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EVALUATING THE INFLUENCE OF VARIED NPK FERTILIZATION ON YIELDING AND MICROELEMENTS CONTENTS AT AMARANTH (*Amaranthus cruentus* L.) DEPENDING ON ITS CULTIVAR AND PLANT SPACING

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Abstract. Amaranth is not only of high dietetic (seeds and leaves), but also pro-health, ecological, agricultural, and ornamental quality. The aim of present research was to analyze the influence of cultivar, plant spacing, and diverse NPK fertilization on yielding and Cu, Zn, Fe, and Mn contents in seeds, leaves, and stems of amaranth (*Amaranthus cruentus* L.). The paper was based on three-year field experiment established by means of randomized sub-blocks (split-plot) in three replicates and included three variable factors: plant cultivar, spacing (two levels each), and NPK fertilization (four levels). Achieved results indicated that applied experimental factors contributed to a substantial differentiation of *Amaranthus cruentus* yields. Amaranth reacted with a significant increase of yields due to NPK fertilization. The highest yields were produced when fertilizing was applied at the rate of 90 kg N·ha^{-1}, 60 kg P·ha^{-1} and 60 kg K·ha^{-1}. Use of the highest NPK fertilization (130 kg N·ha^{-1}, 70 kg P·ha^{-1}, 70 kg K·ha^{-1}) was associated with the decrease of the test plant yielding, regardless of the cultivar or plant spacing. In most cases, the experimental factors exerted significant influence on the contents of analyzed microelements in leaves and seeds of amaranth plants. Analysis of partial eta-squared coefficients indicated that the plant cultivar explained the amaranth's yielding variability to the highest degree, while NPK fertilization – copper, zinc, and iron levels in leaves, and copper and manganese in seeds. Manganese in leaves and zinc in seeds was the best explained by the cultivar of the test plant.

Key words: amaranthus, spacing system, fertilization, yield, content of microelements

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INTRODUCTION

The genus *Amaranthus* includes about 60 herbal plant species that, depending on their application, can be divided into 4 groups: vegetable, ornamental, weed, and seed amaranth [Grajeta 1997]. Vegetable forms of amaranth are represented among others by: *Amaranthus dubius*, *Amaranthus lividus* and *Amaranthus tricolor* [Stallknecht and Schulz-Schaeffer 1993]. Species such as *Amaranthus gengeticum*, *Amaranthus hybidus*, *Amaranthus tricolor* are used as vegetables in India, China, Korea, and Philippines [Stallknecht and Schulz-Schaeffer 1993]. They grow there in a wild and are important source of young leaves consumed as raw. At present, amaranth is a worldwide valued and valuable leafy vegetable. Young leaves of amaranth can be prepared in a form of salad, or boiled in water, or even steamed. Young leaves and stems are the most tasty and the most healthy. Amaranth is readily included in an everyday diet by vegetarians. Its leaves are characterized by very high nutritional value [Makus and Davis 1984, Willis et al. 1984, Teutonico and Knorr 1985, Bailey 1992, Abu Ziada et al. 2008]. They contain from 17.4 to 38.0% d.m. of proteins, that are distinguished by beneficial quantity of exogenous amino acids with large proportion of lysine and small concentrations of sulfur amino acids. At various amaranth species, the amount of fats in fresh weight of leaves can amount from 1 to 10% d.m., while the percentage of crude fiber reaches from 5.4 to 24.6% d.m. [Grajeta 1997]. The most important mineral components present in amaranth leaves are following: calcium, potassium, magnesium, and iron [Gontarczyk 1996, Grajeta 1997].

It is often emphasized that amaranth is particularly valuable vegetable in summer, when leafy vegetables are deficient [Makus and Davis 1984, Singh and Whitehead 1993, 1996]. The seed amaranth belongs to the most important and most valuable group referring to applications in human diet. Most often, such species as *Amaranthus hypochondriacus, Amaranthus cruentus, Amaranthus caudatus* and *Amaranthus edulis* are grown for seeds. In Poland only two cultivars of *Amaranthus cruentus* are cultivated for seeds – Rawa and Aztek. Numerous studies revealed that it is valuable and useful plant with very wide scope of applications. The chemical composition of amaranth seeds predisposes it to wide applications in human diet, because its seeds are abundant not only in proteins and high-quality fat, but also minerals [Sounders and Becker 1983, Grajeta 1997, Januszewska-Jóźwiak and Synowiecki 2008, Skwaryło-Bednarz and Brodowska 2009]. Contents of phosphorus, calcium, potassium, magnesium, and iron are much higher than in other cereals [Bejosano and Corke 1998, Bobrzecka et al. 2000, Tosi et al. 2001, Shukla et al. 2006, Olaniyi et al. 2008, Piecyk et al. 2009, Repo-Carrasco-Valencia et al. 2009].

Poor popularity of amaranth indicates the need to undertake numerous studies upon the complete evaluation of its chemical composition determining its nutritional value. The research hypothesis assumed that nitrogen, phosphorus, and potassium nutrition is one of the main factors shaping the size and quality of amaranth's yields. Moreover, it was assumed that the cultivar and plant spacing have some influence on the yield size as well as microelements contents at the test plant. In order to verify above assumptions, the research aimed at analyzing the influence of varied nitrogen, phosphorus, and potassium rates as well as spacing type of two amaranth cultivars (*Rawa* and *Aztek*) (*Amaran-*

thus cruentus L.) on yielding and microelements (Cu, Zn, Fe, Mn) contents at the test plant, was carried out.

MATERIAL AND METHODS

The research was carried out on a base of three-year field experiment (2007–2009) on an individual farmer's field localized in Bodaczów (N – 50°71′, E – 23°04′) near Zamość. The experiment was performed on brown soil developed from loess and characterized with high abundance of phosphorus (60 mg·kg^{-1}), potassium (120 mg·kg^{-1}), and magnesium (70 mg·kg^{-1}). The soil was slightly acidic (pH $_{KCl}$ – 5.9), its sorption capacity was at the level of 193.7 mmol(+)·kg^{-1} and organic carbon content about 29.5 g·kg^{-1} soil. The experiment was established by means of randomized sub-blocks (split-plot) in triplicate and included three variable factors: plant cultivar (A), spacing (B), and NPK fertilization (C). The plant cultivar and spacing type were applied at two levels, while NPK fertilization at four. The plot area was 4 m^2, while the area of the whole experiment (including paths) – 432 m^2.

Nitrogen fertilization in a form of ammonium nitrate was applied every year of experiment at two doses: before plant sowing and during their intensive growth (6 weeks after plant's emergence). Phosphorus (in a form of granulated triple superphosphate) and potassium fertilization (as potassium salt) was used in autumn before winter plough. Fertilizers were applied by means of sprinkling. Nutrients were introduced into the soil according to the following scheme:

NPK1 (50 kg N·ha^{-1}, 40 kg P·ha^{-1}, 40 kg K·ha^{-1}),
NPK2 (70 kg N·ha^{-1}, 50 kg P·ha^{-1}, 50 kg K·ha^{-1}),
NPK3 (90 kg N·ha^{-1}, 60 kg P·ha^{-1}, 60 kg K·ha^{-1}),
NPK4 (130 kg N·ha^{-1}, 70 kg P·ha^{-1}, 70 kg K·ha^{-1}).

Amaranth (*Amaranthus cruentus* L.) of Raw cv. and Aztek cv. was the test plant. Amaranth seeds were sown in every experimental year at the end of May (2007 – 22 May, 2008 – 23 May, 2009 – 22 May) at narrow- (every 30 cm) and wide-spacing system (every 60 cm). Applied nursery over the test plant was in accordance with requirements of a correct agricultural practice. Before sowing, the stand was mechanically deweeded. After seed sowing, every plot was rolled in order to make moisturizing improved and better contact of seeds with soil. After plant emergence, manual weed control was performed, because no herbicides appropriate for amaranth cultivation was not recorded up-to-date. Only once weed control was applied in every experimental year, because amaranth plants quickly form a compact canopy, which does not favor the weeding. Seventy-five plants per 1 m^2, where amaranth grown in narrow-spacing and 20 plants per 1 m^2 in wide-spacing, were left on plots. Under polish climatic conditions, no influence of diseases nor pests on amaranth plants was observed, therefore no chemical protection was applied. The leaf and stem yields was determined per 1 m^2 at the end of July, whereas the seed yield also per 1m^2 after amaranth harvest at the end of October (2007 – 25 October, 2008 – 24 October, 2009 – 26 October).

Sum of rainfalls in growing season 2007 amounted to 419.8 mm, which was lower than many-year average (1971–2005: 443.8 mm) by 24 mm (source: IMGW and own study). During growing season 2008, rainfall sum was 425.6 mm, which was lower than many-year sum by 18.2 mm, while particularly heavy rainfalls were observed in July (104.6 mm) and September (80.4 mm). Similar distribution of rainfalls in summer occurred in 2007. In 2009, sum of rainfalls was lower than average many-year sum by 9.2 mm, although May and October were abundant in rainfalls (102.6 mm and 100.0 mm, respectively). Sum of air temperatures during vegetation seasons 2007 and 2009 were lower than many-year sum (1971–2005: 2680°C): in 2007 – by 24°C (2656°C), in 2009 – by 141°C (2539°C). Air temperature sum in vegetation season 2008 amounted to 2694°C, which was higher than many-year sum by 14°C.

Amaranth was subject to digestion in concentrated sulfuric acid with H_2O_2 addition, and copper, zinc, iron, and manganese were determined by means of atomic absorption spectrophotometry using Hitachi Z 8200 device. Analyses of plant material were made in two replicates. Data on yields and microelements contents in amaranth presented in tables are mean values for three years of the field experiment. Achieved experimental results were verified applying *ANOVA* test (for factorial systems) using STATISTICA 8.0 software. Statistically uniform groups (for A × B × C) and LSD values were determined by means of HSD Tukey test at significant level of $\alpha = 0.05$. In order to compare the shares of particular experimental factors in explaining the variance of dependent variable, partial eta-squared coefficients η_p^2 were calculated.

RESULTS AND DISCUSSION

The amaranth's yielding and contents of analyzed microelements at test plant depended on its organ and experimental factors applied. Leaf and stem yields ranged – depending on the plot – from 12.10 to 18.13 kg·plot^{-1}, while seed yields from 0.417 to 0.793 kg·plot^{-1} (tab. 1). Analysis of the statistically uniform groups revealed that significantly highest leaf and stem yields of amaranth were achieved for Aztec cv. grown at wide-spacing and moderate NPK2 and NPK3 fertilization (tab. 1). Also significantly highest seeds yields were achieved for the same cultivar grown both at wide-spacing with NPK3 and NPK4 fertilization, and narrow-spacing with NPK3 fertilization. On the other hand, the lowest yields were recorded for seeds of Rawa cv. cultivated at the lowest NPK1 fertilization, regardless of spacing. In the case of leaves and stems, considerably lowest yields were also observed for Rawa cv., however at narrow-spacing and at lowest (NPK1, NPK2) and highest (NPK4) fertilization doses. Applied experimental factors contributed to the significant diversification of yields, both vegetative and generative parts of *Amaranthus cruentus* (tab. 1). Only in the case of amaranth seeds, no remarkable influence of the spacing type (B) on the yields, was recorded. Instead, the significance of interaction between cultivar (A) and plant spacing (B) for yields of vegetative and generative parts, as well as cultivar (A) × fertilization (C) for seeds, was observed in the experiment. Interaction of all three experimental factors (A × B × C) and test plant yields appeared to be significant as well.

It should be stated that higher yields of all analyzed parts of the test plants were harvested in the case of Aztek cv. Such regularity arose for both plant spacings applied in the experiment. The increase ranged from 19% to 35% for leaves and stems, as well as from 12% to 40% in the case of seeds of amaranth. When analyzing the effect of the spacing on amaranth's yielding, it was prominent that considerably higher yields of vegetative parts were recorded in wide-spacing type. The increase was within the range of almost 6% up to over 20%. Research by Igbokwe and Hollins [2000] upon to determine the influence of three within-row plant spacings (0.3, 0.6 and 0.9 m) on the growth, yield, and mineral composition of vegetable amaranth (*Amaranthus cruentus* L.) revealed that leaf dry matter increased as plant spacing increased.

Amaranth reacted with remarkable increase of yields towards nitrogen, phosphorus, and potassium nutrition. An analogous increase of leaves and seeds amaranth's yields was also observed as an effect of higher nitrogen rates in other research [Singh and Whitehead 1996, Olaniyi et al. 2008]. However, it is worth mentioning that applying the highest macronutrient doses in own study was associated with the decrease of the test plant yielding, regardless of the cultivar, nor plant spacing. The highest amaranth's yields were achieved at nitrogen used at the rate of 90 kg $N \cdot ha^{-1}$. Saini and Shekhar [1998] as well as Singh and Whitehead [1996] also recorded the highest amaranth's yields at 90 kg $N \cdot ha^{-1}$ rate, while higher nitrogen levels applied by Saini and Shekhar [1998] caused the decrease of achieved yields of amaranth. It should be added, that scientists get maximum amaranth yields at quite different nitrogen rates oscillating from 50 up to 200 kg $N \cdot ha^{-1}$ [Keskar et al. 1981, Ramachandra and Thimmaraju 1983, Subhan 1989, Olaniyi et al. 2008]. Many authors underline a positive influence of fertilization, not only using nitrogen, but also phosphorus, on growth and development of the above ground biomass of *Amaranthus cruentus* L. [Aufhammer et al. 1995, Gontarczyk 1996, Bobrzecka et al. 1999, Akinbile and Yusoff 2011]. In studies made by Modisane et al. [2009], application of the complete NPK fertilization significantly affected the increase of amaranth's yields, whereas the highest yields were achieved at the rate of 100 kg $N \cdot ha^{-1}$. Eliminating nitrogen from fertilization considerably affected the yield decrease, while lack of potassium had no negative effects on plant's yields in those studies. Research by Pospišil et al. [2006] revealed that applying nitrogen at the levels of 50 and 100 $kg \cdot ha^{-1}$ significantly affected the increase of *Amaranthus* spp. seed yields. Particularly prominent reaction towards the yield increase could be found when high nitrogen rates were applied to vegetable forms of amaranth [Gontarczyk 1996], as similar as other vegetable species as well [Krężel and Kołota 2010]. However, over- fertilization of amaranth plantation due to nitrogen brings negative results for plant's quality, because it leads to accumulation of nitrates in leaves and stems, which in consequence makes a threat for humans and animals [Mahus 1984].

Plant cultivar (A) explained the amaranth's yielding variability (when neglecting other studied effects) to the highest degree (η_p^2 = 96%), whereas, cultivar (A) × plant spacing (B) interaction in the case of seeds (η_p^2 = 36%), and interaction of all three experimental factors (A × B × C) for leaves and stems (η_p^2 = 24%) to the lowest degree (tab. 1).

In present experiment, copper content in seeds ranged from 3.63 to 6.07 $mg \cdot kg^{-1}$ d.m., in leaves 3.27–7.43 $mg \cdot kg^{-1}$ d.m., while in stems 1.37–3.17 $mg \cdot kg^{-1}$ d.m. (tab. 2). Studies made by Gajewska et al. [2002] upon the health quality of amaranth, revealed higher copper levels in seeds (7.5–12.3 $mg \cdot kg^{-1}$ d.m.). Literature references often underlined high copper contents in amaranth seeds [Czerwiński et al. 2004, Januszewska-Jóźwiak

Table 1. Yielding of *Amaranthus cruentus* L. depending on the cultivar, plant spacing, and NPK fertilization
Tabela 1. Plonowanie *Amaranthus cruentus* L. w zależności od odmiany i rozstawy roślin oraz nawożenia NPK

	Fertilization Nawożenie (C)	Cultivar – Odmiana (A)						Spacing system – Rozstawa (B)		
		Rawa			Aztek					
		I*	II**	mean	I	II	mean	I	II	mean
Yield leaves and stems Plon liście i łodygi kg·m^{-2}	NPK1	12.10 ^{a}	13.97 ^{c}	13.04	15.57 ^{ef}	16.93 ^{hi}	16.25	13.84	15.45	14.64
	NPK2	12.20 ^{a}	14.67 ^{d}	13.44	15.93 ^{fg}	17.60 ^{jk}	16.77	14.07	16.14	15.10
	NPK3	12.93 ^{b}	15.13 ^{de}	14.03	16.53 ^{gh}	18.13 ^{k}	17.33	14.73	16.63	15.68
	NPK4	12.17 ^{a}	14.60 ^{cd}	13.39	16.47 ^{gh}	17.37 ^{ij}	16.92	14.32	15.99	15.15
	mean	12.35	14.59	13.47	16.13	17.51	16.82	14.24	16.05	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 0.13 / 99 A × B – 0.24 / 59			B – 0.13 / 96 A × C – n.s.		C – 0.24 / 81 B × C – n.s.		A × B × C – 0.66 / 24	
Yield seeds Plon nasiona kg·m^{-2}	NPK1	0.417 ^{a}	0.437 ^{a}	0.427	0.577 ^{bcd}	0.580 ^{bcd}	0.579	0.497	0.509	0.503
	NPK2	0.557 ^{bc}	0.547 ^{b}	0.552	0.623 ^{d}	0.627 ^{d}	0.625	0.590	0.587	0.589
	NPK3	0.603 ^{cd}	0.567 ^{bc}	0.585	0.763 ^{f}	0.793 ^{f}	0.778	0.683	0.680	0.682
	NPK4	0.587 ^{bcd}	0.557 ^{bc}	0.572	0.697 ^{e}	0.787 ^{f}	0.742	0.642	0.672	0.657
	mean	0.541	0.527	0.534	0.665	0.697	0.681	0.603	0.612	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 0.011 / 96 A × B – 0.021 / 36			B – n.s. A × C – 0.035 / 69		C – 0.021 / 95 B × C – n.s.		A × B × C – 0.056 / 43	

* – Narrow-spacing system – Rozstawa wąskorzędowa, ** – Wide-spacing system – Rozstawa szerokorzędowa

Values (for A × B × C) followed by the same letters are not significantly different ($\alpha = 0.05$) – Wartości (dla A × B × C) oznaczone tymi samymi literami nie różnią się istotnie ($\alpha = 0,05$)

Table 2. Content of copper at *Amaranthus cruentus* L. depending on the cultivar, plant spacing, and NPK fertilization

Tabela 2. Zawartość miedzi w *Amaranthus cruentus* L. w zależności od odmiany i rozstawy roślin oraz nawożenia NPK

	Fertilization Nawożenie (C)	Cultivar – Odmiana (A)						Spacing system – Rozstawa (B)		
		Rawa			Aztek					
		I*	II**	mean średnio	I	II	mean średnio	I	II	mean średnio
Content of copper leaves Zawartość miedzi liście mg·kg^{-1} d.m.	NPK1	4.23 ^{bcd}	3.93 ^{ab}	4.08	3.27 ^{a}	3.53 ^{ab}	3.40	3.75	3.73	3.74
	NPK2	4.13 ^{bc}	6.10 ^{fg}	5.12	5.63 ^{efg}	5.57 ^{efg}	5.60	4.88	5.84	5.36
	NPK3	4.97 ^{cde}	5.07 ^{de}	5.02	5.33 ^{efg}	6.17 ^{g}	5.75	5.15	5.62	5.39
	NPK4	7.40 ^{h}	7.43 ^{h}	7.42	5.60 ^{efg}	5.27 ^{ef}	5.44	6.50	6.35	6.43
	mean	5.18	5.63	5.41	4.96	5.14	5.05	5.07	5.38	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 0.17 / 38 A × B – n.s.			B – 0.17 / 32 A × C – 0.53 / 85		C – 0.31 / 95 B × C – 0.53 / 47		A × B × C – 0.86 / 59	
Content of copper stems Zawartość miedzi łodygi mg·kg^{-1} d.m.	NPK1	1.77 ^{ab}	2.13 ^{bc}	1.95	1.37 ^{a}	2.67 ^{cd}	2.02	1.57	2.40	1.99
	NPK2	2.13 ^{bc}	3.17 ^{d}	2.65	3.03 ^{d}	1.73 ^{ab}	2.38	2.58	2.45	2.52
	NPK3	1.67 ^{ab}	2.83 ^{d}	2.25	2.07 ^{bc}	1.67 ^{ab}	1.87	1.87	2.25	2.06
	NPK4	2.10 ^{bc}	2.07 ^{bc}	2.09	1.53 ^{ab}	2.53 ^{cd}	2.03	1.82	2.30	2.06
	mean	1.92	2.55	2.23	2.00	2.15	2.08	1.96	2.35	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 0.13 / 16 A × B – 0.25 / 31			B – 0.13 / 54 A × C – n.s.		C – 0.25 / 58 B × C – 0.41 / 48		A × B × C – 0.67 / 81	
Content of copper seeds Zawartość miedzi nasiona mg·kg^{-1} d.m.	NPK1	3.93 ^{ab}	3.93 ^{ab}	3.93	4.17 ^{ab}	4.03 ^{ab}	4.1	4.05	3.98	4.02
	NPK2	4.47 ^{bc}	3.97 ^{ab}	4.22	4.57 ^{bc}	4.13 ^{ab}	4.35	4.52	4.05	4.29
	NPK3	5.23 ^{cd}	5.57 ^{de}	5.40	4.60 ^{bc}	5.77 ^{de}	5.19	4.92	5.67	5.29
	NPK4	4.73 ^{bc}	6.07 ^{e}	5.40	3.63 ^{a}	6.07 ^{e}	4.85	4.18	6.07	5.13
	mean	4.59	4.89	4.74	4.24	5.00	4.62	4.42	4.94	–
	LSD$_{0.05}$ / η_p^2 [%]	A – n.s. A × B – 0.30 / 22			B – 0.16 / 59 A × C – 0.50 / 31		C – 0.30 / 86 B × C – 0.50 / 81		A × B × C – 0.82 / 26	

* – Narrow-spacing system – Rozstawa wąskorzędowa, ** – Wide-spacing system – Rozstawa szerokorzędowa

Values (for A × B × C) followed by the same letters are not significantly different ($\alpha = 0.05$) – Wartości (dla A × B × C) oznaczone tymi samymi literami nie różnią się istotnie ($\alpha = 0,05$)

and Synowiecki 2008]; the seeds contained about 1.5-fold more copper than wheat kernels [Pederson et al. 1987, Melaku and Kelbessa 2005]. Analysis of statistically uniform groups for studied effects of interaction of three factors determined with HSD Tukey test, application of the lowest NPK fertilization level for amaranth cv. Aztek, was bound with significantly the lowest copper concentrations at test plant leaves, regardless of the plant spacing (tab. 2). On the other hand, considerably the highest levels of the microelement in leaves were recorded for Rawa cv. in narrow and wide-spacing systems at the highest NPK fertilization rate. In the case of seeds and stems, no such directional influences were observed.

Analysis of achieved data indicated that applied experimental factors exerted significant influence on the content of determined microelement in amaranth (tab. 2). The plant's seeds are the exception, for which no considerable effect of cultivar (A) on copper concentration, was recorded. Moreover, in the case of interaction between experimental factors, no noteworthy influence of plant's cultivar (A) × spacing (B) on copper content in amaranth leaves as well as cultivar (A) × NPK fertilization (C) on the concentration of analyzed element in stems of the test plant, was found either. No univocally directed influence of experimental factors on copper accumulation at test plant was found in the experiment. In the case of Rawa cv. on majority of objects, higher contents of copper were recorded at wide spacing growing. The increase ranged from 1 up to 70%. Lowest concentrations of copper in amaranth on majority of objects were recorded at NPK1 fertilization. Studies upon other vegetables (onion, shallot) revealed the decrease of copper levels resulted from increasing nitrogen dose [Jurgiel-Małecka and Suchorska-Orłowska 2008]. Warechowska [2004] reported synergistic and positive effect of increasing nitrogen rates on copper contents in triticale grains.

Calculated η_p^2 coefficients (partial eta-squared) indicated that NPK fertilization (C) explained variability of copper contents in leaves, seeds, and shoots of amaranth in 95%, 86%, and 58%, respectively (after neglecting other studied effects), while plant spacing (B) in over 50% for seeds and stems, as well as in 32% in case of leaves, explains the dependent variable (tab. 2). In turn, for interaction of plant spacing (B) × NPK fertilization (C) – the copper quantity is explained in almost 50% for leaves and stems, as well as in over 80% for seeds.

Analysis of achieved results indicated that among studied organs of the test plant, the highest zinc concentrations were recorded in leaves (35.5–102.4 mg·kg^{-1} d.m.), whereas the lowest in stems (17.9–50.3 mg·kg^{-1} d.m.) of both cultivars (tab. 3). Experiments involving 30 cultivars of *Amaranthus tricolor* during many-year experiments carried out on experimental plots of National Botanical Research Institute (Lucknow) revealed that zinc content was definitely higher (434.7–1230.0 mg kg^{-1} d.m.) than that recorded in own study [Shukla et al. 2006]. In here performed experiment, zinc level ranged from 3.93 to 6.07 mg·kg^{-1} d.m., which was lower than that found by Gajewska et al. [2002]. Literature references univocally report that amaranth kernels are a valuable source of zinc [Januszewska-Jóźwiak and Synowiecki 2008]. Authors emphasize that amaranth's seeds are characterized by zinc content similar to that at wheat grains [Pederson et al. 1987, Melaku and Kelbessa 2005].

Analysis of the statistically uniform groups revealed that significantly highest zinc contents in amaranth leaves were achieved at the lowest level of NPK fertilization, regardless of the cultivar and plant spacing (tab. 3). On the other hand, considerably lowest concentrations were recorded at two highest NPK fertilization rates (NPK3, NPK4) for Rawa cv., regardless of the amaranth spacing. An interesting situation could be observed in the case of amaranth stems, where significantly the highest zinc concentrations were found at Rawa cv., while remarkably the lowest – for Aztek cv. at the same level of NPK3 fertilization (90 kg N·ha^{-1}, 60 kg P·ha^{-1}, 60 kg K·ha^{-1}). Similar tendency was observed for seeds of the test plant species. Achieved results univocally indicated that the amaranth cultivar (A) as well as fertilization applied (C) exerted some significant influence on zinc content at the test plant. For majority of experimental objects, amaranth of Rawa cv. was characterized by significantly higher contents of analyzed microelement (tab. 3). Differences in zinc contents at both *Amaranthus cruentus* cultivars ranged from 1% to 84% in leaves, from 3% to 97% in seeds, as well as from 2% to 207% in stems. No substantial effect of the spacing type (B) on zinc contents in leaves and seeds of amaranth was recorded. The influence of NPK fertilization (C) on zinc concentration depended on the cultivar of the test plant. In the case of Aztek cv., better soil supply in nitrogen, phosphorus, and potassium was associated with the decrease of analyzed microelement content at all studied organs of the plant. Instead, no univocally directed impact of fertilization on zinc content in examined organs of Amaranth cv. Rawa, was recorded at all. The literature data indicate that nitrogen fertilization contributes to significant changes in microelements contents in yields of other vegetable crops [Jurgiel-Małecka and Suchorska-Orłowska 2008]. These studies revealed that due to increasing nitrogen rates, a decrease of zinc concentration in selected onion and shallot cultivars, occurred.

Analysis of η_p^2 coefficients indicated that the plant cultivar explained the zinc concentration variability in all analyzed plant's organs over 90% (after neglecting other examined effects), while different levels of fertilization – in 73% for seeds and 66% for stems, as well as depended variable is explained in 98% in the case of leaves (tab. 3). Interaction of amaranth cultivar × NPK fertilization explained zinc concentration variability in seeds, stems, and leaves of amaranth in 93%, 89%, and 83%, respectively.

Among analyzed organs of the test plant, the highest iron contents were recorded in amaranth leaves (189.7–526.3 mg·kg^{-1} d.m.) (tab. 4). Results referring to iron levels in *Amaranthus cruentus* leaves achieved in the present study are somehow lower than those determined by Fasuyi et al. [2008]. And similarly, higher iron contents amounted to 1233.8 mg·kg^{-1} d.m., were found in *Amaranthus tricolor* [Shukla et al. 2006]. Literature references often underline the fact of definitely higher iron concentrations in leaves of amaranth rather than spinach, leafy beet or lettuce [Grajeta 1997, Kozik et al. 2009]. Presented studies also confirmed high iron contents in amaranth plants in relation to other elements. In own research, iron concentrations in seeds of the test plant ranged from 17.0 mg·kg^{-1} d.m. up to 60.3 mg·kg^{-1} d.m., which was lower than that achieved by Gajewska et al. [2002], Olaniyi et al. [2008] as well as Sujak and Dziewulska-Hunek [2010]. However, many scientific reports underline that amaranth seeds are valuable source of iron; its level is three [Melaku and Kelbessa 2005] to five times higher than in wheat grains [Becker et al. 1981, Marciniak-Łukasiak and Skrzypczak 2008].

Analysis of table 4 indicates statistical significance of applied experimental factors and their combination to the third power in relation to iron contents in the test plant.

Table 3. Content of zinc at *Amaranthus cruentus* L. depending on the cultivar, plant spacing, and NPK fertilization
Tabela 3. Zawartość cynku w *Amaranthus cruentus* L. w zależności od odmiany i rozstawy roślin oraz nawożenia NPK

	Fertilization Nawożenie (C)	Cultivar – Odmiana (A)						Spacing system – Rozstawa (B)		
		Rawa			Aztek					
		I*	II**	mean średnio	I	II	mean średnio	I	II	mean średnio
Content of zinc leaves Zawartość cynku liście mg·kg^{-1} d.m.	NPK1	95.0 ^{i}	99.8 ^{i}	97.4	102.4 ^{i}	86.7 ^{h}	94.6	98.7	93.3	96.0
	NPK2	67.7 ^{efg}	71.4 ^{fg}	69.6	67.1 ^{def}	59.7 ^{cd}	63.4	67.4	65.6	66.5
	NPK3	61.3 ^{de}	74.9 ^{g}	68.1	37.2 ^{a}	50.1 ^{b}	43.7	49.3	62.5	55.9
	NPK4	67.6 ^{efg}	65.5 ^{def}	66.6	53.2 ^{bc}	35.5 ^{a}	44.4	60.4	50.5	55.5
	mean	72.9	77.9	75.4	65.0	58.0	61.5	68.9	68.0	–
	LSD$_{0.05}$ / η_p^2 [%]		A – 1.5 / 92 A × B – 2.8 / 67		B – n.s. A × C – 4.8 / 84		C – 2.8 / 98 B × C – 4.8 / 81		A × B × C – 7.8 / 43	
Content of zinc stems Zawartość cynku łodygi mg·kg^{-1} d.m.	NPK1	32.1 ^{ef}	38.5 ^{fg}	35.3	22.8 ^{abc}	33.4 ^{ef}	28.1	27.5	36.0	31.7
	NPK2	25.1 ^{bcd}	30.1 ^{de}	27.6	18.9 ^{ab}	29.7 ^{cde}	24.3	22.0	29.9	26.0
	NPK3	45.9 ^{h}	50.3 ^{h}	48.1	18.0 ^{a}	16.4 ^{a}	17.2	32.0	33.4	32.7
	NPK4	32.7 ^{ef}	43.6 ^{gh}	38.2	19.4 ^{ab}	17.9 ^{a}	18.7	26.1	30.8	28.4
	mean	34.0	40.6	37.3	19.8	24.4	22.1	26.9	32.5	–
	LSD$_{0.05}$ / η_p^2 [%]		A – 1.4 / 94 A × B – n.s.		B – 1.4 / 69 A × C – 4.4 / 89		C – 2.6 / 66 B × C – 4.4 / 36		A × B × C – 7.1 / 49	
Content of zinc seeds Zawartość cynku nasiona mg·kg^{-1} d.m.	NPK1	40.2 ^{b}	39.1 ^{b}	39.7	39.2 ^{b}	39.9 ^{b}	39.6	39.7	39.5	39.6
	NPK2	49.3 ^{c}	60.1 ^{d}	54.7	34.9 ^{ab}	32.7 ^{a}	33.8	42.1	46.4	44.3
	NPK3	59.9 ^{d}	59.3 ^{d}	59.6	33.6 ^{a}	30.1 ^{a}	31.9	46.8	44.7	45.7
	NPK4	51.2 ^{c}	53.2 ^{c}	52.2	32.2 ^{a}	30.4 ^{a}	31.3	41.7	41.8	41.8
	mean	50.2	53.0	51.5	35.0	33.3	34.1	42.6	43.1	–
	LSD$_{0.05}$ / η_p^2 [%]		A – 1.0 / 97 A × B – 1.9 / 38		B – n.s. A × C – 3.3 / 93		C – 1.9 / 73 B × C – 3.3 / 40		A × B × C – 5.3 / 47	

* – Narrow-spacing system – Rozstawa wąskorzędowa, ** – Wide-spacing system – Rozstawa szerokorzędowa

Values (for A × B × C) followed by the same letters are not significantly different ($\alpha = 0.05$) – Wartości (dla A × B × C) oznaczone tymi samymi literami nie różnią się istotnie ($\alpha = 0{,}05$)

Table 4. Content of iron at *Amaranthus cruentus* L. depending on the cultivar, plant spacing, and NPK fertilization

Tabela 4. Zawartość żelaza w *Amaranthus cruentus* L. w zależności od odmiany i rozstawy roślin oraz nawożenia NPK

	Fertilization Nawożenie (C)	Cultivar – Odmiana (A)						Spacing system – Rozstawa (B)		
		Rawa			Aztek					
		I*	II**	mean średnio	I	II	mean średnio	I	II	mean średnio
Content of iron leaves Zawartość żelaza liście mg·kg^{-1} d.m.	NPK1	331.3 ^{d}	348.3 ^{e}	339.8	189.7 ^{a}	329.7 ^{d}	259.7	260.5	339.0	299.8
	NPK2	286.7 ^{b}	305.7 ^{c}	296.2	323.3 ^{d}	526.3 ^{k}	424.8	305.0	416.0	360.5
	NPK3	491.0 ^{j}	521.3 ^{k}	506.2	411.7 ^{h}	501.3 ^{j}	456.5	451.4	511.3	481.3
	NPK4	365.3 ^{f}	462.0 ^{i}	413.7	331.0 ^{d}	389.0 ^{g}	360.0	348.2	425.5	386.8
	mean	368.6	409.3	389.0	313.9	436.6	375.3	341.3	423.0	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 2.8 / 75.6 A × B – 5.3 / 96.5			B – 2.8 / 99.0 A × C – 8.9 / 99.1		C – 5.3 / 99.6 B × C – 8.9 / 85.0		A × B × C – 14.5 / 96.6	
Content of iron stems Zawartość żelaza łodygi mg·kg^{-1} d.m.	NPK1	45.7 ^{def}	55.3 ^{fgh}	50.5	32.7 ^{abc}	24.0 ^{a}	28.4	39.2	39.7	39.4
	NPK2	39.0 ^{bcd}	64.0 ^{h}	51.5	50.0 ^{efg}	27.7 ^{a}	38.9	44.5	45.9	45.2
	NPK3	56.3 ^{gh}	64.7 ^{h}	60.5	29.7 ^{ab}	32.3 ^{abc}	31.0	43.0	48.5	45.8
	NPK4	41.7 ^{cde}	51.0 ^{efg}	46.4	26.3 ^{a}	37.7 ^{bcd}	32.0	34.0	44.4	39.2
	mean	45.7	58.8	52.2	34.7	30.4	32.6	40.2	44.6	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 1.9 / 93 A × B – 3.6 / 73			B – 1.9 / 41 A × C – 6.1 / 62		C – 3.6 / 58 B × C – 6.1 / 35		A × B × C – 9.8 / 76	
Content of iron seeds Zawartość żelaza nasiona mg·kg^{-1} d.m.	NPK1	33.0 ^{bc}	38.7 ^{bcd}	35.9	54.0 ^{gh}	54.0 ^{gh}	54	43.5	46.4	44.9
	NPK2	33.7 ^{bc}	46.3 ^{defg}	40.0	32.7 ^{bc}	55.7 ^{gh}	44.2	33.2	51.0	42.1
	NPK3	31.3 ^{b}	50.7 ^{fgh}	41.0	40.3 ^{bcde}	60.3 ^{h}	50.3	35.8	55.5	45.7
	NPK4	17.0 ^{a}	50.0 ^{efg}	33.5	42.0 ^{cdef}	49.0 ^{efg}	45.5	29.5	49.5	39.5
	mean	28.8	46.4	37.6	42.3	54.8	48.5	35.5	50.6	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 2.0 / 80 A × B – 3.7 / 18			B – 2.0 / 88 A × C – 6.3 / 46		C – 3.7 / 44 B × C – 6.3 / 63		A × B × C – 10.3 / 59	

* – Narrow-spacing system – Rozstawa wąskorzędowa, ** – Wide-spacing system – Rozstawa szerokorzędowa

Values (for A × B × C) followed by the same letters are not significantly different ($\alpha = 0.05$) – Wartości (dla A × B × C) oznaczone tymi samymi literami nie różnią się istotnie ($\alpha = 0{,}05$)

Table 5. Content of manganese at *Amaranthus cruentus* L. depending on the cultivar, plant spacing, and NPK fertilization

Tabela 5. Zawartość manganu w *Amaranthus cruentus* L. w zależności od odmiany i rozstawy roślin oraz nawożenia NPK

	Fertilization Nawożenie (C)	Cultivar – Odmiana (A)						Spacing system – Rozstawa (B)		
		Rawa			Aztek					
		I*	II**	mean średnio	I	II	mean średnio	I	II	mean średnio
Content of manganese leaves Zawartość manganu liście mg·kg^{-1} d.m.	NPK1	720.0 ^{h}	733.7 ^{h}	726.9	660.3 ^{g}	655.0 ^{g}	657.7	690.2	694.4	692.3
	NPK2	755.7 ^{i}	839.3 ^{k}	797.5	585.3 ^{f}	437.3 ^{e}	511.3	670.5	638.3	654.4
	NPK3	579.3 ^{f}	773.7 ^{j}	676.5	243.7 ^{a}	342.7 ^{b}	293.2	411.5	558.2	484.9
	NPK4	829.0 ^{k}	881.0 ^{l}	855.0	370.0 ^{c}	390.0 ^{d}	380.0	599.5	635.5	617.5
	mean	721.0	806.9	764.0	464.8	456.3	460.5	592.9	631.6	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 3.2 / 99.9 A × B – 5.9 / 96.7			B – 3.2 / 95.2 A × C – 10.0 / 99.6		C – 5.9 / 99.7 B × C – 10.0 / 98.3		A × B × C – 16.2 / 95.9	
Content of manganese stems Zawartość manganu łodygi mg·kg^{-1} d.m.	NPK1	43.7 ^{ef}	63.0 ^{g}	53.4	75.0 ^{h}	79.3 ^{h}	77.2	59.4	71.2	65.3
	NPK2	31.3 ^{cd}	30.7 ^{cd}	31.0	18.7 ^{a}	19.7 ^{ab}	19.2	25.0	25.2	25.1
	NPK3	53.0 ^{fg}	53.0 ^{fg}	53.0	22.3 ^{abc}	21.7 ^{abc}	22.0	37.7	37.4	37.5
	NPK4	42.3 ^{e}	35.3 ^{de}	38.8	29.7 ^{bcd}	34.0 ^{de}	31.9	36.0	34.7	35.3
	mean	42.6	45.5	44.0	36.4	38.7	37.6	39.5	42.1	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 2.0 / 58 A × B – n.s.			B – 2.0 / 18 A × C – 6.3 / 93		C – 3.8 / 97 B × C – 6.3 / 49		A × B × C – 10.3 / 42	
Content of manganese seeds Zawartość manganu nasiona mg·kg^{-1} d.m.	NPK1	24.7 ^{a}	23.7 ^{a}	24.2	80.7 ^{bc}	82.0 ^{bc}	81.4	52.7	52.9	52.8
	NPK2	72.3 ^{b}	86.0 ^{cd}	79.2	120.0 ^{g}	99.0 ^{ef}	109.5	96.2	92.5	94.3
	NPK3	107.0 ^{f}	94.0 ^{de}	100.5	109.3 ^{fg}	89.7 ^{cde}	99.5	108.2	91.9	100.0
	NPK4	91.3 ^{cde}	87.3 ^{cd}	89.3	94.7 ^{de}	86.3 ^{cd}	90.5	93.0	86.8	89.9
	mean	73.8	72.8	73.3	101.2	89.3	95.2	87.5	81.0	–
	LSD$_{0.05}$ / η_p^2 [%]	A – 2.1 / 94 A × B – 3.9 / 47			B – 2.1 / 56 A × C – 6.6 / 94		C – 3.9 / 98 B × C – 6.6 / 53		A × B × C – 10.8 / 60	

* – Narrow-spacing system – Rozstawa wąskorzędowa, ** – Wide-spacing system – Rozstawa szerokorzędowa

Values (for A × B × C) followed by the same letters are not significantly different ($\alpha = 0.05$) – Wartości (dla A × B × C) oznaczone tymi samymi literami nie różnią się istotnie ($\alpha = 0,05$)

Considering the effect of cultivar on iron accumulation, it should be noted that its higher concentration in the case of vegetative organs (stems, leaves) was recorded for Rawa cv., whereas slightly higher iron content in the case of seeds was determined at Aztek cv. In research by Olaniyi et al. [2008] the content in the leaf, stem and grain differed significantly also among the *Amaranth* varieties. In the present experiment, taking into account the influence of plant spacing on iron content, its higher concentration was recorded in *Amaranthus cruentus* grown in wide-spacing system. In majority analyzed combinations, the increase of nitrogen, phosphorus, and potassium rates contributed to the increase of analyzed microelement concentration in both tested cultivars of *Amaranthus cruentus*. Similarly, during studies upon other plant species (onion, shallot), the increase of iron level in the yield was observed due to the increasing nitrogen doses [Jurgiel-Małecka and Suchorska-Orłowska 2008].

Analysis of statistically uniform groups revealed that for Aztek cv. in wide-spacing cultivation, higher NPK fertilization (NPK1, NPK2, NPK3) did not considerably differentiate the iron contents in stems and seeds of amaranth (tab.4). Analogously, the increasing rates of nitrogen, phosphorus, and potassium did not significantly diversify the content of examined microelement in stems of the test plant for Rawa cv. grown in wide-spacing system.

For amaranth leaves, NPK fertilization (C) explained the iron level variability to the highest degree (η_p^2 = 99.6%) (when other studied effects are ignored); in the case of seeds and stems, spacing (B) and cultivar of the test plant (A) respectively in about 90% (tab. 4). In the case of seeds, the iron content was explained the least by interaction between cultivar (A) × plant spacing (B), while for stems, interaction between plant spacing (B) × NPK fertilization (C).

In presented experiment, the highest manganese contents, ranging from 243.7 to 881.0 mg·kg^{-1} d.m. were recorded in amaranth leaves (tab. 5). These values were higher than those found in studies carried out by other authors [Shukla et al. 2006]. Own research revealed manganese concentrations in seeds from 23.7 to 120.0 mg·kg^{-1} d.m. Literature data indicate that amaranth seeds are abundant in numerous microelements, including manganese [Gajewska et al. 2002, Czerwiński et al. 2004, Januszewska-Jóźwiak and Synowiecki 2008]. Minerals are present in the plant at much higher quantities than in grains of common cereals [Prokopowicz 2001]. Analysis of statistically uniform groups revealed that considerably lowest manganese contents in amaranth seeds were recorded for Rawa cv. at the lowest NPK fertilization rate (NPK1), regardless of the plant spacing, whereas the highest for Aztek cv. at narrow-spacing sowing and at moderate NPK rates (NPK2, NPK3) (tab. 5). Performed studies indicated remarkable influence of experimental factors as well as their interaction on manganese concentrations at the test plant. Only for stems, no significant impact of the interaction between cultivar (A) × spacing type (B) on manganese level, was recorded (tab. 5). Analysis of achieved results indicated that higher manganese contents in leaves were found for Rawa cv., whereas in seeds of majority of studied objects for Aztek cv. Higher manganese concentrations were observed in narrow-spacing system in amaranth seeds in majority of objects.

Analysis of partial eta-squared coefficients (η_p^2) indicated that all applied experimental factors as well as their interactions explained manganese content variability in leaves of the test plant in over 95% (excluding other examined effects) (tab. 5). In the case of seeds, NPK fertilization (C) and interaction between cultivar (A) × NPK fertilization (C) explained the dependent variable (manganese content) to the highest degree (η_p^2 > 94%). In turn, interaction between plant spacing (B) × NPK fertilization (C) explained the manganese concentration variability to the lowest degree (η_p^2 = 53%).

CONCLUSIONS

Analysis of achieved results indicated some remarkable differentiation of *Amaranthus cruentus* yield size as an effect of experimental factors. Among examined cultivars, Aztec cv. produced higher yields of both vegetative parts and seeds. The highest yields were produced at NPK3 fertilization (90 kg N·ha^{-1}, 60 kg P·ha^{-1}, 60 kg K·ha^{-1}).

Substantial influence of experimental factors on the concentrations of analyzed microelements in leaves and seeds of amaranth was recorded for majority of studied objects. No univocally directed influence of the cultivar on copper accumulation at test plant was found in the experiment. Amaranth of Rawa cv. was characterized by significantly higher zinc contents, whereas higher iron and manganese concentrations in leaves were determined for Rawa cv., while in seeds – for Aztek cv.

Considering the influence of plant spacing on copper, iron and manganese content in amaranth leaves, their significantly higher levels were found at wide-spacing. Similarly significantly higher copper and iron concentration was found at amaranth seeds at wide-spacing system. Instead, significantly higher manganese levels in amaranth seeds were recorded at the test plant cultivated in narrow-spacing system.

Analysis of η_p^2 coefficients indicated that plant cultivar explained the *Amaranthus cruentus* yielding variability to the highest degree, while contents of copper and manganese in seeds, and copper, zinc, and iron in leaves – the NPK fertilization, as well as zinc content in seeds and manganese in leaves – the amaranth cultivar.

REFERENCES

Abu Ziada M.E., El-Halawany E.F., Mashaly I.A., Masoud G.F., 2008. Autecology and phytochemistry of genus *Amaranthus* in the nile delta, Egypt. Asian J. Plant Sci. 7, 119–129.

Akinbile Ch.O., Yusoff M.S., 2011. Effect of tillage methods and fertilizer applications on Amaranthus cruentus in Nigeria. Inernat. J. Agric. Res. 6(3), 280–289.

Aufhammer W., Kaul H.P., Herz P., Nalborczyk E., Dalbiak A., Gontarczyk M., 1995. Grain yield formation and nitrogen uptake of amaranth. Eur. J. Agron. 4(3), 379–386.

Bailey J.M., 1992. The leaves we eat. Handbook No. 31. South Pacific Commission.

Becker R., Wheeler E.L., Lorenz K., Stafford A.E., Grosjean O.K., Betschart A.A., Saunders R.M., 1981. A compositional study of Amaranth grain. J. Food Sci. 46, 1175–1180.

Bejosano F., Corke H., 1998. Protein quality evaluation of *Amaranthus* wholemeal flours and protein concentrations. J. Sci. Food Agric. 76, 100–106.

Bobrzecka D., Faruga A., Domska D., Mikulski D., Wojciechowska B., 1999. Wpływ nawożenia NPK, B. Cu i Zn na plon zielonki szarłatu oraz jej wartość jako paszy dla kur. Zesz. Prob. Post. Nauk Roln. 468, 291–299.

Bobrzecka D., Wojciechowska B., Procyk Z., Wojtas A., 2000. Zawartość oraz jakość tłuszczu z nasion szarłatu (*Amaranthus cruentus* L.) w zależności od nawożenia miedzią. Rośliny Oleiste – Oilseed Crops 21, 301–308.

Czerwiński J., Bartnikowska E., Leontowicz H., Lange E., Leontowicz M., Katrich E., Trakhtenberg S., Gorinstein S., 2004. Oat (*Avena sativa L.*) and amaranth (*Amaranthus hypochondriacu*s) meals positively affect plasma lipid profile in rats fed cholesterol-containing diets. J. Nutr. Biochem. 15, 622–629.

Fasuyi A.O., Dario F.A.S., Adeniji A.O., 2008. Tropical vegetable (*Amaranthus cruentus*) leaf meal as alternative protein supplement in broiler starter diets: bionutritional evaluation. J. Central Europ. Agric. 9(1), 23–34.

Gajewska R., Lebiedzińska A., Malinowska E., Szefer P., 2002. Ocena jakości zdrowotnej szarłatu (amarantusa). Roczn. PZH 53, 141–147.

Gontarczyk M., 1996. Szarłat uprawny – *Amaranthus* spp. [W:] Nalborczyk E. (red.), Nowe rośliny uprawne na cele spożywcze, przemysłowe i jako odnawialne źródło energii. Wyd. SGGW, Warszawa, 21–43.

Grajeta H., 1997. Wartość odżywcza i wykorzystanie szarłatu (Rodzaj *Amaranthus*). Bromat. Chem. Toksykol. 30, 17–23.

Igbokwe P.E., Hollins S., 2000. Response of vegetable amaranth to plant spacing. J. Veget. Crop Prod., 6(2), 75–85.

Januszewska-Jóźwiak K., Synowiecki J., 2008. Charakterystyka i przydatność składników szarłatu w biotechnologii żywności. Biotechnologia 3(82), 89–102.

Jurgiel-Małecka G., Suchorska-Orłowska J., 2008. The effect of nitrogen fertilization on content of microelements in selected onions. J. Elementol. 13(2), 227–234.

Keskar B.G., Bhore D.P., Patil A.V., Sonone H.N., Maslekar S.R., 1981. Comparative efficacy of soil and foliar application of nitrogen through urea on yield of leafy vegetable-Chaulai (*Amaranthus blitum* L.) at various seed rates. J. Maharashtra Agr. Univ. 6, 68–69.

Kozik E., Tyksiński W., Komosa A., 2009. Effect of chelated and mineral forms of micronutrients on their content in leaves and the yield of lettuce. Part III. Zinc. Acta Sci. Pol., Hortorum Cultus 8(2), 37–43.

Krężel J., Kołota E., 2010. The effect of nitrogen fertilization on yielding and biological value of spinach grown for autumn harvest. Acta Sci. Pol. Hortorum Cultus 9(3), 183–190.

Mahus D.J., 1984. Evolution of amaranth as a potential regens crop in the Midlesouth. Hort. Science 19 (6), 881–883.

Makus, D.J., Davis D.R., 1984. A mid-summer crop for fresh greens or canning: vegetable amaranth. Ark. Farm Res. 33, 10.

Marciniak-Łukasiak K., Skrzypczak M., 2008. Koncentrat chleba bezglutenowego z dodatkiem mąki z szarłatu. Żywność. Nauka. Technologia. Jakość 4 (59), 131–140.

Melaku U., Kelbessa U., 2005. The chemical composition, protein fractions, mineral contents and nutritional quality of some amaranth grains collected from south western Ethiopia. Chem. Comp., Protein Fract., 15, 2, 77–87.

Modisane P. C., Beletse Y., Du Plooy C. P., 2009. Yield response of Amaranthus and Cleome to fertilizer application. African Crop Sci. Conf. Proceed. 9, 213–216.

Olaniyi I.O., Adelasoye K.A., Jegede C.O., 2008. Influence of nitrogen fertilizer on the growth, yield and quality of grain Amaranth varieties. World J. Agric. Sci. 4, 506–513.

Pederson B., Kalinowski L.S., Eggum B.O., 1987. The nutritive value of amaranth grain (*Amaranthus cadutus*). 1. Protein and minerals of raw and processed grain. Plant Foods Human Nutr. 36, 309–324.

Piecyk M., Worobiej E., Rębiś M., Rębiś Ż., 2009. Zawartość i charakterystyka składników odżywczych w produktach z szarłatu. Bromat. Chem. Toksykol. XLII(2), 147–153.

Pospišil A., Pospišil M., Varga B., Svečnjak Z., 2006. Grain yield and protein concentration of two amaranth species (*Amaranthus* spp.) as influenced by the nitrogen fertilization. Europ. J. Agronomy 25, 250–253.

Prokopowicz D., 2001. Właściwości zdrowotne szarłatu (*Amaranthus cruentus*). Med. Wet. 57(8), 559–561.

Ramachandra H.A., Thimmaraju K.R., 1983. Effect of different levels of nitrogen and phosphorous on growth components and yield of *Amaranthus* (*Amaranthus gangeticus* L.) cv. `A-25'. Mysore J. Agr. Sci. 17, 158–164.

Repo-Carrasco-Valencia R., Peña J., Kallio H., 2009. Dietary fiber and other functional components in two varieties of crude and extruded kiwicha (Amaranthus caudatus). J. Cereal Sci. 49, 219–224.

Saini J.P., Shekhar J., 1998. Effect of nitrogen fertilizer on growth and yield of grain amaranth (*Amaranthus hypochondriacus*) cultivars under dry-temperate. Indian J. Agron. 43(4), 743–746.

Shukla S., Bhargova A., Chatterjee A., Srivastava J., Singh N., Singh S.P., 2006. Mineral profile and variability in vegetable amaranth (*Amaranthus tricolor*). Plant Foods Human Nutr. 61, 23–28.

Singh, B.P., Whitehead. W.F., 1993. Population density and soil pH effects on vegetable amaranth production. [In:] Janick J., Simon J.E. (eds.), New crops. Wiley, New York, 562–564.

Singh B.P., Whitehead W.F., 1996. Management methods for producing vegetable amaranth. [In:] Janick J. (eds.), Progress in new crops. ASHS Press, Arlington, VA., 511–515.

Skwaryło-Bednarz B., Brodowska M.S., 2009. Amaranth (*Amaranthus cruentus* L.) as a plant with pro-health properties. [In:] Pasternak K. (red.), Pierwiastki, środowisko i życie człowieka, 280–287.

Sounders R.M., Becker R., 1983. *Amaranthus*: a potential food and feed resource. Adv. Cereal Sci. Technol. 6, 357–396.

Stallknecht, G.F., Schulz-Schaeffer J.R., 1993. Amaranth rediscovered. [In:] Janick J., Simon J.E. (eds.), New crops. Wiley, New York, 211–218.

Subhan, 1989. Effect of dosage and application time of nitrogen fertilizer on growth and yield of amaranth (*Amaranthus tricolor* L.) (Indonesian, English summary). Penelit. Hort. 17, 31–40.

Sujak A., Dziewulska-Hunek A., 2010. Minerale and fatty acids of amaranth seeds subjected to pre-sowing electromagnetical stimulation. Int. Agrophys. 24, 375–379.

Teutonico R.A., Knorr D., 1985. Amaranth: composition, properties and applications of a rediscovered food crop. Food Tech. 39, 49–60.

Tosi E.A., Lucero E.R.H., Mascarelli R., 2001. Dietary fiber obtained from amaranth (*Amaranthus cruentus*) grain by differential milling. Food Chem. 73, 441–443.

Warechowska M., 2004. Wpływ nawożenia azotem i miedzią pszenżyta jarego na zawartość miedzi w ziarnie i jego wartość technologiczną. Zesz. Probl. Post. Nauk Rol. 502, 395–402.

Willis R.B.H., Wong A.W.K., Scriven F.M., Greenfield H., 1984. Nutrient composition of Chinese vegetables. J. Agr. Food Chem. 32, 413–416.

OCENA WPŁYWU ZRÓŻNICOWANEGO NAWOŻENIA NPK NA PLONOWANIE ORAZ ZAWARTOŚĆ MIKROSKŁADNIKÓW W SZARŁACIE (*Amaranthus cruentus* L.) W ZALEŻNOŚCI OD JEGO ODMIANY I ROZSTAWY ROŚLIN

Streszczenie. Amarantus posiada nie tylko wysokie walory żywieniowe (nasiona i liście), ale także prozdrowotne, ekologiczne, rolnicze oraz ozdobne. Celem niniejszej pracy było przeanalizowanie wpływu odmiany i rozstawy roślin oraz zróżnicowanego nawożenia NPK na plonowanie i zawartości Cu, Zn, Fe i Mn w nasionach, liściach i łodygach szarłatu (*Amaranthus cruentus* L.) odmiany Rawa i Aztek. Podstawę pracy stanowi trzyletnie doświadczenie polowe założone metodą losowanych podbloków (split-plot) w trzech powtórzeniach, w którym czynnikami zmiennymi były: odmiana rośliny i rozstawa, zastosowane na dwóch poziomach oraz nawożenie NPK na czterech. Uzyskane wyniki badań wskazują, że zastosowane czynniki doświadczalne przyczyniły się do istotnego zróżnicowania wielkości plonów *Amaranthus cruentus*. Amarantus reagował istotną zwyżką plonów na nawożenie NPK. Najwyższe plony uzyskano przy nawożeniu w dawce 90 kg N·ha^{-1}, 60 kg P·ha^{-1} i 60 kg K·ha^{-1}. Zastosowanie najwyższego nawożenia NPK (130 kg N·ha^{-1}, 70 kg P·ha^{-1}, 70 kg K·ha^{-1}) wiązało się ze spadkiem plonowania rośliny testowej, bez względu na odmianę czy rozstawę roślin. Zastosowane czynniki doświadczalne w większości przypadków wywarły istotny wpływ na zawartość analizowanych mikroskładników w liściach i nasionach amarantusa. Analiza współczynników η_p^2 wskazuje, że w największym stopniu zmienność plonowania amarantusa wyjaśnia odmiana rośliny, zawartość miedzi, cynku i żelaza w liściach oraz miedzi i manganu w nasionach w największym stopniu wyjaśnia nawożenie NPK, z kolei zawartość manganu w liściach i cynku w nasionach – odmiana rośliny testowej.

Słowa kluczowe: amarantus, rozstawa, nawożenie, plon, zawartość mikroelementów

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