Agronomy Research **19**(4), 1850–1862, 2021
https://doi.org/10.15159/AR.21.110

Leaf nutrient status of tomatoes in coconut coir medium – differences in cultivars, impact on yield and quality

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Received: January 29th, 2021; Accepted: May 12th, 2021; Published: June 22nd, 2021

Abstract. Coconut coir as an alternative to rockwool is increasingly used as a substrate for soilless hydroponic greenhouse production of tomatoes. However, little is known about the nutrient status of tomatoes in coconut coir, especially under intensive production conditions. The aim of this study was to investigate the nutrient status of different tomato cultivars (orange plum 'Organza F1', red cherry 'Daltary RZ F1', red large fruit-sized 'Securitas RZ F1' and pink large fruit-sized 'Fujimaru F1') under industrial greenhouse production, using coconut coir as a substrate to reveal nutrient imbalances, their impact on tomato yield and quality, and cultivar differences. Essential nutrient and leaf SPAD value was detected for the youngest fully developed leaves and the old still vital leaves twice per month from April to August 2020. The total yield, marketable and non-marketable yield was regularly determined. During the crop cycle, the content of most of the nutrients in tomato leaves corresponded to the standard range reported for tomatoes. Only some imbalances were found: all cultivars were characterized by low Zn and high S levels in both young and old leaves. The obtained results identified several differences between the cultivars: cherry tomatoes 'Daltary' had significantly higher N, K, Fe and Zn in leaves compared to other cultivars. The lowest N, Fe and Cu were determined for large fruit-sized 'Securitas'. Regardless of the nutrient status and microclimate conditions, the marketable yield of 'Daltary', 'Organza' and 'Securitas' was almost 100%, indicating on high suitability of these cultivars for hydroponic cultivation in coconut coir.

Key words: different-age leaves, different colour and fruit-size cultivars, natural lighting, *Solanum lycopersicum*, SPAD indices.

INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) are one of the most widely produced and consumed vegetables in the world with high economic, nutritional and health values (Souri & Dehnavard, 2017). Soilless hydroponic greenhouse production has been extensively used in tomato cultivation during the last 30–40 years. Thus, in Europe and Canada, 95% of greenhouse tomatoes are produced in a soilless culture system (Savvas & Gruda, 2018). In general, rockwool medium is the most commonly applied due to its good structure, water holding capacity and porosity. However, rockwool as inorganic material is non-biodegradable and its disposal or recycling after cultivation is expensive

(Gruda, 2019). As an alternative to rockwool, coconut coir as an organic substrate is increasingly used as a growing medium for the greenhouse tomato industry. Coir is the material consisting of the dust and short fibers derived from the mesocarp of the coconut fruits (*Cocos nucifera* L.) and is one of the most abundant organic waste materials in many tropical and subtropical countries (Carlile et al., 2015). Due to its good water retention and aeration properties, coconut coir provides a favorable air and water balance for plant roots (Barrett et al., 2016).

Although mineral nutrition is one of the key factors in determining the yield and quality of vegetables (Ahmadi & Souri, 2018; Souri & Dehnavard, 2018; Souri et al., 2018), little is known on the nutrient status of tomatoes in coconut coir under hydroponic conditions. Only a few studies have evaluated this media type in relation to the provision of nutrients during the growing cycle of vegetables (Kleiber et al., 2012; Xiong et al., 2017; Xing et al., 2019). Adapting fertilizer management to the specific conditions of the substrate as well as to the specific requirements of the cultivars can ensure the production of tomatoes with high yields and quality.

The chlorophyll content is an important indicator of leaf photosynthetic capacity and plant health (Hatamian et al., 2020; Zargar Shooshtari et al., 2020). The determination of chlorophyll content by rapid non-destructive methods is well developed for many fields and greenhouse crops, including tomatoes (Alsina et al., 2016; Jiang et al., 2017), providing valuable diagnostic information for purposes such as climate control, especially lighting, and nutrient assessment. One of the most known and used portable chlorophyll meters is SPAD-502, which offers easy operation in both research and agricultural settings. Although several nutrients are involved in ensuring a successful process of photosynthesis (Hochmal et al., 2015; Mohammadipour & Souri, 2019), SPAD indices are mainly used for real-time assessment of plant nitrogen status and control of nitrogen management (Xiong et al., 2015; Costa et al., 2018). It is based on a high correlation between the green color intensity and chlorophyll, as well as the nitrogen content of the leaves. Little is known about the possibilities of using the SPAD values to determine the status of such nutrients as Mg, S, Fe, Mn and others, whose deficiency can also cause leaf chlorosis, inhibition of photosynthesis and, consequently, reduced yields.

In greenhouse production, several factors are important in the choice of tomato cultivars, such as potential yield, resistance to abiotic and biotic stresses, etc. On the other hand, market-oriented trends and consumer preferences can also be crucial. Different studies showed that diversification of tomato color, taste, shape and texture is required to satisfy consumers, especially for fresh consumption (Casals et al., 2019; Jürkenbeck et al., 2019). In Latvia, historically the consumers prefer large fruit-sized tomatoes, associating them with good quality. However, cherry and plum tomatoes, as well as orange and pink tomatoes also become very popular.

Overall, only a few reports have examined the effects of cultivar differences on nutrient content and chlorophyll meter measurements for vegetables grown under the same fertilization conditions, especially in terms of yield and quality (Waterland & Moon, 2017; Souza et al., 2020). To our knowledge, no comparative study has been published showing differences in the nutrient status of different tomato cultivars under commercial greenhouse conditions in coconut coir substrate.

We hypothesized that the use of a single nutrient solution for different cultivars, widely used in modern soilless greenhouse production of tomatoes, could lead to nutrient imbalances for a particular cultivar. Therefore, the objective of this study was to investigate the dynamics of nutrient status of different tomato cultivars under industrial greenhouse production conditions using coconut coir as a growing substrate to reveal nutrient imbalances, their impact on tomato yield and quality, and cultivar differences.

MATERIALS AND METHODS

The study was carried out in the commercial greenhouse of the farm 'Kligeni', located in Cesis (57°18'N, 25°16'E, sub-boreal climatic zone), Latvia, during the spring-summer season of 2020, without artificial lighting. The greenhouse was equipped with computer-controlled fertilization, irrigation and partly climate system. Four tomato cultivars with different fruit weight, color and shape were used: orange plum 'Organza F1' (average fruit weight 45–50 g), red cherry 'Daltary RZ F1' (average fruit weight 16 g), red large fruit-sized 'Securitas RZ F1' (average fruit weight 260–270 g) and pink large fruit-sized 'Fujimaru F1' (average fruit weight 180 g).

Tomato seedlings were transplanted into coconut coir slabs in mid-February. The planting density was 2.5 plants m^{-2}. All crop management measures were performed in accordance with the current recommendations for tomato growing (Heuvelink, 2018). During the crop cycle, the solar radiation ranged from 248–2643 J cm^{-2} day^{-1}, and the average day/night temperature was at 20.9/18.2 °C, respectively. Pollination was ensured by the use of bumblebees (*Bombus terrestris* L.). Nutrient solutions of the following chemical composition (in mg dm^{-3}): 10–15 N-NH_4, 200 N-NO_3, 40–50 P, 370–450 K, 200–250 Ca, 60–65 Mg, 100–140 S-SO_4, 1.8–3.0 Fe, 0.2–0.6 Mn, 0.40–0.70 Zn, 0.05–0.10 Cu, 0.05 Mo, 0.35 B was used. The pH of the solution was adjusted to 5.40 and the electrical conductivity (EC) was in the range of 2.60–3.20 mS cm^{-1}, according to the growth stage of the tomatoes. Corrections in the micronutrient (Fe, Mn, and Zn) concentrations of the nutrient solution, done till the middle of the crop cycle, were based on the results of leaf analyses. Thus, Fe content was gradually increased from 1.8 mg dm^{-3} to 3.0 mg dm^{-3}, Zn from 0.4 mg dm^{-3} to 0.70 mg dm^{-3}, but Mn content decreased from 0.60 mg dm^{-3} to 0.20 mg dm^{-3}.

To diagnose nutrient status, samples for chemical analysis of 12 essential nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, and B) were collected and chlorophyll content (in SPAD values) was measured for the youngest fully developed leaves and the old still vital leaves twice per month from April 2020 to August 2020. There were 10 sampling times: 1 – 03.04.2020; 2 – 23.04.2020; 3 – 08.05.2020; 4 – 21.05.2020; 5 – 04.06.2020; 6 – 18.06.2020; 7 – 06.07.2020; 8 – 22.07.2020., 9 – 06.08.2020., 10 – 27.08.2020. One average, sample included 20 leaves collected from 10 plants. Collected tomato leaves were quickly rinsed with distilled water, dried at 60 °C in a laboratory dryer with forced air circulation and ground. For the determination of K, P, Ca, Mg, Fe, Cu, Zn, Mn, Mo and B, plant material was dry-ashed in concentrated HNO_3 vapours and re-dissolved in 3% HCl. For detection of total N, wet digestion was done in conc. H_2SO_4, for S - in conc. HNO_3. After mineralization of the plant samples, chemical analyses were done using the following methods: the levels of K, Ca, Mg, Fe, Cu, Zn, and Mn were estimated by microwave plasma atomic emission spectrometer (MP-AES) 4210 Agilent Technologies, the levels of P, Mo, N, and B were determined by colorimetry: P by ammonium molybdate in an acid-reduced medium, Mo by thiocyanate in reduced acid medium, B by hinalizarine in sulfuric acid medium, N by modified Kjeldal method using Nesler's reagent in an alkaline medium, S by turbidimetry by adding $BaCl_2$, with a spectrophotometer JENWAY 6300 (Rinkis et al., 1989).

Non-destructive measurement of the chlorophyll content of 10 tomato leaves at all sampling times for all cultivars was performed with a portable chlorophyll meter SPAD 502 (Minolta, Warrington, UK).

From the beginning of the harvest in mid-April until the end of the harvest in mid-October 2020, the total yield, the percentage of marketable and non-marketable yield per m^2 was determined once a week for all tomato cultivars.

Statistical analyses (standard errors, Student's t-test, $p < 0.05$, Pearson's correlation) were performed to determine differences in nutrient status of cultivars and leaves of different age, as well as to reveal correlations between nutrient content, chlorophyll content, and percentage of tomato marketable yield using MS Excel 2016. To find out the complex differences between the tomato cultivars, the PCA analysis was performed by PCord-6 software (McCune & Grace, 2002).

RESULTS AND DISCUSSION

Despite the significant differences between the tomato cultivars and the differences in macro- and micronutrient content in the leaves found between the cultivars, no symptoms of deficiency or excess of certain nutrients were observed during the tomato cultivation in coconut coir substrate.

The obtained data indicated that, in general, there was no difference between the cultivars in the distribution of nutrient concentrations between new and old tomato leaves. On average, the concentration of only two nutrients - N and Cu, was significantly higher in younger leaves, while significantly higher content of P, Ca, S, Mn, Mo, and B was found in older leaves. There was no difference for different-age leaves regarding Mg, Zn, Fe, and partly K (Tables 1, 2, Fig. 1). In the case of K, lower contents in younger leaves were recorded for cultivars Daltary and Organza. In general, this distribution pattern is closely related to nutrient mobility in plants.

In this study the content of most nutrients in tomato leaves (Tables 1, 2, Fig. 1) corresponded to the standard range for tomatoes reported by Brust (2013), Haifa (2020) and Campbell (2000). According to these references, there was a sufficient level of N, P, K, Ca, Mg, Fe, Cu, Mo and B in tomato leaves for all cultivars.

However, some imbalances were found: all cultivars were characterized by low Zn and high S levels in both young and old leaves. Among the macronutrients, S along with Ca, showed the most striking differences in the distribution within the different aged plant leaves, with the highest concentrations in the older ones. The concentration of these nutrients in young leaves showed and increasing trend during the growing period till mid-crop cycle in June.

Sufficient S content in greenhouse tomato leaves according to various references (Hochmuth, 2018; Campbell, 2000) ranges from 0.4 to 1.0 mg kg^{-1}. According to the data presented in Table 1, the results of our study showed higher than recommended S levels not only in the older but also in the younger leaves for all tomato cultivars. As plants can generally tolerate quite high concentrations of S in the growing media, wide use of Mg, K, Mn, Zn, and Cu fertilizers in the form of sulphates (Hochmuth, 2018), as well as the use of S-containing products for plant disease management (Llorens et al., 2017) is common in greenhouse vegetable production. Although high levels of S may act as antagonists to other nutrients, our study did not reveal a significant negative correlation between S and other nutrients in young and old tomato leaves ($p < 0.05$). This suggests that increased accumulation of S in the leaves could not adversely affect tomato cultivation in coconut coir substrate. This is consistent with studies of Xiong et al., 2017, also showing high uptake of S and K by tomato under coconut coir.

Table 1. Mean macronutrient concentration (mass %, dry matter) in young and old tomato leaves during the crop cycle from April 2020 to August 2020. Sufficiency range in leaves for greenhouse tomatoes was indicated according to Brust (2013), Haifa (2020) and Campbell (2000)

Tomato cultivar	Young leaves		Old leaves		Sufficiecy range
	Range	Mean ± *SE*	Range	Mean ± *SE*	
	N				
Daltary	4.20–5.80	4.70 ± 0.15b[1]B[2]	3.75–4.55	4.10 ± 0.09aB	3.50–6.00
Organza	3.30–5.05	4.19 ± 0.18aA	3.30–4.40	3.87 ± 0.11aB	
Fujimaru	3.70–5.15	4.31 ± 0.15bA	3.20–3.90	3.60 ± 0.08aA	
Securitas	3.45–4.45	4.03 ± 0.11bA	3.00–4.02	3.53 ± 0.11aA	
	P				
Daltary	0.27–0.66	0.43 ± 0.03aA	0.36–0.49	0.43 ± 0.01aA	0.30–1.00
Organza	0.36–0.78	0.51 ± 0.04aA	0.51–0.92	0.72 ± 0.05bB	
Fujimaru	0.48–0.66	0.54 ± 0.02aB	0.47–0.91	0.72 ± 0.05bB	
Securitas	0.44–0.69	0.57 ± 0.03aB	0.63–0.90	0.77 ± 0.03bB	
	K				
Daltary	2.87–4.99	4.18 ± 0.19aB	3.67–7.78	4.94 ± 0.38bB	3.50–6.00
Organza	3.02–4.29	3.59 ± 0.14aA	3.28–5.11	3.98 ± 0.17bA	
Fujimaru	3.37–4.86	4.10 ± 0.13aB	3.12–6.69	4.41 ± 0.34aB	
Securitas	3.51–4.49	3.87 ± 0.09aA	3.27–5.80	3.87 ± 0.26aA	
	Ca				
Daltary	1.46–4.28	3.13 ± 0.29aA	4.44–6.20	5.43 ± 0.17bA	1.20–4.00
Organza	2.04–3.67	2.81 ± 0.21aA	4.57–5.69	5.11 ± 0.14bA	
Fujimaru	1.88–4.44	2.96 ± 0.26aA	4.85–6.18	5.51 ± 0.14bAB	
Securitas	2.52–4.40	3.11 ± 0.19aA	5.19–6.37	5.82 ± 0.12bB	
	Mg				
Daltary	0.17–0.54	0.41 ± 0.03aB	0.19–0.77	0.49 ± 0.05aA	0.30–1.00
Organza	0.28–0.42	0.34 ± 0.01aA	0.27–0.61	0.41 ± 0.04aA	
Fujimaru	0.23–0.56	0.39 ± 0.03aAB	0.30–0.72	0.46 ± 0.04aA	
Securitas	0.27–0.51	0.34 ± 0.02aA	0.32-0.78	0.42 ± 0.05aA	
	S				
Daltary	0.70–2.13	1.39 ± 0.14aA	2.00–3.13	2.50 ± 0.12bA	0.40–1.00
Organza	0.90–2.13	1.28 ± 0.14aA	1.50–3.38	2.32 ± 0.18bA	
Fujimaru	0.85–2.00	1.41 ± 0.12aA	1.63–3.50	2.43 ± 0.17bA	
Securitas	1.10–2.50	1.45 ± 0.14aA	1.88–3.50	2.72 ± 0.14bA	

Values with different letters differ significantly ($p < 0.05$), according to Student's *t*-test; [1]For rows, lowercase letters compare young and old leaves of cultivar for each nutrient (a < b); [2]For column, uppercase letters compare cultivars for each nutrient (A < B).

Although the initial concentration of Zn (0.4 mg dm^{-3}) in nutrient solution was generally in the standard level of 0.3–0.4 mg dm^{-3} (Heuvelink, 2018), Zn deficiency was found from the second plant sampling time (mid-April) which coincided with the start of the tomato harvest (Fig. 1, a). Based on the results of leaf analyses, until the middle of the crop cycle (06.06.2020.), the Zn content in the nutrient solution was gradually increased from 0.4 mg dm^{-3} to 0.70 mg dm^{-3}. This measure resulted in an increase in leaf Zn content and in most cases for young leaves the lower sufficiency level was reached. However, some differences in cultivars were found - for old and young leaves of 'Securitas', and old leaves of 'Fujimaru' and 'Organza', Zn levels do not reach 25 mg kg^{-1} even after increasing Zn in the nutrient solution, or it happened very gradually. As Zn has many biochemical functions in the plant and is required for activation of enzyme system, chlorophyll production, auxin metabolism, water stress tolerance, etc. (Mengel & Kirkby, 2001), attention should be paid to the optimal supply of Zn for tomato growing in coconut coir substrate.

Table 2. Mean micronutrient concentration (mg kg^{-1}, dry matter) in young and old tomato leaves during the crop cycle from April 2020 to August 2020. Sufficiency range in leaves for greenhouse tomatoes was indicated according to Brust (2013), Haifa (2020) and Campbell (2000)

Tomato cultivar	Young leaves		Old leaves		Sufficiecy range
	Range	Mean ± *SE*	Range	Mean ± *SE*	
	Cu				
Daltary	6.40–13.40	9.86 ± 0.64bA	6.20–9.80	7.88 ± 0.33aAB	6.0–25.0
Organza	8.00–18.60	11.04 ± 0.96bA	5.40–11.20	8.62 ± 0.51aB	
Fujimaru	7.60–13.60	10.58 ± 0.58bA	6.80–9.40	8.36 ± 0.27aB	
Securitas	5.40-13.40	9.56 ± 0.82bA	3.80–8.80	6.78 ± 0.58aA	
	Mo				
Daltary	1.00–3.00	2.23 ± 0.20aA	1.80–3.90	2.98 ± 0.20bA	1.0–5.0
Organza	1.60–3.00	2.19 ± 0.13aA	2.08–5.20	3.15 ± 0.37bA	
Fujimaru	1.40–3.40	2.10 ± 0.18aA	1.80–5.20	3.00 ± 0.30bA	
Securitas	1.40–2.72	1.92 ± 0.14aA	1.80–4.40	2.57 ± 0.28bA	
	B				
Daltary	25–50	36.5 ± 3.14aAB	24–66	48.2 ± 3.92bA	25–75
Organza	23–44	30.1 ± 1.98aA	35–68	48.9 ± 3.34bA	
Fujimaru	25–50	33.2 ± 2.40aA	33–70	45.9 ± 3.75bA	
Securitas	23–48	30.6 ± 2.25aA	36–62	48.4 ± 2.65bA	

Values with different letters differ significantly ($p < 0.05$), according to Student's *t*-test; [1]For rows, lowercase letters compare young and old leaves of cultivar for each nutrient (a < b); [2]For column, uppercase letters compare cultivars for each nutrient (A < B).

A rapid increase in Mn concentrations from the beginning of the growing season was observed in both young and old leaves (Fig. 1, b). To limit this, a reduction of Mn concentrations in the nutrient solution was initiated. From the end of April to the beginning of June, the Mn concentration in nutrient solution was gradually reduced from 0.60 mg dm^{-3} to 0.20 mg dm^{-3} and remained the same until the end of the season. This measure stopped the almost linear increase of Mn concentrations in the older leaves and ensured the decrease of Mn in the new leaves - their concentrations reached values within the normal range for all cultivars. High Mn concentrations exceeding 500 mg kg^{-1} can be toxic and may adversely affect the uptake of other nutrients (Mengel & Kirkby, 2001; Kleiber, 2014).

Although the Fe concentration in the leaves was generally in the standard range for tomatoes, the rapid increase in Mn concentration during the crop cycle resulted in an unfavorable Fe: Mn ratio in the leaves, with manganese significantly exceeding the Fe content. Therefore, along with the reduction of the Mn, the increase of the Fe concentration in the nutrient solution was started from 1.8 mg dm^{-3} to 3.0 mg dm^{-3}. As a result, the Fe content of the tomato leaves increased only for cultivars ‘Daltary’ and ‘Fujimaru’, while the ‘Securitas’ and ‘Organza’ had lower Fe levels throughout the season in both new and old leaves, which did not change even after increasing the Fe content in the nutrient solution (Fig. 1, c).

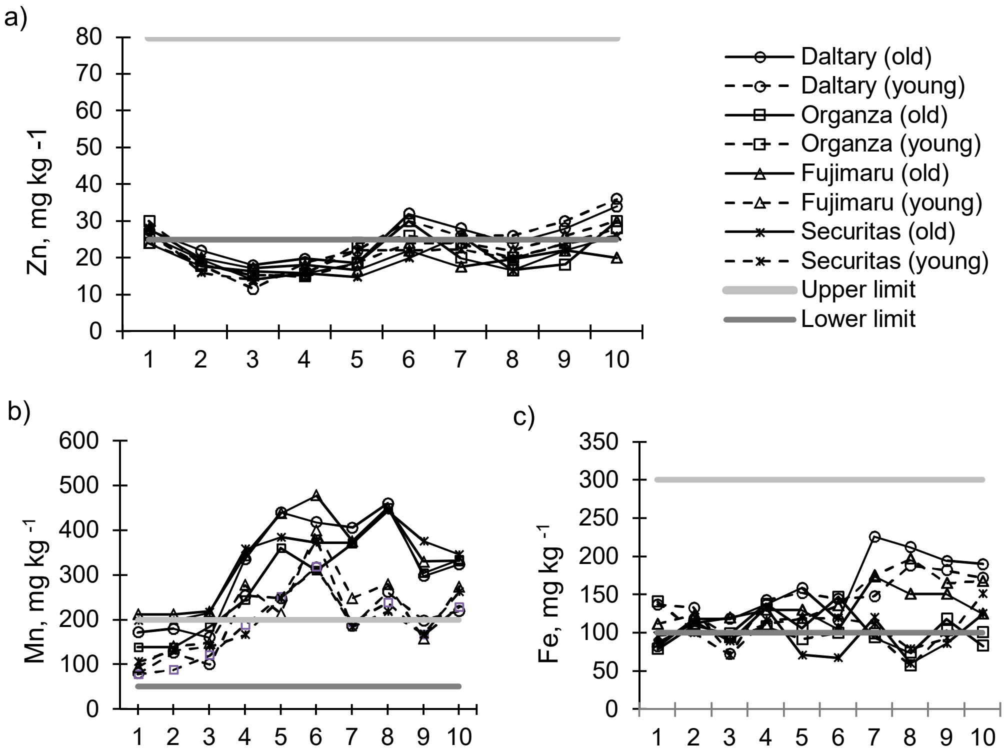

Figure 1. Nutrient content in young and old tomato leaves during the crop cycle from April 2020 to August 2020. Sufficiency range in leaves for greenhouse tomatoes was indicated according to Brust (2013), Haifa (2020) and Campbell (2000). Sampling time: 1 – 03.04.2020; 2 – 23.04.2020; 3 – 08.05.2020; 4 – 21.05.2020; 5 – 04.06.2020; 6 – 18.06.2020; 7 – 06.07.2020; 8 – 22.07.2020; 9 – 06.08.2020; 10 – 27.08.2020.

The obtained results identified several differences between the cultivars in the leaf nutrient content. Thus, cherry tomatoes 'Daltary' had significantly higher mean concentrations of N, K, Fe, Zn, but lower P in leaves compared to most other tomato cultivars. In general, the lowest N, Fe and Cu were determined for the leaves of large fruit-sized ‘Securitas’. The highest response to changes in nutrient solution composition was found for tomato cultivars 'Daltary' and 'Fujimaru'. Indeed, these cultivars accumulated additional Zn and Fe in leaves more efficiently than ‘Organza’ and ‘Securitas’.

Many studies have reported almost linear relationships between chlorophyll meter values and leaf N content of vegetable crops, including tomato (Dehnavard et al., 2017; Jiang et al., 2017; Souri et al., 2017; Padilla et al., 2018). However, the results obtained in our study showed that under optimal N supply conditions no significant correlation was found between the N content in the tomato leaves and the SPAD readings ($p < 0.05$). A narrow range of relatively high N content in tomato leaves may have been responsible for the weak relationships between SPAD measurements and plant N content. Such a plateau response when chlorophyll meters can become partially saturated at high N and chlorophyll contents has also been reported for greenhouse-grown cucumbers (Padilla et al., 2017) and basil (Walters & Currey, 2018). In tomato, in two cases it is possible to have low SPAD value induced by leaf N status: one when N is in the deficient range in leaf due to low application of N or its uptake and another due to ammonium nutrition and associated toxicity that generally results in leaf senescence and yellowing (Souri et al., 2009; Souri & Roemhald, 2009; Dehnavard et al., 2017).

In contrary to N, our results showed a significant positive correlation between leaf SPAD value and the concentrations of S in young tomato leaves for all cultivars except 'Organza'. Of the macronutrients, Ca in the new leaves also positively correlated with SPAD in all cultivars except 'Securitas' (Table 3). A significant positive correlation was also found between SPAD indices and concentrations of micronutrients Fe, Mn, Zn and B in tomato leaves, especially in young leaves of all studied cultivars. Previously, significantly higher levels of chlorophyll in vegetable leaves have been reported for foliar Ca, Fe, Zn and Mn application (Roosta & Mohsenian, 2012; Bin et al., 2020), convincingly demonstrating the important role of these nutrients in chlorophyll biosynthesis and photosynthetic processes in plants. Therefore, to ensure intensive photosynthesis as a prerequisite for high yield, it is important to monitor the nutrient status of tomato plants and make timely adjustments by optimizing their supply, especially for micronutrients.

Table 3. Pearson's correlation coefficients between leaf nutrient concentrations and SPAD values for young leaves of tomato cultivars (n = 10; $p < 0.05$; $r > 0.578$; ns – not significant)

	Ca	S	Fe	Mn	Zn	B
Daltary	0.800	0.621	0.795	0.770	0.756	0.901
Organza	0.585	ns	ns	0.721	ns	0.678
Fujimaru	0.697	0.819	0.955	ns	0.832	0.698
Securitas	ns	0.783	0.689	0.69	0.578	0.685

The data of total yield during crop cycle were as follows: for 'Daltary' - 21.56 kg m^{-2}, 'Organza' - 30.41 kg m^{-2}, 'Fujimaru' 36.41 kg m^{-2}, 'Securitas' - 46.71 kg m^{-2}. Overall, the total yield for cherry tomato 'Daltary', obtained without artificial lighting, can be regarded as high and comparable with the yields obtained in the Netherlands and Italy with the same tomato topology and supplemental lighting: e.g. 21–25 kg m^{-2} (Dueck et al., 2012; Palmitessa et al., 2020). While the average yields for beefsteak tomatoes in the Netherlands and other leading tomato-growing countries reach 50–60 kg m^{-2} and more (Heuvelink, 2018). Therefore, the yield obtained for large fruit-sized 'Securitas' in coconut coir substrate is generally in line with the cultivar and growing conditions, although improvements are possible.

The study included 4 tomato cultivars with different fruit size and weight. Therefore, the percentage of marketable fruit production in the total yield was compared. The results revealed that regardless of the nutrient content, for the cultivars 'Daltary', 'Organza' and 'Securitas', the proportion of marketable yield was close to 100% and amounted to 99.95%, 96.65% and 95.43%, respectively. This indicates the high suitability of these cultivars for industrial greenhouse cultivation. However, higher yields could potentially be achieved by addressing some nutrient imbalances.

Since the nutrient concentrations in leaves had a significant impact on photosynthesis, chlorophyll content and tomato yield, all these data have been used in the PCA analysis. The 1st axis explained 34.44% and 23.54% of the total variances, the

2nd axis - 21.13% and 17.39% of the total variances for young and old leaves, respectively (Fig. 2, a, b). PCA confirmed that the chemical composition of 'Daltary' generally differed from other cultivars. It was particularly pronounced for old leaves. Overall, 'Daltary' had a higher content of N, Zn, Fe and marketable fruit production. Individual sampling points for young leaves of different cultivars were more scattered in the ordination space, mainly grouped by sampling time, which indirectly indicates plant age, the period of a growth cycle, and the possible impact of microclimate. Thus, PCA indicated on substantial differences in leaf nutrient concentrations by course of time in the crop cycle.

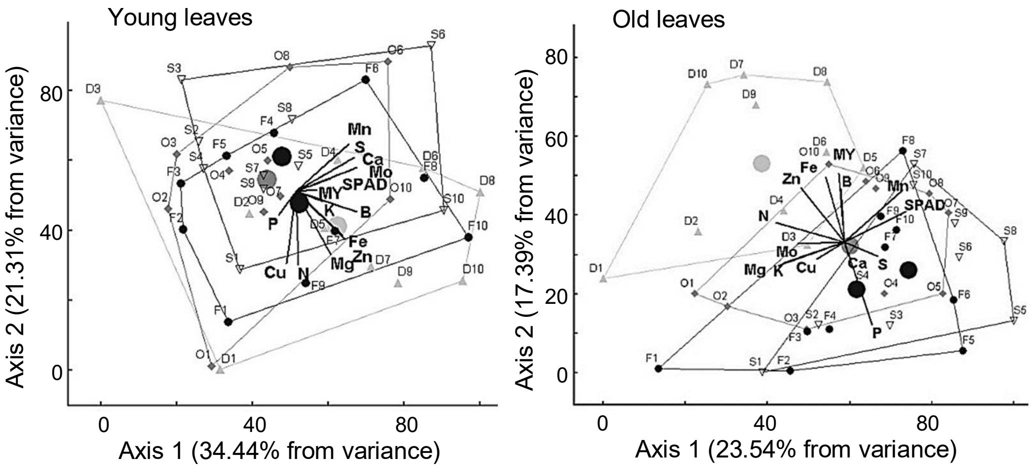

Figure 2. Distribution of four studied tomato cultivars within the axes of principal component analysis (PCA) of dataset of leaf chemical results, SPAD values and tomato marketable yield. a – young leaves, b – old leaves (D – 'Daltary'; O – 'Organza'; F – 'Fujimaru'; S – 'Securitas'; MY – marketable yield).

Analysis of correlation between marketable yield, leaf nutrient content and SPAD values was performed for 'Fujimaru', the only cultivar for which a significant proportion of non-marketable tomato yield (on average 13.53%) was found. The obtained results confirmed the importance of Ca, S, Fe, Zn, and B in ensuring high quality of fruit yield (Table 4). A positive correlation between these nutrients in young leaves indicated some synergy in the uptake processes. Thus, our research revealed a significant positive correlation between Ca and S, Mn, B; S and Fe, Mn; Fe and Zn, B; Zn and B ($0.601 < r < 0.825$, $p < 0.05$).

Table 4. Pearson's correlation coefficients between leaf nutrient concentrations, SPAD values and marketable yield of tomato cultivar 'Fujimaru' ($n = 10$, $p < 0.05$, $r > 0.578$)

Young leaves		Old leaves	
Nutrient	*r*	*Nutrient*	*r*
Ca	0.688	K	-0.580
S	0.734	B	0.588
Fe	0.854	SPAD	0.739
Zn	0.805		
B	0.853		
SPAD	0.884		

Although K has an undeniable positive impact on the quality of tomatoes preventing such physiological damage as uneven fruit coloring and incomplete ripening (Schwarz et al., 2013; Hernández-Pérez et al., 2020), the only significant negative correlation was found for K in older leaves and marketable fruit yield of ‘Fujimaru’. A significant negative correlation was also found between SPAD indices and K concentration in old leaves of ‘Fujimaru’. According to various studies, competitive interaction between nutrients occurring among Ca, Mg, and K are a widespread phenomenon in tomato cultivation, sometimes leading to the choice of either increasing the supply of K to improve fruit quality in terms of storage or taste or reducing K levels by reducing the risk of physiological Ca disorders (Pujos & Morard, 1997; Fanasca et al., 2005; Sambo et al., 2019). Although our study did not reveal Ca and mg deficiency nor a negative correlation between K-Ca and K-Mg in ‘Fujimaru’ leaves, a high K: mg ratio was found both for young and old leaves: 10.0 and 11.3, respectively, comparing to optimum range 6–8, reported by Brust, 2013. As a similar K: mg ratio in the leaves was typical also for the other studied tomato cultivars with almost 100% fruit quality, K-Mg antagonism was unlikely possible. In general, physiological disorders such as blossom-end rot (BER) and blotchy ripening were not observed for ‘Fujimaru’ fruits, thus suggesting that the non-marketable crop production was not related to shortcomings in the supply of K, Ca, and Mg.

The tomato quality problems that led to the non-marketable part of ‘Fujimaru’ harvest were related to the non-compliance of the fruit with the average weight of the cultivar, the irregular shape of the fruit and the deformation of the tomato fruit called 'catface'. The incidence of such fruit disorders are generally attributed to the microclimate in a greenhouse, mainly low temperatures and light levels during flowering, as well as incomplete pollination (Peet, 2009). Our study found a significant positive correlation between the percentage of marketable yield and day temperature, 24-hour average temperature, and solar radiation 6 weeks before harvest ($0.414 < r < 0.658$, $p < 0.05$). The largest deviations from the recommended optimal daily temperature range (19 to 20 °C), as well as the lowest light intensity level were observed between February and mid-April, which also determined a higher percentage of defective fruit at the beginning of the harvest. Cultivation of moderate-climate vegetables, such as tomatoes during spring months without artificial lighting in the geographical latitudes of Latvia is complicated and may not provide a high and 100% quality yield. However, our study revealed cultivar differences - ‘Daltary’, ‘Organza’ and ‘Securitas’ were less sensitive to deviations from optimal microclimate conditions.

CONCLUSIONS

- During the crop cycle, the content of most of the nutrients in the tomato leaves corresponded to the standard range reported for tomatoes. Only a few imbalances were found: all cultivars were characterized by low Zn and high S levels in both young and old leaves, as well as by high concentrations of Mn in older leaves.
- Several differences were identified between the cultivars. Thus, cherry tomatoes 'Daltary' had significantly higher mean concentrations of N, K, Fe, and Zn in the leaves compared to other tomato cultivars, The lowest N, Fe and Cu were determined in the leaves of large fruit-sized ‘Securitas’. The highest response to changes in nutrient solution composition was found for 'Daltary' and 'Fujimaru' - these cultivars accumulated additionally Zn and Fe in leaves more efficiently than ‘Organza’ and ‘Securitas’.
- Regardless of the nutrient status and microclimate conditions in a greenhouse without artificial lighting, for ‘Daltary’, ‘Organza’ and ‘Securitas’, the proportion of

marketable yield was close to 100%, indicating on high suitability of these cultivars for industrial greenhouse cultivation in coconut coir.

- Tomato defects as non-compliance of the fruit with the average weight of the cultivar and the deformation of the fruit indicated that 'Fujimaru' was more sensitive to deviations from optimal microclimate in a greenhouse.

ACKNOWLEDGEMENTS. The financial support provided by the European Agricultural Fund for Rural Development for project 'Determining of optimum growing conditions for vegetables, using hydroponics growing method with an artificial and day light', No 18-00-A01612-000017, are acknowledged.

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