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ORIGINAL PAPER

MINERAL COMPOSITION OF FRUITS AND LEAVES OF SAN ANDREAS® EVERBEARING STRAWBERRY IN SOILLESS CULTIVATION*

Krzysztof Gondek[1], Monika Mierzwa-Hersztek[1], Michał Kopeć[1], Tomasz Zaleski[2], Stanisław Bogdał[3], Monika Bieniasz[4], Jan Błaszczyk[4], Elżbieta Kaczmarczyk[4], Barbara Kowalczyk[4], Jarosław Knaga[5], Jacek Nawrocki[6], Michał Pniak[7], Renata Jarosz[1]

[1] Department of Agricultural and Environmental Chemistry
[2] Department of Soil Science and Agrophysics
University of Agriculture in Krakow, Poland
[3] Stanflex-Polski Instytut Truskawki Sp.z o.o., Poland
[4] Department of Horticulture
[5] Department of Bioprocess Engineering, Power Engineering and Automation
[6] Department of Botany, Plant Physiology and Protection
University of Agriculture in Krakow, Poland
[7] BIOCONT, Poland

Abstract

Technological progress in the cultivation of horticultural and fruit plants makes the use of soil becoming less and less important. Growing plants in soilless substrates is becoming more and more common. The aim of the study was to determine the variability of the mineral composition of fruits and leaves of everbearing strawberry of the San Andreas® variety in soilless cultivation. Research was carried out at the experimental plantation of Polski Instytut Truskawki Sp. z o.o. (geographical coordinates: 50°02′11″N and 19°81′19″E). The cultivation of everbearing strawberry of the San Andreas® variety was carried out in a gutter system under covers

prof. dr hab. inż. Krzysztof Gondek, Department of Agricultural and Environmental Chemistry, University of Agriculture in Krakow, al. Mickiewicza 21, 31-120 Krakow, Poland, phone +48 12 662 43 46, fax +48 12 662 43 41, e-mail: krzysztof.gondek@urk.edu.pl, rrgondek@cyf-kr.edu.pl

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in coconut substrate. The stability of the chemical composition of strawberry leaves and fruits depends on fertilisation, weather factors, and the quality of water used for fertigation. Despite maintaining the content of nutrient in the rhizosphere at the level recommended for organic substrates, low potassium and calcium content and high magnesium content in strawberry leaves were determined. Among the macroelements analysed in strawberry leaves, the lowest variation coefficient values were found for nitrogen, magnesium and calcium, and in fruits – for nitrogen, phosphorus, and magnesium. The highest variation coefficients were obtained for phosphorus and sodium in strawberry leaves, and for sulphur and sodium in strawberry fruits. Variation coefficient values of copper, zinc, and manganese content in leaves were similar. The content of iron in leaves and zinc in fruits was characterised by the lowest variation coefficients during the growing period.

Keywords: mineral composition, everbearing strawberry, soilless cultivation.

INTRODUCTION

Technological progress in the cultivation of horticultural and fruit plants makes the use of soil becoming less and less important. Growing plants in soilless substrates, which offers a wide range of possibilities of controlling the plant feeding process, is becoming more and more common.

A dynamic increase in strawberry production has been observed in the last thirty years. In 2016, the production of this fruit in the world market amounted to 9.2 million tonnes. It is estimated that the consumption of strawberries will continue to increase in the near future. Due to the growing population and awareness of the pro-health properties of strawberries, the production of this fruit in 2025 may increase to 11.5 million tonnes. Currently, Poland is one of the leading producers of strawberry fruits in Europe, second only to Spanish and German producers (Fijoł-Adach et al. 2016). The growing importance of strawberry cultivation results from the relatively easy production of seedlings and low nutritional requirements for the substrate. Strawberry fruits are a valuable source of L-ascorbic acid and polyphenolic compounds as well as other easily digestible organic compounds (Aaby et al. 2007, Muthukumaran et al. 2017). They have one of the highest antioxidant properties among fruits (Hannum 2004, Fijoł-Adach et al. 2016). Strawberries also show antimicrobial activity, especially against *Salmonella* and *Staphylococcus* bacteria (Puupponen-Pimia et al. 2005, Fijoł-Adach et al. 2016). It should also be emphasised that the structure and chemical composition of strawberry fruits significantly expand the spectrum of their use (Kopytowski et al. 2006).

Proper irrigation and mineral fertilisation of strawberry plants is very important for the right plant nutritional status and crop quality. Optimal irrigation and supply of minerals allow one to maintain physiological processes on an adequate level, which determines the crop volume and quality (Koszański et al. 2005). The use of properly balanced and stable fertilisation significantly affects the vegetative potential of plants and the content of some macroelements and microelements in both leaves and fruits. There are also scientific reports about the positive effect of bacterial inoculation of strawberry seedlings. Depending on a variety, it can significantly affect the plant height and the number of crowns as well as the content of macroelements and microelements in leaves, while also stimulating the generative potential and morphometric and chemical parameters of fruits (Tomic et al. 2015). It is also worth mentioning that although strawberry plants have relatively modest requirements with respect to substrates, the latter can significantly influence the effectiveness of agrotechnical treatments, mainly fertilisation. Currently, growing plants (including strawberries) on coconut fibre is gaining growing popularity. Unlike peat, coconut fibre is a material whose application for plant growing (e.g. strawberries) does not entail the use of environmental resources. The length of the day, temperature, and the often-neglected quality of water used for fertigation are important factors influencing flower formation (Kopeć et al. 2019a)

The aim of the study was to determine the variability of mineral composition of fruits and leaves of everbearing strawberry of the San Andreas® variety in soilless cultivation.

MATERIAL AND METHODS

Tests were carried out at the experimental plantation of Polski Instytut Truskawki Sp. z o.o. located in Tyniec near Krakow, geographical coordinates: 50°02′11″N and 19°81′19″E. The cultivation of everbearing strawberry (4 ha) of the San Andreas® variety was carried out in a gutter system, under covers, on an inert medium, i.e. coconut substrate from the previous growing season, and in white 200 mm × 100 mm × 1000 mm foil. Before planting strawberry seedlings, mat buffering was carried out with a calcium nitrate solution (pH=5.5, EC=1.2-1.7 mS cm^{-1}). Strawberry seedlings (Fragaria×ananassa Duch) were planted at the beginning of May 2019 at a density of 8 pieces per mat.

Six overflow stations were installed on the plantation. They were placed at sites where, due to a change in the gutter inclination over a distance of 4 linear meters and the presence of holes, it was possible to collect leachate (drainage) in order to monitor its volume and chemical composition (Kopeć et al. 2019*b*). Nutrient composition during the cultivation is given in Table 1. The year 2019 was hot and dry at the location of the experiment. The maximum and minimum temperatures measured 10 cm above the plants are shown in Figure 1.

As part of the study, mass and number of strawberry fruits were recorded weekly from the beginning of fruiting (mid-June) (Palencia et al. 2013). Representative samples of biological material (fruits and leaves) for chemical

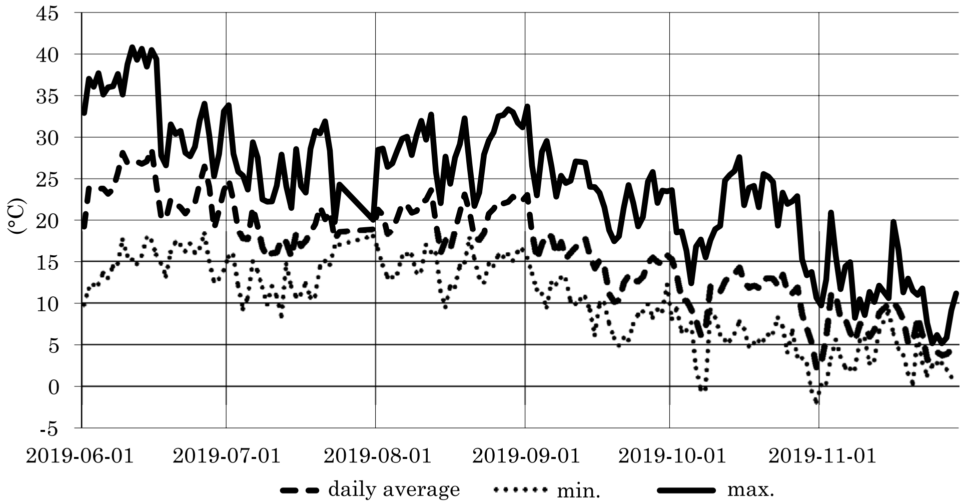

Fig. 1. The average daily as well as minimum and maximum air temperature during the experiment

Table 1

Average content of nutrients in solutions used for fertigation of plants

Nutrient	Starter	Fruting
	(mg dm^{-3})	
N-NH$_4$	23.5	9.35
N-NO$_3$	100.9	83.6
P	75.2	40.3
K	125.2	181.0
Ca	62.7	33.5
Mg	25.3	21.8
Fe	1.82	1.81
Mn	2.65	2.18
Zn	0.48	0.49
B	0.08	0.06
Cu	0.09	0.06
Mo	0.05	0.05

tests were collected at monthly intervals (WÓJCIK et al. 2014). Leaf blades (30 to 50 pieces) from the center of plants were taken for analysis. Fruit samples were taken at full maturity. Fruit and leaf samples were dried at 60°C in a WGL-125B forced air drying oven. After drying, the plant samples were weighed to determine the dry matter content, and then ground in an IKA M20 laboratory mill. The total ash content in the samples was determined in a chamber furnace after ashing an analytical sample at 550°C (ŁUCZAK et al. 2012). The content of nitrogen and sulphur was determined on a CNS analyser (Vario EL Cube, Elementar). The content of other macro- (P, K, Ca, Mg, Na) and microelements (Cu, Zn, Mn, Fe) was determined after mineralising a sample in a chamber furnace at 450°C for 12 h and dissolving the residue in diluted (1:2) nitric acid. The content of the mentioned elements was determined in the solutions by inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer Optima 7300 DV) (Oleszczuk et al. 2007). The values of the content of macroelements in strawberry leaves were used to calculate the following equivalent ratios: K:Ca; K:Mg; K:(Ca+Mg); (K+Na):(Ca+Mg). Calculations were made according to the following formula:

$$MgR = M / W$$

where: MgR – element gram equivalent, M – element molar mass, W – number of element ion charges.

The experiment was carried out in three replicates. The data obtained were compiled with the use of Statistica 12.5 (StatSoft Inc.). The mean values of the analysed properties were compared using the Duncan's multiple range test at $p \leq 0.05$. Variations within the period were determined by calculating the standard deviation (± SD), and between periods – by using a variation coefficient (V%).

RESULTS AND DISCUSSION

There is a limited number of studies on the yield and chemical composition of strawberries grown in soilless substrates, especially under covers and using coconut fibre. Therefore, the current results (especially strawberry biomass chemical composition) were also referred to the chemical composition of plants grown under field conditions. The key elements for the yield of strawberry grown without soil are irrigation, including the quality of water used for fertigation, and balanced fertilisation (Jarosz, Konopińska 2010, Kopeć et al. 2019*a*). The use of coconut substrates, which are an alternative to perlite or peat and which have significantly different physical and chemical properties, requires specific fertilisation, especially with respect to nitrogen (Jarosz, Konopińska 2010). The San Andreas variety yield in 2019 was conditioned by one more factor, namely the high air temperature. During the study period, the air temperature was not conducive to flowering and therefore was not beneficial for good strawberry yielding (MacKenzie et al. 2011, Palencia et al. 2013) – Figure 1. The highest yield of fresh San Andreas fruits per plant was obtained at the end of August (Figure 2). After this period, a gradual decrease in strawberry yielding was noted until the turn of September and October, when the strawberry yielding potential was partially restored. In their study, Jarosz and Konopińska (2010) used peat substrate and peat mixed with bark or pine sawdust for cultivation, and the yield of variery Elsanta strawberries per plant was higher. It should

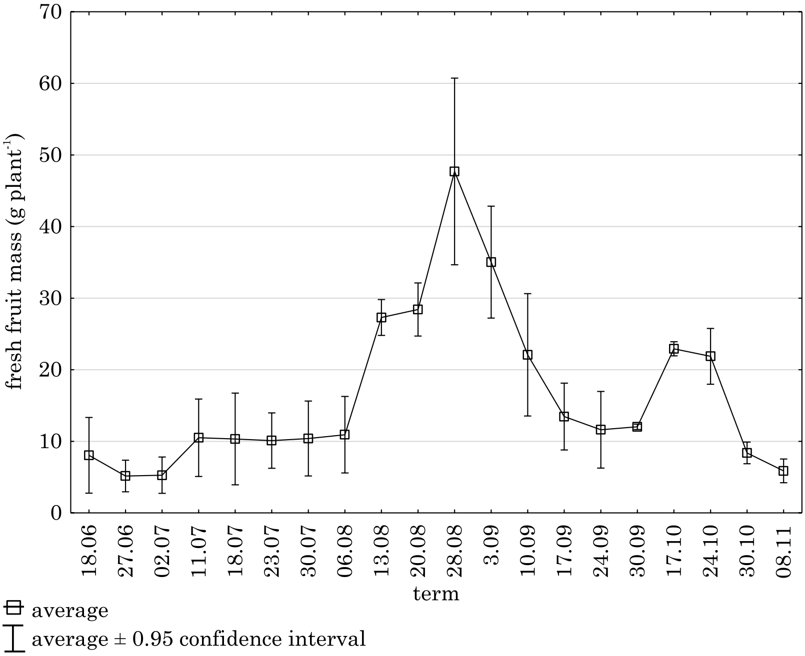

Fig. 2. Strawberry yielding (fresh fruit mass g plant^{-1}) in the study period

be noted that the content of nutrients in the rhizosphere was maintained at a level corresponding to plant nutritional requirements. Considering the plant's nutritional status, especially the nitrogen content in leaves, it was found that nitrogen was not a determinant of the yielding of San Andreas strawberries grown in coconut substrate (MARKIEWICZ et al. 2008). Many studies indicate temperature as an important factor for both the content of various substances in strawberries and their yielding (MACKENZIE et al. 2011, PALENCIA et al. 2013).

The chemical composition of strawberry leaves and fruits depends mainly on a variety, climatic conditions and, in the case of fruits, on their degree of ripeness. In their study, RECAMALES et al. (2008) showed that a cultivation technology and fertilisation are also important determinants of yielding and crop quality.

The average dry matter content in leaves was 255±102 g kg^{-1} with a significant standard deviation (Table 2). The highest dry matter content in leaves was recorded in October and November. In the entire period (June – November), the dry matter content in fruits was 107±12 g kg^{-1} on average (Table 3). The highest dry matter content in strawberry fruits was recorded in July and October. Our results correspond to these of CHEŁPIŃSKI et al. (2010), who studied the effect of different fertilisation on yielding and quality of var. Kent strawberries.

The ash content in strawberry leaves reached its highest value in July

Table 2

Dry matter, ash and macroelement content in San Andreas strawberry leaves

Determina-tion	Sampling date						
	18.06	18.07	13.08	10.09	7.10	8.11	V%
Dry matter (g kg^{-1})	283*b*±17	276*b*±10	253*a*±19	275*b*±21	325*c*±27	332*c*±21	40
Ash (g kg^{-1} DM)	98.2*c*±1.9	110.1*d*±5.4	101.8*c*±0.0	79.1*b*±0.0	62.0*a*±1.2	66.1*a*±1.9	23
N (g kg^{-1} DM)	34.1*b*±0.3	36.9*b*±3.7	29.9*a*±2.0	28.1*a*±0.2	28.7*a*±0.7	28.5*a*±0.2	12
P (g kg^{-1} DM)	3.78*f*±0.10	3.51*e*±0.04	1.84*a*±0.11	2.05*b*±0.08	2.59*d*±0.04	2.24*c*±0.14	30
K (g kg^{-1} DM)	18.8*e*±0.8	16.2*d*±0.2	8.6*a*±0.1	11.7*b*±1.0	12.9*c*±0.0	12.2*bc*±0.4	27
S (g kg^{-1} DM)	0.69*a*±0.03	1.23*c*±0.04	1.08*b*±0.07	1.02*b*±0.03	1.10*b*±0.08	1.54*d*±0.05	25
Ca (g kg^{-1} DM)	11.4*d*±0.2	9.0*c*±0.4	7.1*a*±0.0	12.1*d*±0.1	8.1*b*±0.1	9.4*c*±0.0	20
Mg (g kg^{-1} DM)	4.28*c*±0.01	3.09*a*±0.07	3.31*ab*±0.03	4.30*c*±0.29	3.29*ab*±0.00	3.42*b*±0.00	15
Na (g kg^{-1} DM)	0.05*a*±0.01	0.05*a*±0.01	0.04*a*±0.00	0.06*a*±0.00	0.10*b*±0.00	0.20*c*±0.03	72

Mean values marked with the same letters do not differ significantly at $\alpha \leq 0.05$ (according to the Duncan's test).

(110.1±5.4 g kg^{-1}) – Table 2. In the next months (collection dates), the ash content was significantly lower. The ash content in fruits decreased as the growing season progressed (Table 3).

The analysis of strawberry leaf vegetative material showed that the nitrogen content did not differ significantly (Table 2); however, the tendency towards a reduced N content in the subsequent months of plant growing was clearly marked, as confirmed by Nurzyński et al. (1990). Based on the results of our statistical analysis, it was found that the N content in strawberry leaf biomass from August to November was significantly lower (28.6 g kg^{-1} on average) than that determined in June and July (35.5 g kg^{-1} on average). Higher nitrogen content in strawberry leaves can cause excessive plant growth and increase the risk of fruit infection with grey mould (Wójcik et al. 2014). According to Wójcik et al. (2014), the optimal nitrogen content in strawberry leaves ranges between 23.0-26.0 g kg^{-1}. As in the case of leaves, the nitrogen content in strawberry fruits did not vary much, although differences between sampling dates were significant (Table 3). From August to November, excluding September, the nitrogen content in strawberry fruits was similar.

Similar trends, with much lower content than that of nitrogen, were noted for phosphorus in strawberry leaves (Table 2). However, during the

Table 3

Dry matter, ash and macroelement content in San Andreas strawberry fruits

Determination	Sampling date						
	18.06	18.07	13.08	10.09	7.10	8.11	V%
Dry matter ($g\ kg^{-1}$)	99*a*±8	122*b*±19	93*a*±20	101*a*±17	120*b*±11	105*ab*±21	11
Ash ($g\ kg^{-1}$ DM)	63.5*b*±5.6	82.1*c*±8.8	65.9*b*±1.2	52.8*a*±3.0	44.7*a*±1.7	45.1*a*±0.8	25
N ($g\ kg^{-1}$ DM)	10.4*a*±0.2	13.4*c*±0.1	12.4*b*±0.4	10.7*a*±0.2	12.8*b*±0.3	12.5*b*±0.1	10
P ($g\ kg^{-1}$ DM)	2.84*c*±0.32	2.58*bc*±0.01	2.16*a*±0.24	2.33*ab*±0.11	2.27*ab*±0.05	2.47*ab*±0.17	10
K ($g\ kg^{-1}$ DM)	20.2*c*±1.9	17.5*b*±0.2	14.6*a*±0.7	15.6*a*±0.1	15.2*a*±0.3	15.0*a*±0.6	13
S ($g\ kg^{-1}$ DM)	0.35*a*±0.05	0.74*b*±0.01	0.83*c*±0.04	0.71*b*±0.03	0.91*d*±0.03	1.11*e*±0.04	33
Ca ($g\ kg^{-1}$ DM)	2.01*d*±0.09	1.33*ab*±0.14	1.50*b*±0.06	1.79*c*±0.00	1.15*a*±0.05	1.40*b*±0.22	21
Mg ($g\ kg^{-1}$ DM)	1.59*e*±0.08	1.15*a*±0.00	1.31*bc*±0.02	1.50*de*±0.05	1.27*b*±0.01	1.40*cd*±0.11	12
Na ($g\ kg^{-1}$ DM)	0.39*bc*±0.04	0.13*a*±0.00	0.72*d*±0.01	0.47*c*±0.12	0.29*b*±0.14	0.42*bc*±0.02	48

Mean values marked with the same letters do not differ significantly at $a \leq 0.05$ (according to the Duncan's test).

study period, the variation coefficient value (V%) for the P content was more than two-fold higher than for the N content. This was probably due to a significant decrease in the leaf P content in August (1.84±0.11 $g\ kg^{-1}$) and inadequate quality parameters of water used for fertigation (Kopeć et al. 2019*a*). When comparing the determined phosphorus content in the collected test material with the limit values of this element in strawberry leaves, it was found that the P content was deficient only in the material collected in August (Wójcik et al. 2014). As for the phosphorus content in fruits, the variation coefficient (V%) did not exceed 10 (Table 3). It should be noted that the highest phosphorus content in strawberry fruits was determined at the beginning of full fruiting (on 18 June), i.e. on the first date of plant material collection. The P content determined in strawberry fruits was smaller than that reported by Chełpiński et al. (2010).

The potassium content in strawberry leaves differed between the sampling dates. The K content in leaves was significantly the highest in biomass collected in June and July (17.5 $g\ kg^{-1}$) – Table 2. On the other dates, the K content in strawberry leaves did not exceed 12.9 $g\ kg^{-1}$. This value is within the range provided by Jarosz and Konopińska (2006); however, these authors considered it low. Also, according to the limit values published by Wójcik et al. (2014) for the macronutrient content in strawberry leaves, the K content below 15.0 $g\ kg^{-1}$ is low. The average potassium content in strawberry fruits in the studied period was 16.3±2.1 g kg^{-1}, and the variation coefficient value (V%) did not exceed 15 (Table 3). As in the case of phosphorus, the highest potassium content in strawberry fruits was determined at the beginning of fruiting (i.e. on 18 June). In the study of CHEŁPIŃSKI et al. (2010), strawberry fruits of the Kent variety contained from 16.9 g to 17.5 g K kg^{-1} DM. The average potassium content determined in fruits of the San Andreas variety in our experiment was within this range. Exceeding optimal K doses in strawberry cultivation can worsen plant growth and development conditions, which will undoubtedly be reflected in the quantity and quality of fruit yielding (SOUSA et al. 2014).

Plants well fed with sulphur are more resistant to stress during cultivation. In our study, the sulphur content in strawberry leaves, apart from the June date (0.69 g kg^{-1}), ranged 1.02-1.54 g kg^{-1} with a relatively small variation coefficient (V% = 25) – Table 2. Based on the results obtained, it can be argued that the leaf sulphur content increases with the decreased nitrogen content. In general, the sulphur content in strawberry fruits was increasing on the subsequent dates (Table 3). Comparing June and November, it was found that the S content increased more than 3 times.

Like sulphur, calcium is also considered an element that affects plant quality. Scientific studies show that plants properly nourished with calcium have a better developed root system, which translates into the more efficient uptake of water and nutrients. The average calcium content in strawberry leaf biomass was 9.5±1.9 g kg^{-1} (Table 2). Plant leaves collected in September (12.1±0.1 g kg^{-1}) had significantly the highest content of this component. The calcium content in the San Andreas strawberry leaves was higher than the upper limit of the range (5.3-9.1 g kg^{-1}) proposed by JAROSZ and KONOPIŃSKA (2010), although it was still considered low (ALMALIOTIS et al. 2002). The variation of calcium content in strawberry leaves and fruits was at a similar level (Tables 2 and 3). For both leaves and fruits, the highest content of this element was determined in samples collected in June and September.

The study results revealed a very high content of magnesium in strawberry leaves, regardless the plant material sampling date (WÓJCIK et al. 2014) – Table 2. Considering the excess of this component in plant leaves, it should be mentioned that it is the main component of chlorophyll, hence it certainly intensifies photosynthesis and positively affects the nitrogen management in the plant as well as limiting the content of nitrates. It also improves phosphorus transport to generative parts in a plant. The magnesium content in strawberry fruits was more than twice lower than the content indicated in the leaves (Table 3). The average content of this element in strawberry fruits was 1.40±0.2 g kg^{-1}, with significant variation between dates. The determined Mg content in strawberry fruits was comparable to the content reported by CHEŁPIŃSKI et al. (2010). With differentiated fertilisation of the Kent strawberry variety, the Mg content determined by these authors ranged from 1.25 g to 1.52 g kg^{-1} DM. The Mg content in the San

Andreas variety presented herein and by Chełpiński et al. (2010) was smaller than the content determined by Ochmian et al. (2008) in fruits of the Senga Sengana strawberry variety.

The sodium content in strawberry leaves from June to September was relatively stable (0.05±0.01 g kg^{-1} on average) – Table 2. In leaves collected on the last two dates, i.e. in October and in November, the content of Na increased two and four times, respectively, compared to the average. The sodium content in fruits was much higher than in leaves (0.40±0.19 g kg^{-1} on average) – Table 3). Comparing the stability of the content of this element in strawberry fruits, a significantly greater variation in the Na content in fruits was found.

Content of microelements in strawberry leaves and fruits is presented in Table 4. Comparing the content of the microelements analysed, it was found that there was more Fe, Cu, Zn, and Mn in leaves than in fruits. This is confirmed by the study of Mikiciuk and Mikiciuk (2010), who determined 146.3 to 273.1 mg Fe kg^{-1} DM in the leaves of the Elsanta strawberry variety. In the study of Gawęda and Ben (2004), the iron content in strawberry leaves reached 475 mg kg^{-1} DM.

The copper content in leaves was significantly the highest on the last three dates, i.e. from March to November (Table 4). There was no such relationship in strawberry fruits. Both leaves and fruits of the San Andreas variety contained less copper than leaves and fruits of the Elsanta variety analysed by Gawęda and Ben (2004).

The zinc content in strawberry leaves and fruits was the highest in samples collected in June (Table 4). On the subsequent dates, significantly lower content of this element was found in the analysed strawberry biomass. In both leaves and fruits of the San Andreas variety, the determined zinc content was lower than the value obtained by Gawęda and Ben (2004) for the leaves (50 mg kg^{-1}) and fruits (31 mg kg^{-1}) of the Elsanta variety.

The manganese content in both strawberry leaves and fruits showed significant dynamics in the analysed period (Table 4). It is difficult to show unequivocally clear trends here, but significantly the highest Mn content in leaves and fruits was noted in June. The content of manganese discovered by Gawęda and Ben (2004) in var. Elsanta fruits was 54 mg kg^{-1} DM, while in leaves it reached 137 mg kg^{-1} DM. The comparison of the average manganese content in fruits and leaves of the tested San Andreas variety with the content determined by Gawęda and Ben (2004) revealed that the Mn content in fruits was lower by over 10 mg kg^{-1} DM, while in leaves it was higher by 5 mg kg^{-1} DM.

The iron content showed less variation in strawberry leaves than in fruits (Table 4). The lowest element content in leaves was recorded in August (59.5 mg kg^{-1}), while in fruits, in October (20.3 mg kg^{-1}). In the study of Mikiciuk and Mikiciuk (2010), the iron content in var. Elsanta strawberries was from 59.56 mg to 79.66 mg kg^{-1} D.M. According to Gawęda

Table 4

Microelement content in San Andreas strawberry leaves and fruits

Microelement	Sampling date						
	18.06	18.07	13.08	10.09	7.10	8.11	V%
	Leaves						
Cu (mg kg^{-1} DM)	2.50*b*±0.03	2.58*b*±0.08	1.95*b*±0.01	3.20*c*±0.06	3.64*d*±0.08	3.33*c*±0.13	22
Zn (mg kg^{-1} DM)	27.4*d*±0.2	17.2*c*±0.9	14.2*b*±0.7	15.6*b*±0.5	17.7*c*±0.4	17.1*c*±0.5	26
Mn (mg kg^{-1} DM)	194*e*±9	96*a*±2	105*b*±3	164*d*±2	132*c*±6	161*d*±1	27
Fe (mg kg^{-1} DM)	78.6*b*±1.5	94.6*d*±7.4	59.5*a*±3.7	81.6*bc*±1.3	76.7*b*±2.6	88.7*cd*±9.3	15
	Fruits						
Cu (mg kg^{-1} DM)	2.28*c*±0.21	1.67*b*±0.21	1.45*ab*±0.11	2.10*c*±0.10	1.66*b*±0.27	1.21*a*±0.02	23
Zn (mg kg^{-1} DM)	13.4*b*±2.0	12.6*b*±0.6	10.6*a*±0.8	9.8*a*±0.4	9.5*a*±0.9	9.9*a*±0.7	15
Mn (mg kg^{-1} DM)	52.0*c*±6.4	41.6*b*±1.9	31.5*a*±0.3	46.3*bc*±2.1	40.2*b*±7.8	31.8*a*±2.8	20
Fe (mg kg^{-1} DM)	30.1*b*±6.9	38.0*c*±2.9	25.2*ab*±2.5	23.1*a*±2.1	20.3*a*±1.3	23.1*a*±1.3	24

Mean values marked with the same letters do not differ significantly at $\alpha \le 0.05$ (according to the Duncan's test).

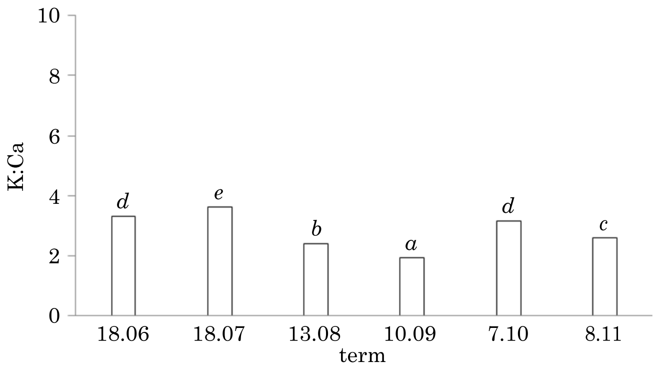

Fig. 3. K:Ca equivalent ratio in strawberry leaves

and BEN (2004), the Elsanta variety produced fruits containing up to 103 mg Fe kg^{-1} DM. The iron content in fruits of the San Andreas variety was lower than in both cases mentioned above.

Individual cations cross semipermeable membranes at different rates. It is not only the content but also the ratios of individual elements that are significant in terms of yielding and quality of the crop obtained. Maintaining

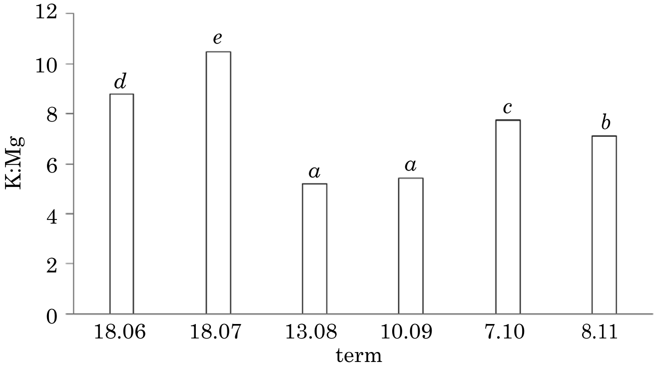

Fig. 4. K:Mg equivalent ratio in strawberry leaves

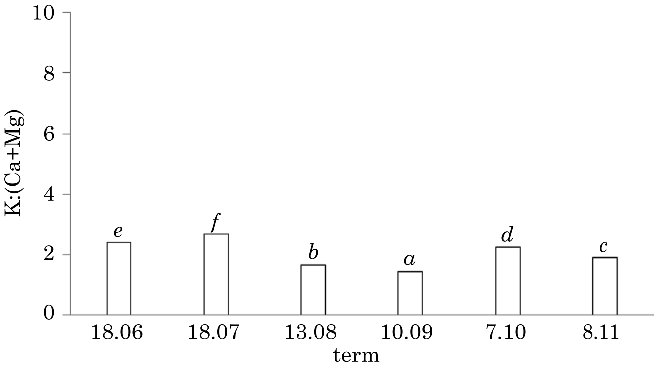

Fig. 5. K : (Ca + Mg) equivalent ratio in strawberry leaves

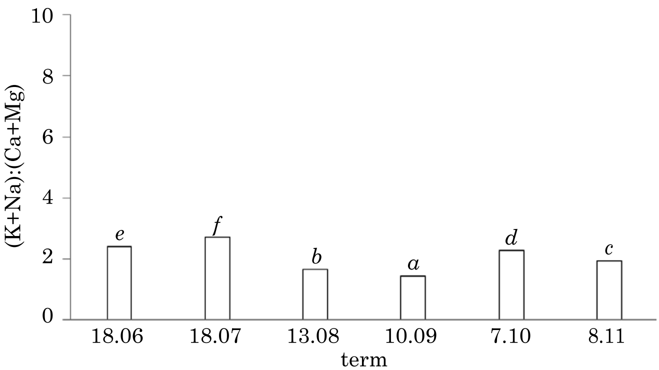

Fig. 6. (K + Na) : (Ca + Mg) equivalent ratio

the recommended content of individual nutrients in the rhizosphere is not a guarantee of the optimal quantitative and qualitative intake of nutrients. Values of the tested equivalent ratios K:Ca; K:Mg; K:(Ca+Mg); (K+Na): :(Ca+Mg) in strawberry leaves were a derivative of their chemical composition (Figures 3-6). Higher values of all the ratios were noted in strawberry leaves collected on the first two dates, i.e. 18 June and 18 July. On the next two dates, i.e. 13 August and 10 September, a significant decrease in values of individual ratio was determined.

The use of excessive amounts of calcium and magnesium in fertilisation may cause potassium deficiency in plants. In the study, both potassium and calcium content in strawberry leaves was in low ranges. It was only the magnesium content that was high. It should be noted that an excess of this element may cause interference with the intake of other nutrients, e.g. K, which in consequence creates competition for carriers in cell membranes. Problems related to maintaining optimal relationships between individual nutrients may be compounded by the chemical composition of the water (hard water) used for fertigation. Certainly, competition between monovalent and divalent ions is not the only case of antagonism between nutrients. The relationships between macronutrients and microelements are important for the plant nutrition. For example, an excessively high concentration of potassium may prevent the absorption of some micronutrients, such as zinc. Another issue that needs to be addressed is the similarity of Na^+ and K^+ ion rays, because carriers in the cell membrane can transport Na^+ ions instead of K^+ ions (Parida, Das 2005). It seems that this is the main reason for the imbalance between Na^+ and K^+ ions in the plant.

CONCLUSIONS

1. The stability of chemical composition of strawberry leaves and fruits depends on fertilisation and weather factors.

2. Despite maintaining the nutrient content in the rhizosphere at a level recommended for organic substrates, the study revealed low potassium and calcium content and high magnesium content in strawberry leaves.

3. Among the macroelements analysed in strawberry leaves, the lowest variation coefficient values were found for nitrogen, magnesium and calcium, and in fruits - for nitrogen, phosphorus, and magnesium.

4. The highest variation coefficients were detected for phosphorus and sodium in strawberry leaves, those for sulphur and sodium were the highest in strawberry fruits.

5. Variation coefficient values for the copper, zinc, and manganese content in leaves were similar. The content of iron in leaves and zinc in fruits was characterised by the lowest variation coefficients during the growing period.

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