The dependent chemical composition of tomatoes grown in high plastic tunnels from the plant growth medium and the supply of heat

KALINA SIKORSKA-ZIMNY[1], WALDEMAR KOWALCZYK[2],
PAWEŁ KONOPACKI[3], RYSZARD HOŁOWNICKI[3]
[1]Fruit and Vegetables Storage and Processing Department, Division of Fruit and Vegetables Storage and Postharvest Physiology,
[2]Laboratory of Chemical Analysis,
[3]Agroengineering Department,
Research Institute of Horticulture,
Skierniewice, Konstytucji 3 Maja 1/3 Street,
POLAND
kalina.sikorska@inhort.pl

Abstract: - There is a necessity to reduce cultivation cost, use bio-rationale energy sources, and recycle growing media in greenhouse production of tomato (*Solanum lycopersicum* L). The experiment was conducted on tomatoes grown in a mix of peat moss with bark or coconut fiber in unheated tunnels fitted with rock-bed heat accumulators. At harvest acidity, vitamin C, total and reducing sugars and lycopene levels were estimated. Tomatoes cultivated with a coconut fiber substrate had a higher content of total acids, reducing sugars and vitamin C. Cultivation of tomato in peat substrate increased total sugar levels in fruit. Type of bio-rationale substrate did not affect tomato fruit chemical composition. There was no effect of heat form rock-accumulator application on chemical composition of tomatoes.

Key-Words: - Solanum lycopersicum, lycopene, rock-accumulator; substrate; vitamin C

1 Introduction

Cost reduction of cultivation is always an important factor. Profitability of greenhouse cultivation for tomato (Solanum lycopersicum L., cv. Tamaris) depends mostly on energy costs, which may be reduced by storage of surplus solar energy and its further recovery for heating [1,2]. Research for storage of surplus solar energy was with accumulators using: water, stone, volcanic material, and chemical solutions [3,4,5].

Benefits from use of heat accumulators are lack of need to heat the production space (reducing the cost) and equalization of amplitude of the daily temperature. Heat stored during the day can be delivered to plants during the night. This would result in lower differences between day/night temperatures producing more uniform temperatures during growth and likely better fruit quality. Fruit quality is the level of lycopene, vitamin C, sugars and acid content that affect fruit flavor. Lycopene is a carotenoid widely present in orange/red colored plants produced during maturation and exposure to the sun. Lycopene contributes to protecting plant tissue against solar radiation which may cause photooxidative damage [6]. Its synthesis is limited under 16 and above 26°C [7,8]. In the human body, lycopene is reported to have a protective role against cancer [9,10,11]. Lycopene content varies between cultivars, stage of maturity, growing conditions and the skin and flesh of a fruit where it is located [12,13]. Vitamin C as an antioxidant neutralizes free radicals and other substances that may cause cell destruction. Vitamin C is produced during growth of the plant, as a prevention against biotic and abiotic challenge. Tomatoes cultivated in greenhouses could contain less vitamin C than fruit grown in the field [14]. Vitamin C decomposes under UV radiation. In addition, mechanical processing speeds up its degradation, it easily oxidises in aqueous solutions, in presence of metals, and in an alkaline environment [15]. Level of sugars (especially reducing ones) in tomatoes rise during fruit development. As consumers prefer sweet tomatoes (rich in reducing sugars), producers try to increase reducing sugars in fruit. The level of sugars in tomatoes cultivated in greenhouses tend to be higher [16,17]. Another parameter influencing tomato taste is acidity. Higher levels of acidity cause a sour taste. A balance between sugars and acids in tomatoes influences flavor [18]. Level of acids is affected by type of cultivation, variety and production region which also affects acid content in tomatoes [19,20].

An important factor influencing plant growth is type of substrate used. The most common for greenhouse production are: peat, composted bark from conifers, coconut fiber, wood fiber, straw, sawdust and their

mixes [21]. Other substrates are: coir, perlite, vermicompost, compost, pumice, and maize, in different proportions [22,23,24].
The experiment was conducted over 4 consecutive years to evaluate the influence of substrate and heating on tomato quality.

2 Problem Formulation

A comparison between accumulator materials for thermal capacity, suitability for an applied range of temperatures, thermal conductivity, thermal expansion and stability, and lack of chemical reactivity indicated a rock-bed (31.5-63 mm porphyry breakstone) exhibits the most beneficial parameters. It was necessary to adjust the size of a rock-bed heat accumulator to local climate conditions. The optimal capacity of an accumulator (for Polish climate conditions) would be around 560 $kJ/m^2 \cdot K$ [25,26] for the 0.7 m depth of the bed. Such a construction was built in Skierniewice (Poland, 51°58'N 20°8'E) for soilless tomato cultivation, to establish a storage of an excess of energy converted from solar radiation into heat in high plastic tunnels. The research was carried out with rock-bed heat accumulators located below a high plastic tunnel (9×15 m; double pumped 150 μm PE foil with shading screens HS 880; NovaVert, Greven, Germany), containing 1 section of 26.1 m^3 of rock and 2 sections of 12.7 m^3 of rock (31.5-63 mm porphyry breakstone). The estimated heat capacity of the whole accumulator was 561.7 $kJ/m^2 \cdot K$. "Charging the accumulator was conducted during the day by extracting warm air from the top part of the tunnel (above the level of shading screens) employing a radial fan, which pumped the air through the breakstone (Figure 1).

Fig. 1 Charging the heat accumulator during a warm day [27].

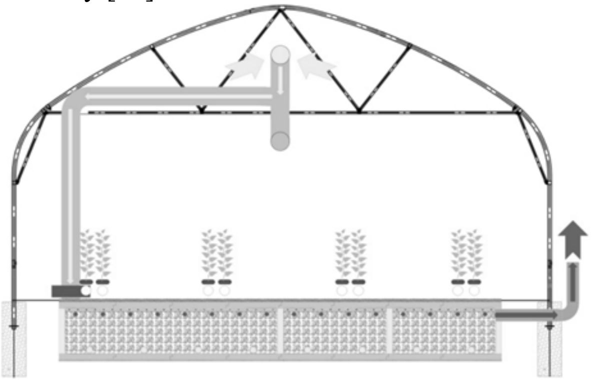

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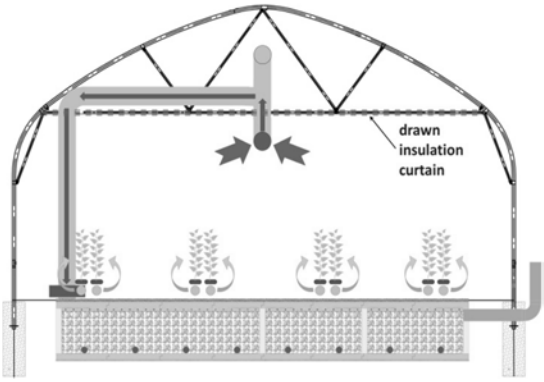
Fig. 2 Discharging the accumulator for plant heating during the night or cold day [27].



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Charging was started when air temperature between plants (at 1.5 m) exceeded 18°C and the temperature at the top of the tunnel exceeded the temperature of the accumulator's rock-bed by 4°C. It was stopped when either air temperature between plants dropped below 18°C, or the difference in air temperatures between the accumulator inlet and outlet dropped below 4°C. For discharging the accumulator and heating the plants (occurring mainly at night, or in the event of low temperatures) air was sucked by the same fan from between plants. After passing through the warm rock-bed warmed air was distributed through perforated pipes along gutters (Figure 2). Heating of plants began when temperature between plants dropped below 21°C while the accumulator rock-bed was warmer. Heating of plants was terminated when either the temperature between plants reached 22°C; the difference in air temperatures between the accumulator outlet and inlet dropped below 4°C, or air temperature at the accumulator outlet was lower than the temperature between plants" [27].

The experiment was conducted each year from 2012 to 2015, at the Research Institute of Horticulture, in Skierniewice. The tomato, cv. Tamaris F_1 (HM. Clause, Polska Ltd., Warszawa, Poland), was grown during the extended season from 1 April until the end of October in each year. Seed were sown 0.5 cm deep in a medium containing peat moss, perlite and vermiculite and maintained at 24°C. On sunny days, irrigation began about 2.5 h after sunrise and ended 3 h before sunset. On cloudy days irrigation was from 3 h after sunrise to 4-5 h before sunset. During periods of strong sunlight in the afternoon, usually between 11 am and 3 pm, nutrient solution dose was increased, or the demand supplemented with an additional irrigation cycle. The chemical properties of the growing medium were adjusted during irrigation to recommended levels before plants were established.

During cultivation, chemical properties change depending on plant development phase, temperature and insolation. Chemical analyses of the substrate (every 3-4 weeks) and drainage water (daily pH and EC) were performed to make appropriate correction of nutrient composition adjusted to the current tomato development phase. In the case of adverse conditions affecting the proper nutrition of plants, pH and EC control of drainage waters was performed separately 3 times per day (morning, noon and afternoon). After approx. 6 days tomato seed germinated and were transplanted on a rockwool blocks. After 30 days plants were placed on top of a slab (3 plants per slab). Seedlings were planted in mid-April on treatment substrates. Harvest was from the beginning of June until the end of October, with a vegetative growth period of 184-194 days. An irrigation system in the greenhouse was used to provide a nutrient solution with the composition changing depending on plant growth phase. The air temperature, relative humidity and solar radiation in polytunnels were recorded with a computerized environmental control program (Masterclim-Anjou Automation, Mortagne-sur-Sèvre, France). Relative humidity in varied between 65 and 75%. Average temperature inside the tunnel varied between 16.2 and 21.3°C. During cloudy days, when daily solar effect of the sun was not possible, accumulated energy was sufficient to heat the plants for at least 3 consecutive nights. Tunnels were equipped with a gutter for soilless cultivation (AG/PL Metazet FormFlex, Raba Wyżna, Polska), computer climate control (Masterclim-Anjou Automation) and fertilizer solution meter (NetaJet™ 4G, Hatzerim, Israel). Coconut substrate and peat moss were used as a soilless substrate due to its high nutrient exchange capacity and physical characteristics [28,29,30,31,32]. Tomatoes were grown in a mix of peat moss with bark or a mix of peat moss with coconut coir (Table 1).

Table 1. Concentration of nutrients in a solution and initial mineral content of peat moss and he coconut fiber substrates [21].

	Subst.	**Solution comp. [a]**	**Peat moss [b]**	**Coconut fiber [b]**	**Recommended in tomato cultivation [21]**
Nutrient conc.(mg/dm^3)	N-NO_3^-	236	160	1.4	220-270
	N-NH_4^+	0	94.5	0.12	<60
	P	45	164	10.7	190-230
	K	302	290	136	250-300
	Ca^{2+}	213	240	21.8	500-1500
	Mg^{2+}	61	47.8	7.8	180-220
	Na^+	np	38	65.4	<100
	Cl^-	13	44.9	135	<100
	SO_4^{2-}	286	794	108	50-100

[a]Medium used from the flowering phase of the 4th truss.
[b]Chemical properties of mats brought to recommended levels of minerals before planting.
np-not present

Heat delivered from the rock-bed accumulator was distributed using plastic tubes placed beneath gutters. The results were compared to an unheated tunnel with standard equipment.

To evaluate effectiveness of the rock-bed heat accumulator, and the influence of the substrate used, lycopene, vitamin C, and sugar (total and reducing) contents, and titratable acidity were estimated. Lycopene level was determined according to Fish et al. [33] with spectrometric measurements (spectrophotometer SPECORD S600 with carousel, Analytik Jena AG, Jena, Germany), using hexane, acetone and ethanol as solvents (ChemPur, all HPLC grade, Piekary Śląskie, Poland) [34,35]. Vitamin C content was determined with the 2,6-dichloroindophenol titrimertric method [36]. Sugar (total and reducing) levels were determined with Bertrand's method [37]. The titratable acidity was determined by base titration in presence of the color indicator [38].

Tomato fruit were collected 4 times each year. All analysis was conducted in 3 replicates.

The data were subjected to analysis of variance in Statistica 9.1 (StatSoft Polska, Kraków, Poland). If interactions were significant, they were used to explain results. If interactions were not significant means were separated with the Tukey post-hoc test.

3 Problem Solution

The temperature is important during the whole growing season of the plant but is more crucial during the development of tomato fruit [39]. The average day/night temperature between 14 ºC and 26 °C is most favourable from anthesis to fruit maturity [40]. The conducted experiments showed that night and early morning use of heat (collected in the accumulator during the day) increases the air temperature by about 3.5-6.0 °C. This increase contributes to the improvement of tomato growing conditions. Smaller amplitudes of temperatures between days/night improve the quality of the fruits [41].
Usage of different substrate point its high potential not only as an ecological product but also allowing to maintain high quality tomatoes..

3.1 The titratable acidity of tomatoes

The titratable acidity of tomatoes was higher in a combination where coconut fibre was used (5.6 - 5.9 g/kg FW) compared to the peat moss substrate (4.1 - 4.4 g/kg FW) (Table 2). A slightly higher content of acids was obtained when the plastic tube heat delivery system was used.
The titratable acidity of tomatoes cultivated in the peat moss substrate was similar to the values obtained by other authors for tomatoes cultivated in greenhouses (0.4 - 0.75 %) [42,43]. In the tomatoes cultivated in coconut fibre, the acidity was lower and more similar to cultivation conducted in an open field: 0.25 - 0.44 % [44]. Domeño et al. [45] determined acidity in tomato fruits cultivated in coconut fibre at a level of 4.8 and 3.5 g/l (for summer-autumn and winter-spring season respectively). Correspondingly, similar values for tomatoes cultivated in coconut fibre were obtained by Kowalczyk et al. [44]: 0.44 % and Jankauskienė, et al. [47] 0.5 %. Borji, et al [48] and Zaliha and Anwaruddin [49] in their research did not find any impact of the used substrate on fruit titratable acidity. Slightly higher acidity (no significant differences) were determined for tomatoes cultivated where heat delivery system was applied, therefore it could be suggested that a heat delivered system promotes a higher acidity of tomatoes, although there are no available literature data where a comparison between the heat delivery system, different substrate and chemical parameters of cultivated plants were examined.

Table 2. The titratable acidity content in the tomatoes cultivated at different substrates and with different methods of heat delivery.

Substrate/ heat delivery method	Titratable acidity (g/kg FW)				
	Year				mean for substrate
	2012	2013	2014	2015	
coconut/ film tube	4.6 ab	4.6 ab	8.5 c	5.7 b	5.9 a
coconut/ control	4.8 ab	4.7 ab	7.3 c	5.5 b	5.6 a
peat/film tube	4.2 ab	3.7 a	4.3 ab	5.2 ab	4.4 a
peat/ control	4.1 ab	3.7 a	4.2 ab	4.4 ab	4.1 a

Values followed by the same letters are not significantly different at $p \leq 0.05$ according to the ANOVA analysis of variation, Tukey post-hoc test.

3.2 The vitamin C level in tomatoes

The vitamin C content was higher in tomatoes cultivated in the coconut fibre (22.05 mg/100g FW) (Table 3). A slightly lower amount of vitamin C was determined in tomatoes cultivated with a heating system based on film tubes usage, though the differences were not significant.
Dumas et al. [50] and Tringovska et al. [51] reported vitamin C content in tomatoes as 15 - 23 mg/100g FW and pointed to the fact that greenhouse cultivated tomatoes have a lower vitamin C level than these from a field cultivation. The determined vitamin C level is slightly smaller than the average for tomatoes, which stands at 23 mg/100g [52]. Although Atherton and Rudich [53] highlighted large differences in vitamin C level among different tomatoes varieties (8 - 119 mg/100g).
Jankauskienė et al. [47] determined vitamin C in tomatoes cultivated on peat substrate at a level of 22 mg/100g. Lower values of vitamin C in tomatoes cultivated in peat moss were determined by Majkowska-Gadomska et al. (14.36 mg/100g) [43].
Higher values of vitamin C in tomatoes are determined when the cultivation is conducted in coconut fibre. Kowalczyk et al. [46] determined this value as: 32.3 mg/100g FW, and according to a Suvo et al. [54] experiment also witnessed higher levels of ascorbic acid in tomatoes fruit cultivated in coconut fibre, although the ascorbic acid level strongly varies among cultivars. Borji et al. [48] in his research did not find any impact of the used substrate on ascorbic acid content.
In both cultivations when the heating system was used, the amount of vitamin C was a little lower. The result is opposite to Tilahun et al. [55] where they indicated that vitamin C content is positively correlated with temperature (although temperature 27-32 °C inhibits ascorbates [56]). Nonetheless, Raffo et al. [57] highlighted the stronger influence

of cultivar, radiation or salinity on vitamin C content in tomatoes than temperature impact.

Table 3. The vitamin C content in the tomatoes cultivated at different substrates and with different methods of heat delivery.

Substrate/ heat delivery method	Vitamin C (mg/100g FW)				
	Year				mean for substrate
	2012	2013	2014	2015	
coconut/ film tube	10.3 a	13.1 a	34.8 d	23.3 bc	20.4 a
coconut/ control	13.3 a	15.4 a	39.8 d	21.5 b	22.5 a
peat/film tube	13.3 a	12.1 a	24.6 bc	26.6 bc	19.1 a
peat/ control	14.5 a	12.6 a	22.3 bc	27.5 c	19.2 a

Values followed by the same letters are not significantly different at p≤0.05 according to the ANOVA analysis of variation, Tukey post-hoc test.

3.3 Total and reducing sugars content

The differences in total sugar content were observed between substrates (not significant). The highest content of total sugar was determined in the peat substrate (39.0 - 40.4 g/kg FW) (Table 4). Slightly higher amounts of the determined sugar were noticed in both substrates cultivation when the heat was delivered by a plastic tube, although the differences were not statistically significant.

As was suspected and according to data available in the literature, the tomatoes cultivated in a greenhouse had a higher level of total sugar than tomatoes cultivated in a field (33.1 – 32.0 g/kg FW) [52,58]. Similar results of total sugars in tomatoes cultivated in coconut fibre were obtained by Kowalczyk et al. – 3.14 % [46] and Jankauskienė et al. – 3.26 % [47]. Although Rodica et al. [59] and Majkowska-Gadomska et al. [43] obtained higher values of total sugars in tomatoes cultivated in peat substrate 2.10 - 2.83 % and 1.72 g/100g (for [59], and [43] respectively), however, the results were below the average content of total sugars in tomatoes. However, it should be noted that the substrate used might differ because of origin, therefore, its chemical and physical composition might not be the same. Even if it is known that sugar content is strongly correlated with solar radiation, there is still very little data about heat delivery influencing sugar content [53].

Table 4. The total sugars content in the tomatoes cultivated at different substrates and with different methods of heat delivery.

Substrate/ heat delivery method	Total sugars (g/kg FW)				
	Year				mean for substrate
	2012	2013	2014	2015	
coconut/ film tube	10.3 a	13.1 a	34.8 d	23.3 bc	20.4 a
coconut/ control	13.3 a	15.4 a	39.8 d	21.5 b	22.5 a
peat/film tube	13.3 a	12.1 a	24.6 bc	26.6 bc	19.1 a
peat/ control	14.5 a	12.6 a	22.3 bc	27.5 c	19.2 a

Values followed by the same letters are not significantly different at p≤0.05 according to the ANOVA analysis of variation, Tukey post-hoc test.

A slight difference in the level of reducing sugars was observed in tomato fruit among different used substrates (Table 4). The higher reducing sugars were determined in tomatoes from coconut than from peat substrate, and for heat delivered than in control (for both substrates).

Since "°Brix is a measure of the Total Soluble Solid (TSS) content in the tomato or tomato product, the TSS in tomatoes is mainly sugars (fructose)" [60], the obtained results of reducing sugars expressed in g/kg can be basically compared to other authors results expressed in °Brix.

Domeño et al. [45] determined total soluble solids content (°Brix) of tomatoes fruit cultivated in coconut fibre at a level of 4.7. Kowalczyk et al. [46] determined total soluble solids at a level of 5.6. By comparing the used substrate, the reducing sugars level was slightly higher in tomatoes grown on the coconut substrate which agrees with Inden and Torres [61] examination, where the determined total soluble solids content (°Brix) was the highest in tomatoes cultivated in coconut fibre compared to fruits cultivated in other substrates (Rockwool, perlites plus carbonised rice hull or cypress bark).

Zaller [22,30] determined a much lower level (50 mg/g) of reducing sugars in tomato fruit cultivated in peat moss substrate but Dannehl et al. [62] estimated TSS at a level of 55 g/100g FW. This shows significant differences occurring between the used substrate (origin).

Table 5. The reducing sugars content in the tomatoes cultivated at different substrates and with different methods of heat delivery.

Substrate/ heat delivery method	Reducing sugars (g/kg FW)				
	Year				mean for substrate
	2012	2013	2014	2015	
coconut/ film tube	6.6 a	5.1 a	14.8 c	6.3 a	8.2 a
coconut/ control	7.4 a	4.4 a	11.0 c	7.6 a	7.6 a
peat/film tube	6.7 a	4.4 a	9.2 b	7.4 a	6.9 a
peat/ control	6.9 a	4.5 a	8.1 b	7.3 a	6.7 a

Values followed by the same letters are not significantly different at $p \le 0.05$ according to the ANOVA analysis of variation, Tukey post-hoc test.

3.4 The lycopene content

A higher lycopene content was determined in tomatoes cultivated on the coconut fibre, although none of the factors influences significantly on the lycopene content (Table 5). The obtained results agree with Dannehl et al. [62] research where they found that secondary metabolites (incl. lycopene) were not significantly affected by the usage of different growing sub¬strates.

The obtained values were higher than indicated in the literature, which varies from 8.8 to 69.0 mg/kg [63,64,65]. Javanmardi and Kubota [65] noticed the increase of lycopene content is caused by a higher temperature, but Brandt et al. [63] showed that above 30°C the lycopene synthesis is inhibited. Helyes et al. [66] claimed that greenhouse tomatoes tend to have 40% more lycopene compared to field cultivation.

Table 6. The lycopene content in the tomatoes cultivated at different substrates and with different methods of heat delivery.

Substrate/ heat delivery method	Lycopene (mg/kg FW)				
	Year				mean for substrate
	2012	2013	2014	2015	
coconut/ film tube	54.2 a	77.7 ab	95.1 ab	60.9 ab	72.0 a
coconut/ control	62.8 ab	77.6 ab	101.0 b	74.3 ab	79.1 a
peat/film tube	53.1 a	59.3 ab	88.2 ab	71.2 ab	67.9 a
peat/ control	60.9 ab	61.7 ab	92.5 ab	67.7 ab	70.7 a

Values followed by the same letters are not significantly different at $p \le 0.05$ according to the ANOVA analysis of variation, Tukey post-hoc test.

4 Conclusion

The research conducted over four consecutive years showed that the method of heat delivery to the cultivated tomatoes influenced a trend of different average contents of individual compounds. Heat delivered through plastic tubes increased reducing sugars in the tomatoes cultivated in the peat moss with bark and decreased the vitamin C content in the coconut fibre substrate. However, within the substrate used (peat moss with bark or coconut fibre) in the cultivation of tomato, the content of reducing and total sugars and titratable acidity, when a heating tube system was used - were higher. Since a relationship between physical parameters and the temperature behavior inside the substrates is known (faster warming of a growth media with easily available water and high air volume) [67], the explanation of a slightly higher amount of examined substances (except vitamin C and lycopene level were not influenced by the substrate), in objects where the tube heating system was applied can be an explanation of this phenomena. Although the substrate and the heating of polytunnels can have an influence on the determined parameters, a much stronger impact was the year of cultivation.

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References:

[1] Jaffrin, A. and Cadler, P., Latent heat storage applied to horticulture. La Baronne solar greenhouse. *Solar Energy, Vol.* 28, 1982, pp. 313-321.

[2] Nash, R. and Williamson, J., Greenhouse heating using solar energy, In: Bilgen, E. and K.G.T. Hollands (eds.). *Proceedings International Solar Energy Society Solar World Congress* Atlanta, GA, 28 May-1 June 1979, pp. 64-69.

[3] Huang, B. K., Toksoy, M., and Cengel, Y. A., Transient response of latent heat storage in greenhouse solar system. *Solar Energy*, 1986, Vol. 37 No. 4, pp. 279-292.

[4] Kürklü, A., Energy storage applications in greenhouses by means of phase change materials (PCMs): A review. *Renewable Energy*, Vol. 13 No. 1, 2003, pp. 89-103.

[5] Öztürk, H. H., and Başçetinçelik, A., Energy and exergy efficiency of a packed-bed heat storage unit for greenhouse heating.

Biosystems Engineering, Vol. 86 No. 2, 2003, pp. 231-245.

[6] Thompson, K., Marshall, M., Sims, C., Wei, C., Sargent, S., and Scott, J., Cultivar, maturity, and heat treatment on lycopene content in tomatoes. *International Journal of Food Science and Technology,* Vol. 65, 2000, pp. 791-795.

[7] Turk, R., Seniz, V., Ozdemir, N., and Suzen, M. A., Changes in the chlorophyll carotenoid and lycopene contents of tomatoes in relation to temperature. *Acta Horticulturae,* Vol. 368, 1994, pp. 856-862.

[8] Nguyen, M.L., and Schwartz, S.J., Lycopene: chemical and biological properties. *Food Technology,* Vol. 53, 1999, pp. 38-45.

[9] Agarwal, S. and Rao, A., Tomato lycopene and its role in human health and chronic diseases. *Canadian Medical Association Journal,* Vol. 163, 2000, pp. 739-44.

[10] Clinton, S., Tomatoes, lycopene, and prostate cancer. *Thirteenth Annual AACR International Conference on Frontiers in Cancer Prevention Research*; September 27 - October 1, New Orleans, LA, 2014.

[11] Shi, J., Xue, S., Chen, L., Wang, W., Lin, H., Ma, Y., and Mittal, G., Bioactive stability and antioxidative property of lycopene from Tomatoes during processing, In: Shi, J. (ed.). *Functional food ingredients and nutraceuticals processing technologies*, 2nd ed. CRC Press, Boca Raton, FL. pp. 609-638, 2015. doi: 10.1201/b19426-25.

[12] George, B., Kaur, C., Khurdiya, D., and Kapoor, H., Antioxidants in tomato (Lycopersium esculentum) as a function of genotype. *Food Chemistry,* Vol. 84, 2004, pp. 45-51.

[13] Sahlin, E., Savage, G.P., and Lister, C.E., Investigation of the antioxidant properties of tomatoes after processing. *Journal of Food Composition and Analysis,* Vol. 17, 2004, pp. 635-647.

[14] Ntagkas, N., Min, Q., Woltering, E., Labrie, C., Nicole, C., and Marcelis, L., Illuminating tomato fruit enhances fruit vitamin C content. *Acta Horticulturae,* Vol. 1134, 2016, pp. 351-356. doi: 10.17660/ActaHortic.2016.1134.46, http://dx.doi.org/10.17660/Acta Horti.,2016.1134. 46.

[15] Sikorska-Zimny, K., and Badełek, E. Zmiany zawartości witaminy C w czasie przechowywania dwóch odmian kapusty brukselskiej Ajax F1 i Louis F1. (Changes in vitamin C content during storage of two cultivars of brussels sprout Ajax F1 i Louis F1). *Zeszyty Naukowe Instytutu Ogrodnictwa*, Vol. 22, 2014, pp. 121-127.

[16] Auerswald, H., Schwarz, D., Kornelson, C., Krumbein, A., and Brückner, B., Sensory analysis, sugar and acid content of tomato at different EC values of the nutrient solution. *Scientia Horticulturae,* Vol. 82, 1999, pp. 227-242.

[17] Mahajan, G., and Singh, K., Response of greenhouse tomato to irrigation and fertigation. *Agricultural Water Management,* Vol. 84, 2006, pp. 202-206.

[18] Domis, M., Papadopoulos, A.P., and Gosselin, A., Greenhouse tomato fruit quality. *Horticultural Reviews*, Vol. 26, 2002, pp. 239-349.

[19] Suárez, M., Rodríguez, E., and Romero, C., Analysis of organic acid content in cultivars of tomato harvested in Tenerife. Eur. Food Res. Technol. Vol. 226, 2008, pp. 423-435.

[20] Lahoz, I., Leiva-Brondo, M., Martí, R., Macua, J., Campillo, C., Roselló, S., and Cebolla-Cornejo, J., Influence of high lycopene varieties and organic farming on the production and quality of processing tomato. *Scientia Horticulturae,* Vol. 204, 2016, pp. 128-137.

[21] Hołownicki, R., Kurpaska, S., Latała, H., Sas-Paszt, L., Treder, W., Doruchowski, G., Konopacki, P., Kowalczyk, W., Nowak, J., Wysocka-Owczarek, M., Trzciński, P., and Weszczak, K., Magazynowanie ciepła w produkcyjnych tunelach foliowych, (*Storage of surplus heat from the plastic tunnel in the accumulator stone*) Instytut Ogrodnictwa, Skierniewice, Poland, 2014.

[22] Zaller, J. G. Vermicompost as a substitute for peat in potting media: Effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. *Scientia Horticulturae,* Vol. 112 No. 2, 2007, pp. 191-199.

[23] Tzortzakis, N. G., and Economakis, C. D., Impacts of the substrate medium on tomato yield and fruit quality in soilless cultivation. *Journal of Horticultural Science,* Vol. 35 No. 2, 2008, pp. 83-89.

[24] Ghehsareh, A. M., Borji, H., and Jafarpour, M., Effect of some culture substrates (date-palm peat, cocopeat and perlite) on some growing indices and nutrient elements uptake in greenhouse tomato. *African Journal of Microbiology Research,* Vol. 5 No. 12, 2011, pp. 1437-1442. https://doi.org/10.5897/AJMR10.786.

[25] Kurpaska, S., Latała, H., Rutkowski, K., Hołownicki, R., Konopacki, P., Nowak, J., and Treder, W., Magazynowanie nadwyżki ciepła z tunelu foliowego w akumulatorze ciała stałego (Storing heat surplus from a plastic tunnel in a rock – bed storage). *Inżynieria Rolnicza*, Vol. 2 No. 137, 2012, pp. 157-167.

[26] Hołownicki, R., Konopacki, P., Nowak, J., Treder, W., Kurpaska, S., and Latała, H., Rock bed accumulator for heat surplus storage in high horticulture plastic tunnel. *International Conference of Agricultural Engineering*, 6-10 July, Zurich, Switzerland, 2014

[27] Konopacki, P. J., Treder, W., and Klamkowski, K., Comparison of vapour pressure deficit patterns during cucumber cultivation in a traditional high PE tunnel greenhouse and a tunnel greenhouse equipped with a heat accumulator. *Spanish Journal of Agricultural Research,* Vol. 16 No. 1, 2018, pp. 1-10. https://doi.org/10.5424/sjar/2018161-11484.

[28] Arenas, M., Vavrina, C. S., Cornell, J. A., Hanlon, E. A., and Hochmuth, G. J., Coir as an alternative to peat in media for tomato transplant production. *Horticultural Science,* Vol. 37, 2002, pp. 309-312.

[29] Carrijo, O. A., Vidal, M. C., Reis, N. V. B., Souza, R. B., and Makishima, N., Tomato crop production under different substrates and greenhouse models. *Horticultura Brasileira,* Vol. 22, 2004, pp. 5-9.

[30] Zaller, J. G., Vermicompost in seedling potting media can affect germination, biomass allocation, yields and fruit quality of three tomato varieties. *European Journal of Soil Biology,*Vol. 3 No. 1, 2007, pp. S332-S336.

[31] Pires, R. C. M., Furlani, P. R., Sakai, E., Lourenção, A. L., Silva, E. A., Torre-Neto, A., and Melo, A. M. T., Tomato development and yield under different irrigation frequencies in greenhouse. *Horticultura Brasileira,* Vol. 27, 2009, pp. 228-234.

[32] Pires, R. C. M., Furlani, P. R., Ribeiro, R., Bodine, D., Sakai, E., Lourenção, A. L., and Torre Neto, A., Irrigation frequency and substrate volume effects in the growth and yield of tomato plants under greenhouse conditions. *Scientia Agriculturae,* Vol. 68 No. 4, 2011, pp. 400-405. https://dx.doi.org/10.1590/S0103-90162011000400002.

[33] Fish, W., Perkins-Veazie, P., and Collins, J., A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. *Journal of Food Composition and Analysis,* Vol. 15, 2002, pp. 309-317.

[34] Davis, A., Fish, W., and Perkins-Veazie, P. A rapid spectrophotometric method for analyzing lycopene content in tomato and tomato products. *Postharvest Biology and Technology* Vol. 28, 2002, pp. 425-/430.

[35] Barba, A., Hurtado, M., Mata, M., Ruiz, V., and Tejada, M., Application of a UV–vis detection-HPLC method for a rapid determination of lycopene and β-carotene in vegetables. *Food Chemistry,* Vol. 95, 2006, pp. 328-336.

[36] Anonymous. Method No 967.21, Official Method of Analysis, 19th ed., *Association of Official Agricultural Chemists*, Arlington, VA, 2012.

[37] Lati, M., Boughali, S., Bouguettaia, H., Mennouche, D., Bechki, D., Khemgani, M., and Ben, Z., Effect of solar drying on the quality of potato. International Conference on Green Energy and Environmental Engineering (GEEE-2017). *International Journal of Scientific Research and Engineering Technology*, Vol. 5, 2017, pp. 1-4.

[38] Garner, D., Crisosto, C. H., Wiley, P., and Crisosto, G. M., Measurement of pH and titratable acidity. *Central Valley Postharvest Newsletter*, Vol. 17 No. 2, 2008, pp. 2.

[39] Ploeg, J. D., van der, and Heuvelink, E., Influence of sub-optimal temperature on tomato growth and yield: A review. *Journal of Horticultural Science,*Vol. 80 No. 6, 2005, pp. 652-659. doi: 10.1080/14620316.2005.11511994.

[40] Adams, S. R., Cockshull, K. E., and Cave, C. R. J., Effect of temperature on the growth and development of tomato fruits. *Annals of Botany,* Vol. 88 No. 5, 2001, pp. 869-877.

[41] Koning, A. N. M. The effect of different day/night temperature regimes on growth, development and yield of glasshouse tomatoes. *Journal of Horticultural Science,*Vol. 63 No. 3, 1988, pp. 465-471. doi: 10.1080/14620316.1988.11515880.

[42] Toor, R. K., Savage, G. P., and Lister, C. E., Seasonal variations in the antioxidant composition of greenhouse grown tomatoes. *Journal of Food Composition and Analysis,* Vol. 19, 2006, pp.1-10.

[43] Majkowska-Gadomska, J., Francke, A., and Wierzbicka, B., Effect of soil substrate on the chemical composition of fruit of some tomato cultivars grown in an unheated plastic tunnel. *Journal of Elementology*, Vol. 13 No. 2, 2008, pp. 261-267.

[44] Jabłońska-Ryś, E. and Zalewska-Korona, M., Ocena przydatności do przetwórstwa owoców pomidora gruntowego nowych linii hodowlanych (Evaluation of processing usefulness of new breeding ground tomato lines). *Nowości Warzywnicze*, Vol. 55, 2010, pp. 19-28.

[45] Domeño, I., Irigoyen, I., and Muro, J., New wood fibre substrates characterization and evaluation in hydroponic tomato culture. *European Journal of Horticultural Science,* Vol. 75 No. 2, 2010, pp. S89-S94.

[46] Kowalczyk, K., Gajc-Wolska, J., and Marcinkowska, M., The influence of growing medium and harvest time on the biological value of cherry fruit and standard tomato cultivars. *Vegetable Crops Research Bulletin,* Vol. 74 No. 1, 2011, pp. 51-59. doi: https://doi.org/10.2478/v10032-011-0004-8.

[47] Jankauskienė, J., Brazaitytė, A., and Viškelis, P., Effect of different growing substrates on physiological processes, productivity and quality of tomato in soilless culture. Soilless Culture: Use of substrates for the production of quality horticultural crops. InTech, Rijeka, Croatia. 2015.

[48] Borji, H., Ghahsareh, A., and Jafarpour, M., Effects of the substrate on tomato in soilless culture effects of the substrate on tomato in soilless culture. *Research Journal of Agriculture and Biological Sciences,* Vol. 6 No. 6, 2010, pp. 923-927.

[49] Zaliha, W. S. and Anwaruddin, M., Growth and quality of lowland cherry tomato (Solanum lycopersicum var. cerasiforme) as influenced by different substrates of biochar in soilless culture media. *Transactions of the Malaysian Society of Plant Physiology*, Vol. 24, 2017, pp. 36-42.

[50] Dumas, Y., Dadomo, M., Lucca, G., and Grolier, P., Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. *Journal of the Science of Food and Agriculture,* Vol. 83, 2003, pp. 369-382.

[51] Tringovska, I., Yankova, V., Markova, D., and Mihov, M., Effect of companion plants on tomato greenhouse production. *Scientia Horticulturae,* Vol. 186, 2015, pp. 31-37.

[52] Kunachowicz, H., Nadolna, I., Przygoda, B., and Iwanow, K., Food composition tables. Wydawnictwo Lekarskie PZWL, Warszawa, Poland, 2005.

[53] Atherton, J. and Rudich, J., The Tomato crop: A scientific basis for improvement. *Technology and engineering. Springer, Dordrecht*, The Netherlands. 1986.

[54] Suvo, T. P., Biswas, H., Jewel, M. H., Islam, M. S., and Khan, M. S. I., Impact of substrate on soilless tomato cultivation. *International Journal of Agricultural Research, Innovation and Technology*, Vol. 6 No. 2, 2016, pp. 82-86.

[55] Tilahun, S., Park, D. S., Seo, M. H., and Jeong, C. S., Review on factors affecting the quality and antioxidant properties of tomatoes. *African Journal of Biotechnology,*Vol. 16 No. 32, 2017, pp. 1678-1687.

[56] Gautier, H., Diakou-Verdin, V., Bénard, C., Reich, M., Buret, M., Bourgaud, F., Poëssel, J. L., Caris-Veyrat, C., and Génard, M., How does tomato quality (sugar, acid, and nutritional quality) vary with ripening stage, temperature, and irradiance? *Journal of Agricultural and Food Chemistry,* Vol. 56 No. 4, 2008, pp. 1241-1250. doi: 10.1021/jf072196t.

[57] Raffo, A., La Malfa, G., Fogliano, V., Maiania, G., and Quaglia, G., Seasonal variation in antioxidant components of cherry tomatoes (Lycopersicon esculentum cv. Naomi F1). *Journal of Food Composition and Analysis,* Vol. 19, 2006, pp. 11-19.

[58] Kowalska, I., Wpływ zróżnicowanego poziomu siarczanów w pożywce i rodzaju podłoża na plonowanie, stan odżywienia i jakość owoców pomidora uprawianego w systemie CKP (The effect of different sulphate levels in the nutrient solution and type of medium on the yield, mineral composition and quality of tomato grown in the NFT). *Acta Scientiarum Polonorum Hortorum Cultus,*Vol. 3, 2004, pp. 153-164.

[59] Rodica, S., Apahidean, S. A., Apahidean, M., Maniutiu, D., and Paulette, L., Yield, physical and chemical characteristics of greenhouse tomato grown on soil and organic substratum. *43rd Croatian and 3rd International Symposium of Agriculture,* 18-21 February, Opatija. Croatia, 2008.

[60] Yara website, https://www.yara.us/crop-nutrition/tomato/managing-tomato-taste/ access 21.11.2018

[61] Inden, H., and Torres, A., Comparison of four substrates on the growth and quality of tomatoes. *Acta Horticulturae,* Vol. 644, 2004, pp. 205-210. doi: 10.17660/ActaHortic.2004.644.27.
[62] Dannehl, D., Suhl, J., Ulrichs, C., and Schmidt, U., Evaluation of substitutes for rock wool as growing substrate for hydroponic tomato production. *Journal of Applied Botany and Food Quality,* Vol. 88, 2015, pp. 68-77. https://doi.org/10.5073/JABFQ.2015.088.010.
[63] Brandt, S., Pék, Z., Barna, E., Lugasi, A., and Helyes, L., Lycopene content and colour of ripening tomatoes as affected by environmental conditions. *Journal of the Science of Food and Agriculture,* Vol. 86, 2006, pp. 568-572.
[64] Roldán-Gutierrez, J., and Castro, M., Lycopene: The need for better methods for characterization and determination. *Trends in Analytical Chemistry,* Vol. 26, 2007, pp. 163-170.
[65] Javanmardi, J., and Kubota, C., Variation of lycopene, antioxidant activity, total soluble solids and weight loss of tomato during postharvest storage. *Postharvest Biology and Technology,* Vol. 41, 2006, pp. 151-155.
[66] Helyes, L., Lugasi, A., and Pék, Z., Effect of natural light on surface temperature and lycopene content of vine-ripened tomato fruit. *Canadian Journal of Plant Science,* Vol. 87, 2008, pp. 927-929.
[67] Guo-Jing, L., Zhi-Hao, X., Benoit, F., and Ceustermans, N., The application of polyurethane ether foam (PUR) to soilless culture as a reusable and environmental sound substrate. *Acta Agriculturae Zhejiangensis*, Vol. 13, 2001, pp. 61-66.