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Mineral fertilization as a factor determining technological value of grain of *Triticum aestivum* ssp. *spelta* L.

Nawożenie mineralne jako czynnik determinujący wartość technologiczną ziarna *Triticum aestivum* ssp. *spelta* L.

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Słowa kluczowe: nawożenie azotem, nawożenie mikroelementami, parametry technologiczne, *Triticum aestivum* ssp. *spelta* L.

Abstract
In Poland, in recent years, there has been a great interest in growing spelt wheat. This is dictated not only by an increasing demand for food with higher healthy properties and unique taste, but also by a possibility of attracting farmers' attention to this cereal as an alternative crop, with smaller requirements regarding the use of fertilization, as compared with common wheat. The aim of this study was to carry out the assessment of value of some technological characters of grain and flour of spelt wheat depending on different fertilizations with nitrogen (*I* factor, *n*=3, 25 and 50 kg N·ha^{-1} + control treatment) and foliar application of microelements (II factor, *n*=4, Mn, Cu, combined fertilization with Mn and Cu + control treatment). Based on the performed study, it was found that fertilization with nitrogen, microelements and their interaction had, on average for years, a significant effect on the values of technological characters. Introduction of 25 kg N·ha^{-1} caused an increase in the value of falling number, whereas total protein content, wet gluten content and sedimentation value increased as a result of increasing nitrogen rates up to a level of 50 kg·ha^{-1}. Of the variants of fertilization with microelements, the highest values of the analysed baking indices were found in the effects of combined foliar application of copper and manganese.

Streszczenie
W Polsce w ostatnich latach wzrosło zainteresowanie uprawą pszenicy orkisz. Podyktowane to jest nie tylko rosnącym zapotrzebowaniem na żywność o wyższych właściwościach zdrowotnych, unikalnym smaku, ale także możliwością zwrócenia uwagi rolników na to zboże jako na roślinę alternatywną, m.in. o mniejszych wymaganiach w odniesieniu do stosowania nawożenia w porównaniu do pszenicy zwyczajnej. Celem badań było przeprowadzenie oceny wartości wybranych cech technologicznych ziarna i mąki pszenicy orkisz w zależności od zróżnicowanego nawożenia azotem (I czynnik, n=3, 25 i 50 kg N·ha^{-1} + obiekt kontrolny) oraz dolistnej aplikacji mikroelementów (II czynnik, n=4: Mn, Cu, Mn+Cu i obiekt kontrolny). Na podstawie przeprowadzonych badań stwierdzono, że nawożenie azotem, mikroelementami oraz ich interakcja wpływały, średnio dla lat, w istotny sposób na wartości cech technologicznych. Zastosowanie 25 kg N·ha^{-1} powodowało wzrost wartości liczby opadania, natomiast zawartość białka, ilość glutenu i wartość wskaźnika sedymentacji wzrastały w wyniku zwiększaniu dawek azotu do poziomu 50 kg·ha^{-1}. Wśród wariantów nawożenia mikroelementami, najwyższe wartości analizowanych wskaźników wypiekowych stwierdzono w wyniku łącznej dolistnej aplikacji manganu i miedzi.

1. INTRODUCTION

Wheats, as some of the oldest cultivated crops, occupy the main place among cereals (besides rye and maize) that are consumed as staple food in the world. In Poland, apart from the most common wheat species, in recent years, there have been a growing interest in the cultivation of spelt wheat (*Triticum aestivum* ssp. *spelta* L.) [Troccoli, Codiani 2005, Konvalina et al. 2012, Wojtkowiak, Stępień 2015, Knapowski et al. 2016]. This is dictated not only by a growing demand for food with higher health promoting values, but also unique taste qualities and high nutritive and dietetic value [Pospišil et al. 2011, Zaharieva et al. 2010]. It also results from attracting the attention of producer-farmers to this cereal as an alternative crop, with a higher resistance to unfavourable climatic and soil conditions. This crop has lower nutrition requirements as compared with common wheat, which favours reduction in the applied rates of mineral fertilizers and chemical crop-protection preparations, which is of importance for the natural environment [Márton et al. 2007]. The observed renewed interest of growing spelt wheat and dynamic progress in breeding process should be supported with the indication of optimal agricultural factors adapted to the site conditions and their mutual relationships that enable obtaining a high grain yield with the required quality standards. Using a suitable material for production will only ensure high quality of the obtained product, thus increasing the competitiveness and productive abilities of

agriculture. An analysis of the literature concerning the effect of individual cultivation practices indicates that there is no explicit information about the direction of changes in the technological value of spelt wheat grain determined for different fertilization levels and their mutual interactions [Knapowski et al. 2016]. Although spelt is a species that is undemanding with respect to nitrogen fertilization, which does not mean less sensitive than common wheat, the amount of data describing the response of spelt wheat to fertilization with this element during cultivation should be regarded as highly insufficient. Similarly, the results of the studies concerning fertilization of cereals with microelements do not give an explicit answer to the question about the usefulness and determinants of this practice, which probably results from different conducting conditions. While the problem of fertilization of common wheat with microelements is the subject of research [Warechowska, Domska 2006, Domska et al. 2009, Warechowska 2009], the question of its effect on the grain quality of spelt wheat has not been recognised yet. The aim of this study was to assess some selected technological characters of grain and flour of spelt wheat as affected by different nitrogen fertilization rates and applied foliar fertilization with the microelements: Mn and Cu and combined Mn+Cu application.

2. MATERIALS AND METHODS

The present study was based on a two-factorial field experiment conducted over 2009–2011 at the Research Station of the University of Technology and Life Sciences at Minikowo (53°10′2″N, 17°44′22″E, Kuyavian-Pomeranian voivodeship), established with the randomised split-plot design. Material derived from this experiment comprised grain of spelt wheat grown in conditions of varied fertilization with nitrogen and foliar application of microelements and continuous fertilization with P and K. The experiment was carried out in three replications in typical lessive soil, classified by FAO-UNESCO as Albic Luvisols (very good rye complex, soil quality class III a). Its chemical analysis performance before the experiment showed that it undergoes a neutral reaction, and contents of available forms of P, K, Mg and Mn were high or medium. In contrast, the concentrations of Cu and Zn were at low levels. The first experimental factor was fertilization with nitrogen (n=3), which was applied in the form of 34% ammonium sulphate in the following rates and times: 25 kg·ha^{-1} (N_{25}) to soil, at full tillering (BBCH 23–29), 50 kg·ha^{-1} (N_{50}) was divided: 25 kg to soil, at full tillering (BBCH 23–29), 15 kg on leaves at full shooting stage (34–37 BBCH) and 10 kg on leaves at the start of heading (stage 50–51 acc. to the BBCH scale) and the control treatment without nitrogen (N_0). The other factor (n=4) was different fertilization with microelements, i.e. treatments where the following foliar rates were applied: Mn as the fertilizer Adob Mn (1.5 dm^3·ha^{-1}), Cu as the fertilizer Adob Cu (1.0 dm^3·ha^{-1}), combined application of Mn and Cu and the control without microelements (Mn_0Cu_0). Spraying was performed on one day (until the one-node stage, i.e. BBCH 30), diluting appropriately the fertilizers in the water volume corresponding to 300 dm^3·ha^{-1}. A constant level of phosphorus and potassium fertilization was applied. The previous crop for the examined cereal was oats. All cultivation practices, sowing and harvest were performed according to the agricultural requirements for the given species. Measurements of the following technological parameters were made in appropriately prepared plant material (the grain was cleaned and separated) obtained from collected representative samples: falling number [according to Hagberg, PN-EN ISO 3093:2010], protein content [according to Kjeldahl, PN-EN ISO 20483:2007], wet gluten content [PN-EN ISO 21415-2:2008], sedimentation value [according to Zeleny, PN-EN ISO 5529:2010]. The obtained results of the study 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, and they were analysed using simple linear regression and correlation.

3. RESULTS AND DISCUSSION

The enzymatic properties of a grain are characterized by its falling number (FN). Based on this number, the storage and technological usefulness of grain for flour production and its further use in the baking industry can be inferred [Knapowski et al. 2015a]. The mean value of this number in the bakery should be 200–300 s [Bojňanská, Frančáková 2002, Krawczyk et al. 2008a, Ralcewicz et al. 2009]. In the present experiment, this value in the spelt wheat grain was 371 s (Table 1). Knapowski et al. [2016], analysing the grain of this cereal, obtained values ranging from 260 to 410 s. High FN were also observed in other studies [Rachoń et al. 2009, Szumiło et al. 2009]. The higher values of this number in the grain of *Triticum aestivum* ssp. *spelta* L. obtained in the present study and those by the cited authors does not rule out the grain under discussion as a raw material in the baking industry, since spelt wheat may be used to make mixtures with common wheat [Radomski et al. 2007, Szumiło et al. 2009, Knapowski et al. 2015b].

Because of this method of preparation, bread, the obtained final product, will be characterized by a better taste and smell, and a higher nutritive value. Moreover, the fact that bread made from only spelt wheat flour, due to its inadequate fermentation properties, and thus baking value, will not meet the requirements of an average consumer, in spite of exceptional healthy values, necessitates the use of mixtures. In the present experiment, irrespective of fertilization with microelements, the application of nitrogen at a rate of 25 kg·ha^{-1} resulted in a significant increase in the FN value, as compared with the value obtained on the control treatment (Table 1). According to many authors, the differentiated response of wheats manifested by an increase or decrease in FN and often in its lack, which is confirmed by the results of the author's own studies, after the application of higher nitrogen rates, results from a significant effect of genetic properties of the cultivar and the weather conditions on its value [Ralcewicz et al. 2009, Knapowski et al. 2016].

The most essential indirect indicators of baking value include markers characterizing the protein complex of grain, i.e. protein content (PC), wet gluten content (WG) and sedimentation value (SV). Much attention has been dedicated to these parameters in the literature [Marconi et al. 2002, Sulewska 2004, Abdel-Aal 2008, Kohajdová, Karavičová 2008, Krawczyk et al. 2008a,b, Sulewska et al. 2008, Knapowski et al. 2009, Biel et al. 2010].

Table 1. The values of technological parameters of *Triticum aestivum* ssp. *spelta* L. after the application of fertilizers (the average of 2009–2011)

Fertilization	Parameter			
	Falling number [s]	Protein content [g·kg^{-1}]	Wet gluten content [%]	Sedimentation value [cm^3]
Nitrogen (N) [kg·ha^{-1}]				
0 (control)	358 ± 36.9^b	175 ± 15.6^c	34.8 ± 2.33^c	34.8 ± 5.74^c
25	378 ± 34.5^a	190 ± 15.3^b	38.5 ± 1.95^b	38.5 ± 6.34^b
50	378 ± 30.2^a	197 ± 15.0^a	40.7 ± 2.50^a	40.7 ± 7.32^a
Microelements (M)				
0 (control)	371 ± 36.4	185 ± 18.8^b	48,8 ± 4.1^c	37.8 ± 6.3^b
Mn	372 ± 37.9	188 ± 18.7^a	48.8 ± 3.8^c	37.6 ± 7.5^b
Cu	369 ± 38.1	188 ± 18.6^a	49.8 ± 4.1^b	37.3 ± 7.7^b
Mn+Cu	374 ± 35.2	188 ± 15.8^a	51.1 ± 4.9^a	39.2 ± 6.9^a
Mean total	371 ± 35.3	187 ± 17.5	49.6 ± 4.2	41.2 ± 6.7
Interaction (N x M)	12.4*	2.4*	0.89*	1.4*

a, b, c - values followed by the same letter in each column in each fertilization, are not significantly different at the 0.05 level according to the Tukey's test

* Significant interaction: nitrogen fertilization × micronutrients fertilization

In the present experiment, irrespective of the research factors, the mean PC in the grain amounted to 187 g·kg^{-1}d.m. (Table 1). Lower values, in the range from 86 to 162 g·kg^{-1} d.m., were found in the studies by many authors [Marconi et al. 2002, Majewska et al. 2007, Krawczyk et al. 2008b, Makowska et al. 2008, Biel et al. 2010]. By contrast, the study by Bojňanska and Frančákova [2002] and by Sulewska et al. [2008] showed a large differentiation in the content of this element depending on the year of cultivation (125–195 g·kg^{-1}) and the cultivar or line *Triticum spelta* (133-215 g·kg^{-1}). While the problem of the effect of fertilization with nitrogen and microelements on the quality of yield, including PC, in common wheat grain is the subject of some studies [Domska et al. 2009, Ralcewicz et al. 2009], there is no explicit data in the available literature about their effect on quality characters, which significantly determine the technological value of spelt wheat as a valuable material for bread production. In the present experiment, the use of increasing nitrogen rates up to 50 kg·ha^{-1} caused on average a significant increase in PC and in comparison with treatments N_{25} and N_0, it amounted to: 3.7 and 12.6%, respectively. In studies by Biel et al. [2010] and Knapowski et al. [2016], each increase in nitrogen fertilization level (0–120 and 0–100 kg) caused an increase in the content of this element in spelt wheat grain: from 133 to 179 and from 107 to 151 g·kg^{-1}d.m., respectively. The use of individual variants of fertilization with microelements in the present experiment, irrespective of nitrogen fertilization, resulted in obtaining the same content of PC (188 g·kg^{-1}d.m.) and it was significantly higher compared with the control treatment, by 1.6% (Table 1). The significant effect of microelements on the value of the character in question is reported by studies of other researchers [Wojtkowiak & Stępień 2015, Knapowski et al. 2016]. In the present experiment, together with an increase in PC, gluten yield also increased, which corresponds to the results obtained for spelt wheat in the study by Krawczyk et al. [2008b] and Rachoń and Szumiło [2009]. The amount of WG modifies the physical characters of bread [Różyło et al. 2010]. In the present experiment, the mean WG was 49.6% (Table 1). Bojňanská and Frančáková [2002] observed a similar or lower amount of this element, which was in the range from 30.7% (cv. Holstenkorn) to 51.9% (cv. Schwabenkorn). Lower values of gluten yield (27.5-37.2%), as compared with the results of the author's own studies, were also obtained in other studies [Radomski et al. 2007, Krawczyk et al. 2008b, Makowska et al. 2008, Zieliński et al. 2008]. Differences in WG are largely dependent on the properties of the given cultivar, as well as the used cultivation technology, including mostly fertilization [Podleśna & Cacak-Pietrzak 2006, Kohajdová & Karavičová 2008, Rachoń et al. 2013, Biel et al. 2010]. It was found that irrespective of the application of microelements, each increase in the level of nitrogen fertilization caused a significant increase in WG. After the application of a rate of N_{25}, it was significantly higher as compared with N_0 by 5.1 percentage points (Table 1). An increase in rate by 25 kg N ha^{-1} resulted in a further significant increase in WG by 3.6 percentage points. The relationship of the effect of the obtained nitrogen fertilization and the amount of gluten, similar to the study by Knapowski et al. [2016], confirms the significant positive simple correlation coefficient (r=0.85; Table 2).

The important role of microelements in determining values of grain quality characters is stressed by Warechowska and Domska [2006], Warechowska [2009] and Knapowski et al. [2009], who focused particular attention to plant fertilization with copper. Of different variants of fertilization with microelements used in studies, the highest WG was found after the combined application of Mn+Cu (Table 1). It was significantly higher as compared with the value of this character obtained on the treatment fertilized with Cu, by 1.3 percentage points, and Mn and Mn_0Cu_0, by 2.3 percentage points. A significantly higher gluten yield was obtained on the treatments fertilized only with Cu, both in comparison with the amount from the treatments fertilized only with Mn and with Mn_0Cu_0, by 1 percentage point. An increase in WG in grain as a result of the foliar application of microelements was observed in studies by Potarzycki [2004] and Knapowski et al. [2016]. Based on the calculated analysis of variance, it was also found that WG was significantly determined by the combined effect of the applied

Table 2. Values of significant correlation coefficients between the features of wheat

Parameter	1	2	3	4
N fertilization	n.s.	0.52	0.85	0.36
Falling number (1)		n.s.	0.40	0.94
Protein content (2)			0.62	n.s.
Wet gluten content (3)				0.54
Sedimentation value (4)				-

n.s. – not significant

different fertilization with nitrogen and variants of fertilization with microelements. The higher amount of gluten (56.6%) was obtained on the treatment N_{50} with the application of Mn+Cu.

In the conducted experiment, the studied spelt wheat flour was characterized by the value of sedimentation index, on average for the years of the study, at a level of 38.0 cm^3 (Table 1). Similar or slightly higher values of this character were found in studies by some authors (37.5–42 cm^3) [Bojňanská, Frančáková 2002, Marconi et al. 2002], whereas lower values (12–31 cm^3) were reported by other researchers [Majewska et al. 2007; Krawczyk et al. 2008a]. Flour obtained from spelt wheat grain is characterized by a lower SV value, as compared with flour from common wheat. This indicates that in spite of the lower PC and WG, common wheat grain is characterized by a more favourable protein quality than that of spelt wheat, in respect of the needs of milling and baking industries [Majewska et al. 2007]. Irrespective of fertilization with microelements, application of 25 kg $N \cdot ha^{-1}$ in the study caused a significant increase in SV value compared with the control, by as much as 10.6%. Increasing fertilization up to 50 kg $N \cdot ha^{-1}$ resulted in a further significant increase in its value, by as much as 5.7%, as compared with N_{25}. An increase in the SV value of spelt wheat flours as a result of increasing the level of fertilization with nitrogen was also observed in studies by other authors [Podleśna, Cacak-Pietrzak, 2006; Knapowski et al. 2016]. As a result of application of the studied variants of microelement application, the highest value of this property was found on the treatment with combined fertilization with manganese and copper. That was significantly higher in comparison with the sedimentation index values obtained on the treatments fertilized only with copper, only with manganese and the control, by: 5.1, 4.3 and 3.7%, respectively (Table 1). The obtained results of the study allowed also for calculation of linear regression equations. These indicate that an increase in PC and WG in grain, e.g. by 10 units, may increase the amount of gluten by 1.49% (Fig. 1A) and the value of SV by 8.67 cm^3 (Fig. 1B). The above relationships were obtained in other works concerning cereals [Knapowski et al. 2009, Ralcewicz et al. 2009].

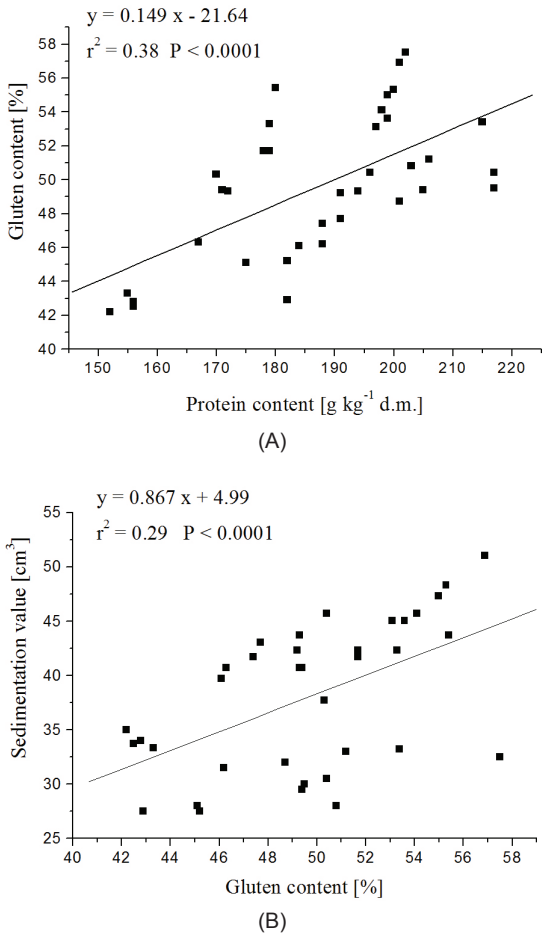

Figure 1. Relationships between the protein content and the wet gluten content (A) and between the wet gluten content and the sedimentation value (B) of spelt

4. CONCLUSIONS

The mean values of technological parameters characterizing amylolytic activity (falling number) and grain protein complex (total protein content, wet gluten content and sedimentation value), irrespective of the application of microelements, were significantly positively determined by the applied nitrogen rates. Application of microelements, and particularly combined foliar application of Mn and Cu, also had a significant effect on the growth in values of the above-mentioned properties of the protein complex, irrespective of fertilization with nitrogen. The positive response of spelt wheat to fertilization factors studied in the present experiment, and the results obtained based on the currently conducted experiments with this species, can have direct application in the agricultural practice and arouse the interest of agricultural producers in growing this cereal not only in conditions of organic farms. This would reduce the costly import of this material, which would be connected with a reduction in the costs of bread production with a proportion of flour obtained from this cereal at preserving its appropriate quality.

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