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THE IMPACT OF AGRONOMIC FACTORS ON THE CONTENT OF SELECTED MICROELEMENTS IN NAKED OAT (*Avena sativa* var. *nuda*) GRAIN

WPŁYW ZABIEGÓW AGROTECHNICZNYCH NA ZAWARTOŚĆ WYBRANYCH MIKROPIERWIASTKÓW W ZIARNIE OWSA NAGOZIARNISTEGO (*Avena sativa* ver. *nuda*)

Abstract: The components crucial for fulfilling plant nutrient needs are, beside macroelements, also microelements. Microelement content in plant raw materials is often modified by various agronomic measures, therefore it does not always meet the requirements for this element. The research was conducted to determine the effect of agronomic factors on the content of zinc, copper, iron, cobalt and manganese in oat grain. Three field experiments were set up acc. to fractional factorial designs (2^{5-1} and 3^{4-1}) in two localities (Wierzbica and Prusy) in 2003. Akt cv. revealed a lower content of zinc, copper, iron and manganese in comparison with STH 7000 and STH 4770 strains. Microelement concentrations in oat grain were determined by the selection of oat cultivar/strain and growth regulator dose. Zinc content in oat grain fulfilled the requirements for plants designed for human consumption and animal feeds. Optimal iron content but deficient contents of manganese, copper and cobalt were registered in oat grain treated as fodder.

Keywords: naked oat, microelements, fertilization, plant growth regulator

Introduction

Ensuring proper metabolism in human organism is conditioned by supplying not only main nutrients but also microelements. Most agricultural systems do not guarantee the content of these components in agricultural products on proper levels [1]. Researchers must more precisely characterize whole grains and analyze the role played by whole

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grains in the protection against diseases [2]. According to Butt et al [3] oat is the cereal species with a unique chemical composition. Oat grain constitutes a good source of vitamins from B group, crucial amino acids, unsaturated fatty acids and microelements.

Agronomic factors applied within the agricultural system modify the content and uptake of microelements by plants and in result determine their content in plant raw materials. The proper level of mineral and also foliar fertilization, seems to have a particularly significant effect ensuring proper plant supply in macro- and microelements [4]. The content of microelements in plants is diversified and depends on the habitat, genotype or absorption method [5–10]. Due to a considerable share of cereals in a daily food ration of people and potential excess of their permissible content in plant raw material, this group of plant should be particularly intensively researched in view of its chemical composition, including microelement concentrations. Oat reveals a considerable changeability of its chemical composition depending on agronomic factors and its being a plant commonly used in nutrition. It justifies the necessity to conduct such research [11, 12].

Microelement content in oat grain not always corresponds to consumer requirement for these components. Therefore, in the light of very few research reports on this issue, identification of the impact of various factors, including also agronomic ones, on zinc, copper, iron, cobalt and manganese content in oat grain, seems to be important.

Materials and methods

Field experiments were conducted in 2003 on two sites: Prusy (50°07′N, 20°04′E) (one experiment) and in Wierzbica (50°29′N, 19°45′E) (two experiments). Agricultural practices were carried out in accordance with the principles of oat cultivation.

The experiment in Prusy was set up according to fractional factorial design 3^{4-1} in two replications. The factors and their levels were presented in Table 1.

Table 1

Agronomic factors and their levels in experiments conducted in Prusy

Agronomical factor	Factor level		
	1 [low]	2 [average]	3 [high]
Genotype	Strain STH 7000	Cultivar Akt	Strain STH 4770
PK fertilization	$0\ \mathrm{kg \cdot ha^{-1}}$ PK	$72\ \mathrm{kg \cdot ha^{-1}}$ P	$256\ \mathrm{kg \cdot ha^{-1}}$ PK
Foliar nitrogen application	$0\ \mathrm{kg \cdot ha^{-1}}$ N	$9\ \mathrm{kg \cdot ha^{-1}}$ N	$18\ \mathrm{kg \cdot ha^{-1}}$ N
Plant growth regulator Moddus	$0\ \mathrm{dm^3 \cdot ha^{-1}}$	$0.4\ \mathrm{dm^3 \cdot ha^{-1}}$	$0.6\ \mathrm{dm^3 \cdot ha^{-1}}$

The size of plots for harvest was $10\ \mathrm{m^2}$. Sowing density was 500 germinating seeds $\cdot\ \mathrm{m^{-2}}$ of genotypes *Avena sativa* ver. *nuda*. The soil of the experimental field was degraded chernozem formed from loess wit pH 6.8. In Wierzbica, field experiments were set up according to fractional factorial design 2^{5-1} in two replications. The plot area was $6\ \mathrm{m^2}$, but the yield and its components were estimated on the basis of sample area of $1\ \mathrm{m^2}$. Sowing density was also 500 germinating seeds $\cdot\ \mathrm{m^{-2}}$ of genotypes *Avena sativa* ver. *nuda*. Experimental factors and their levels were presented in Table 2.

Table 2

Agronomic factors and their levels in experiments conducted in Wierzbica

Agronomical factor	Factor levels	
	1 [low]	2 [high]
Genotype [experiment I]	Strain STH 4770	Cultivar Akt
Genotype [experiment II]	Strain STH 7000	Cultivar Akt
PK fertilization	$0\ \mathrm{kg \cdot ha^{-1}}$ PK	$226\ \mathrm{kg \cdot ha^{-1}}$ PK
Foliar nitrogen application	$0\ \mathrm{kg \cdot ha^{-1}}$ N	$17\ \mathrm{kg \cdot ha^{-1}}$ N
Plant growth regulator Moddus	$0\ \mathrm{dm^3 \cdot ha^{-1}}$	$0.4\ \mathrm{dm^3 \cdot ha^{-1}}$
Plant growth regulator Promalin	$0\ \mathrm{dm^3 \cdot ha^{-1}}$	$0.15\ \mathrm{dm^3 \cdot ha^{-1}}$

The experiments in Wierzbica were conducted on typical brown soil with pH 5.9. The contents of bioavailable P, K and Mg forms were from low to average level.

The strains were chosen for the experiments on the basis of their particular characteristics: 1. increased 1000 grain weight (STH 4770) and 2. short culm (STH 7000).

Papers on field experiments conducted using fractional designs have recently started to appear in the literature of the subject. At this point papers by Witkowicz and Antonkiewicz [13] and Witkowicz [14] should be mentioned or the work by Fabjan et al [15]. However, it should be pointed out that the method used by Fabjan et al [15] to present his results is quite different, since it does not use the standard regression coefficients, which would allow for an additional comparative assessment of the studied sources of variability.

In oat grain from each replication, dry-combustion in a muffle furnace at 550 $^{\mathrm{o}}$C for eight hours, after the ash dissolution in 20 % nitric (V) acid, the contents of copper, zinc, iron, manganese and cobalt were assessed using ICP-AES method [16].

The results obtained were subjected to statistical analysis using analysis of variance procedure. For the experiment conducted in Prusy, where each factor occurred on three levels, factors variability was divided into linear and square factors. Zero working hypotheses:

$$\mathrm{H}_0 : \sum_{i=1}^{k} k_i^2 = 0$$

were verified on the basis of F-Fisher test. Before the analyses of variance were conducted, the goodness of fit of features distribution with normal distribution was tested using Kołmogorow-Smirnow test, and the assumption of variance of error homogeneity by means of Bartlett's chi-square test. A multiple regression analysis was also conducted using analyses of variance models. For better comparison of the influence of individual factors, also standardized regression coefficients, whose statistical significance confirms statistically significantly effect of the appropriate source of variability, were compiled in the tables. For the factors occurring on three levels, the square coefficients of effects were also determined.

Results and discussion

Microelement content in oat grain was determined by all sources of variability that were analyzed. The contents of microelements ranged from 49.5 to 64.3 mgFe; 37.9–43.8 mgMn; 25.3–57.2 mgZn; 2.2–3.6 mgCu; 0.021–0.034 mgCo · kg^{-1} d.m. (Tables 3, 4).

Table 3

Content of microelements in oat grain [mg · kg^{-1} d.m.] from experiments situated in Wierzbica

Factor	Experiment I			Experiment II		
	The factor levels and standardized regression coefficient					
	1	2	Coefficient	1	2	Coefficient
Zn						
Genotype	53.8	44.8	–0.567***	57.2	44.8	–0.780***
PK	51.1	47.5	–0.224	50.5	51.6	0.066
N	46.9	51.7	0.299*	50.2	51.8	0.099
Moddus	48.7	49.9	0.077	48.9	53.2	0.270
Promalin	48.5	50.2	0.109	50.5	51.5	0.060
Cu						
Genotype	2.56	2.47	–0.026	3.50	2.47	–0.294
PK	2.65	2.37	–0.079	3.22	2.75	–0.134
N	2.40	2.62	0.062	2.84	3.13	0.084
Moddus	2.80	2.21	–0.166	3.36	2.61	–0.213
Promalin	2.56	2.46	–0.027	3.10	2.86	–0.068
Fe						
Genotype	61.6	60.0	–0.097	64.4	60.0	–0.261
PK	60.0	61.7	0.105	61.6	62.8	0.076
N	59.6	62.0	0.147	62.4	62.0	–0.024
Moddus	61.6	60.0	–0.098	60.4	64.0	0.221
Promalin	62.3	59.4	–0.177	63.4	61.0	–0.146
Co						
Genotype	0.021	0.031	0.351	0.029	0.031	0.070
PK	0.028	0.024	–0.164	0.032	0.027	–0.164
N	0.024	0.027	0.117	0.027	0.032	0.211
Moddus	0.031	0.021	–0.398*	0.033	0.026	–0.258
Promalin	0.028	0.023	–0.164	0.030	0.029	–0.023
Mn						
Genotype	40.6	38.0	–0.274*	43.8	38.0	–0.610**
PK	38.5	40.0	0.159	39.5	42.3	0.292
N	38.8	39.7	0.094	41.3	40.4	–0.092
Moddus	38.4	40.2	0.188	39.5	42.3	0.294
Promalin	38.7	39.8	0.113	40.7	41.1	0.039

* $0.01 < \alpha < 0.05$; ** $0.001 < \alpha < 0.01$; *** $\alpha < 0.001$.

Also Kashin and Ubugunov [8] also observed this diminishing sequence and approximate microelement content in oat grain. The experiments revealed that, irrespective of habitat conditions, Act cv. was characterized by a lower content of zinc, copper, iron and manganese in comparison with STH 4770 and STH 7000 strains.

Table 4

Content of microelements in oat grain [mg · kg^{-1} d.m.] from the experiment situated in Prusy

Factor	The factor levels			Standardized regression coefficient of effects	
	1	2	3	linear	square
			Zn		
Genotype	28.57	25.39	30.79	0.201*	0.488***
PK	28.07	27.17	26.85	–0.110	0.082
N	26.81	27.87	26.34	–0.042	–0.079
Moddus	25.38	28.29	26.72	0.150	–0.174*
			Cu		
Genotype	2.80	3.29	3.66	0.204	0.028
PK	3.24	3.15	3.55	0.035	0.073
N	3.29	3.44	2.78	–0.145	–0.050
Moddus	3.07	3.27	3.42	0.261	–0.238
			Fe		
Genotype	56.26	51.31	54.02	–0.210	0.332*
PK	49.51	53.48	55.34	0.067	0.143
N	53.72	51.83	55.27	0.053	0.152
Moddus	52.94	53.27	52.47	0.009	0.028
			Co		
Genotype	0.030	0.028	0.023	–0.172	0.014
PK	0.034	0.024	0.028	–0.150	0.253
N	0.027	0.029	0.022	–0.129	–0.072
Moddus	0.031	0.026	0.027	–0.150	0.123
			Mn		
Genotype	42.22	39.63	42.99	0.084	0.437***
PK	41.13	40.18	42.70	0.170	0.286**
N	39.41	41.83	40.29	0.096	–0.167
Moddus	39.30	41.63	40.91	0.164	–0.111

* $0.01 < \alpha < 0.05$; ** $0.001 < \alpha < 0.01$; *** $\alpha < 0.001$.

The effect of factors on the content of selected microelements in naked oat was discussed, according to their sequence, in Tables 3 and 4. A statistically significant (by 0.299 of standard deviation unit) increase in oat grain zinc concentration in effect of foliar nitrogen application was observed in the experiment I conducted in Wierzbica.

The same dependence was registered in experiment II, but it was not statistically confirmed. In Prusy, copper content in grain was close to statistical modification only by application Moddus growth regulator (tendency). No statistically significant effect of agronomic factors on iron concentrations in grain was noted in either of the two experiments conducted in Wierzbica or in Prusy. In Wierzbica, cobalt concentrations in grain in first experiment (I) declined by 0.398 of standard deviation unit under the influence of applied Moddus growth regulator. On the other hand, the genotype affected this microelement content with the strength close to statistical significance (0.351), which means that Act cv. contained by 0.01 mg $\cdot$ kg^{-1} more of cobalt than strains. In Prusy, cobalt content in grain was close to statistical modification owing to phosphorus-potassium fertilization. Application of phosphorus fertilization only caused a decrease in this microelement content in comparison both with the control and full fertilization. In Wierzbica, manganese concentrations in oat grain were shaped only by the genotype. On the other hand, in Prusy manganese content was changing according to square effects for the genotype and phosphorus-potassium fertilization.

The analyses of variance that were performed on the data from experiments confirmed also statistically significant influence of some interactions of the studied factors on microelement concentrations in oat grain (only in Wierzbica). The most often observed and statistically significant was the interaction of foliar nitrogen application with Moddus growth regulator, which also shaped the content of iron and cobalt. In both experiments with no nitrogen foliar fertilization applied, the use of Moddus growth regulator caused an increase in iron content. Application of foliar nitrogen fertilization generally caused increase in iron content but in the presence of the regulator, a decline in this microelement content was noted in oat grain (in comparison with combination without nitrogen fertilization) (Fig. 1, 2). Iron content was also shaped by the interaction of the genotype with Moddus growth regulator (experiment I). Application of the regulator caused a decrease in case of STH4770 strain and in Akt c.v. increase in iron content in grain (Fig. 3). However, interaction of the genotype with phosphorus and potassium fertilization bears on the content of zinc in experiment II (Fig. 4). In case of STH 4770 strain application of phosphorus-potassium fertilization led to increase in this

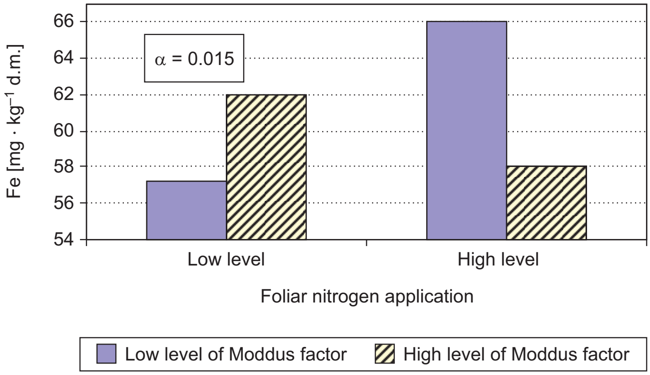

Fig. 1. Concentration of Fe in oat grain under the influence of interaction between urea foliar application and Moddus plant grow regulator (experiment I)

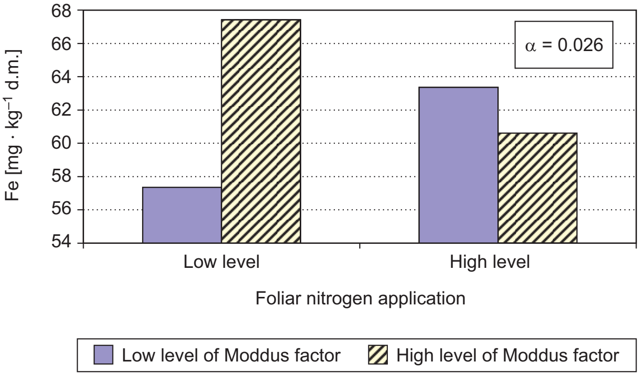

Fig. 2. Concentration of Fe in oat grain under the influence of interaction between urea foliar application and Moddus plant grow regulator (experiment I)

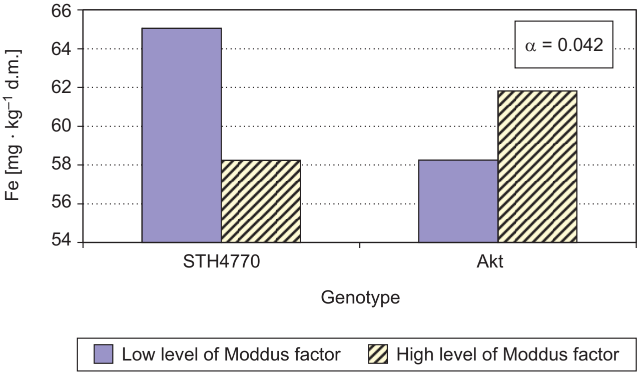

Fig. 3. Concentration of Fe in oat grain under the influence of interaction between genotype and Moddus plant grow regulator (experiment I)

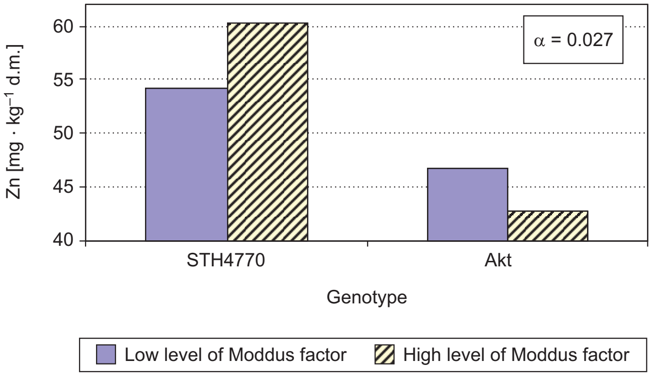

Fig. 4. Concentration of Zn in oat grain under the influence of interaction between genotype and PK fertilization (experiment II)

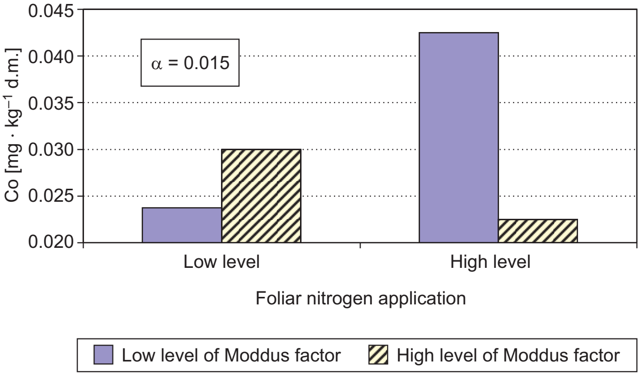

Fig. 5. Concentration of Co in oat grain under the influence of interaction between genotype and PK fertilization (experiment II)

element content, but in case of Akt c.v. led to a slight decline. Decreasing zinc content in Akt cv. grain may be connected with this metal precipitation in the insoluble form (zinc phosphates), *ie* unavailable to plants [17, 18]. The last interaction which has a statistically proven effect on cobalt concentrations in grain (experiment II) was the interaction of nitrogen foliar fertilization and Moddus growth regulator (Fig. 5). At the lack of nitrogen fertilization, application of Moddus growth regulator caused increased content of this element in grain, whereas a decline in the content was noted when foliar fertilization was applied.

According to the IUNG-PIB guidelines [19] the critical contents of zinc and copper in plant material destined for consumption are respectively: 50 mgZn $\cdot$ kg^{-1} and 20 mgCu $\cdot$ kg^{-1} d.m. In the experiment situated in Prusy no effect was registered of either genotype or fertilization level and growth regulator on exceeding the permissible zinc concentration in oat grain. On the other hand, in the experiment in Wierzbica a slightly exceeded critical content of zinc was observed in STH 4770 and STH 7000 strains. Copper content in oat grain was on a very low level and from the perspective of farm animals needs it was an insufficient amount, because requirements of most animal groups are on the level of 20–30 mgCu $\cdot$ kg^{-1} d.m. [20]. Optimum contents of iron and manganese in plants destined for fodders are 40–100 mgFe $\cdot$ kg^{-1} d.m. and 50–60 mgMn $\cdot$ kg^{-1} d.m. [21–23]. According to this criterion, iron concentrations in oat grain was on the optimal level, whereas manganese concentrations were below the optimal value. Mechanism of absorption and accumulation of zinc, copper and manganese allows to accumulate considerable amounts of these elements in grain and therefore may pose toxic hazard [8]. Microelement fertilization, which becomes more and more commonly applied particularly to plant raw materials, enhances the necessity of control and research on their content in plant raw materials. Blaziak [7] also confirmed in her research that under specific conditions of soil moisture the contents of these microelements in barley and oat grain were exceeded. The research on the effect of irrigation and NPK fertilization conducted by Koszanski et al [24] point to the effect of these factors on microelement content, but the authors did not confirm the fact by a statistical analysis. Pisulewska et al [9] observed not only the effect of NPK fertilization on iron concentration in oat grain but also the lack of this factor effect on the contents of copper, manganese and zinc. Moreover, they did not notice any differences in these microelements concentrations between the traditional Dukat cv. and naked Akt cv.

Bergmann [25] divided cobalt content in plants designed for fodder into three classes: unsatisfactory – below 0.07 mg; average abundant – from 0.07 to 0.12 mg and sufficient over 0.12 mgCo $\cdot$ kg^{-1} d.m. Comparison of oat grain cobalt concentrations obtained in the experiments with German standards used for fodder value assessment shows that oat grain had insufficient content of this element.

Feed quality depends also on mutual quantitative relations between macro- and microelements. Stated value of the relations between elements has a cognitive importance (Tables 5, 6). A considerable range of proportion variability was found in the grain of studied genotypes, which evidences a big tolerance of oat to agronomic measures. Literature generally presents only selected proportions between elements, with reference to animal feed needs. Optimal iron to manganese ratio is 1.5–2.5:1 [20]. It is estimated that the ratio below 1.5 testifies a surplus of manganese and deficiency of iron, whereas when the iron to manganese ratio is over 2.5, a manganese deficiency and iron surplus occur in plants. The experiments showed that oat grain obtained in the experiment in Wierzbica revealed the optimal value of this ratio, whereas numerical value of this ratio in oat grain obtained in Prusy revealed a slight manganese surplus and iron deficiency.

Table 5

Relations between elements in oat grain in Prusy

Factor	The factor level			The factor level		
	1	2	3	1	2	3
	Relation Fe : Mn			Relation Fe : Co		
Cultivar/Strain	1.3	1.3	1,3	1875	1832	2349
PK	1.2	1.3	1,3	1456	2228	1976
N	1.4	1.2	1,4	1990	1787	2512
Moddus	1.3	1.3	1,3	1708	2049	1943
	Relation Mn : Co			Relation P : Zn		
Cultivar/Strain	1407	1415	1869	139.3	161.5	139.3
PK	1210	1674	1525	143.6	150.5	159.0
N	1460	1442	1831	154.8	148.9	152.6
Moddus	1268	1601	1515	159.6	147.0	153.4

It is considered that the limit value of phosphorus to zinc ratio should be 400:1 [20]. At the same time it has been emphasized that the value of this ratio may be often a better indicator of plant supply in zinc than this microelement content in plants. This ratio in sick plants, underfed with zinc is wider than in healthy plants. The research shows that the oat grain revealed an optimal content of zinc and the limit value of phosphorus-zinc ratio was not exceeded.

Table 6

Relations between elements in oat grain in Wierzbica

Factor	Experiment I		Experiment II		Experiment I		Experiment II	
	The factor levels				The factor levels			
	1	2	1	2	1	2	1	2
	Relation Fe : Mn				Relation Fe : Co			
Cultivar/Strain	1.5	1.6	1.5	1.6	2935	1936	2219	1936
PK	1.6	1.5	1.6	1.5	2142	2571	1924	2327
N	1.5	1.6	1.5	1.5	2484	2298	2311	1937
Moddus	1.6	1.5	1.5	1.5	1988	2858	1829	2462
Promalin	1.6	1.5	1.6	1.5	2225	2581	2113	2103
	Relation Mn : Co				Relation P : Zn			
Cultivar/Strain	1933	1225	1511	1224	68.9	82.6	68.5	82.6
PK	1376	1668	1234	1566	71.2	79.1	75.2	73.9
N	1618	1471	1531	1264	78.8	71.5	76.0	73.1
Moddus	1238	1913	1196	1627	73.3	76.7	75.1	74.1
Promalin	1384	1731	1357	1416	78.2	72.1	77.5	71.6

The ratios of iron to cobalt and manganese to cobalt were diversified in oat grain and depended on the level of agronomic measures, including mineral fertilization. Introducing foliar application of nitrogen definitely declined numerical values of these ratios, whereas the application of phosphorus and potassium fertilization and growth regulators led to widening of these ratios. The research demonstrated that proportions between elements in oat grain were modified by agronomic factors. Spann et al [26] also observed disturbed chemical balance in plants under the influence of fertilization. As different whole grains have different composition, technologies should be developed to allow the use of versatile grain raw material, also multigrain products and knew product concepts [27].

Conclusions

1. It was observed, that irrespective of site conditions in which experiments were conducted, Akt c.v. generally revealed lower concentrations of zinc, copper, iron and manganese in comparison with STH4770 and STH 7000 strains.
2. Assessing zinc, copper and cobalt concentrations in oat grain from the angle of standardized regression coefficients values, it should be stated that generally their content to the greatest extent depended on Moddus growth regulator application.
3. The agronomic factors taken into consideration did not lead to exceeding the permissible content of zinc in oat grain destined for consumption.

4. Oat grain obtained in the experiments, perceived as fodder grain revealed the optimal contents of iron but deficiency of manganese, copper and cobalt.
5. Proportions among the elements in oat grain were modified by agronomic factors.

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WPŁYW ZABIEGÓW AGROTECHNICZNYCH NA ZAWARTOŚĆ WYBRANYCH MIKROPIERWIASTKÓW W ZIARNIE OWSA NAGOZIARNISTEGO (*Avena sativa* var. *nuda*)

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Abstrakt: Składnikami niezbędnymi do pokrycia potrzeb pokarmowych roślin, obok makroskładników, są również mikroelementy. Zawartość mikroelementów w surowcach roślinach jest często modyfikowana różnymi zabiegami agrotechnicznymi, dlatego też nie zawsze odpowiada zapotrzebowaniu na ten składnik. Celem przeprowadzonych badań było określenie wpływu czynników agrotechnicznych na zawartość cynku, miedzi, żelaza, kobaltu i manganu w ziarnie owsa. Trzy eksperymenty polowe założono według planów frakcyjnych (2^{5-1} i 3^{4-1}) w dwóch miejscowościach (Wierzbica i Prusy) w 2003 r. Odmiana Akt cechowała się niższą zawartością cynku, miedzi, żelaza i manganu w porównaniu do rodów STH 7000 i STH 4770. Zawartość mikropierwiastków w ziarnie owsa była determinowana doborem odmiany/rodu owsa oraz dawką regulatora wzrostu. Zawartość cynku w ziarnie owsa spełniała wymogi stawiane roślinom przeznaczonym na cele konsumpcyjne i paszowe. Stwierdzono optymalną zawartość żelaza, a niedoborową manganu, miedzi i kobaltu w ziarnie owsa traktowanego jako pasza.

Słowa kluczowe: owies nagoziarnisty, mikroelementy, nawożenie, regulator wzrostu