelementami, *Triticum aestivum* ssp. spelta L., zawartość miedzi, manganu i cynku w ziarnie

Abstract
The aim of the study was to determine the effect of application of small amounts of nitrogen to the soil together with foliar application of micronutrients on the content of copper, manganese and zinc in the grain of spelt (*Triticum aestivum* ssp. *spelta* L.). The study was based on a two-factor field experiment conducted in 2009–2011 on very good rye complex soil. Nitrogen was applied in the form of ammonium nitrate (34% N), and manganese and copper were applied to the leaves in the form of the fertilisers Adob Mn (1.5 l·ha^{-1}) and Adob Cu (1.0 l·ha^{-1}), respectively. The results indicated that the nitrogen fertilisation, the foliar application of micronutrients and the interaction of these factors significantly determined the contents of copper, manganese and zinc in the grain. The highest content of Cu and Mn in the material was obtained following the application of 50 kg N·ha^{-1}, and an increase in nitrogen application (to 50 kg·ha^{-1}) caused a decrease in the content of zinc in the grain. Foliar application of Cu, Mn and both elements together resulted in significant changes in the concentrations of Cu, Mn and Zn in the plant material as compared to treatment without the application of micronutrients. The mineral fertilisers at the rates applied had a beneficial effect on the chemical composition of the grain, and thus on its quality, and this was achieved with substantially lower consumption of agrochemicals than that in the case of agrotechnical procedures for traditional cereals. It can, therefore, be concluded that this practice is environment friendly and can significantly reduce the negative impact of agricultural activity.

Streszczenie
Celem pracy było określenie zawartości miedzi, manganu i cynku w ziarnie orkiszu pszennego (*Triticum aestivum* ssp. *spelta* L.), który uprawiano na glebie nawożonej zróżnicowanymi, niewielkimi dawkami azotu i wybranymi mikroelementami. Podstawą badań, które przeprowadzono w latach 2009-2011 na glebie kompleksu żytniego bardzo dobrego, było dwuczynnikowe doświadczenie polowe. Nawożenie azotem stosowano w formie saletry amonowej (34% N), a aplikację dolistną manganu i miedzi w formie nawozów Adob Mn (1,5 l·ha^{-1}) i Adob Cu (1,0 l·ha^{-1}). Na podstawie uzyskanych wyników stwierdzono, że nawożenie azotem, aplikacja dolistna mikroelementów oraz współdziałanie wymienionych czynników istotnie determinowały zawartości miedzi, manganu i cynku w ziarnie. Najwyższą ilość Cu i Mn w badanym materiale roślinnym uzyskano po doglebowym zastosowaniu 50 kg N·ha^{-1}, a zwiększanie poziomu nawożenia azotem do 50 kg·ha^{-1} powodowało spadek zawartości cynku w ziarnie. Dolistna aplikacja Cu, Mn oraz łącznie Cu+Mn skutkowała istotnymi zmianami w koncentracji Cu, Mn i Zn w analizowanym materiale roślinnym, w stosunku do obiektu bez nawożenia mikroelementami. Zastosowane dawki nawozów mineralnych wpłynęły korzystnie na skład chemiczny ziarna, a tym samym na jego jakość przy zdecydowanie niższym zużyciu agrochemikaliów w porównaniu do agrotechniki tradycyjnych zbóż. Zatem działanie takie było przyjazne dla środowiska naturalnego i w znacznym stopniu może ograniczać negatywne skutki prowadzenia działalności rolniczej.

1. INTRODUCTION

In Poland, soil, an environmental factor, is of relatively low quality because of the predominance of light soils. For this reason, with a nearly 75% share of cereals in the crop distribution, cereal monoculture should be limited to hold back the processes of soil degradation. An improvement over currently used crop rotations may contribute to better utilisation of habitat resources and reduce the spread of diseases, pests and weeds, and thus limit the use of agrochemicals [Krasowicz et al. 2011, Święcicki et al. 2011]. The results of research in the dynamically growing field of food science, in conjunction with the analysis of the relationship between diet and human health, have led to a new appreciation for old plant species. One of these is spelt, which is grown with little or no mineral fertilisers or plant protection products. The original traits retained in the grain of *Triticum aestivum* ssp. *spelta* L., which is a rich source of valuable nutrients, are sought by consumers as an element of a healthy diet [Marconi et al.

2002, Ruibal-Mendieta et al. 2005, Abdel-Aal 2008, Kohajdová, Karavičová 2008, Konvalina et al. 2008, Zieliński et al. 2008, Biel et al. 2010, Korczyk-Szabó, Lacko-Bartošová 2013, Knapowski et al. 2015]. Spelt is distinguished not only by higher nutrient content but also by lower habitat requirements and smaller expenditures on farm inputs when as compared to common wheat [Sulewska et al. 2008, Knapowski et al. 2016a]. Cultivation of this species is thus environment friendly, as besides the limited use of mineral fertilisers, especially those containing nitrogen, which can increase the content of harmful nitrates in plant products and degrade the soil environment, leading to eutrophication of water, it also does not require the use of pesticides. Spelt also contributes to the diversification of the agricultural landscape dominated by traditional cereals. The demand for the grain of this cereal has created the necessity for multi-faceted research on factors influencing its quality characteristics, especially because the high quality of a spelt product is only guaranteed by the use of suitable raw material for production. A requisite for obtaining specific values for individual parameters is the ability to select a cultivation technology suited to the given soil and climate conditions and to a specific cultivar. Recommendations for spelt cultivation lack conclusive information on its response to agrotechnical procedures, including fertilisation [Wojtkowiak, Stępień 2015, Knapowski et al. 2016ab]. Whilst this cereal has low requirements for nitrogen application but considerable sensitivity to deficiencies of this element, the data describing the response of spelt grown in Poland to nitrogen fertiliser are regarded as inadequate. Furthermore, the beneficial effect of fertilisation of cereals with micronutrients, particularly in conjunction with nitrogen application, has been receiving increasing attention [Sulewska et al. 2008, Kaniuczak et al. 2009, Warechowska 2009ab, Shi et al. 2010, Wojtkowiak, Stępień 2015, Knapowski et al. 2016b]. In the case of application of micronutrients for the cultivation of spelt, there is lack of specific data regarding the advisability of their use and the conditions in which the procedure should be carried out. Thus the determination of fertilisation requirements will not only verify the recommendations regarding the application rates of individual nutrients but also show their interactions.

2. MATERIAL AND METHODS

The study was based on a two-factor field experiment carried out in 2009–2011 at the Research Station of the University of Technology and Life Sciences in Minikowo (53°10′2″N, 17°44′22″E, Kuyavian-Pomeranian Voivodeship), set up in a split-plot design. Material derived from this experiment comprised grain of spelt wheat grown in conditions of varied fertilisation with nitrogen and foliar application of microelements and continuous fertilisation with P and K. The experiment was carried out in three replications in typical lessive soil, classified by the UN Food and Agricultural Organisation and United Nations Educational, Scientific and Cultural Organisation as albic luvisols (very good rye complex, soil quality class III a). The chemical analysis performed before establishment of the experiment showed that it has neutral reaction and that the contents of the available forms of P, K, Mg and Mn were high or medium. In contrast, the concentrations of Cu and Zn were low. The first experimental factor was fertilisation with nitrogen (n = 3), which was applied in the form of ammonium sulphate (34% N) at the following rates and times: 25 kg·ha^{-1} (N_{25}) to soil at full tillering (BBCH 23–29); 50 kg N·ha^{-1} (N_{50}) divided into three doses, 25 kg to soil at full tillering (BBCH 23–29), 15 kg on leaves at full shooting stage (BBCH 34–37) and 10 kg on leaves at the start of heading (stage 50–51 acc. to the BBCH scale); and control treatment without nitrogen (N_0). The other factor (n = 4) was different fertilisation with microelements, that is, treatments in which the following foliar rates were applied: Mn as the fertiliser Adob Mn (1.5 dm^3·ha^{-1}), Cu as the fertiliser Adob Cu (1.0 dm^3·ha^{-1}), combined application of Mn and Cu and control without microelements (Mn_0Cu_0). Spraying was performed on one day (until the 1-node stage, i.e. BBCH 30), diluting the fertilisers appropriately in the water volume corresponding to 300 dm^3·ha^{-1}. A constant level of phosphorus and potassium fertilisation was applied. The previous crop for the examined cereal was oats. All cultivation practices, including sowing and harvesting, were performed according to the agricultural requirements for the given species. Grain samples were collected from each of the experimental plots for chemical analyses. Measurements of the following parameters were made in appropriately prepared plant material (the grain was cleaned and separated) obtained from the collected representative samples. Prepared samples of spelt grain were used to determine the content of copper, manganese and zinc (by atomic absorption spectrometry, with a Varian AA240FS Spectrometer, following mineralisation of the plant material in a mixture of HNO_3 and HCl). The results obtained were subjected to statistical analysis using the analysis of variance according to the model corresponding to the experimental design, using Tukey's test to assess the significance of differences.

3. RESULTS AND DISCUSSION

The copper content in the spelt grain was significantly determined by fertilisation with nitrogen and micronutrients. The concentration of this nutrient was also determined by the interaction of the factors (Table 1). Significantly, the highest (4.99 mg·kg^{-1}) content of this element was noted in the grains treated with the application of nitrogen and copper in the form of Adob Cu at a rate of 0.2 kg·ha^{-1}, and the lowest (4.14 mg·kg^{-1}) following the foliar application of manganese without nitrogen; the difference was 20.5%. The mean content of copper in the spelt grain was 4.48 mg·kg^{-1}. In the experiments by Ceglińska and Gromulska [2008], copper content in spelt grain was over two times higher, ranging from 10.0 to 11.5 mg·kg^{-1}. In contrast, lower copper content in spelt grain was reported by Knapowski et al. [2015], who noted a mean value of 4.05 mg·kg^{-1} for the Rokosz cultivar. Wojtkowiak and Stępień [2015] reported a content of 3.40 and 3.41 mg·kg^{-1} DW, depending on the year, whilst in an experiment by Rachoń and Szumiło [2009], the values ranged from 2.85 to 2.99 mg·kg^{-1}, depending on the strain of the cereal. These last results, in contrast with the present study, are consistent with the content of copper in other cereals, that is, common wheat and spring triticale, tested in experiments of other authors [Kulczycki,

Table 1. The copper content in the grain of spelt wheat [mg·kg^{-1} d.m.].

Nitrogen fertilisation (first factor) [kg·ha^{-1}]	Micronutrients fertilisation (second factor)				
	0	Mn	Cu	Mn + Cu	Mean
0 N_0	4.19	4.14	4.25	4.22	4.20
25 N_{25}	4.45	4.62	4.40	4.37	4.41
50 N_{50}	4.25	4.75	4.99	5.17	4.79
Mean	4.30	4.50	4.54	4.59	4.48
LSD (p = 0.05) for:	I	II	I × II	II × I	
	0.13	0.11	0.19	0.18	

Grocholski 2004, Kohajdová, Karavičová 2008, Knapowski et al. 2012].

Higher copper content in grain, as reported by Borkowska [2004], is determined by an increased level of nitrogen fertilisation, and differences in its content result from different atmospheric conditions prevailing during plant growth. In a study by Knapowski et al. [2015], the use of increasing nitrogen application rates generally increased the copper content with respect to the control, with the significantly highest content noted in the grain from the treatments with 20 kg N·ha^{-1}, wherein where it was 40.3% higher than that in the control. The lowest copper content was noted in grains obtained from the treatment with 40 kg nitrogen, and it was only 0.85% higher than that in the control plots. The use of increasing nitrogen application rates in the experiment caused positive changes in the copper content irrespective of the application of micronutrients. The significantly highest content of this element was noted in the grain obtained following nitrogen application at a rate of 50 kg·ha^{-1}. The differences were 14.1% and 8.6% when compared with the control and the N_{25} treatment, respectively, and 5.0% between the N_{25} treatment and the control. Irrespective of nitrogen application, the highest content of copper was noted in the treatment with combined manganese and copper application (4.59 mg·kg^{-1}, Table 1). This was significantly higher (by 6.7%) than that in the treatment without application of micronutrients. It should be stressed that foliar application of Mn or Cu alone in the spelt crop, as compared to the control, also resulted in a significant increase in this nutrient in the grain by 5.6% and 4.6%, respectively. These correlations are not confirmed by the results of the study by Knapowski et al. [2015], in which the highest Cu content was observed following the application of copper alone (4.29 mg·kg^{-1}) and was significantly higher than the values obtained in the treatments with manganese application (by 9.4%) and Cu + Mn + Zn together (by 14.1%). The authors also report that foliar application of Mn alone or Cu + Mn + Zn together decreased the content of this mineral in the grain as compared to the control. The content of copper in the spelt grain was determined by the interaction of the factors tested (Table 1). The highest significant value for this nutrient (5.17 mg·kg^{-1}) was noted in the case of the highest level of nitrogen application together with combined foliar application of manganese and copper. This interaction of fertilisation with nitrogen and micronutrients for this cereal is confirmed by the results of an experiment conducted by Knapowski et al. [2015].

In the present study, the mean content of zinc in the spelt grain was 26.33 mg·kg^{-1} (Table 2), which was 23.1% lower than that obtained in an experiment by Rachoń et al. [2009], that is, 34.25 mg·kg^{-1}. The zinc concentration in the 'Schwabenkorn' cultivar of spelt ranged from 33.7 to 36.5 mg·kg^{-1} [Wojtkowiak, Stępień 2015]. Substantial variation in the content of this mineral has been observed in the grain of common wheat; Zieliński et al. [2008] reported a range from 21.0 to 35.4 mg□kg^{-1}. Zinc content in cereal grain depends on numerous factors, including mineral fertilisation. In the present study, as in a study by Knapowski et al. [2015], it was significantly dependent on the factors tested, that is, nitrogen fertilisation, foliar application of micronutrients and their interaction (Table 2). On an average, each 25 kg·ha^{-1} increase in the level of nitrogen application in the spelt crop led to a decrease in the content of zinc in the grain as compared to the N_0 treatment. It should be noted, however, that statistical significance was not obtained until nitrogen application was increased to 50 kg·ha^{-1}, and the value obtained in this treatment was lower than that in both the 25 kg treatment and the control, by 5.9% and 6.7%, respectively. In the experiment cited above, each 20 kg N·ha^{-1} increase in the level of fertilisation resulted in a decrease in zinc content in the spelt grain as compared to the N_0 treatment. Following the application of nitrogen at rates of 40, 60, 80 and 100 kg·ha^{-1}, a significant decrease was observed as compared to the control, by 16.8%, 17.0%, 23.9% and 25.7%, respectively. Application of single micronutrients caused a decrease in zinc content in comparison with the grain from the control. The statistically highest significant mean decrease in the content of this element as compared to the control was noted in the case of foliar application of manganese (6.7%) followed by copper (6.5%). In the case of combined spraying of Cu and Mn in the spelt plantation, the changes took a different direction. The zinc concentration in the grain increased slightly and the difference was statistically significant. Knapowski et al. [2015] reported that the greatest mean decrease in zinc content in the grain of the Rokosz variety of winter spelt in comparison with the control was noted in the case of Mn application and the least for combined application of Cu + Mn + Zn. The results of the present study indicate a significant interaction of the factors tested on the content of this element. Its highest content was noted following the application of 25 kg N·ha^{-1} and combined foliar application of copper and manganese.

The mean content of manganese in the spelt grain was 50.13 mg·kg^{-1} (Table 3), which was higher than the concentrations

Table 2. The zinc content in the grain of spelt wheat [mg·kg^{-1} d.m.].

Nitrogen fertilization (first factor) [kg·ha^{-1}]	Micronutrients fertilisation (second factor)				
	0	Cu	Mn	Cu + Mn	Mean
0 N_0	29.78	25.95	26.79	27.13	27.42
25 N_{25}	28.72	25.43	23.98	28.09	26.56
50 N_{50}	23.03	24.87	25.29	26.92	25.03
Mean	27.18	25.42	25.36	27.38	26.33
LSD (p = 0.05) for:	I	II	I × II	II × I	
	1.106	0.171	1.014	0.296	

Table 3. The manganese content in the grain of spelt wheat [mg·kg^{-1} d.m.].

Nitrogen fertilisation (first factor) [kg·ha^{-1}]	Micronutrients fertilisation (second factor)				
	0	Mn	Cu	Mn + Cu	Mean
0 N_0	44.70	46.69	50.33	48.66	47.59
25 N_{25}	49.23	49.11	52.30	51.48	50.53
50 N_{50}	49.73	51.82	54.98	52.48	52.25
Mean	47.89	49.20	52.54	50.87	50.13
LSD (p = 0.05) for:	I	II	I × II	II × I	
	1.14	0.56	1.29	0.97	

reported by Rachoń and Szumiło [2009], Wojtkowiak and Stępień [2015] and Stankowski et al. [2016], which ranged from 18.74 to 43.8 mg·kg^{-1}, depending on the cultivar and strain of spelt. In studies conducted on common wheat, the content of manganese in the grain was lower than that in our study, ranging from 30.40 to 61.01 mg·kg^{-1} [Borkowska 2004, Kaniuczak et al. 2009]. The content of manganese in spelt grain is differentiated by the cultivar factor [Stankowski et al. 2016]. The experimental factors and their interaction significantly determined the content of Mn in the grain of *Triticum spelta* (Table 3). Increasing the level of nitrogen fertiliser has been shown to decrease the manganese content in the grain of certain wheat cultivars whilst increasing it in others [Borkowska 2004].

Stankowski et al. [2016] found that nitrogen application did not significantly differentiate the manganese content in spelt grain; the authors did note an increase in Mn in the grain following the application of up to 50 kg·ha^{-1} nitrogen whilst subsequent levels (100 and 150 kg) caused it to decrease. In the present study on spelt, irrespective of the application of micronutrients, an increase in the rate of nitrogen application caused a significant increase in the Mn content in the grain. The highest content of this micronutrient was found in the grain fertilised with 50 kg N·ha^{-1}, which was 3.4% and 9.8% higher than that in the treatment with 25 kg N·ha^{-1} and the control, respectively. Application of micronutrients in the present study also significantly modified the content of manganese in the spelt grain (Table 3). Its highest average concentration was obtained in samples from the treatments with foliar application of copper. It was higher than the manganese content in the grain following spraying of the plantation with Mn, combined application of Mn + Cu and no application of micronutrients by 6.8%, 3.3% and 9.7%, respectively. Foliar spraying of manganese and Mn + Cu together also caused a statistically confirmed increase in the mean concentration of this element in the grain as compared to the treatment without the application of micronutrients by 2.7% and 6.2%, respectively. The interaction of the research variables had a significant effect on this trait. The highest manganese concentration was noted in the grain from the plants fertilised with 50 kg N·ha^{-1} and sprayed with copper; this was as much as 23.0% higher than that in the control.

4. CONCLUSIONS

Cultivation of primitive cereals, which include spelt, is an environment-friendly practice because it places a minor burden on the natural environment, particularly the soil. The soil environment provides the opportunity for agricultural production to meet the demands for food, animal feed, energy and raw materials for energy and industry. The present study showed that the mineral composition of the spelt grain was significantly determined by the varied levels of nitrogen application, foliar application of micronutrients and the interaction of these factors. A statistically confirmed increase in the copper and manganese content in the grain of the winter cereal as compared to the control was observed following the application of both 25 and 50 kg N·ha^{-1}. The highest concentrations of these nutrients were also observed following foliar application of manganese and copper together and copper alone, irrespective of nitrogen fertilisation. Increasing the level of nitrogen application and of foliar application of single micronutrients caused, on an average, a statistically confirmed decrease in the content of zinc in the grain of *Triticum aestivum* ssp. *spelta* L. To sum up, the relatively low levels of mineral fertilisers used in the experiment had a beneficial effect on the chemical composition of the grain. The consumption of agrochemicals to grow this species was markedly lower than that in the case of agrotechnical procedures for traditional cereals. It can, therefore, be concluded that rational management of soil resources in each region of Poland, including systematic reduction of the use of high levels of mineral fertilisers in crop production, is an important direction of development and, at the same time, a necessity for protecting the natural environment.

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