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ORIGINAL PAPER

EFFECTS OF NITROGEN FERTILIZATION ON THE MINERAL STATUS OF PLANTS AND THE CHEMICAL COMPOSITION OF SCALLOP SQUASH FRUITS

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Abstract

A field study was conducted to evaluate the effects of increased doses of nitrogen supplied as a preplant (60, 120, 180, 240 kg N ha^{-1}) or split (120 + 60, 120 + 60 + 60 kg N ha^{-1}) fertilization treatment on the content of macronutrients in index plant parts and fruits of scallop squash. Leaf petioles used as the index parts were collected 3 times during the growing period, while fruits with a diameter of 3-6 cm, 6.1-12 cm and >12 cm were harvested at the maximum fruit setting. The data indicate that nitrogen fertilization strongly affected the nitrate content in leaf petioles of scallop squash at the onset of fruit harvest, while its influence was much weaker in later stages of the growth period. The content of phosphorus, potassium, calcium and magnesium was not dependent on either the nitrogen dose or the size of harvested fruits. Heavy N fertilization caused substantial enhancement of the total N and nitrate accumulation in fruits, but did not change the concentrations of P, K, Ca and Mg. Fruits harvested when having the 3-6 cm diameter contained higher amounts of total N, phosphorus, potassium, magnesium and nitrates than the ones which had a diameter of 6.1-12 cm and >12 cm. However, even at the maximum concentration of nitrates in fruits harvested early, which was 317 mg NO_3^- kg^{-1} f.w., scallop squash should be treated a minor contributor to dietary nitrate intake by consumers. The data indicate that tissue nitrate analysis may be successfully used as the basis for determination of the crop's nitrogen requirement during the early growth period.

Keywords: N dose, fruit size, index parts, fruit composition.

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INTRODUCTION

Cucurbitaceae family consists of many economically important vegetable crops such as cucumber, melon, watermelon, and summer and winter squashes. Scallop squash, which belongs to the group of summer squashes (*Cucurbita pepo* L.), is still a minor vegetable species in our country, cultivated mainly in home gardens. However, a growing interest is observed to cultivate it for industrial purposes, such as food canning, freezing or drying. Immature fruits of scallop squash are highly appreciated as a rich source of valuable bioactive compounds such as vitamin C, carotenoids and polyphenols (Gajc-Wolska, Skąpski 1994, Balbierz, Kołota 2012, Kołota, Balbierz 2015) with only a weak tendency to accumulate nitrates and heavy metals (Daničenco 2000, Grzeszczuk 2009).

Relatively little attention in the literature has been paid to vegetables and fruits as dietary sources of minerals, despite their substantial role in their total intake by humans. According to Levander (1990), they contribute in 35% to the total intake of potassium, 11% of phosphorus, 7% of calcium and 24% of magnesium. Quantities of minerals contained in cultivated plants are greatly influenced by numerous and complex factors such as genotype-specific properties of crop species, climatic conditions, soil characteristics, fertilization practice and degree of maturity (Perucka 1999, Grzeszczuk, Falkowski 2002, Aliu et. al. 2012, Martinez-Ballesta et. al. 2010, Kołota, Czerniak 2010, Kołota, Balbierz 2015, Martinez-Valdivieso et. al. 2015). Scallop squash fruits are proved to be a rich source of minerals, especially potassium, phosphorus, calcium and magnesium, showing high variability depending on a cultivar and size of harvested fruits (Grzeszczuk, Falkowski 2002, Grzeszczuk 2009, Kołota, Balbierz 2015).

Numerous reports have been published regarding the effects of nitrogen fertilizer application no crop yield and mineral accumulation in most important vegetable crops (Sorennsen 1999, Smoleń et. al. 2012, Krężel, Kołota 2014, Pitura, Michałojć 2015). However, no information was found about the effects of this nutrient on concentrations of mineral elements in leaf tissue during a growing season and in fruits at different stages of maturity.

This study was performed to examine the effects of nitrogen doses and dates of nitrogen application on the mineral status of plants and nutritional value of scallop squash fruits harvested at different stages of development at the time of harvest.

MATERIAL AND METHODS

The experiment was carried out in 2011-2013, in the Experimental Station of Horticultural Department of the Wrocław University of Environmental and Life Sciences (latitude 51.19° N and longitude 17.00° E). A field study was set up sandy clay soil with pH in H_2O equal 7.3, and organic matter content of 1.8%. The available forms of nutrients were 75-79 mg P, 150-175 mg K, 360-430 mg Ca, 30-66 mg Mg, and 22-32 mg mineral nitrogen (NH_4 + NO_3-N) per 1 dm^3 of the soil, depending on the year of the trial. During the early spring tillage stage, the amounts of phosphorus and potassium were increased to the standard level of 80 mg P and 200 mg K per 1 dm^3 by supplying triple superphosphate and potassium sulphate as sources of these nutrients.

Nitrogen was applied in doses of 60, 120, 180 and 240 kg N ha^{-1} in preplant application or in split fertilization with one top dressing (120 + 60 kg N ha^{-1}) or two top dressings (120 + 60 + 60 kg N ha^{-1} – in the form of ammonium nitrate), conducted at the stage of 3-4 leaves and two weeks later. All the fertilizers were incorporated into the soil by harrowing, and next black agrotextile weighing 30 g per 1 m^2 was used as mulch to protect from weed infestation. Seeds of the Sunny Delight F_1 cultivar were sown directly into the field, spaced 0.8 m apart in the rows and 1.0 between the rows, on 10-15 of May. The crop management followed the standard recommendations for this vegetable crop species.

Three times during the growing period, samples of plants were collected for chemical analysis to determine the mineral status of scallop squash grown at different levels of nitrogen applied. Twelve petioles of fully developed leaves, regarded as the index parts, were collected from each plot. The first sampling was conducted at the beginning of plant yielding (end of June), and it was repeated twice at one-month intervals (at the maximum fruit setting and at the end of harvest). The content of nitrates was analyzed in fresh plant tissues, while the concentrations of phosphorus, potassium, calcium and magnesium were assayed after drying at 105°C and extraction in 2% acetic acid.

At the time of maximum scallop squash yielding (end of July), 15 fruits having a diameter of 3-6 cm, 6.1-12 cm and >12 cm were collected from each plot in order to determine the content of total N, nitrates, P, K, Ca and Mg. The following methods of nutrient evaluation were used in analyses of the index parts and fruits: NO_3^- − potentiometric method, P and Mg – colorimetric method, Ca and K – photometric method, total N in edible parts – Kjeldahl method.

The experiment was arranged in a two-factorial design with four replications, on plots size 8.0 m^2 (1.6 x 5.0 m). Data consisting of the results of chemical plant tissue and fruit analyses, shown as means for 3 years of the study, were subjected to statistical evaluation via analysis of variance for both tested factors. The least significant differences were calculated by the Tukey test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Tissue mineral analyses are frequently used as the basis for determination of a crop's fertilization demand in respect of top dressing treatment. Data from the literature indicate that leaf petioles of vegetable crops generally contain higher amounts of minerals and show greater variation in the mineral composition between underfed plants and those with an adequate nutrient supply, which makes them more suitable for diagnosing the nutritional status of the crop than the other plant parts. As it was proved in our study, the nitrate content in leaf petioles was greatly influenced by a nitrogen dose and stage of the plant growth. However, a close relationship between the applied N dose and nitrate content in petioles was observed only at the onset of fruit harvest (Figure 1). The concentration of nitrates increased from 380 mg NO_3^- kg^{-1} f.w. to 4141 mg NO_3^- kg^{-1} f.w. in plants supplied with preplant doses 60 kg N ha^{-1} and 240 kg N ha^{-1}, respectively. A stronger impact on the nitrate content in leaf petioles at this stage of growth was produced by the split application of fertilizer, which increased the level of nitrates from 1485 mg NO_3^- kg^{-1} f.w. to 2848 mg NO_3^- kg^{-1} f.w. when used at the dose of 120 + 60 kg N ha^{-1} while 120 + 60 + 60 kg N ha^{-1} resulted in a change from 4141 mg NO_3^- kg^{-1} f.w. to 5305 mg NO_3^- kg^{-1} f.w., if compared to the same doses supplied in a preplant fertilization treatment.

A substantial decrease in the content of nitrates in the index plant parts was observed at the maximum fruit setting, although their level was still significantly dependent on a fertilizer dose, and varied within 306 and 524 mg NO_3^- kg^{-1} f.w. A further slight decrease in nitrates in leaf petioles was observed at the end of the growth period. Their amounts in leaf blades at this time was not affected by a fertilizer dose or method of its application. On all the evaluated dates of sampling, no significant effect was observed of the size of harvested fruits on the nitrate accumulation in the index parts. Contrary to this finding, the research conducted by Słociak (2003) on zucchini proved that plants from which less matured fruits were collected contained higher amounts of nitrates in petioles of fully developed leaves than those from which the harvest of fruits was delayed.

Phosphorus uptake expressed by its content in leaf petioles was on a similar level on the subsequent dates of sampling and was not dependent on the size of harvested fruits (Figure 2). Heavy nitrogen fertilization, over 120 kg N ha^{-1}, was associated with a significant decrement of the phosphorus uptake at all stages of the plant growth. This disadvantageous effect was not observed in some other studies conducted by Adamczewska-Sowińska (1996) on early leek, and by Słociak (2003) on zucchini.

The potassium content in leaf petioles of scallop squash decreased along with the subsequent dates of analysis (Figure 3). At the maximum fruit setting and at the end of the growing period, the nitrogen fertilization dose of over 120 kg N ha^{-1} adversely affected its amount in the index parts. A reverse

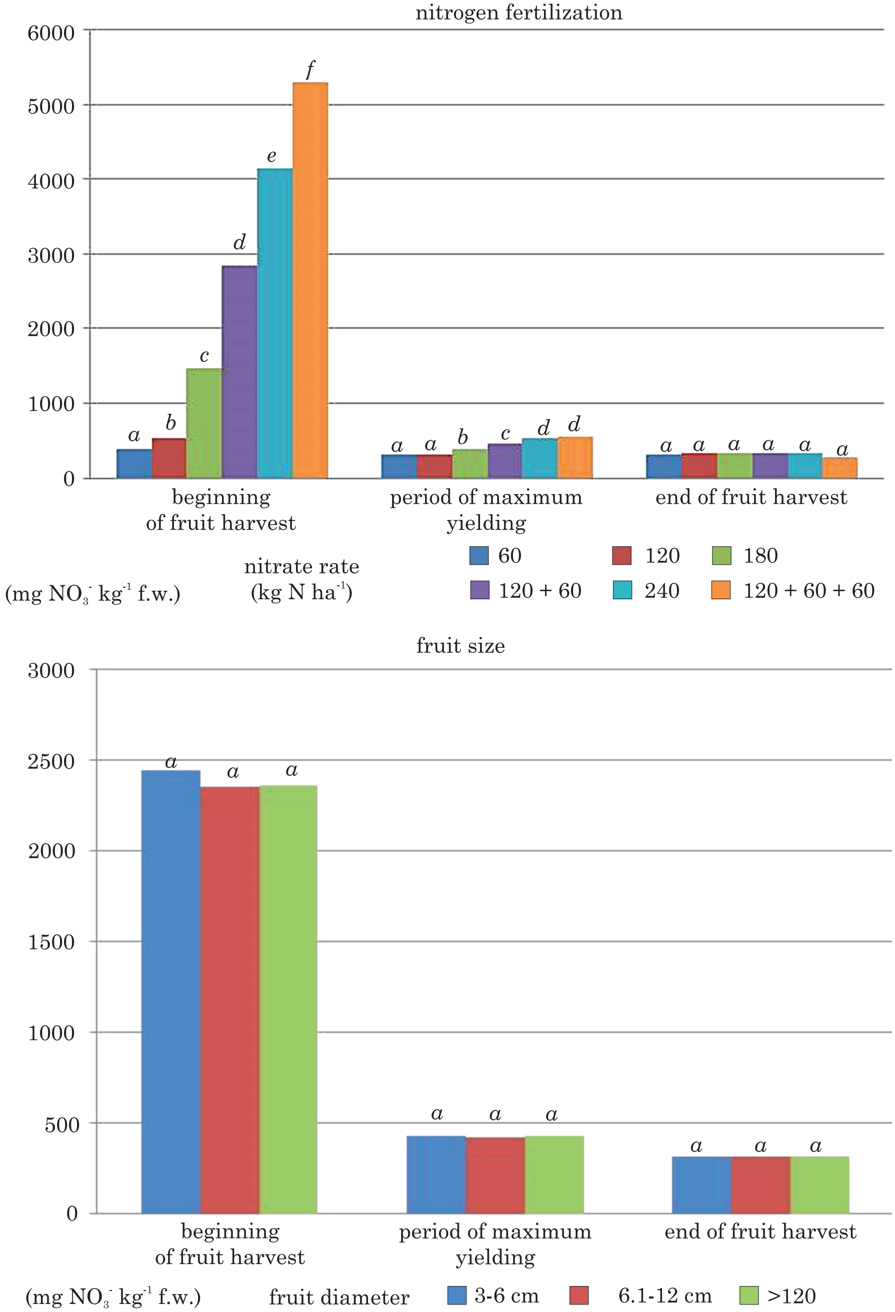

Fig. 1. Nitrate content in the index parts of scallop squash as affected by nitrogen fertilization and size of harvested fruits (means 2011-2013). Any means at a particular stage of the plant growth not followed by the same letter are significantly different at $\alpha = 0.05$ the Tukey test

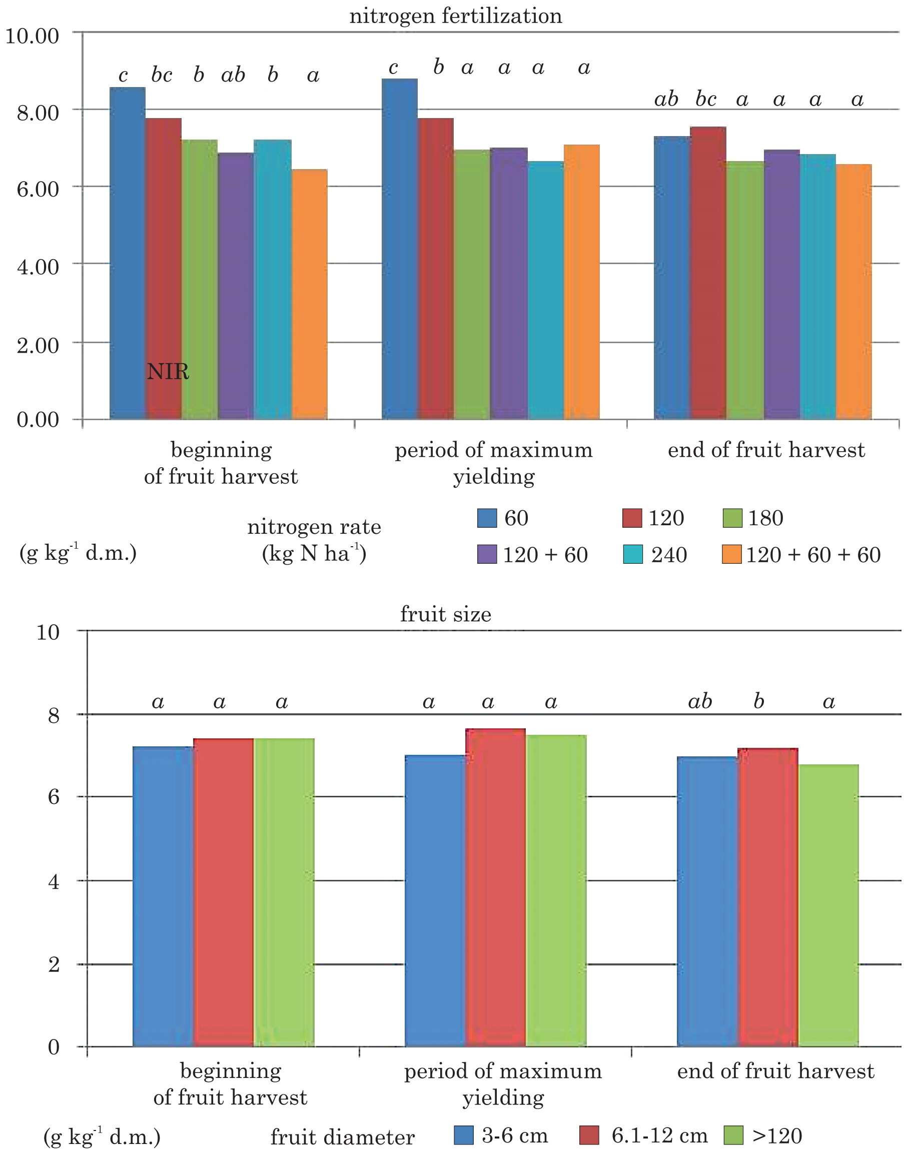

Fig. 2. Phosphorus content in the index parts of scallop squash as affected by nitrogen fertilization and size of harvested fruits (means from the 2011-2013 data). Any means at a particular stage of the plant growth not followed by the same letter are significantly different at $\alpha = 0.05$ the Tukey test.

effect of nitrogen fertilizer was observed in the case of calcium, whose content was enhanced by an application of 240 kg N ha^{-1} on all the dates of sampling (Figure 4). Plants from which more matured fruits were harvested showed significantly higher amounts of Ca at the second and third term of

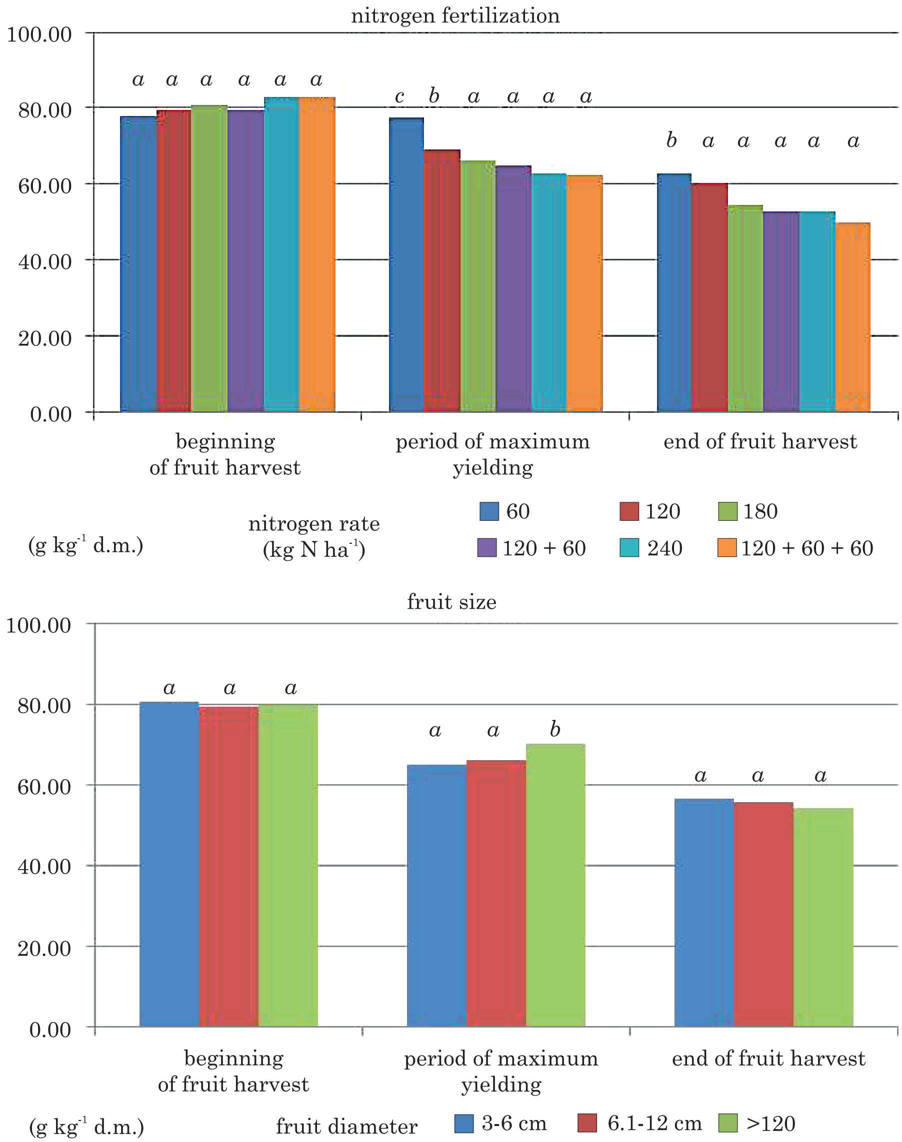

Fig. 3. Potassium content in the index parts of scallop squash as affected by nitrogen fertilization and size of harvested fruits (means from the 2011-2013 data). Any means at a particular stage of the plant growth not followed by the same letter are significantly different at $\alpha = 0.05$ the Tukey test.

chemical analysis. The magnesium content in leaf petioles was rather stable during the growing period and not dependent on a N dose or a size of harvested fruits from plants (Figure 5).

The above data are the first report in the literature evaluating the effects on nitrogen fertilization on the mineral status of plants at different

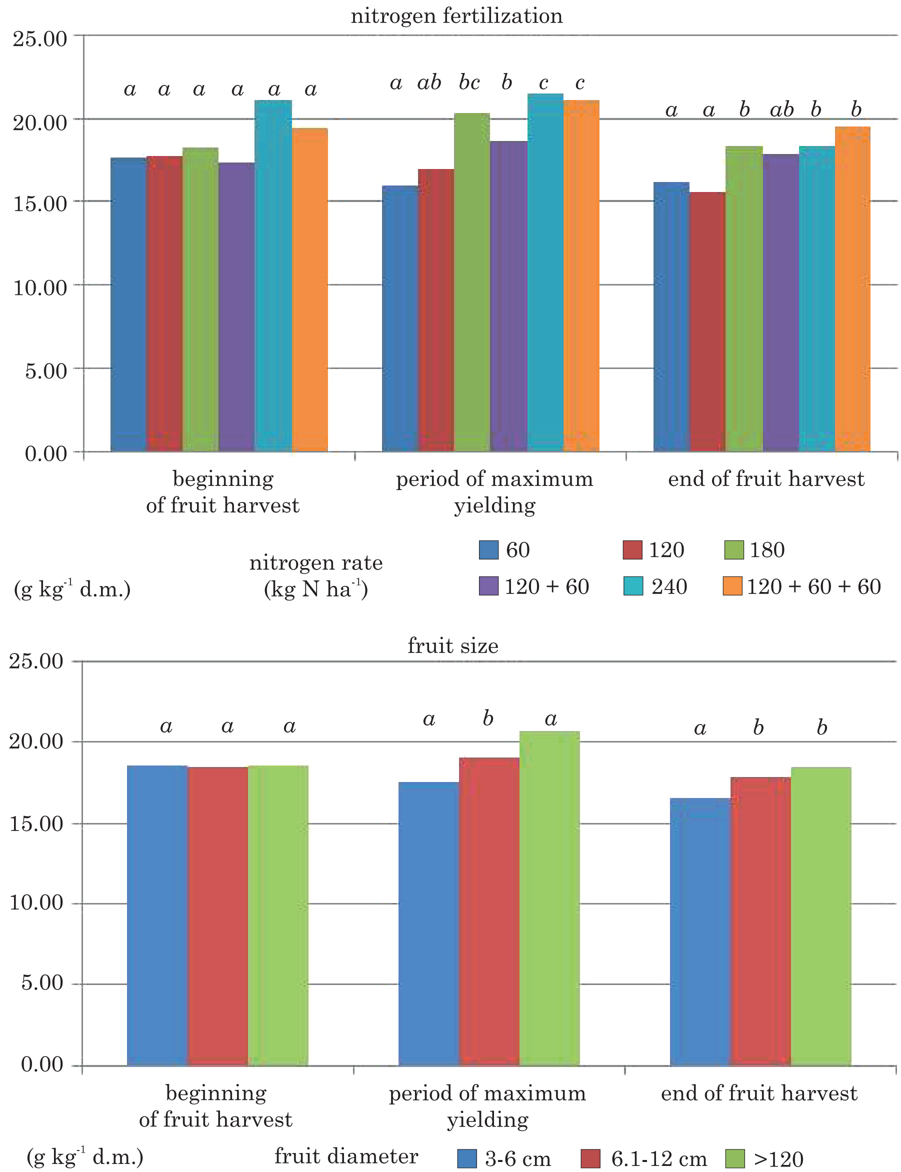

Fig. 4. Calcium content in the index parts of scallop squash as affected by nitrogen fertilization and size of harvested fruits (means 2011-2013). Any means at a particular stage of the plant growth not followed by the same letter are significantly different at $\alpha = 0.05$ the Tukey test.

stages of the plant growth, although some articles have been published previously regarding the mineral composition of scallop squash fruits. Research results prove that fruits of this vegetable crop may be seen as a rich source of such minerals as potassium, calcium, iron and magnesium (GRZESZCZUK, FALKOWSKI 2002). Such conclusions are in agreement with our own data, indi-

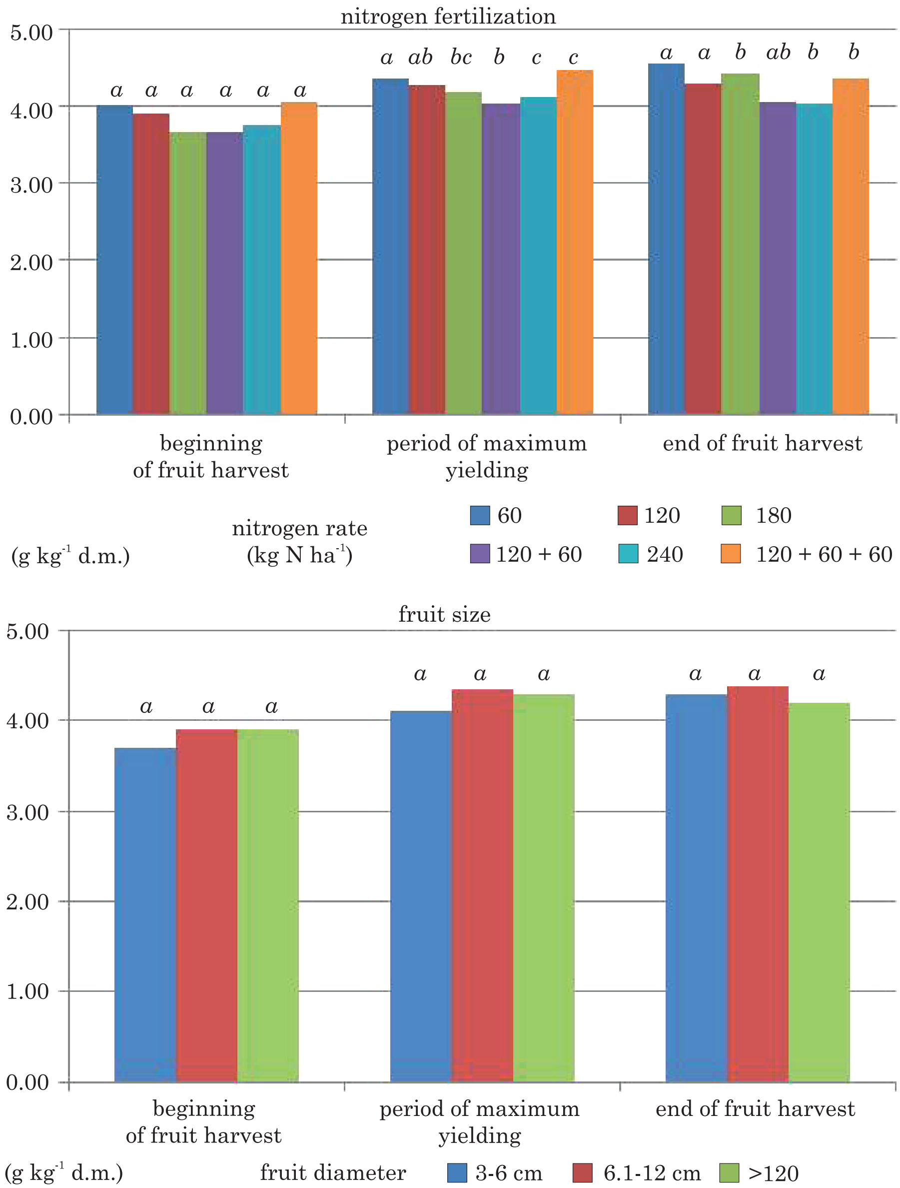

Fig. 5. Magnesium content in the index parts of scallop squash as affected by nitrogen fertilization and size of harvested fruits (means from the 2011-2013 data). Any means at a particular stage of the plant growth not followed by the same letter are significantly different at $a = 0.05$ the Tukey test.

cating especially high amounts of potassium, which can supply an apprecia-ble quantity of this compound in a human diet (Table 1). Generally, foods of plant origin havea potassium content of 20 - 730 mg 100 g^{-1} f.w. (Martinez-

Table 1

Effect of nitrogen fertilization on the mineral composition of scallop squash fruits (means from the 2011-2013 data)

N rate (kg ha^{-1})	Total N (g kg^{-1} d.m.)	NO_3^- (mg kg^{-1} f.m.)	P (mg kg^{-1} f.m.)	K (mg kg^{-1} f.m.)	Ca (mg kg^{-1} f.m.)	Mg (mg kg^{-1} f.m.)
60	33.20*a*	230.0*a*	475.1*a*	3365*b*	276,2*a*	212.8*a*
120	33.90*a*	243.0*a*	457.2*a*	3377*b*	283,1*a*	226.5*a*
180	34.80*b*	277.0*b*	456.3*a*	3425*b*	296.5*a*	222.2*a*
120 + 60	35.00*b*	313.0*c*	458.8*a*	3295*ab*	291.7*a*	235.8*a*
240	36.70*c*	315.0*c*	462.8*a*	3193*a*	316.6*a*	227.3*a*
120 + 60 + 60	38.00*d*	299.0*c*	458.5*a*	3133*a*	328.6*a*	231.5*a*
Mean	35.27	280.0	461.5	3298	298.8	226.0

Any means within a column not followed by the same letter are significantly different at $\alpha = 0.05$ the Turkey test.

-Ballestra et. al. 2010), while its average level in scallop squash fruits equals 336.49 mg 100 g^{-1} f.w.

The level of minerals in vegetables depends on numerous factors, including genetic properties, climatic conditions, soil properties, crop management and degree of maturity at the time of harvest. The impact of nitrogen fertilization appeared to be significant in the case of total N and nitrates. Like in another study on tomato (Cserni et. al. 2008), scallop squash grown under different N doses produced fruits containing significantly higher levels of total N and an antagonistically decreased K level in response to strong nitrogen fertilization. A similar effect of nitrogen application on the content of this macronutrient was observed in other vegetable crops, such as spinach, lettuce, celeriac or kale (Krężel, Kołota 2014, Pitura, Michałojć 2015).

It is well documented that an application of nitrogen improves plants' growth and yield. Some disadvantages of high concentrations of this nutrient include contamination of the environment and high nitrate accumulation in vegetable crops. By raising its dose from 60 to 240 kgN ha^{-1} the content of NO_3^- in scallop squash fruits was increased from 230 to 315 mg kg^{-1} f.w. Split applications of high N doses were ineffective in terms of the accumulation of nitrates in fruits. The detected level seems not to cause any risk to consumers. The reason for low nitrate accumulation by scallop squash is the type of an edible part, which is an immature fruit. Acording to Santamaria et. al. (1999) and Meah et al. (1994), vegetable organs can be listed according to a decreasing nitrate content in the following order: petiole > leaf blade > stem > root > inflorescence > tuber > bulb > fruits > seed. In the classification of vegetables according to the NO_3^- content, elaborated by Santamaria (2006), summer squash, including scallop squash, belongs to a group characterized by a weak tendency towards nitrate accumulation, below 200 mg kg^{-1} f.w. The content of phosphorus, potassium, magnesium and calcium in fruits was not influenced by a dose and time of N application.

Table 2

Mineral composition of scallop squash fruits depending on the stage of maturity (means from the 2011-2013 data)

Fruit diameter (cm)	Total N (g kg^{-1} d.m.)	NO_3^- (mg kg^{-1} f.m.)	P (mg kg^{-1} f.m.)	K (mg kg^{-1} f.m.)	Ca (mg kg^{-1} f.m.)	Mg (mg kg^{-1} f.m.)
3-6	44.50*c*	317.0*c*	579.1*c*	4470*c*	295,6*a*	289.7*c*
6.1-12	34.20*b*	286.0*b*	453.7*b*	3187*b*	292,0*a*	214.3*b*
>12	27.10*a*	235.0*a*	351.5*a*	2438*a*	308.8*a*	174.0*a*

Any means within a column not followed by the same letter are significantly different at $\alpha = 0.05$ the Turkey test.

The mineral composition of scallop squash fruits was greatly affected by the stage of maturity at the time of harvest (Table 2). This finding is in agreement with the statement of Lester (2006), indicating that the size of vegetables or fruits is a factor with a major impact on the concentration of available phytonutrients.

It is generally agreed that the vitamin C content, which is one of the most important compounds, decreases with an increased size or stage of maturity of vegetables (Gajc-Wolska, Skąpski 1994, Lester 2006, Grzeszczuk 2009). A similar trend was also observed in the mineral composition of scallop squash fruits analyzed in our study. Fruits harvested at an early stage of development and having a diameter of 3 - 6 cm had the highest nutritional value expressed by the content of total N, phosphorus, potassium and magnesium. The only exception was calcium, whose amount was not dependent on the fruit maturity stage. The data are in agreement with those reported by Grzeszczuk, Falkowski (2002), Grzeszczuk (2003) on scallop squash, and by Biesiada et. al. (2007) on leek, zucchini and kohlrabi. In the case of calcium, variable effects observed, and in some cases its concentration was higher in more matured plants.

An undesirable feature of fruits harvested in an early stage of the growth (diameter 3-6 cm) was their higher level of nitrates than detected in fruits collected when having a diameter of 6.1 - 12 cm and >12 cm. However, even at its maximum concentration in early harvested fruits equal to 317 mg NO_3^- kg^{-1} f.w., scallop squash should be treated as a minor contributor to the dietary nitrate intake by consumers.

CONCLUSIONS

1. Nitrogen fertilization strongly affected the content of NO_3^- in leaf petioles of scallop squash at the the beginning of fruit harvest, while only a slight or no effect was observed in later stages of the growth period.

2. High N doses, exceeding 120 kg N ha^{-1}, caused a decrease in the con-

tent of P and also K at the later growth stages, while raising the content of Ca in the index parts of scallop squash.

3. The data indicate that tissue nitrate analysis may be successfully used as the basis for determination of the crop's nitrogen demand during the early growth period.

4. Strong nitrogen fertilization caused a significant increase in the total N and nitrate accumulation in fruits, leaving the content of P, K, Ca and Mg unaffected.

5. Fruits harvested in the early stage of maturity (diameter 3-6 cm) contained higher amounts of total N, phosphorus, potassium and magnesium than those with a diameter of 6.1 - 12 cm and >12 cm. A rverse effect was observed in the case of nitrate accumulation.

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