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SELECTED BIONUTRIENT CONTENTS IN SPAGHETTI SQUASH DEPENDING ON SOWING DATE AND PLANT SPACING

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Abstract. Minerals are the most important compounds for human nutrition that are supplied by vegetables. The content of mineral in vegetables depends on the species and the cultivar, but it is subject to changes under the influence of environmental conditions and agricultural factors. This study examined the effect of sowing date (5, 15 and 25 May) and plant spacing (1 × 0.6 m, 1 × 0.8 m and 1 × 1 m) on selected bionutrient contents (P, K, Ca, Mg and Fe) in the fruits of two spaghetti squash cultivars, 'Makaronowa Warszawska' and 'Pyza', originating from Poland. A field experiment was carried out in central-eastern Poland on loamy sand soil. Fully-mature spaghetti squash fruits were harvested from the beginning of September to the beginning of October. The sowing date of the spaghetti squash did not affect the dry matter content, K, Ca or Mg in fruits. The P content was the highest for plants sown on 25 May. In contrast, the highest Fe content was found for plants sown on 5 May. The dry matter content was highest in the fruits of plants sown with 1 × 1 m. The increase in the distance between plants in a row from 0.6 to 0.8 or 1 m resulted in a decrease in Fe content only for plants sown on 15 May. Plant spacing did not have a significant effect on the remaining bionutrient content in the spaghetti squash fruits. The content of dry matter, P, K, Ca, Mg and Fe in the fruits of both cultivars did not differ significantly, although 'Pyza' tended to accumulate the most Ca and had lower K and Fe levels.

Key words: *Cucurbita pepo* L. subsp. *pep*o, cultivar, dry matter, mineral components

INTRODUCTION

Spaghetti squash (*Cucurbita pepo* L. subsp. *pepo*), also known as vegetable spaghetti, vegetable marrow or noodle squash, is widely grown in Israel, the United States and in southern European countries [Edelstein et al. 1989, Lim 2012, Schultheis et al.

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2014], but until recently has been classified as a minor crop in Poland, cultivated mainly in home gardens. In Israel, small-scale commercial production of spaghetti squash began in 1981 [Edelstein et al. 1989]. Success induced other growers to try the crop in the following years. Several spaghetti squash cultivars have been released in the past ten years [Schultheis et al. 2014]. Spaghetti squash, belonging to winter squash, is harvested and consumed as mature fruit. Its fruits, like other winter squash, can be stored for several months after harvest and consumed during the winter. Spaghetti squash is a speciality – when raw, the flesh is solid and similar to other raw squash but, upon cooking, the flesh of mature fruits changes into thin strands which look like spaghetti. Spaghetti squash can be baked, boiled, steamed or micro-waved and it can be used for preparing interesting and tasty meals [Lim 2012]. This vegetable should be popularized due to its nutritional value, gustatory and dietetic values, as well as its easy cultivation and high fruit yield, even in less-suitable climatic conditions [Beany et al. 2002, Wojdyła et al. 2007, Castagnino et al. 2008, Wadas and Kalinowski 2010, Schultheis et al. 2014]. Developing new kinds and types of vegetable crops may be beneficial to both growers and consumers. Cucurbits, including pumpkin and squash, have long been cultivated for food as well as their medicinal properties. Pumpkins and squash consist of many biologically-active compounds, which fulfil an important role in preserving health and in the prevention of various diseases, especially diabetes, cardiovascular diseases and gastrointestinal cancer [Perkins-Veazie 2010, Hosseinzadeh Colagar and Amjadi Souraki 2012, Lim 2012]. Spaghetti squash is a rich source of many nutrients, including carotenoids, particularly β-carotene, ascorbic acid, foil acid and potassium [Wojdyła et al. 2007, Biesiada et al. 2011, Lim 2012, Schultheis et al. 2014]. Some researchers have discussed the effect of agronomic factors on the chemical composition of various species of squash, although there are few studies concerning spaghetti squash [Danilchenko 2002, Wadas et al. 2012]. The research conducted to date has mainly concerned comparisons of the content of sugars, carotenoids, retinol and vitamin C in the fruits of several cultivars of spaghetti squash [Paris 1993, Beany et al. 2003, Wojdyła et al. 2007, Biesiada et al. 2011, Schultheis et al. 2014], and there has been relatively little attention paid to mineral components [Beany et al. 2002, Biesiada et al. 2011]. The clinical and epidemiological evidence clearly indicates a significant role of plant food minerals in human health [Ghosh and Joshi 2008, Martinez-Ballesta et al. 2010]. Fruits and vegetables usually contribute 35% of the total K, 24% of Mg, 11% of P and Na, 7% of Ca and 16% of Fe to the dietary intake of humans [Levander 1990]. Mineral contents depend on the species or cultivar and the specific plant organ, as well as environmental factors such as light and temperature, composition of the nutrient solution, crop management practices and the interaction of all these factors [Martinez-Ballesta et al. 2010]. Lim [2012] reported that raw spaghetti squash per 100 g edible portion (exclude refuse of 29% rind and seed) contains 108 mg K, 23 mg Ca, 12 mg P, 12 mg Mg and 0.31 g Fe. Research conducted in Lithuania demonstrated that fruits of 'Makaronowa Warszawska' spaghetti squash (originating in Poland) obtained through organic cultivation contained fewer mineral components, with a similar content of dry matter as in conventional cultivation [Danilchenko 2002]. Wojdyła et al. [2007] showed that 'Pyza' (originating in Poland) fruits contained more dry matter immediately after harvest and after storage during six months than 'Makaronowa Warszawska'. Spaghetti squash fruits from drip-irrigated plots were characterized by a decreased content of dry matter compared to those harvested from non-irrigated plots. Biesiada et al. [2011]

reported that the dry matter content in 'Makaronowa Warszawska' and 'Pyza' fruits did not significantly differ immediately after harvest, but after three months of storage dry matter, the content of 'Makaronowa Warszawska' fruit was relatively higher. The content of P and Ca in fruits of 'Pyza' was higher and the content of K was lower than in fruits of 'Makaronowa Warszawska', while the content of Mg in fruits of both cultivars did not differ significantly, either immediately after harvest or after storage.

The aim of the study was to determine the effect of the sowing date and plant spacing on the content of some bionutrients in the fruits of two cultivars of spaghetti squash 'Makaronowa Warszawska' and 'Pyza'.

MATERIALS AND METHODS

Experimental design. The effect of sowing date (5, 15 and 25 May) and plant spacing (1 × 0.6 m, 1 × 0.8 m and 1 × 1 m, i.e. 16,668, 12,500 and 10,000 plants per hectare) on the content of some bionutrients (P, K, Ca, Mg and Fe) in the fruits of two cultivars of spaghetti squash 'Makaronowa Warszawska' and 'Pyza' (Department of Plant Genetics, Breeding and Biotechnology Warsaw University of Life Sciences – SGGW, Poland) was investigated. The 'Makaronowa Warszawska' features a bush plant habit with a medium-sized, oblong, green spotted fruit with a light orange flesh. The 'Pyza' features a bush plant habit with medium-sized, elliptical, orange fruit with a cream-coloured flesh. The field experiment was established in the split-block-split-plot design in three replications. Fully-mature spaghetti squash fruits were harvested from the beginning of September until the beginning of October. The total fruit yield and marketable yield (mature fruits exceeding 0.500 kg, without any damage to the skin) per hectare were determined, as well as the number of marketable fruits per plant and the average weight of the marketable fruit. For laboratory studies, ten fruits of each treatment were taken. The edible parts of the fruits comprised the research material. Fruits were peeled with a stainless steel knife and the seeds were separated. The dry matter content was determined using the oven-drying gravimetric method. Mineral components where determined by combustion at 450°C. The flame photometric method was used for Ca and K, and the atomic absorption spectrometry (AAS) method was used for Mg, the colorimetric o-phenanthroline method was used for Fe, while the vanadium-molybdenum colorimetric method was used for P determination. Chemical analyses were conducted immediately after the spaghetti squash fruit harvest.

Experimental site and season. A field experiment was carried out at the Agricultural Experimental Station of the Siedlce University of Natural Sciences and Humanities, in central-eastern Poland (52°03'N, 22°33'E) during three growing seasons from 2007–2009, on loamy soil with a low-to-medium content of available potassium, a medium-to-high content of phosphorus and a medium content of magnesium, with a pH in H_2O of 6.1–6.7 (tab. 1). The plot area was 20 m^2. Farmyard manure was applied in the autumn, at a rate of 30 t/ha, and mineral fertilizers were applied in rates of 120 kg N (ammonium nitrate), 52 kg P (superphosphate) and 200 kg K (potassium sulphate) per hectare in spring. Two-thirds of the nitrogen and potassium rates were applied before sowing and 1/3 while the first fruits were setting.

Statistical analysis. The results of the study were analysed statistically by means of analysis of variance (ANOVA) for the split-block-split-plot design. The significance of differences was verified using Tukey's test at P = 0.05.

Table 1. Selected soil chemical properties at the experimental site during three years of the experiment duration

Year	pH in H2O	Available forms of nutrients (mg·dm-3 of soil)			
		P	K	Ca	Mg
2007	5.95	29	70	280	25
2008	5.50	25	30	180	25
2009	5.87	56	80	340	20

Table 2. Mean air temperature and precipitation sums in the vegetation period of spaghetti squash

Months	Temperature (°C)				Rainfalls (mm)			
	2007	2008	2009	mean 1981–2005	2007	2008	2009	mean 1981–2005
May	14.6	12.7	12.9	11.9	59.1	85.6	68.9	49.7
June	18.2	17.4	15.7	16.7	59.0	49.0	145.2	63.0
July	18.9	18.4	19.4	19.5	70.2	69.8	26.4	60.3
August	18.9	18.5	17.7	18.4	31.1	75.4	80.9	59.8
September	13.1	12.3	14.6	13.1	67.6	63.3	24.9	53.0

Weather conditions. In the three-year period of study, favourable thermal and moisture conditions for the growth and development of spaghetti squash only occurred in 2007 (tab. 2). In 2008 and 2009, low air temperature and intensive precipitation in May resulted in poor emergence and a very cool period which began in the middle of September 2008, with a nearly 10°C drop in average temperature and intensive precipitation which delayed fruit ripening.

RESULTS AND DISCUSSION

The total fruit yield of the 'Pyza' was on average higher by 8.50 t ha^{-1} (20%), and marketable yield was higher by 9.04 t ha^{-1} (22%) than 'Makaronowa Warszawska'. The number of marketable fruits per plant did not significantly differ, but the weight of the 'Pyza' fruit was on average higher by 0.442 kg (38%). The highest yield per hectare and the largest number of marketable fruits per plant was obtained with a sowing date of 5 May. Delaying the sowing date resulted in a decrease in the yield per hectare and in the number of marketable fruits per plant, although the average weight of marketable fruit sown on 15 and 25 May did not significantly differ in comparison to sowing on 5 May. Increasing the spacing between plants from 1 × 0.6 m to 1 × 1 m resulted in lowering the yield per hectare, but the number of marketable fruit per plant was larger. Plant spacing did not have a significant effect on the weight of a marketable fruit. The results were discussed by Wadas and Kalinowski [2010].

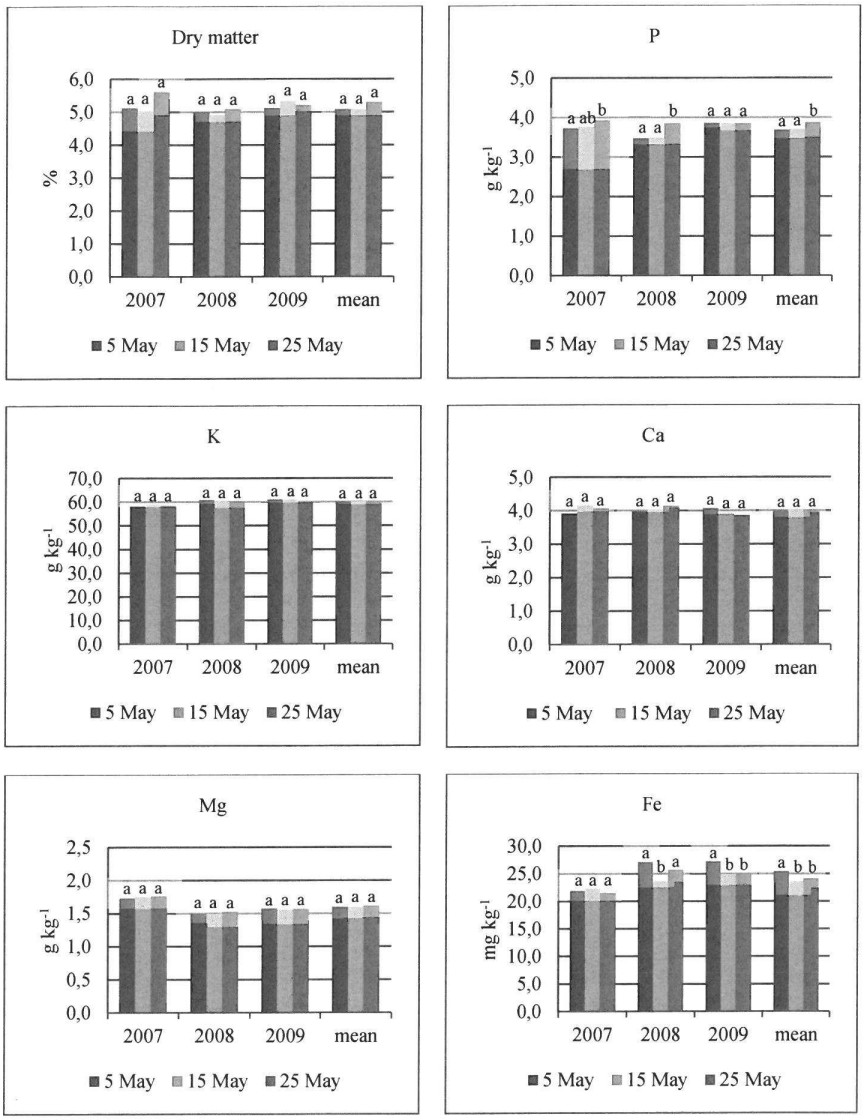

Fig. 1. Dry matter and mineral component content in spaghetti squash fruits depending on sowing date and growing season (average for cultivar and plant spacing) – mean values marked with the same letters do not differ significantly at $\alpha = 0.05$

The experiment did not show any significant effects of the spaghetti squash sowing date on the content of dry matter in fruits (fig. 1). The dry matter content in spaghetti squash fruits depended, to a higher degree, on plant spacing. The highest dry matter content was found in the fruits of plants sown with 1 × 1 m spacing (fig. 2). The decrease in the distance between plants in a row resulted in a decrease of the dry matter content in fruits. The content of dry matter in the fruits of plants sown with 1 × 1 m

spacing (10,000 plants per hectare) was higher, on average, by 0.47% in comparison to 1 × 0.6 m spacing (16,668 plants per hectare). Greater plant densities result in lower dry matter content due to the competition for water, light and nutrients between plants. A positive effect of the higher plant density was observed on dry matter accumulation and distribution to fruits of pickling cucumber plants [Schvambach et al. 2002]. Abdel-Rahman et al. [2012] reported that closer in-row spaces may have a limited area for root growth and space for shoot growth and, therefore, produce plants with longer vines with a greatly reduced number of leaves. Although a narrow in-row space seemed to exert enforcement conditions leading to slight early pumpkin (*C. moschata*) female flower anthesis and increased femininity, it was clearly unprofitable with regards to the produced inferior fruit quality (dry matter and carotene contents). The sowing date and plant spacing interaction effect on dry matter content was not statistically confirmed. The dry matter content in fruits of 'Makaronowa Warszawska' and 'Pyza' did not significantly differ (tab. 3), which was confirmed by Biesiada et al. [2011].

The sowing date of the spaghetti squash had a significant effect on the content of P and Fe in fruits (fig. 1). The highest content of P was found in plants sown on 25 May. The early sowing date resulted in a decrease of this compound in fruits. The content of P for plants sown on 25 May was higher, on average by 0.173 mg kg^{-1} of dry matter in comparison to plants sown on 5 and 15 May. The sowing date of the spaghetti squash had the greatest effect on P accumulation in fruits in 2008, with the lowest air temperature and very intensive rainfall in the first half of May, and quite heavy rainfall in July-September, in the period of fruit growth. In that year, for plants sown on 25 May, the P content in fruits was higher, on average, by 0.370 g kg^{-1} of dry matter in comparison to the plants sown on 5 and 15 May. In contrast, a higher content of Fe was found for plants sown on 5 May. The delay in the sowing date resulted in a decrease of this compound in fruits. The content of Fe for plants sown on 5 May was higher, on average, by 1.573 mg kg^{-1} of dry matter compared to plants sown on 15 and 25 May. The sowing date of spaghetti squash had the greatest effect on Fe accumulation in fruits in 2009, with drought periods during fruit growth. In that year, for plants sown on 5 May, the Fe content in fruits was higher, on average, by 2.220 mg kg^{-1} of dry matter compared to the plants sown on 15 and 25 May. Nutrient uptake from soil is associated with the size of root system and root morphology. The roots play a principal role in the absorption of the mineral elements that will be translocated to the above-ground parts of the plants. Drought can affect nutrient uptake and impair translocation of some nutrients. The duration of water stress during fruit development can influence the mineral content [Wang et al. 2008, Martinez-Ballesta et al. 2010]. Martínez-Valdivieso and Gómez [2015] found positive correlations between P-Fe, K-Fe and Mg-Fe in fruits of different summer squash morphotypes. These results imply that high Fe content might be accompanied by high P, K and Mg content or vice-versa, which was not confirmed by the present study. The study did not find any significant effect of the spaghetti squash sowing date on the content of K, Ca and Mg in fruits (fig. 1).

Plant spacing had no significant effect on the P, K, Ca, Mg and Fe contents in spaghetti squash fruits (fig. 2). The sowing date and plant spacing interaction effect on Fe content in spaghetti squash fruit was statistically confirmed. The increase in the distance between plants in a row from 0.6 to 0.8 m or 1 m resulted in a decrease in Fe content only for plants sown on 15 May.

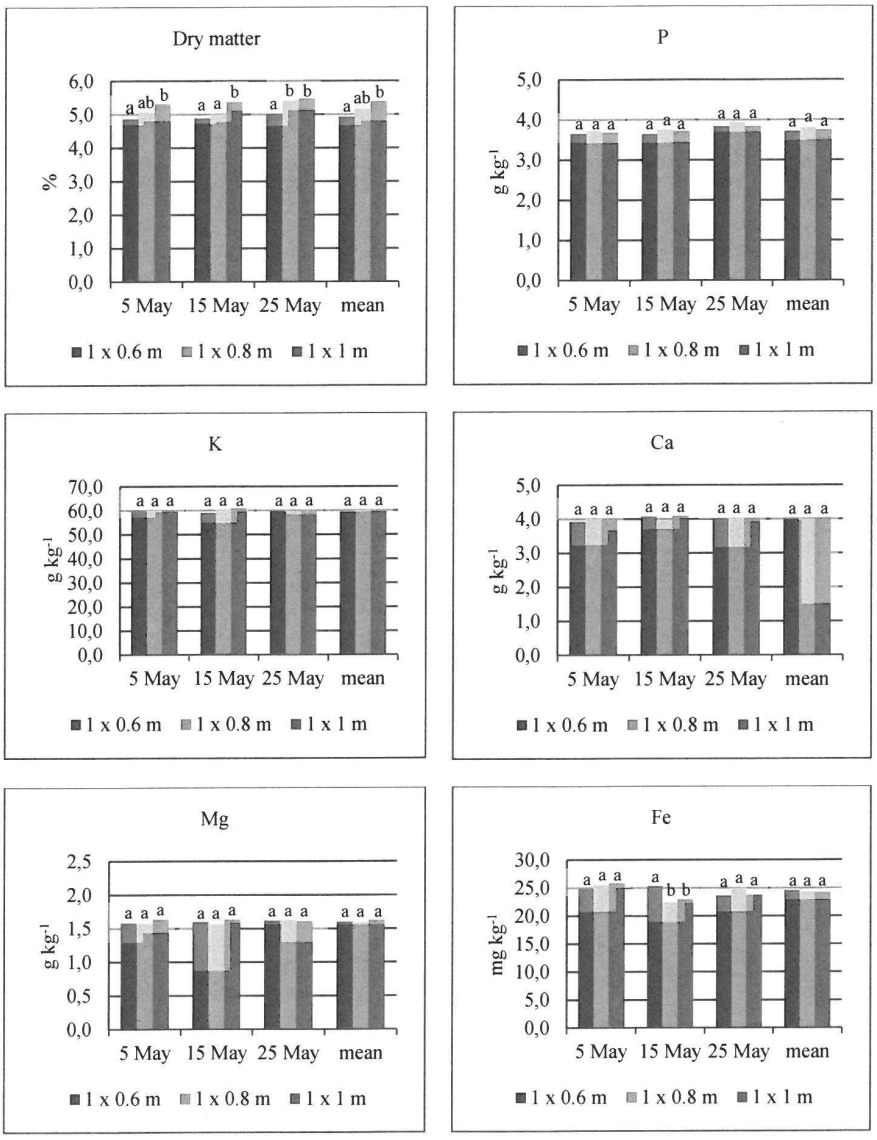

Fig. 2. Dry matter and mineral component content in spaghetti squash fruits depending on sowing date and plant spacing (average for cultivar and growing season) – mean values marked with the same letters do not differ significantly at $\alpha = 0.05$

The content of P, K, Ca, Mg and Fe in fruits of the spaghetti squash cultivars 'Makaronowa Warszawska' and 'Pyza' did not differ significantly, but 'Pyza' tended to accumulate the most Ca and a lower K and Fe (tab. 3), which was confirmed in a study conducted by other authors [Biesiada et al. 2011]. In the present study, the content of K, Ca and Mg in the fruits of 'Makaronowa Warszawska' and 'Pyza' was similar and the

content of P in the fruits of 'Pyza' was lower than in a study carried out on fine clay soil in south-western Poland [Biesiada et al. 2011]. The content of P and Mg in the fruits of 'Makaronowa Warszawska' was similar, and the content of K, Ca and Fe was higher than for both conventionally and organically grown squash in Lithuania [Danilchenko 2002]. This indicates that mineral content in spaghetti squash fruit is influenced by soil type, climatic conditions and geographic location. The content of P, K, Ca and Mg in fruits of spaghetti squash cultivars 'Makaronowa Warszawska' and 'Pyza' was similar, or higher, than in cultivars originating in Israel and the United States [Beany et al. 2002]. Aliu et al. [2012] showed significant genetic variation of mineral composition between *Cucurbita pepo* L. genotypes.

Table 3. Dry matter and mineral component content in spaghetti squash fruits depending on cultivar (average for years 2007–2009)

Cultivar	Dry matter (%)	P (g kg-1)	K (g kg-1)	Ca (g kg-1)	Mg (g kg-1)	Fe (mg kg-1)
Makaronowa Warszawska	5.32 a	3.761 a	61.240 a	3.854 a	1.618 a	25.551 a
Pyza	5.00 a	3.750 a	58.714 a	4.180 a	1.593 a	22.813 a

Mean values marked with the same letters do not differ significantly at $\alpha = 0.05$

Table 4. Dry matter and mineral component content in spaghetti squash fruits depending on growing season (average for cultivars)

Year	Dry matter (%)	P (g kg-1)	K (g kg-1)	Ca (g kg-1)	Mg (g kg-1)	Fe (mg kg-1)
2007	5.25 a	3.810 a	58.510 a	4.052 a	1.747 a	21.880 a
2008	5.00 a	3.605 b	60.575 b	4.052 a	1.504 b	25.439 b
2009	5.22 a	3.852 a	60.846 c	3.948 b	1.566 b	25.728 b

Mean values marked with the same letters do not differ significantly at $\alpha = 0.05$

The meteorological conditions during the spaghetti squash vegetation period had a significant effect on the content of mineral elements in the fruits (tab. 4). Both the highest content of P, Ca and Mg and the lowest content of K and Fe were recorded in the warmest and moderately moist growing season of 2007. The supply of plants with mineral nutrients is the result of interaction between the availability of the nutrients in the soil and the ability of plants to acquire nutrients from the soil. Soil moisture greatly influences crop yield and quality by directly affecting physiological and biochemical processes in the plants, and indirectly influences it by changing the nutrient availability in soil [Wang et al. 2008]. The potential of roots to absorb nutrients generally declines in water-stressed plants. The duration of water stress during fruit development can influence the mineral content [Martinez-Ballesta et al. 2010].

CONCLUSIONS

1. The plant spacing had a greater effect on the dry matter content in spaghetti squash fruits than sowing date. The dry matter content in fruits was highest for plants sown with 1 × 1 m spacing.

2. The sowing date of spaghetti squash did not affect the content of K, Ca and Mg in fruits. The content of P was the highest in the fruits of plants sown on 25 May, and the highest content of Fe was found in the fruits of plants sown on 5 May.

3. Plant spacing did not have a significant effect on the content of P, K, Ca, Mg or Fe in the fruits. The increase in the distance between plants in a row from 0.6 to 0.8 or 1 m resulted in a decrease in Fe content in the fruits only of plants sown on 15 May.

4. The content of dry matter and P, K, Ca, Mg and Fe in fruits of 'Makaronowa Warszawska' and 'Pyza' did not differ significantly, although 'Pyza' tended to accumulate more Ca and less K and Fe.

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ZAWARTOŚĆ WYBRANYCH BIOPIERWIASTKÓW W DYNI MAKARONOWEJ W ZALEŻNOŚCI OD TERMINU SIEWU I ROZSTAWY ROŚLIN

Streszczenie. Warzywa są ważnym źródłem składników mineralnych. Zawartość biopierwiastków w warzywach zależy od gatunku i odmiany, ale może ulegać zmianom pod wpływem warunków środowiska i czynników agrotechnicznych. Badano wpływ terminu siewu (5, 15 i 25 maja) i rozstawy roślin (1 × 0,6 m, 1 × 0,8 m i 1 × 1 m) na zawartość wybranych biopierwiastków w owocach dwóch odmian dyni makaronowej, 'Makaronowa Warszawska' i 'Pyza'. Doświadczenie polowe przeprowadzono w środkowo-wschodniej Polsce na glebie piaszczysto-gliniastej. Owoce dyni makaronowej zbierano w fazie pełnej dojrzałości, od początku września do początku października. Termin siewu dyni makaronowej nie miał wpływu na zawartość suchej masy, K, Ca i Mg w owocach. Zawartość P była największa w owocach uzyskanych z siewu 25 maja, a Fe z siewie 5 maja. Zawartość suchej masy była największa w owocach roślin uprawianych w rozstawie 1 × 1 m. Zwiększenie odległości między roślinami w rzędzie z 0,6 do 0,8 m i 1 m powodowało zmniejszenie zawartości Fe tylko w owocach uzyskanych z siewu dyni makaronowej 15 maja. Rozstawa roślin nie miała istotnego wpływu na zawartość innych biopierwiastków oznaczanych w owocach dyni makaronowej. Zawartość suchej masy, P, K, Ca, Mg i Fe w owocach obu odmian nie różniła się istotnie. Rośliny odmiany 'Pyza' wykazywały tendencje do gromadzenia w owocach większej ilości Ca i mniejszej ilości K i Fe.

Słowa kluczowe: *Cucurbita pepo* L. subsp. *pepo*, odmiana, sucha masa, składniki mineralne

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