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EFFECT OF FERTILIZATION WITH MULTINUTRIENT COMPLEX FERTILIZERS ON TUBER QUALITY OF VERY EARLY POTATO CULTIVARS

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Abstract. Fertilization is one of the most important factors which can significantly affect potato tuber quality. The effect of multi-nutrient complex fertilizers (HydroComplex, Nitrophoska Blue Special and Viking 13 representing the nitrophoska group, and Polimag S from the amophoska group), and single-nutrient fertilizers (ammonium nitrate, single superphosphate and potassium sulphate) on tuber quality of very early potato cultivars ('Aster', 'Fresco', 'Gloria') was compared in a three-year field experiment. It was found that the single-nutrient and multi-nutrient complex fertilizers did not affected the dry matter, starch and L-ascorbic acid content in tubers of very early potato cultivars, but they increased nitrate (V) content. Of the multi-nutrient complex fertilizers, only HydroComplex containing most of magnesium and sulphur of all with the nitrophoska group significantly increased nitrate (V) content in tubers, on average by 4.0 mg $N\text{-}NO_3$ kg^{-1} of fresh weight and, as result, reduced the ascorbate-nitrate index, compared with the single-nutrient fertilizers. The fertilizers applied in the study had no effect on the content of mineral compounds in potato tubers, except of potassium. The potassium content increased as the result of HydroComplex applied, on average by 0.86 g kg^{-1} of dry matter. The kind of fertilizer had a greater effect on the quality of 'Aster' and 'Gloria' than 'Fresco' tubers. Tubers of 'Aster' and 'Gloria' contained more dry matter and starch, and less nitrates (V) and calcium than 'Fresco'. The content of L-ascorbic acid, phosphorus, potassium and magnesium in tubers of the examined potato cultivars was similar.

Key words: dry matter, starch, L-ascorbic acid, nitrates (V), ascorbate-nitrate index, mineral compounds

INTRODUCTION

Potatoes (*Solanum tuberosum* L.) play an important role in human nutrition in Europe. The potato tuber provides significant amounts of protein, vitamin C and mineral compounds, and is relatively low in calories. A typical meal of 200 g boiled potatoes (at

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least three average-sized tubers) included in the diet provides about 50% of the recommended daily amount of vitamin C, 30% of potassium, 8–15% of magnesium and 8–12% of phosphorus [Leszczyński 2000, Haase 2008]. Apart from nutrients, potatoes also contain substances which have an adverse effect on human health such as nitrates and glycoalkaloids. Potato is a plant which accumulates small amounts of nitrates. However, due to high potato consumption, it is a source of substantial quantities of these compounds. As much as 27% of daily nitrate intake with food can be derived from potatoes [Matin et al. 1998]. There was a significant correlation found between the ascorbic acid content and nitrate level in potato tubers [Cieślik 1994]. The reciprocal level of these compounds can be represented by means of the ascorbate-nitrate index which is the ratio of ascorbic acid amount and nitrate amount [Lachman et al. 1997]. The chemical composition of potato tubers depends on the genetic character of the cultivar, tuber size and maturity, but may change under climatic and agronomic factors [Sawicka and Mikos-Bielak 1995, Ilin et al. 2002, Leszczyński 2002, Kołodziejczyk and Szmigiel 2005, Boguszewska 2007]. Fertilization, especially nitrogen fertilization, is one of the most important agronomical factors which can significantly affect potato tuber quality. Fertilizers should provide essential nutrients for crop production without worsening tuber quality. In the coming years it is expected that there will be an increase in multi-nutrient fertilizer usage. Multi-nutrient fertilizers supply crops with primary (nitrogen, phosphorus, and potassium) and secondary (calcium, magnesium and sulphur) nutrients and micronutrients (iron, zinc, manganese, copper, boron and molybdenum). Multi-nutrient complex fertilizers have the advantage of having each nutrient in each granule. They are more expensive than the equivalent quantity of nutrients achieved by applying equivalent quantities of single-nutrient fertilizers [Wadas and Łęczycka 2010]. The aim of the study was to compare the effect of an application of multi-nutrient complex fertilizers as well as single-nutrient fertilizers on the tuber quality of very early potato cultivars.

MATERIAL AND METHODS

The effect of multi-nutrient complex fertilizers HydroComplex (NPKMgS 12-11-18-2,6-8 + B, Mn, Zn, Fe; produced by Yara International ASA Norway), Nitrophoska Blue Special (NPKMgS 12-12-17-2-6 + B, Zn; produced by COMPO GmbH&Co.KG Germany), Viking 13 (NPKMgCaS 13-13-21-1,2-4-1,4; produced by Yara International ASA Norway) representing the nitrophoska group and Polimag S (NPKMgS 10-8-15-5-14 + B, Cu, Mn, Zn; produced by Zakłady Chemiczne POLICE S.A. Poland) from the amophoska group, and single-nutrient fertilizers (ammonium nitrate 34%, superphosphate 19%, potassium sulphate 50%) on the tuber quality of very early potato cultivars 'Aster' (Polish), 'Fresco' (The Netherlands) and 'Gloria' (German) was compared.

The study was carried out at the Agricultural Experimental Station of Siedlce University of Natural Sciences and Humanities (52°09'N, 22°16'E), during the three growing seasons 2005–2007. The field experiment was established in the split-plot design with three replications, on a podzolic soil. The organic carbon content in the soil ranged from 5.5 to 6.1 g kg^{-1} of soil, pH in 1 mol dm^{-3} KCl from 5.0 to 6.8. The content of available phosphorus in soil ranged from 89 to 102 mg P kg^{-1}, potassium from 75 to 100 mg K kg^{-1} and magnesium from 34 to 39 mg Mg kg^{-1} of soil. The plot area was 15 m^2. In each year of the study, spring triticale was grown as a potato forecrop. Farmyard manure was applied in autumn, at a rate of 30 t ha^{-1}. The multi-nutrient complex fertilizers and single-nutrient fertilizers were applied in spring, in the amounts equivalent to the recommended rates for the cultivars tested (100 kg N ha^{-1}). The remaining elements in the single-nutrient fertilizers were applied at rates which guarantee an appropriate N : P : K proportion for edible potatoes, i.e. 1 : 1 : 1.5. In successive years, 4-week pre-sprouted seed potatoes were planted on 15, 20 and 18 April, at the spacing 62.5 × 30 cm. Potato cultivation was carried out according to the rules of correct agronomical practice. Potatoes were harvested at the tubers physiological maturity stage, on 25 and 31 July and 8 August respectively. Laboratory studies were conducted on samples of 50 different-sized tubers taken from each treatment. Fresh tubers were used in chemical analyses which were conducted immediately after potato harvest. The content of dry matter with the oven-drying gravimetric method, starch with polarimetric method according to Ewers [Mitchell 1990], L-ascorbic acid with the titration method with 2,6-dichlorphenolindophenol according to Tillmans [Polish Standard PN-90/A-75101.11], nitrate (V) with ionselective nitrate electrode and chlorine-silver reference electrode [Kolbe and Müller 1987], phosphorus with the vanadium-molybdenum colorimetric method, magnesium with atomic absorption spectrometry (AAS) method, potassium and calcium with the photometric method were determined. The ascorbate-nitrate index as the ratio of L-ascorbic acid amount-to-nitrate (V) amount in potato tubers [Lachman et al. 1997] was also calculated. The results of the study were analysed statistically by means of analysis of variance. The significance of differences was verified using Tukey's test at P = 0.05.

The most favourable thermal and moisture conditions for the cultivation of very early potato cultivars were in the growing season of 2007 (tab. 1). In 2005, there was a drought from mid-June to the end of the growing season, and in 2006 there was a mild drought throughout the growing season.

RESULTS

Weather conditions during the potato growing season had a significant effect on the chemical composition of tubers. Irrespective of the kind of fertilizer applied, the most dry matter and starch were accumulated by potato tubers in 2006, which had the lowest rainfall during the growing season. In contrast, nitrates (V), phosphorus, potassium, calcium and magnesium accumulation in tubers in this year were the lowest (tab. 2–6). Lowest L-ascorbic acid and most nitrates (V) were accumulated by potato tubers in 2005, when the air temperature was the lowest and accompanied by deficiency of precipitation from mid-June to the end of the growing season. The highest ascorbate-nitrate index value was characteristic of tubers harvested in 2006, which had the highest precipitation shortages during the potato growing season.

The fertilizers applied in the experiment had no effect on dry matter, starch or L-ascorbic acid content in tubers but they significantly increased nitrate (V) content

Table 1. Mean air temperature and precipitation sums in the vegetation period of potato
Tabela 1. Średnie temperatury powietrza i sumy opadów atmosferycznych w okresie wegetacji ziemniaka

	Years Lata	Months and ten day periods – Miesiące i dekady											
		April – Kwiecień			May – Maj			June – Czerwiec			July – Lipiec		
		I	II	III	I	II	III	I	II	III	I	II	III
Temperature Temperatura (°C)	2005	8.5	10.8	6.7	10,7	10.5	17.8	12.9	17.8	17.0	19.7	20.7	20.2
	2006	5.9	7.2	12.1	14.0	14.5	12.3	11.6	18.3	21.6	22.5	21.2	23.1
	2007	6.1	9.6	10.0	9.4	14.3	20.2	18.4	19.9	16.3	16.8	21.2	18.7
Rainfalls Opady (mm)	2005	1.0	1.6	9.7	33.6	30.5	0.6	12.5	29.6	2.0	1.5	7.2	77.8
	2006	13.8	11.8	4.2	4.0	17.0	18.6	15.4	0.3	8.3	0.0	13.8	2.4
	2007	18.9	2.1	0.2	20.7	23.3	15.1	16.6	16.4	26.0	40.9	7.0	22.3
Sielianin's hydrothermal coefficient Współczynnik hydrotermiczny Sielianinowa	2005	0.1	0.2	1.4	3.1	2.9	0.0	1.0	1.7	0.1	0.1	0.4	3.5
	2006	2.3	1.6	0.4	0.3	1.2	1.4	1.3	0.0	0.4	0.0	0.7	0.1
	2007	3.1	0.2	0.0	2.2	1.6	0.7	0.9	0.8	1.6	2.4	0.3	1.2

Table 2. Dry matter and starch content in potato tubers in relation to the kind of fertilizer and cultivar
Tabela 2. Zawartość suchej masy i skrobi w bulwach ziemniaka w zależności od rodzaju nawozu i odmiany

	Kind of fertilizer Rodzaj nawozu	Cultivar – Odmiana												Mean Średnia
		Aster				Fresco				Gloria				
		2005	2006	2007	mean średnia	2005	2006	2007	mean średnia	2005	2006	2007	mean średnia	
Dry matter (% f. w.) Sucha masa (% św. m.)	without fertilizers bez nawożenia mineralnego	22.12	22.25	21.33	21.90	20.49	21.05	19.75	20.43	22.66	22.68	19.25	21.53	21.28
	singlenutrient fertilizers nawozy jednoskładnikowe	21.65	22.70	20.57	21.64	20.55	19.65	19.48	19.89	23.28	22.37	19.52	21.72	21.08
	HydroComplex	21.41	22.72	19.94	21.36	20.20	20.91	20.07	20.39	22.24	21.56	19.08	20.96	20.90
	Nitrophoska Blue Special	22.54	23.40	21.36	22.43	19.60	21.07	20.80	20.49	22.87	22.57	20.26	21.90	21.61
	Viking 13	21.54	22.41	21.37	21.78	19.86	19.59	19.43	19.63	23.11	22.76	18.65	21.51	20.97
	Polimag S	22.55	22.78	20.56	21.96	19.59	21.18	20.33	20.37	22.62	22.68	20.15	21.82	21.38
	mean – średnia	21.97	22.71	20.85	21.84	20.05	20.58	19.98	20.20	22.80	22.44	19.49	21.57	21.20
	LSD – NIR $_{0.05}$: years – lata = 0.44, kind of fertilizer – rodzaj nawozu = ns – nist, cultivar – odmiana = 0.47, years × cultivar – lata × odmiana = 0.81													
Starch (% f. w.) Skrobia (% św. m.)	without fertilizers bez nawożenia mineralnego	12.72	14.57	13.33	13.54	11.82	12.63	13.30	12.58	14.04	12.37	12.47	12.96	13.03
	singlenutrient fertilizers nawozy jednoskładnikowe	12.33	13.07	13.77	13.05	11.71	14.30	13.53	13.18	15.18	12.07	12.03	13.09	13.11
	HydroComplex	14.40	14.03	13.63	14.02	10.95	13.60	13.70	12.75	14.49	14.10	12.23	13.61	13.46
	Nitrophoska Blue Special	14.04	14.00	12.53	13.52	12.12	12.33	12.83	12.43	12.57	13.67	12.30	12.84	12.93
	Viking 13	13.12	13.83	14.13	13.70	10.69	13.53	12.17	12.13	14.08	13.60	12.33	13.34	13.05
	Polimag S	13.47	14.27	12.13	13.29	12.12	13.27	11.83	12.41	13.23	14.17	12.90	13.43	13.04
	mean – średnia	13.35	13.96	13.26	13.52	11.57	13.28	12.89	12.58	13.93	13.33	12.38	13.21	13.10
	LSD – NIR $_{0.05}$: years – lata = ns – nist, kind of fertilizer – rodzaj nawozu = ns – nist, cultivar – odmiana = 0.58, years × cultivar – lata × odmiana = 1.00													

Table 3. L-ascorbic acid and nitrates (V) content in potato tuber in relation to the kind of fertilizer and cultivar
Tabela 3. Zawartość kwasu L-askorbinowego i azotanów (V) w bulwach ziemniaka w zależności od rodzaju nawozu i odmiany

	Kind of fertilizer Rodzaj nawozu	Cultivar – Odmiana												Mean Średnia
		Aster				Fresco				Gloria				
		2005	2006	2007	mean średnia	2005	2006	2007	mean średnia	2005	2006	2007	mean średnia	
L-ascorbic acid ($mg\ kg^{-1}$ f. w.) Kwas L-askorbinowy ($mg\ kg^{-1}$ św. m.)	without fertilizers bez nawożenia mineralnego	139.2	169.3	146.7	151.7	136.5	149.3	147.7	144.5	140.6	127.3	157.7	141.9	146.0
	singlenutrient fertilizers nawozy jednoskładnikowe	138.5	167.7	146.3	150.8	142.5	159.3	141.3	147.7	142.3	145.7	144.7	144.2	147.6
	HydroComplex	137.5	126.3	141.0	134.9	143.1	140.0	146.7	143.2	147.7	139.3	145.3	144.1	140.8
	Nitrophoska Blue Special	146.7	161.0	143.7	150.4	135.2	134.7	143.0	137.6	145.0	168.7	151.0	154.9	147.6
	Viking 13	139.6	137.0	138.3	138.3	147.1	155.3	151.7	151.4	138.7	145.7	142.7	142.3	144.0
	Polimag S	142.3	163.3	146.3	150.6	142.7	140.7	147.7	143.7	137.5	154.3	151.7	147.8	147.4
	mean – średnia	140.6	154.1	143.7	146.2	141.2	146.6	146.3	144.7	142.0	146.8	148.8	145.9	145.6
	LSD – NIR $_{0.05}$: years – lata = 6.6, kind of fertilizer – rodzaj nawozu = ns – nist , cultivar – odmiana = ns – nist													
Nitrates (V) (mg $N\text{-}NO_3\ kg^{-1}$ f. w.) Azotany (V) (mg $N\text{-}NO_3 \cdot kg^{-1}$ św. m.)	without fertilizers bez nawożenia mineralnego	72.3	75.0	84.3	77.2	78.7	72.7	75.7	75.7	66.7	71.0	83.3	73.7	75.5
	singlenutrient fertilizers nawozy jednoskładnikowe	91.3	81.7	81.7	84.9	83.7	78.0	79.0	80.2	92.0	82.3	78.0	84.1	83.1
	HydroComplex	89.3	83.7	85.3	86.1	88.7	87.0	81.3	85.7	94.3	94.7	79.7	89.6	87.1
	Nitrophoska Blue Special	81.7	75.7	79.0	78.8	82.7	77.7	81.3	80.6	80.3	75.7	78.7	78.2	79.2
	Viking 13	80.7	76.3	80.0	79.0	85.7	79.7	84.3	83.2	85.7	78.0	76.3	80.0	80.7
	Polimag S	78.0	75.3	80.0	77.8	90.0	85.3	86.7	87.3	76.7	74.3	80.0	77.0	80.7
	mean – średnia	82.2	77.5	81,7	80.6	84.9	80.1	81.4	82.1	82.6	79.3	79.3	80.4	81.1
	LSD – NIR $_{0.05}$: years – lata = 1.9, kind of fertilizer – rodzaj nawozu = 3.3, years × kind of fertilizer – lata × rodzaj nawozu = 5.7, cultivar – odmiana = 1.6, kind of fertilizer × cultivar – rodzaj nawozu × odmiana = 4.7													

Table 4. Ascorbate-nitrate index for potato tuber in relation to the kind of fertilizer and cultivar
Tabela 4. Indeks askorbinowo-azotanowy dla bulw ziemniaka w zależności od rodzaju nawozu i odmiany

Kind of fertilizer Rodzaj nawozu	Cultivar – Odmiana												Mean Średnia
	Aster				Fresco				Gloria				
	2005	2006	2007	mean –średnia	2005	2006	2007	mean – średnia	2005	2006	2007	mean – średnia	
Without fertilizers Bez nawożenia mineralnego	1.92	2.26	1.74	1.92	1.74	2.05	1.95	1.91	2.11	1.79	1.89	1.93	1.94
Singlenutrient fertilizers Nawozy jednoskładnikowe	1.52	2.05	1.79	1.79	1.70	2.04	1.79	1.84	1.57	1.77	1.86	1.73	1.79
HydroComplex	1.54	1.51	1.65	1.56	1.63	1.61	1.80	1.68	1.58	1.48	1.83	1.63	1.62
Nitrophoska Blue Special	1.80	2.13	1.82	1.92	1.64	1.73	1.76	1.71	1.80	2.23	1.92	1.98	1.87
Viking 13	1.73	1.79	1.73	1.75	1.72	1.95	1.80	1.82	1.62	1.87	1.87	1.78	1.78
Polimag S	1.82	2.16	1.83	1.94	1.59	1.66	1.71	1.65	1.79	2.08	1.90	1.92	1.84
Mean – Średnia	1.72	1.98	1.76	1.82	1.67	1.84	1.80	1.77	1.74	1.87	1.88	1.83	1.81

LSD – NIR $_{0.05}$: years – lata = 0.09, kind of fertilizer – rodzaj nawozu = 0.16, years × kind of fertilizer – lata × rodzaj nawozu = 0.28, cultivar – odmiana = ns – nist, kind of fertilizer × cultivar – rodzaj nawozu × odmiana = 0.22

Table 5. Phosphorus and potassium content in potato tuber in relation to the kind of fertilizer and cultivar
Tabela 5. Zawartość fosforu i potasu w bulwach ziemniaka w zależności od rodzaju nawozu i odmiany

	Kind of fertilizer Rodzaj nawozu	Cultivar – Odmiana												Mean Średnia
		Aster				Fresco				Gloria				
		2005	2006	2007	mean średnia	2005	2006	2007	mean średnia	2005	2006	2007	mean średnia	
Phosphorus ($g\ P\ kg^{-1}$ d. m.) Fosfor ($g\ P \cdot kg^{-1}$ s. m.)	without fertilizers bez nawożenia mineralnego	2.32	2.20	2.43	2.32	2.35	2.16	2.51	2.34	2.24	2.14	2.55	2.31	2.32
	singlenutrient fertilizers nawozy jednoskładnikowe	2.34	2.32	2.42	2.36	2.24	2.26	2.60	2.37	2.23	2.00	2.64	2.29	2.34
	HydroComplex	2.24	2.25	2.39	2.29	2.25	2.39	2.66	2.43	2.31	2.16	2.62	2.36	2.36
	Nitrophoska Blue Special	2.25	2.39	2.68	2.44	2.18	2.24	2.64	2.35	2.30	2.16	2.54	2.33	2.38
	Viking 13	2.24	2.23	2.38	2.28	2.26	2.32	2.55	2.38	2.22	2.31	2.46	2.33	2.33
	Polimag S	2.12	2.30	2.36	2.26	2.35	2.22	2.48	2.35	2.14	2.35	2.31	2.27	2.29
	mean – średnia	2.25	2.28	2.44	2.33	2.27	2.26	2.57	2.37	2.24	2.19	2.52	2.32	2.34
	LSD – NIR $_{0.05}$: years – lata = 0.084, kind of fertilizer – rodzaj nawozu = ns – nist, cultivar – odmiana = ns – nist													
Potassium ($g\ K\ kg^{-1}$ d. m.) Potas ($g\ K \cdot kg^{-1}$ s. m.)	without fertilizers bez nawożenia mineralnego	16.08	14.55	15.07	15.23	16.69	16.09	16.71	16.50	16.28	15.96	17.21	16.48	16.07
	singlenutrient fertilizers nawozy jednoskładnikowe	16.22	16.10	17.18	16.50	17.63	15.65	16.82	16.70	17.36	15.39	16.15	16.30	16.50
	HydroComplex	17.81	16.34	17.30	17.15	17.00	15.31	17.28	16.53	18.19	15.12	18.03	17.11	16.93
	Nitrophoska Blue Special	16.62	16.00	17.70	16.77	16.05	15.10	16.00	15.72	16.66	15.98	17.63	16.76	16.42
	Viking 13	17.45	16.24	17.94	17.22	16.57	15.24	16.74	16.18	17.16	15.10	16.54	16.26	16.56
	Polimag S	16.39	15.25	16.21	15.95	16.84	15.04	17.14	16.34	15.82	16.19	17.47	16.49	16.26
	mean – średnia	16.77	15.75	16.90	16.47	16.80	15.41	16.78	16.33	16.91	15.62	17.17	16.57	16.46
	LSD – NIR $_{0.05}$: years – lata = 0.453, kind of fertilizer – rodzaj nawozu = 0.794, cultivar – odmiana = ns – nist													

Table 6. Calcium and magnesium content in potato tuber in relation to the kind of fertilizer and cultivar
Tabela 6. Zawartość wapnia i magnezu w bulwach ziemniaka w zależności od rodzaju nawozu i odmiany

	Kind of fertilizer Rodzaj nawozu	Cultivar – Odmiana												Mean Średnia
		Aster				Fresco				Gloria				
		2005	2006	2007	mean – średnia	2005	2006	2007	mean – średnia	2005	2006	2007	mean – średnia	
Calcium (g Ca kg^{-1} d. m.) Wapń (g Ca·kg^{-1} s. m.)	Without fertilizers Bez nawożenia mineralnego	0.38	0.41	0.43	0.41	0.40	0.46	0.45	0.44	0.47	0.41	0.45	0.44	0.43
	Singlenutrient fertilizers Nawozy jednoskładnikowe	0.42	0.46	0.45	0.44	0.50	0.44	0.44	0.46	0.40	0.40	0.44	0.41	0.44
	HydroComplex	0.46	0.45	0.44	0.45	0.49	0.48	0.43	0.47	0.44	0.41	0.47	0.44	0.45
	Nitrophoska Blue Special	0.42	0.43	0.45	0.43	0.44	0.44	0.46	0.45	0.43	0.44	0.45	0.44	0.44
	Viking 13	0.49	0.43	0.45	0.46	0.43	0.40	0.46	0.43	0.43	0.39	0.44	0.42	0.44
	Polimag S	0.40	0.40	0.45	0.42	0.43	0.44	0.46	0.45	0.40	0.38	0.43	0.40	0.42
	Mean – Średnia	0.43	0.43	0.45	0.44	0.45	0.45	0.45	0.45	0.43	0.40	0.45	0.43	0.44
	LSD – NIR $_{0.05}$: years – lata = ns – nist, kind of fertilizer – rodzaj nawozu = ns – nist, cultivar – odmiana = 0.019													
Magnesium (g Mg kg^{-1} d. m.) Magnez (g Mg·kg^{-1} s. m.)	Without fertilizers Bez nawożenia mineralnego	1.19	0.91	0.98	1.03	1.12	0.96	1.10	1.06	1.22	0.97	1.04	1.08	1.06
	Singlenutrient fertilizers Nawozy jednoskładnikowe	1.29	1.00	1.01	1.10	1.24	1.06	1.11	1.14	1.25	0.98	1.04	1.09	1.11
	HydroComplex	1.21	0.98	1.08	1.09	1.26	1.02	1.04	1.11	1.26	0.95	1.14	1.11	1.10
	Nitrophoska Blue Special	1.27	1.03	1.03	1.11	1.14	0.87	0.99	1.00	1.24	1.00	1.04	1.09	1.07
	Viking 13	1.39	1.10	1.07	1.19	1.21	0.90	1.02	1.04	1.05	0.85	0.94	0.95	1.06
	Polimag S	1.04	0.87	0.95	0.95	1.27	0.99	1.04	1.10	1.28	1.02	0.96	1.09	1.04
	Mean – Średnia	1.23	0.98	1.02	1.08	1.21	0.97	1.05	1.08	1.22	0.96	1.03	1.07	1.07
	LSD – NIR $_{0.05}$: years – lata = 0.051, kind of fertilizer – rodzaj nawozu = ns – nist, cultivar – odmiana = ns – nist													

(tab. 2 and 3). Compared with cultivation without mineral fertilization, the application of single-nutrient fertilizers resulted in higher nitrate (V) contents, the increase was 7.6 mg $N\text{-}NO_3$ kg^{-1} of fresh weight, on average. An increase obtained as a result of the application of multi-nutrient complex fertilizers ranged from 3.7 to 11.6 mg $N\text{-}NO_3$ kg^{-1} of fresh weight. Of the multi-nutrient complex fertilizers applied, only HydroComplex significantly increased nitrate (V) content compared with single-nutrient fertilizers. Following an application of HydroComplex nitrate (V), the content was 4.0 mg $N\text{-}NO_3$ kg^{-1} of fresh weight higher, on average. The highest HydroComplex-related increase in nitrate (V) content was recorded in 2006, with the greatest precipitation shortages over the growing season of potato. The nitrate (V) content in tubers was, on average, by 7.7 mg $N\text{-}NO_3$ kg^{-1} of fresh weight higher compared with the single-nutrient fertilizers, and by as much as 15.5 mg $N\text{-}NO_3$ kg^{-1} of fresh weight higher compared to the cultivation without mineral fertilization. The application of the remaining multi-nutrient complex fertilizers produced nitrate (V) content in tubers that was similar or even lower than the content associated with single-nutrient fertilizers. The lowest level of nitrates (V) was accumulated by tubers of potatoes fertilized with Nitrophoska Blue Special, which yielded a nitrate (V) content that was on average by 3.9 mg $N\text{-}NO_3$ kg^{-1} of fresh weight lower (over the three-year period) compared with the single-nutrient fertilizers. The greatest differences were found in 2005 when the air temperature was the lowest and precipitation shortages occurred in the second half of the potato growing season. The application of Nitrophoska Blue Special resulted in lower nitrate (V) content in tubers, the reduction being 7.4 mg $N\text{-}NO_3$ kg^{-1} of fresh weight, on average.

The highest ascorbate-nitrate index value (1.94 on average) was obtained for the tubers of potato cultivated without mineral fertilization. When single-nutrient and multi-nutrient complex fertilizers were applied, the ascorbate-nitrate index value was by 0.15 and 0.07–0.32 lower on average, respectively, over the three-year period (tab. 4). The lowest average ascorbate-nitrate index value (1.62) was determined following fertilization with HydroComplex. The value of the index was by 0.17 lower (when averaged across the three-year period) compared with the single-nutrient fertilizers. The greatest was the difference in 2006, with a mild drought throughout the whole potato growing season. The ascorbate-nitrate index value recorded after HydroComplex was applied was then 0.43 lower, on average. The remaining multi-nutrient complex fertilizers produced similar or slightly higher ascorbate-nitrate index values compared with single-nutrient fertilizers.

The fertilizers applied in the experiment had no effect on phosphorus, calcium or magnesium content in tubers but they increased potassium content (tab. 5 and 6). Compared with cultivation without mineral fertilization, the application of HydroComplex resulted in higher potassium contents, the increase was 0.86 g kg^{-1} of dry matter, on average.

Regardless of the kind of fertilizer applied, tubers of ‘Aster’ and ‘Gloria’ contained more dry matter and starch than ‘Fresco’. The greatest were the differences in 2005, with a lowest air temperature and precipitation shortages occurred in the second half of the potato growing season. Tubers of the examined potato cultivars had similar L-ascorbic acid, phosphorus, potassium and magnesium contents, but ‘Fresco’ tended to accumulate the most nitrates (V) and calcium (tab. 2–6). The nitrate (V) content of

'Fresco' tubers was on average by 1.6 mg N-NO_3 kg^{-1} of fresh weight higher (over the three-year period) than in the tubers of 'Aster' and 'Gloria'. The difference, although not very high, was statistically significant. Fertilization with HydroComplex increased nitrate (V) content in the tubers of 'Fresco' and 'Gloria' more than 'Aster'. The calcium content of 'Fresco' tubers was 0.01 g kg^{-1} of dry matter higher than in 'Aster' on average and by 0.02 g kg^{-1} of dry matter higher compared to 'Gloria'.

The mean ascorbate-nitrate index values calculated for tubers of the examined potato cultivars did not differ significantly (tab. 4). The kind of fertilizer exerted a greater influence on the quality of 'Aster' and 'Gloria' than 'Fresco' tubers. When HydroComplex was applied, the ascorbate-nitrate index value for 'Aster' tubers was 0.23 lower compared to single-nutrient fertilizers, on average. The ascorbate-nitrate index calculated for 'Gloria' tubers was highest when Nitrophoska Blue Special was applied. The value of the index was 0.25 higher compared with single-nutrient fertilizers, on average.

DISCUSSION

The chemical composition of potato tuber – and thus their nutritional value – to a higher degree depended on the weather conditions over the growing season and the genetic character of the cultivar than on the fertilizers applied. In warm and dry years, potato tubers contain more dry matter and starch. The rainfall in the period May-June had no significant effect on the vitamin C content in potato tubers, whereas higher air temperatures in this period favourably stimulated the vitamin C accumulation in the tubers of very early potato cultivars [Sawicka and Mikos-Bielak 1995, Boguszewska 2007], which was also confirmed in the present study. The highest level of nitrates (V) was accumulated by potato tubers in a year characterized by a rather high amount of precipitation and low air temperature in the growing season. Seasonal precipitation shortages and high temperature, along with excessive precipitation and low temperature during of the vegetation period decreased the speed of the reduction of nitrates in plants [Cieślik 1995, Grudzińska and Zgórska 2008]. Phosphorus, potassium, calcium and magnesium content in tubers were lower in the years with less rainfall in the potato growth season, which was confirmed by studies carried out by other authors [Kołodziejczyk and Szmigiel 2005].

The fertilizers applied in the study had no effect on the content of dry matter, starch or L-ascorbic acid in potato tubers, although in a study carried out by Jabłoński [2006] the application of new generation multi-nutrient fertilizers (Nitrophoska 12 Special and Nitrophoska 15 Perfect) increased starch content in tubers, compared with single-nutrient fertilizers.

The application of multi-nutrient fertilizers in potato cultivation may induce changes in nitrate (V) concentration in tubers [Jabłoński 2001, Knittel and Mannheim 2002]. Of the multi-nutrient complex fertilizers applied, only HydroComplex significantly increased nitrate (V) content in tubers and, as a result, reduced the ascorbate-nitrate index value compared to the single-nutrient fertilizers. Nitrate (V) content in plants depends on sustainable fertilization with mineral elements and microelements. Nitrate (V) accumulate in plants when their uptake is greater than the possibility of reduction. Of the multi-nutrient complex fertilizers with the nitrophoska group applied, HydroComplex contains the most magnesium and sulphur. An increased amount of magnesium in plant fertilization can contribute to an increase in nitrate (V) concentration by a decrease in nitrate reductase activity [Buczek 1980]. In turn, a increase in sulphates results in a considerable decrease in the uptake of molybdenum by plants, which is a component of nitrate reductase [Mokrzecka 1990]. The application of the remaining multi-nutrient complex fertilizers reduced the tendency for potatoes to accumulate nitrates (V) in tubers compared with single-nutrient fertilizers. However, a significantly lower nitrate (V) content and higher ascorbate-nitrate index were obtained only when Nitrophoska Blue Special was applied. In contrast, Jabłoński [2006] reported no significant effect of Nitrophoska 12 Special on nitrate content in potato tubers. The application of Polimag S (amophoska group) resulted in similar nitrate (V) content compared with Nitrophoska Blue Special and Viking 13. Of the multi-nutrient complex fertilizers applied, Polimag S contains most magnesium and sulphur. Nitrate content in plants depends on form of nitrogen. The ammonium form of nitrogen stimulates the nitrate reductase activity [Serio et al. 2004]. Despite a substantial increase in the nitrate content of tubers fertilized with HydroComplex, the level of these compounds did not exceed the permissible content of 200 g NO_3 kg^{-1} of fresh weight. Moreover, the ascorbate-nitrate index value was greater than 1, which indicates that the tubers were safe for human health. The higher the value of the ascorbate-nitrate index is, the more potent is the action of ascorbic acid and the less harmful is the effect of nitrates in the plant to the human body [Lachman et al. 1997]. On the other hand, the nitrate contents in potatoes are significantly reduced during culinary processes [Mozolewski and Smoczyński 2004].

The fertilizers applied in the study had no effect on the content of mineral compounds in potato tubers, except for potassium, which was confirmed by other authors [Krzywy et al. 2001, Trawczyński and Socha 2006]. Compared with the cultivation without mineral fertilization, potassium content in tubers was higher when HydroComplex was applied. Cieślik and Sikora (1998) showed a negative correlation between potassium content and the levels of nitrates (V) in tubers, which was not confirmed in the present study. When HydroComplex was applied, the nitrate (V) content in tubers was also higher.

An appropriate choice of cultivar is very important in early potato production. Regardless of the conditions of potato growth and the kind of fertilizer applied, the lowest dry matter and starch content was in the tubers of the Netherland cultivar 'Fresco', compared with the Polish cultivar 'Aster' and German cultivar 'Gloria'. The content of L-ascorbic acid, phosphorus, potassium and magnesium in tubers of the examined potato cultivars was similar, however, the highest levels of nitrates (V) and calcium were accumulated in the tubers of 'Fresco'. The very early potato cultivars responded differently to the fertilizers applied. The increase in nitrate content was the lowest in 'Aster' tubers following the application of HydroComplex. In contrast, 'Gloria' tubers had the highest ascorbate-nitrate index value following fertilization with Nitrophoska Blue Special.

CONCLUSIONS

1. The multi-nutrient complex fertilizers HydroComplex, Nitrophoska Blue Special, Viking 13 and Polimag S can be successfully used to fertilize very early potato cultivars. The kind of fertilizer (single- or multi-nutrient) did not affected the dry matter, starch or L-ascorbic acid content in tubers.
2. Of the multi-nutrient complex fertilizers, only HydroComplex (containing the most magnesium and sulphur in the nitrophoska group) significantly increased nitrate (V) content in tubers and, as result, reduced the ascorbate-nitrate index compared to the single-nutrient fertilizers. The ascorbate-nitrate index value was higher then 1, which indicates that the potatoes were safe for human health.
3. The single-nutrient and multi-nutrient complex fertilizers applied in the study had no effect on the content of mineral compounds in potato tubers, except for potassium. The potassium content increased as a result of the HydroComplex applied.
4. The very early potato cultivars responded differently to the fertilizers applied. The kind of fertilizer had a greater effect on the quality of 'Aster' (Poland) and 'Gloria' (Germany) than 'Fresco' (The Netherlands) tubers.

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WPŁYW WIELOSKŁADNIKOWYCH NAWOZÓW KOMPLEKSOWYCH NA JAKOŚĆ BULW BARDZO WCZESNYCH ODMIAN ZIEMNIAKA

Streszczenie. Nawożenie jest jednym z najważniejszych czynników, które mogą wpływać na jakość bulw ziemniaka. Porównywano wpływ wieloskładnikowych nawozów kompleksowych (HydroComplex, Nitrophoska Blue Special i Viking 13 z grupy nitrofosek, i Polimag S z grupy amofosek), i nawozów jednoskładnikowych (saletra amonowa, superfosfat pojedynczy i siarczan potasu) na jakość bulw bardzo wczesnych odmian ziemniaka (‘Aster’, ‘Fresco’, ‘Gloria’). Nawozy jednoskładnikowe i wieloskładnikowe nawozy kompleksowe nie miały wpływu na zawartość suchej masy, skrobi i kwasu L-askorbinowego w bulwach bardzo wczesnych odmian ziemniaka, ale powodowały wzrost zawartości azotanów (V). Spośród wieloskładnikowych nawozów kompleksowych, tylko HydroComplex zawierający najwięcej magnezu i siarki ze wszystkich stosowanych nitrofosek powodował istotny wzrost zawartości azotanów (V) w bulwach, średnio o 4,0 mg·kg^{-1} świeżej masy i w efekcie obniżenie indeksu askorbinowo-azotanowego w porównaniu z nawozami jednoskładnikowymi. Stosowane w badaniach nawozy nie miały wpływu na zawartość składników mineralnych w bulwach ziemniaka, z wyjątkiem potasu. Zawartość potasu w bulwach zwiększyła się po zastosowaniu HydroComplexu, średnio o 0,86 g·kg^{-1} suchej masy. Rodzaj stosowanego nawozu miał większy wpływ na jakość bulw odmian 'Aster' i 'Gloria' niż 'Fresco'. Bulwy odmian 'Aster' i 'Gloria' zawierały więcej suchej masy i skrobi, a mniej azotanów (V) i wapnia niż odmiany 'Fresco'. Zawartość kwasu L-ascorbinowego, fosforu, potasu i magnezu w bulwach badanych odmian ziemniaka była podobna.

Słowa kluczowe: sucha masa**,** skrobia, kwas L-askorbinowy, azotany (V), indeks askorbinowo-azotanowy, składniki mineralne

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