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CONTENT OF SELECTED NUTRIENTS IN WHEAT, BARLEY AND OAT GRAIN FROM ORGANIC AND CONVENTIONAL FARMING

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Abstract

The success of organic farming results from the need to produce top-quality food and, additionally, to protect the natural environment by applying eco-friendly agricultural practices and abandoning synthetic fertilizers and chemical pesticides. The aim of this study was to assess the impact of organic and conventional production systems on the content of minerals and fatty acids in grain of oat, wheat and hulled and naked barley.

Wheat grain from organic farming was characterized by a higher content of Mn and by significantly higher content of Fe, Zn, Ca and Mg when compared to grain originating from conventional farming. The increased availability of potassium in soil, caused by the applied potassium salt fertilization, was reflected in a higher content of this macronutrient in grain of all cereals from conventional cultivation. The tillage system was found not to exert the same effect on the content of Ca and Mg in all the cereals examined. Lower content of iron and zinc was determined in organic grains of barley and oat. Grain from the conventional cropping system (except naked barley) proved to be richer in lipids. Crude oil of organic cereals was richer in the most valuable polyunsaturated fatty acids than that of the conventionally-grown crops The study demonstrated a stronger dependency between the level of the elements examined and cereal species than between the level of elements and cultivation system.

Key words: organic farming, conventional farming, mineral elements, fatty acids, cereal.

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ZAWARTOŚĆ WYBRANYCH SKŁADNIKÓW ODŻYWCZYCH W ZIARNIE PSZENICY, JĘCZMIENIA I OWSA Z UPRAWY EKOLOGICZNEJ I KONWENCJONALNEJ

Abstrakt

Popularność rolnictwa ekologicznego wynika z poszukiwania żywności o najwyżej jakości oraz z potrzeby ochrony środowiska naturalnego, przez stosowanie zabiegów agrotechnicznych przyjaznych ekosystemowi. Celem pracy była ocena wpływu ekologicznego i konwencjonalnego systemu uprawy na zawartość składników mineralnych i kwasów tłuszczowych w ziarnie owsa, pszenicy oraz jęczmienia oplewionego i nagiego.

Ziarniaki pszenicy z uprawy ekologicznej zawierały więcej Mn oraz istotnie więcej Fe, Zn, Ca i Mg w porównaniu z pochodzącymi z uprawy konwencjonalnej. Zwiększona dostępność potasu w glebie, spowodowana zastosowanym nawożeniem w postaci soli potasowej, odzwierciedla się wyższą zawartością tego makroskładnika w ziarniakach wszystkich zbóż z uprawy konwencjonalnej. Nie stwierdzono jednokierunkowego wpływu systemu uprawy na zawartość Ca i Mg w przypadku wszystkich badanych zbóż, natomiast niższą zawartość żelaza i cynku stwierdzono w ziarniakach jęczmienia i owsa z upraw ekologicznych. Ziarniaki z uprawy konwencjonalnej były zasobniejsze w tłuszcz (wyjątek stanowił jęczmień nagi). Tłuszcz zbóż ekologicznych był bogatszy w większość cennych kwasów wielonienasyconych w porównaniu ze zbożami konwencjonalnymi. Obserwowano silniejszą zależność zawartości badanych składników od gatunku zboża niż od systemu uprawy.

Słowa kluczowe: uprawa ekologiczna, uprawa konwencjonalna, składniki mineralne, kwasy tłuszczowe, zboże.

INTRODUCTION

Both in Poland and in the world, agricultural plant production relies on crop cultivation for food and feed. Cereals are obviously at the top of the food pyramid. As important sources of carbohydrates, proteins and mineral compounds, they are characterized by a species-specific combination of nutritive properties. The absorption and accumulation of nutrients by plants are affected by numerous factors, e.g. the concentration and form of ions available in soil as well as pH of soil solution (Zörb et al. 2009). More and more food products are made from wholemeal flour and provide valuable nutrients, including mineral compounds, which so far have been removed along with the seed coat. Daily consumption of food products containing 200 g of wholemeal flour may satisfy over 70% of the recommended daily intake of Cu, Fe, Mg, Zn, Mn, etc. (Hussain et al. 2010)

The growing success of organic farming results from the need to produce top-quality food and, additionally, to protect the natural environment by applying ecosystem-friendly agricultural practices and abandoning synthetic fertilizers and chemical pesticides. Investigations conducted globally have focused mainly on the effect of organic crop tillage on parameters of soil or crop yield (Röhling, Engel 2010). Recently, however, researchers have been paying more attention to assessment of nutrients in organic food products. The aim of this study has been to assess the impact of organic and conventional production systems on the content of mineral elements and fatty acids in grain of oat, wheat and hulled and naked barley.

MATERIAL AND METHODS

The experiment was conducted with grain of cereals cultivated in the organic and conventional systems. Grain of winter wheat (cultivar Legenda), spring barley (gymnospermous cv. Rastik and hulled cv. Skarb), and oat (cv. Borowiak) originated from a plot experiment conducted by the Department of Herbology and Crop Cultivation Technology at the Experimental Farm Czesławice – harvest of 2009. The experiment was established on 2nd complex soil (quality class II), characterized by the humus content of 1.2-1.6%, high to very high content of potassium, magnesium and phosphorus, and acid to slightly acid pH.

The experiment included two, five-field cereal rotations:

– organic crop: sugar beet ? hulled/naked spring barley + additional red clover → red clover → winter wheat + tansy phacelia/white mustard (stubble intercrop) → oat + broad bean and pea (stubble intercrop);
– conventional crop: sugar beet → hulled/naked spring barley + additional red clover → red clover → winter wheat → oat.

In the organic system, the cereals were cultivated without mineral fertilization. Their needs for nutrients and fertilizers were met by plowing the intercrops and by increased fertilization with manure, whereas weed control was assured by stubble intercrops and harrowing.

Fertilizers and pesticides applied to the cereals are specified in Table 1.

The grains were analyzed for the content of mineral elements: Ca, K, Mg, Cu, Mn, Fe, and Zn with atomic absorption spectrometry (AAS) after incineration in a muffle furnace. Crude lipids were determined with the extraction method by Soxhlet (PN-64/A-74039) in a Soxtec System HT 1043 apparatus. Fatty acids were separated with the gas chromatography method using a UNICAM 610 apparatus with flame-ionization detector (FID).

Table 1

Elements of agrotechnology of cereals in the conventional cultivation system

Specification		Oat	Wheat	Barley
Mineral fertilization	N	70 kg ha^{-1} ammonium nitrate (34%) 60% before sowing 40% tillering phase	140 kg ha^{-1} ammonium nitrate (34%): 50% before moving vegetation 35% the stage of shooting 20% the stage of earing	90 kg ha^{-1} ammonium nitrate (34%) 60% before sowing 40% tillering phase
	P_2O_5	70 kg ha^{-1} triple superfosfate, granulated (46%) 100% before sowing	60 kg ha^{-1} triple superfosfate, granulated (46%) 100% before sowing	70 kg ha^{-1} triple superfosfate, granulated (46%) 100% before sowing
	K_2O	100 kg ha^{-1} potassium salt (60%) 100% before sowing	80 kg ha^{-1} potassium salt (60%) 100% before sowing	90 kg ha^{-1} potassium salt (60%) 100% before sowing
Seed dressing		Vitawax 200 SF	Divident 030FS	Vitawax 200 SF
Fungicides		not applicable	Alert 375 SC dose 1 dm^3 ha^{-1} Tilt Plus 400 SC dose 1 dm^3 ha^{-1}	Alert 375 SC dose 1 dm^3 ha^{-1} Tilt Plus 400 SC dose 1 dm^3 ha^{-1}
Herbicides		Chwastoksem Turbo 340 SL dose 2 dm^3 ha^{-1}	Apyros 75 WG dose 26.5 g ha^{-1} Tomigan 250 EC dose 0.7 dm^3 ha^{-1} applied together	Basagran 600 SL dose 2 dm^3 ha^{-1}
Insecticides		Karate 025 E^C dose 0.15 dm^3 ha^{-1}	Karate 025 EC dose 0.15 dm^3 ha^{-1}	Karate 025 EC dose 0.15 dm^3 ha^{-1}
Retardants		Antywylegacz płynny 675 SL dose 2 dm^3 ha^{-1}	Stabilan 750 SL dose 1 dm^3 ha^{-1}	Celefon 465 SL dose 1.5 dm^3 ha^{-1}

RESULTS AND DISCUSSION

Mineral compounds in plants serve a variety of functions, e.g. they are structure-forming elements (macronutrients) and participate in the regulation of biochemical processes (micronutrients) (BARCZAK et al. 2006). They are also essential for the proper growth and development of humans and animals. Their accumulation in cereal grain is influenced by multiple factors, including species and soil conditions: organic matter content, pH, and fertilization applied (WIŚNIOWSKA-KIELIAN, KLIMA 2007). Most of the research addressing the issue of mineral content in organic grain has focused on wheat (HUSSAIN et al. 2010, ZÖRB et al. 2009).

In the reported experiment, grain of oat, wheat as well as hulled and naked barley was analyzed for the content of 3 macronutrients, whose level was decreasing in the following order: K, Mg, Ca (Table 2). Oat grain proved to be the poorest in these cations (except for potassium). A higher content of these macronutrients in oat, than in barley had been determined earlier by MAKARSKA et al. (2006). In turn, the lowest content of Mg and Ca was assayed in wheat grain.

The highest content of potassium was found in the grain of hulled barley (E=6.87 mg kg^{-1}, C=7.03 mg kg^{-1}). A tendency for its considerably higher content (significantly higher in the case of wheat) was observed when

Table 2

Content of mineral elements in grain of oat, wheat and barley from organic (E) and conventional (C) cultivation

Specification	K	Ca	Mg	Cu	Mn	Fe	Zn
	g kg^{-1}			mg kg^{-1}			
Oat E	4,159*a*	0.411*a*	0.871*a*	3.386*a*	30.39*a*	44.47*a*	28.90*a*
Oat C	4.437*a*	0.475*b*	0.837*b*	3.182*a*	28.25*a*	45.76*a*	30.71*a*
LSD $_{p \leq 0.05}$	0.328	0.008	0.015	1.715	3.020	19.83	15.61
Wheat E	3.984*a*	0.295*a*	0.692*a*	2.091*a*	29.20*a*	27.59*a*	29.05*a*
Wheat C	5.666b	0.245*b*	0.630*b*	2.548*a*	25.64*a*	22.91*b*	21.57*b*
LSD $_{p \leq 0.05}$	0.332	0.0019	0.0122	1.000	13.27	3.64	2.45
Hulled barley E	6.868*a*	0.365*a*	0.802*a*	3.702*a*	11.99*a*	30.19*a*	30.56*a*
Hulled barley C	7.028*a*	0.393*a*	0.848*b*	3.675*a*	10.45*b*	36.08*a*	32.18*a*
LSD $_{p \leq 0.05}$	1.225	0.0031	0.0167	1.891	0.629	6.096	12.04
Naked barley E	4.912*a*	0.330*a*	0.827*a*	3.208*a*	9.40*a*	30.40*a*	28.58*a*
Naked barley C	4.030*a*	0.306*b*	0.871*b*	3.576*b*	9.46*a*	38.12*b*	32.51*a*
LSD $_{p \leq 0.05}$	2.619	0.0206	0.037	0.288	0.331	2.490	6.461

a,b – mean values marked with the same letter do not differ statistically at $p \leq 0.05$

compared to the organic grain, which is presumably caused by potassium salt fertilization.

The content of magnesium was significantly higher in the grain of oat and wheat from organic cultivation than in conventionally grown crops. In turn, the level of this element in both cultivars of barley turned out to be higher in the grain from conventional crop. Hence, the farming methods were not confirmed to exert the same effect on all cereals. ZÖRB et al. (2009) attributed a slightly lower magnesium content in conventional wheat grain (analogous dependency was also observed in our study) to the better filling and higher volume of kernels.

Grains of wheat and naked barley from organic crops were significantly richer in calcium than those from the conventional cultivation system. A reverse dependence was observed in the case of oat. In hulled barley, the lower content of that element in organic grain was not statistically significant. ZÖRB et al. (2009) did not find any significant differences in the calcium content between wheat grain from organic and conventional cultivation, although grain from the organic biodynamic system was characterized by its higher content. Despite a few significant system-based differences, no tendency towards higher or lower levels of mineral elements in any farming system was suggested by MÄDER et al. (2007).

The level of such cations as iron, manganese, and copper in grain plays a very significant role. The mean content of micronutrients in grain of the analyzed cereals is presented in Table 2. The lowest content of Cu and Fe (analogously to macronutrients) appeared in wheat. The lowest level of Mn was found in both cultivars of barley. The lowest content of Zn was found in grain of conventional wheat and organic naked barley.

In turn, the highest content of copper was determined in grain of hulled barley (E=3.70 mg kg^{-1}, C=3.67 mg kg^{-1}). Differences in the copper content between grain from organic and conventional cultivation were statistically significant only in the case of naked barley cv. Rastik, with a higher content of copper noted in the conventionally-cultivated crop (E=3.21 mg kg^{-1}, C=3.58 mg kg^{-1}). The same tendency was observed in wheat grain (E=2.09 mg kg^{-1}, C=2.55 mg kg^{-1}). Among the analyzed cereals, the highest content of Mn was determined in oat (E=30.39 mg kg^{-1}, C=28.25 mg kg^{-1}) and wheat grain (E=29.20 mg kg^{-1}, C=25.64 mg kg^{-1}). More Mn was found in grain from the organic cultivation system, except naked barley, in which the Mn content was identical in both organic and conventional grain.

Further analyses demonstrated the highest content of iron in oat grain (E=44.47 mg kg^{-1}, C= 45.76 mg kg^{-1}), and the highest content of zinc in hulled and naked barley from conventional cultivation (32.18 and 32.18 mg kg^{-1}, respectively). In the grain of oat and both barley cultivars, the content of iron and zinc was higher in the crops with mineral fertilization and chemical protection. In contrast, statistically significantly higher content of Fe and Zn was determined in the organic grain of wheat. RYAN et al. (2004) attributed a higher content of zinc in organic grain to improved colonization of the crops by *Arbuscular mycorrhizal* fungi, which improved absorption of mineral elements (including Ca and Zn).

The content of crude lipids in grain was higher in conventionally grown crops, except naked barley (Table 3). The richest source of crude lipids was oat grain (E=4.36% and C=4.49%), whereas hulled barley from organic cultivation contained the smallest amounts of these compounds. The results of our determinations of the lipid content in grain of oat and barley from the organic cultivation system are similar to the findings reported by BOBKO et al. (2009). In contrast, SZUMIŁO and RACHOŃ (2006), who analyzed lipids in naked and hulled oat, found differences due to the level of pesticides applied, namely stronger pest control meant a lower content of lipids in naked oat but more lipids in hulled grain.

The ratio of fatty acids in grain lipids of the analyzed cereals is shown in Table 3. A higher level of saturated fatty acids (SFA) was found in lipids of cereals from the conventional cropping system, whereas grain from organic farming was richer in unsaturated fatty acids (UFA). In both cases, it was only wheat grain that responded differently. A tendency for enhanced synthesis of monounsaturated fatty acids (MUFA) was observed in the conventional crops except oat. This relationship was evident in the case of crude lipids of wheat monoens. Cereal grain is an excellent source of essential polyunsaturated fatty acids, especially linoleic acid. A higher percentage of these acids was demonstrated in crude lipids of grain from the organic system. When comparing the analyzed cereals, the highest content of linoleic acid (18/2) was determined in lipids of organic wheat grain, whereas the lowest one – in oat grain from both cropping system. A lower percentage of polyunsaturated fatty acids in oat grain is compensated for by a very high content of crude lipids in grains of that cereal and an exceptionally high level of ecosadienoic acid (22/2), compared to other cereals. In addition to linoleic acid, grain oil is rich in both oleic (18/1) and palmitic acids (16/0). Conventional grain (except for oat) appeared to be richer in this monoenic acid. However, lipids of organic kernels of wheat and naked barley, and conventional kernels of oat and hulled barley were richer in saturated palmitic acid.

Table 3

Content of crude lipids and percentage contribution of fatty acids in lipids of the analyzed cereals from organic (E) and conventional (C) cultivation system

Specification	Crude lipids (%)	14/0	16/0	18/0	18/1 (N9)	18/1 (N7)	18/2	18/3	20/0	20/1	20/2	22/0	22/2	24/0	SFA	UFA	MUFA	PUFA
		percentage contribution (%)													percentage contribution (%)			
Oat E	4.36	0.278	16.27	1.474	35.13	0.824	38.29	1.278	0.138	0.703	0.033	0.068	5.316	0.027	18.35	81.65	36.71	44.94
Oat C	4.49	0.269	16.53	1.502	34.24	0.766	37.29	1.275	0.152	0.667	0.046	0.070	6.954	0.071	18.68	81.32	35.73	45.59
Wheat E	1.43	0.105	17.02	0.963	14.89	0.896	60.13	4.248	0.150	0.689	0.068	0.107	0.069	0.111	18.67	81.33	16.67	64.66
Wheat C	1.53	0.083	13.62	0.117	33.67	0.521	46.77	3.459	0.301	0.566	0.071	0.097	0.304	0.097	14.49	85.51	34.89	50.62
Hulled barley E	1.35	0.343	21.52	1.141	11.55	0.510	56.06	7.024	0.209	0.641	0.111	0.228	0.077	0.142	23.78	76.22	12.91	63.32
Hulled barley C	1.45	0.362	22.56	1.310	12.57	0.666	56.50	1.972	0.000	0.000	0.087	0.241	0.136	0.158	24.88	75.12	16.39	58.73
Naked barley E	1.79	0.203	20.42	1.189	12.44	0.614	57.34	6.006	0.166	0.857	0.083	0.152	0.120	0.118	22.40	77.60	14.03	63.57
Naked barley C	1.66	0.201	20.46	1.211	13.00	0.644	56.83	5.815	0.158	0.899	0.075	0.162	0.130	0.083	22.46	77.54	14.68	62.87

SFA – saturated fatty acids, UFA – unsaturated fatty acids, MUFA – monounsaturated fatty acids, PUFA – polyunsaturated fatty acids

CONCLUSIONS

1. Wheat grain from the organic cropping system was characterized by a higher content of Mn and a significantly higher content of Fe, Zn, Ca and Mg when compared to grain from conventional cultivation.

2. Lower content of iron and zinc was determined in organic grain of barley and oat but the cropping system was found not to exert the same effect on the content of Ca and Mg in any of the examined cereals.

3. Crude oil of organic cereals was richer in the most valuable, polyunsaturated fatty acids than that of conventionally grown crops

4. The study has demonstrated that the content of the macro- and micronutrients was more strongly dependent on a cereal species than a cultivation system.

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