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EFFECT OF THE RATE OF NITROGEN AND ZINC ON THE ZINC AND COPPER ACCUMULATION IN GRAIN OF SPRING TRITICALE CULTIVAR KARGO

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Abstract

Modest stand requirements, high yielding potential and high nutritive value have made triticale an alternative crop to other cereals in Poland. The grain of that cereal is mostly used for making animal feed, although it can also be processed by the food industry. Triticale yields and the quality of grain are largely determined by agro-technical factors, including mineral fertilisation. Over the recent years, more attention has been attracted to the favourable effect of cereal fertilisation with microelements, especially more intensive nitrogen nutrition. In 2005–2007, a two-factor field experiment in a split-plot design was set up at the Agricultural Experimental Station in Minikowo, which belongs to the University of Technology and Life Sciences in Bydgoszcz. The aim of the paper was to evaluate the effect of different nitrogen rates and foliar zinc application on the content of zinc and copper in grain of cv. Kargo spring triticale. The plots, 20 m^2 each, were treated with two nitrogen fertilisation rates (factor I, n=2): 80 kg N ha^{-1} (N_{80}) and 120 kg N ha^{-1} (N_{120}) and three zinc fertilisation rates (factor II, n=3): Zn_0 (without zinc), Zn_1 (0.1 kg ha^{-1}) and Zn_2 (0.3 kg ha^{-1}) against fixed, pre-sowing phosphorus and potassium fertilisation. It was found that the rate of 120 kg N ha^{-1} resulted in a significant increase in the zinc content and a decrease in the copper concentration in grain of the cultivar Kargo spring triticale, as compared with the treatment which received 80 kg N ha^{-1}. Foliar zinc application, in all the rates applied, resulted in a significant increase in the zinc content and a decrease in the copper concentration in spring triticale grain.

Key words: spring triticale, nitrogen and zinc fertilisation, microelements.

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ODDZIAŁYWANIE DAWKI AZOTU I CYNKU NA AKUMULACJĘ CYNKU I MIEDZI W ZIARNIE PSZENŻYTA JAREGO ODMIANY KARGO

Abstrakt

Niewielkie wymagania w stosunku do stanowiska, duży potencjał plonowania i wysoka wartość pokarmowa spowodowały, że pszenżyto stanowi alternatywę dla uprawy innych zbóż w Polsce. Ziarno tego zboża wykorzystywane jest przede wszystkim na cele pastewne, ale może być również stosowane w przemyśle spożywczym. Plonowanie i jakość ziarna pszenżyta są determinowane w dużym stopniu czynnikami agrotechnicznymi, w tym nawożeniem mineralnym. W ostatnich latach coraz większą uwagę zwraca się na korzystny wpływ nawożenia zbóż mikroelementami, szczególnie w przypadku intensyfikacji nawożenia azotem. W latach 2005-2007 w Rolniczym Zakładzie Doświadczalnym Uniwersytetu Technologiczno-Przyrodniczego w Minikowie przeprowadzono dwuczynnikowe doświadczenie polowe, założone metodą losowanych podbloków. Celem pracy była ocena wpływu zróżnicowanych dawek azotu i dolistnej aplikacji cynku na zawartość cynku i miedzi w ziarnie pszenżyta jarego odmiany Kargo. Na poletkach o powierzchni 20 m^2 zastosowano dwa poziomy nawożenia azotem (I czynnik, n=2): 80 kg N ha^{-1} (N_{80}) i 120 kg N ha^{-1} (N_{120}) i trzy poziomy nawożenia cynkiem (II czynnik, n=3): Zn_0 (bez cynku), Zn_1 (0,1 kg ha^{-1}) i Zn_2 (0,3 kg ha^{-1}) na tle stałego przedsiewnego nawożenia fosforem i potasem. W wyniku badań stwierdzono, że dawka 120 kg N ha^{-1} istotnie wpłynęła na wzrost zawartości cynku oraz zmniejszenie koncentracji miedzi w ziarnie pszenżyta jarego odmiany Kargo, w porównaniu z obiektem, gdzie stosowano 80 kg N ha^{-1}. Dolistna aplikacja cynku, w całym zakresie stosowanych dawek, powodowała istotny wzrost zawartości cynku i zmniejszenie koncentracji miedzi w ziarnie pszenżyta jarego.

Słowa kluczowe: pszenżyto jare, nawożenie azotem i cynkiem, mikroelementy.

INTRODUCTION

For maintaining proper bodily functions, animals need a daily supply of basic nutrients (carbohydrates, proteins, fats) and the elements, often in trace amounts, participating in the metabolism (Borkowska 2004). A crucial role in animal nutrition is played by processed cereal grains, of which triticale grain is gaining in importance. Owing to a big progress in breeding, triticale has become the fifth cereal species grown in Poland (Maćkowiak 2003). Modest stand requirements, high yielding potential and high nutritive value have made it an alternative crop to other cereals in Poland. Triticale grain is used most often for animal feed, although it can also be processed by the food industry (Karczmarczyk et al. 2000, Tohver et al. 2005, Knapowski et al. 2009). Triticale yielding and grain quality are largely determined by agro-technical factors, including mineral fertilisation, especially with nitrogen (Pisulewska et al. 1998, Borkowska 2004, Mut et al. 2005, Spychaj-Fabisiak et al. 2005). Over the recent years, more attention has also been paid to the effect of cereal fertilisation with microelements, especially more intensive nitrogen nutrition (Czuba 2000, Wojtkowiak 2004, Knapowski et al. 2009). The need for fertilisation of cereals with microelements, including zinc, is indicated by Korzeniowska (2004), who demonstrated a distinct decrease in the amount of zinc in grain. Microelements regulate enzymatic processes, participate in carbohydrate and protein transformations and improve the effect of fertilisation with macroelements, which is why they help to achieve higher yields and better biological yield value (GRZYŚ 2004, BARCZAK et al. 2006, MAJCHERCZAK et al. 2006). Fertilisation with macro- and microelements affects concentrations of minerals in grain and, consequently, contributes to the nutritive value of animal feeds given to farm animals (PISULEWSKA et al. 1998).

Zinc participates in transformations of proteins, carbohydrates and nucleic acids in human and animal bodies; it also activates enzymes essential for the immune system. Copper is indispensable for triggering the reserves of iron needed for the synthesis of haemoglobin and erythrocyte production; it is also incorporated in many tissue enzymes and participates in the metabolism. Therefore, the content of microelements in rations should meet animal requirements. Both a deficit and an excess of macro- and microelements in the grain can induce unfavourable changes in an animal's metabolism (WHITAKER et al. 1997, KOROL et al. 2006, KLEBANIUK, GRELA 2008). Thus, it is necessary to assess the impact of mineral fertilisation on the chemical composition of grain.

The aim of the present paper was to evaluate to what extent different nitrogen and zinc rates determine the accumulation of zinc and copper in grain of the spring triticale cultivar Kargo.

MATERIAL AND METHODS

The research consisted of a two-factor field experiment in a split-plot design carried out in 2005–2007 at the Agricultural Experimental Station in Minikowo (the Kujawy and Pomorze Province), which belongs to the University of Technology and Life Sciences in Bydgoszcz. The spring triticale cultivar Kargo (C1 certified material) was the tested plant. It was grown under different nitrogen fertilisation and foliar zinc application. The experiment, with three replications, was performed on proper grey soil (good wheat complex), classified as Albic Luvisols according to the international FAO-UNESCO classification (MARCINEK, KOMISAREK 2011). The soil reaction was neutral and the content of available phosphorus, potassium and magnesium was very high or high. The copper content, on the other hand, was moderate and manganese and zinc appeared in amounts below the lower threshold values. The detailed physicochemical properties of the soil are given in Table 1.

20 m^2 plots were treated with two nitrogen fertilisation rates (factor I, n=2): 80 kg N ha^{-1} (N_{80}) and 120 kg N ha^{-1} (N_{120}) and three zinc fertilisation rates (factor II, n=3): Zn_0 (with no zinc), Zn_1 (0.1 kg ha^{-1}) and Zn_2 (0.3 kg ha^{-1}) against fixed, pre-sowing phosphorus fertilisation at

Table 1

Physicochemical properties of soil

Parameter			Range	Mean
Total N		$g\ kg^{-1}$	0.75 - 0.89	0.82
Organic C			6.96 - 8.64	7.85
Available	P	$mg\ kg^{-1}$	69.9 - 83.8	78.3
	K		179 - 219	206
	Mg		51.7 - 94.7	76.0
	Zn		6.94 - 13.8	8.76
	Cu		5.50 - 7.10	6.40
	Mn		205 - 417	380
pH in KCl			6.3 - 7.0	6.7
Hydrolityc acidity		$mmol(+)\ kg^{-1}$	11.9 - 17.5	14.9

60 kg P_2O_5 ha^{-1} as triple superphosphate (46% P_2O_5) and potassium at 120 kg K_2O ha^{-1} as potassium salt (57% K_2O). Nitrogen fertilisation was applied in the form of urea (46% N) according to the following schedule:

- the rate of 80 kg N ha^{-1} (N_{80}) was divided into 40 kg applied pre-sowing to soil and 40 kg as foliar fertilisation (10% urea solution) at the full stem elongation stage (stage 34 on the Zadoks scale);
- the rate of 120 kg N ha^{-1} (N_{120}) was divided into 40 kg applied pre-sowing into soil, 40 kg as foliar fertilisation (10% urea solution) at the full stem elongation stage (stage 34 on the Zadoks scale) and 40 kg as a foliar fertiliser (5% urea solution) at early inflorescence emergence (stage 50-51 on the Zadoks scale).

The foliar application of zinc consisted of $ZnCl_2$ sprays applied to triticale plants at the full stem elongation phase (stage 34 on the Zadoks scale). The preceding crop was oat harvested for grain. Spring triticale cv. Kargo was sown as ORIUS 060 FS-seed-dressed grain (60 g of the active substance per 1 dm^3) at the density of 5.5 mln ha^{-1}. All the soil tillage treatments, sowing and the cereal harvest were performed compliant with the agrotechnical guidelines for this species. The content of zinc and copper in the grain was determined by atomic absorption spectroscopy (AAS), having mineralized the plant material in a mixture of chloric and nitric(V) acids. The research results were statistically verified with the analysis of variance and using Tukey's test to determine the significance of differences.

The weather conditions throughout the experiment (2005-2007) are presented according to Sielianinov's hydrothermal coefficient (Table 2). The values of this coefficient confirm the changeability of the weather conditions in the subsequent years. The highest temperature and precipitation fluctuations occurred in the 2006 growing season, which had the biggest water

Table 2

Sielianinov's coefficient values throughout the research period

Years	Months				
	Apr	May	June	July	Aug
2005	0.99	2.19	0.68	0.75	0.84
2006	2.86	1.53	0.44	0.70	2.14
2007	0.71	1.71	1.94	1.88	0.76

deficits (Sielianinov's hydrothermal coefficient reached an average value of 0.44 in June, and 0.70 in July). In the April of that year, the coefficient reached the highest mean value (K=2.86), which proved the occurrence of very moist conditions. The year 2005 was more stable in terms of temperature and precipitation than the other years. Besides, it had little rainfall from June to August.

RESULTS AND DISCUSSION

The relevant literature suggests that, among all agro-technical factors, mineral fertilisation plays a special role and significantly determines cereal yields and grain quality (Nieróbca 2004, Mut et al. 2005, Spychaj-Fabisiak et al. 2005, Barczak et al. 2006, Majcherczak et al. 2006, Knapowski et al. 2009, Wareсhowska 2009).

The zinc requirements in most animal groups can be defined as 30 mg kg^{-1} d.m. (Smulikowska, Rutkowski 2005, Jamroz 2009). In the present experiment, the annual average content of zinc in triticale grain was 28.01 mg kg^{-1} (Table 3). A relatively low zinc content in cereal grain was also reported by Kulczycki and Grocholski (2004) as well as Medyńska et al. (2009): 20.8-29.0 and 19.4-25.1 mg kg^{-1}, respectively. In contrast, a content higher than reported by those authors or found in the present experiment is claimed by Karczmarczyk et al. (2000) – 34.50-37.80 mg kg^{-1}, Jackowska and Borkowska (2002) – 33.43 mg kg^{-1}, Wareсhowska (2009) – 28.47-31.05 mg kg^{-1} and Makarska et al. (2010) – 47.5-72.3 mg kg^{-1}.

In the present experiment, analogously to the reports by Dziamba and Jackowska (2001), Jackowska and Borkowska (2002) and Borkowska (2004), most zinc (the mean for the whole equal 29.85 mg kg^{-1} d.m.) was reported in grain after the application of the higher nitrogen rate (Table 3). The use of 120 kg N ha^{-1} resulted in a significant increase in the zinc content (by 3.68 mg kg^{-1} d.m.), as compared with the value reported for the treatment with 80 kg N ha^{-1}. Interestingly, similar relationships were recorded for all the research years, although the increase in the concentration of that

Table 3

Content of zinc (mg kg^{-1} d.m.) in spring triticale grain

Years	N fertilisation	Zn fertilisation (kg ha^{-1})			Mean	$LSD_{p=0.05}$ for fertilisation	
		Zn_0	Zn_1	Zn_2		N	Zn
2005	80 (N_{80})	23.95	25.65	27.80	25.80	interaction IxII- n.s.	IIxI- n.s.
	120 (N_{120})	25.41	28.22	29.90	27.84		
Mean		24.68	26.94	28.85	26.82	2.03	1.01
2006	80 (N_{80})	26.99	27.85	31.51	28.78	interaction IxII- n.s.	IIxI- n.s.
	120 (N_{120})	31.95	33.72	37.90	34.52		
Mean		29.47	30.78	34.71	31.65	4.80	2.55
2007	80 (N_{80})	20.38	24.04	27.36	23.93	interaction IxII- n.s.	IIxI- n.s.
	120 (N_{120})	23.49	27.30	30.76	27.18		
Mean		21.93	25.67	29.06	25.55	0.26	2.23
2005-2007	80 (N_{80})	23.77	25.85	28.89	26.17	interaction IxII- n.s.	IIxI- n.s.
	120 (N_{120})	26.95	29.75	32.85	29.85		
Mean		25.36	27.80	30.87	28.01	1.24	0.80

microelement in cv. Kargo spring triticale grain ranged from 2.04 to 5.74 mg kg^{-1} d.m., which agrees with the results reported by WARECHOWSKA (2004) who, having applied 120 kg N ha^{-1}, noted a significant increase in the zinc content in spring triticale grain, as compared with the fertilisation treatments of 80 kg N ha^{-1}. KARCZMARCZYK et al. (2000), on the other hand, noted an increase in the Zn concentration in spring triticale grain as a result of increasing the nitrogen rate to 150 kg ha^{-1}.

Similarly, the increasing zinc fertilisation modified the content of this nutrient in grain (Table 3). The highest (mean for the three years) zinc content in spring triticale grain (30.87 mg kg^{-1} d.m.) was noted after foliar application of Zn at the rate of 0.3 kg ha^{-1}. The value was significantly higher than that of the control and than the treatment where 0.1 kg Zn ha^{-1} was applied (5.51 and 3.07 mg kg^{-1} d.m., respectively). On the other hand, WARECHOWSKA (2009) recorded a lower concentration of this nutrient in wheat grain after the foliar application of 0.2 kg Zn ha^{-1} than in the control.

The average copper content in triticale grain was 4.62 mg kg^{-1} d.m. (Table 4) and it was higher than in the grain of the cereals investigated by JACKOWSKA and BORKOWSKA (2002) – 2.05-2.58 mg kg^{-1}, KULCZYCKI and GROCHOLSKI (2004) – 2.8-3.3 mg kg^{-1}, MEDYŃSKA et al. (2009) – 3.1-3.9 mg kg^{-1} and RACHOŃ and SZUMIŁO (2009) – 2.84-3.86 mg kg^{-1}. BORKOWSKA (2004) reported a higher content of this nutrient in the grain of all the tested spring wheat cultivars (6.07-7.75 mg kg^{-1}) than in the present research.

Table 4

Content of copper (mg kg^{-1} d.m.) in spring triticale grain

Years	N fertilisation	Zn fertilisation (kg ha^{-1})			Mean	$LSD_{p=0.05}$ for fertilisation	
		Zn_0	Zn_1	Zn_2		N	Zn
2005	80 (N_{80})	4.90	4.40	4.32	4.54	interaction IxII - 0.32 IIxI - 0.15	
	120 (N_{120})	4.03	4.24	4.27	4.18		
Mean		4.47	4.32	4.30	4.36	0.31	0.11
2006	80 (N_{80})	4.49	4.26	4.21	4.32	interaction IxII- n.s. IIxI- n.s.	
	120 (N_{120})	3.84	4.10	4.10	4.01		
Mean		4.16	4.18	4.15	4.17	0.10	n.i. n.s.
2007	80 (N_{80})	5.77	5.44	5.27	5.49	interaction IxII - 0.14 IIxI - 0.13	
	120 (N_{120})	5.13	5.23	5.20	5.19		
Mean		5.45	5.34	5.23	5.34	0.11	0.09
2005-2007	80 (N_{80})	5.05	4.70	4.60	4.78	interaction IxII - 0.08 IIxI - 0.05	
	120 (N_{120})	4.33	4.52	4.52	4.46		
Mean		4.69	4.61	4.56	4.62	0.08	0.03

The results given in Table 4 point to a relatively high variation across the years. The average copper content in the grain in 2007 was higher than in 2005 and in 2006 (22.5% and 28.1% more, respectively). Similar relationships, showing variation in the content of copper in spring wheat grain over years, were noted by Borkowska (2004). For example, an average content of this nutrient was almost 50% higher in 1998 than in 1999.

The analysis of variance, both throughout the research period and in particular years, confirmed a significant effect of the different nitrogen fertilisation rates on the copper content in spring triticale grain (Table 4). The increase in the nitrogen fertilisation level from 80 to 120 kg ha^{-1} resulted ina 6.7% decrease (an average for the three years) in the copper concentration in grain. The increase in the Cu content in spring wheat grain as a result of the increasing nitrogen fertilisation level was recorded by Dziamba and Jackowska (2001). Borkowska (2004), on the other hand, recorded a lower copper content in grain following the application of 150 kg N ha^{-1}, as compared with the fertilisation treatment which involved 50 kg N ha^{-1}.

The copper content in the grain was also determined by the increasing zinc fertilisation (Table 4). As an average for the three years, the highest Cu content in spring triticale grain (4.69 mg kg^{-1} d.m.) was reported for the treatment with no zinc fertilisation. It was significantly higher than the values recorded for the treatments treated with 0.1 kg Zn ha^{-1} and 0.3 kg Zn ha^{-1}, by 0.08 and 0.13 mg kg^{-1} d.m., respectively.

On average, a significant effect of the interaction between the nitrogen and zinc fertilisation on the copper concentration in grain was noted. The highest Cu content was found for the triticale grain harvested from the $N_{80}Zn_0$ treatments, where it equalled 5.05 mg kg^{-1} d.m. (Table 4).

CONCLUSIONS

1. The rate of 120 kg N ha^{-1} significantly increased the zinc content and decreased the copper concentration in the Kargo cultivar spring triticale grain, as compared with the treatment where 80 kg N ha^{-1} was applied.

2. The foliar zinc application resulted in a significant increase in the zinc content and a decrease in the copper concentration in spring triticale grain.

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