ACTA Acta Sci. Pol., Hortorum Cultus 11(3) 2012, 79-89

YIELDING AND CHEMICAL COMPOSITION OF GREENHOUSE TOMATO FRUIT GROWN ON STRAW OR ROCKWOOL SUBSTRATE

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Abstract. Studies were conducted with tomato of Admiro F_1 cultivar grown in glasshouse in the years 2008–2009. Four substrates were applied: 1) triticale straw, 2) triticale straw + high peat (3:1 v:v), 3) triticale straw + pine bark (3:1 v:v), 4) rockwool (100 × 20 × 7.5 cm = 15 dm^3). Straw, cut into pieces, (2–3 cm) was put in plastic boxes (height of the box ca. twice its width) with the capacity of 15 liters. In each box/slab two plants grew. Experiments were conducted with the use of complete randomization method, in seven repetitions. Drop fertigation was applied in a closed system, without nutrient solution recirculation. In the period of high temperatures the daily nutrient solution consumption equaled 4.2 dm^3 on a one-off basis in 10–12 doses with about 20% overflow. In the conducted studies full usefulness of triticale straw was demonstrated as the substrate for tomato grown in glasshouse. Higher yield was obtained from growing in the substrate of triticale straw+ pine bark, as well as triticale straw + peat compared to rockwool, and these differences were not statistically significant. The highest dry matter content was found in the fruit grown in straw substrates, the least – in those from rockwool substrates. No significant differences were demonstrated in the contents of N, P, K, Ca and Mg in fruit with reference to the examined substrates. After 33 weeks of vegetation (end of the studies) about 70% of the straw was mineralized.

Key words: triticale straw, yield, dry matter, vitamin C, sugars

INTRODUCTION

In glasshouse cultivations the applied substrates can be divided into three groups: organic, mineral and synthetic. In assessing the particular substrates the physical, chemical and biological properties of these materials should be considered, i.e. the humus contents, sorption complex for cations and anions, as well as pathogenic factors. The cost of substrate purchase, as well as the possibility of its development after fin-

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ished cultivation as post-production waste are very important. The commonly applied substrates are peat, rockwool and perlite. Due to decreasing peat resources, as well as problematic rockwool and perlite recycling, there arises the need to study the use of other materials as substrates for glasshouse growing of vegetables and decorative plants. When a glasshouse is equipped with fertigation apparatuses, then there is a possibility of using many various materials, both organic and mineral, as substrates.

In glasshouse cucumber and tomato growing interesting results were obtained, with the use of cut rye and wheat straw, wood and coconut fiber. The obtained yield and its quality did not significantly differ compared to growing in peat and rockwool [Nurzyński 2006, Mahamud and Manisah 2007, Piróg et al. 2010, Kowalczyk and Gajc-Wolska 2011]. In the studies with the use of sawdust from various tree species as substrates for tomato growing [Dorais et al. 2007, Egret and Helmer 2009] their usefulness was demonstrated on condition that they should have been composted before, simultaneously considering their different effects upon the grown plant species. For instance the sawdust from thuja (*Thuja sp.*) are toxic for tomato.

The results of studies with the application of organic substrates as mixtures of various organic or inorganic materials with a little addition of mineral materials are promising. Nichualain et al. [2011], as well as Raviv [2011] point out to the substrate obtained as a mixture of peat with compost. Compost can be obtained from various organic materials, having decomposed them in oxygen conditions and there cannot be more compost than 50%. A good substrate was also obtained as a mixture of comminuted feathers, pine bark and perlite [Evans and Vancey 2007]. Feathers are highly porous and so as much as 30% of this material can be added.

In tomato growing it is recommended to apply substrates prepared as a mixture of comminuted corn stems with pumice, rice hulls with peat and perlite, coconut fiber with zeolite [Tzortzakis and Economakis 2007, Gachukia and Awans 2008, Fecondini et al. 2011]. These substrates have good physical properties and are free from pathogenic factors.

Mineral materials, as substrates for glasshouse cultivations are also applied and the yield obtained is identical to that of plants grown in rockwool. In tomato growing in sand [Nurzyński 2005], in gravel [Neocleus 2010], in expanded clay [Jarosz and Dzida 2011] also very good quality fruit was obtained and these subtrata belong to the cheapest.

The presented paper comprises studies on growth and yielding of tomato grown in a glasshouse in the cut triticale straw, mixture of triticale straw with peat and pine bark.

MATERIAL AND METHODS

Studies were conducted in the glasshouse of Department of Soil Cultivation and Fertilization of Horticultural Plants, University of Life Sciences in Lublin. The tomato of Admiro F_1 cultivar was grown in the period from 10^{th} February to 21st October 2008 and from 4^{th} February to 15^{th} October 2009 for 22 clusters at the density of 2.4 plants for $1m^2$. The following substrates were examined: 1) triticale straw, 2) triticale straw + high peat (3:1 v:v), 3) triticale straw + pine bark (3:1 v:v), 4) rockwool (100 × 20 × 7.5 cm

= 15 dm^3). Straw was cut into pieces (2–3 cm) and placed in rectangular boxes 14 cm high, bottom width: 8 cm and capacity 15 dm^3. During the growing period about 70% straw has been decomposed. Evaluation of straw decomposition was done by comparing the weight of air dry weight of straw before the experience with the mass after the experiment (after removal of roots). In each box/slab two plants grew. The experiments were conducted with the use of complete randomization method in seven repetitions.

Drip fertigation method was applied in closed system without recirculation of nutrient solution that contained all the macrocomponents (tab. 1) and microelements ($mg \cdot dm^{-3}$): Fe – 2.0; Mn – 0.95; B – 0.54; Cu – 0.09; Zn – 0.56; Mo – 0.09. In the period of high temperatures the nutrient solution was applied in the daily amount of about 4.2 dm^3 per plant in 10–12 single doses with 20% nutrient solution effusion from the box/slab.

Table 1. The mean content of macroelement in triticale straw (% d.m.), in water and in nutrient solution ($mg \cdot dm^{-3}$)
Tabela 1. Średnia zawartość makroelementów w słomie pszenżyta (% s.m.) oraz w wodzie i pożywce ($mg \cdot dm^{-3}$)

Substrate Podłoże	N-mineral	P	K	Ca	Mg	Cl	$S\text{-}SO_4$	pH	EC ($mS \cdot cm^{-1}$)
Triticale straw Słoma pszenżytnia	0.52*	0.03	0.75	0.51	0.05	0.05	0.06	-	-
Water Woda	3.5	3.0	5.0	95.0	10.0	8.0	8.5	7.1–7.4	0.7
Nutrient solution Pożywka	210.0	54.0	340.0	250.0	80.0	20.0	150.0	5.7–5.9	2.4

*Note: N-total, N-ogółem

Bombus terrestris used for plant pollination, Greenhouse Whitefly (*Frialeurodes vaporariorum*) was biologically controlled with *Encarsia formosa*.

The fruit was collected twice a week. The marketable yield were fruits with the diameter of 4.5–6.0 cm. Vitamin C was determined in fruit with the use of Tillmans's method, sugars according to Schorl-Rogenbogen, N-total using Kiejdahl's method (Tecator), P-colorimetrically with ammonium vanadomolybdate (Nicole Evolution 300), K, Ca, Mg using AAS method (Perkin Elmer, Analyst 300). For the analyses 10 ripe fruits were sampled, of the diameter of 7–9 cm, of the weight of 200 g in three repetitions. In the substrates (solution from the root environment) N-mineral ($N\text{-}NH_4 + N\text{-}NO_3$) was determined with the use of Bremner's distillation method in Starck's modification, whereas K and Ca – using AAS method.

Statistical elaboration of results was conducted using the method of variance analysis on mean values, applying Tukey's test for assessing differences, at significance level of $\alpha = 0.05$.

RESULTS

The examined triticale straw, cut into 2–3 cm sections with the addition of small amounts of peat (25%) and pine bark are organic substrates, whereas the commonly used rockwool was admitted as comparative substrate. Organic substrates have a range of advantages, both physical and chemical.

The conducted studies and obtained results indicate a range of interesting relationships. In triticale straw substrates, as well as in those with added peat and bark the plants grew normally throughout the whole vegetation period, just like in the rockwool substrate. High fruit yield was obtained, which, for 1 m^2 of glasshouse surface gives 39.45 kg (tab. 2). Comparing the yields obtained from cultivation in the examined substrates no significant differences were found and the advantageous effect of bark or peat added to the straw should be emphasized. In these objects the yield was higher. Triticale straw contains all the nutrients needed by the plants (tab. 1), but in small amounts. Because of the applied nutrient solution, which was the same for all plants grown on all the substrates and water with slight fluctuations in chemical composition (tab. 1), tomato, irrespective of the substrate it grew in, was correctly nourished. Only in the first weeks of vegetation in organic substrates a decrease in mineral nitrogen content was reported because of its albumization (proteinization), and it cannot affect the plant growth because every day nutrient solution was supplied to plants 7–9 times and two times at night. However what affected the fruit yield quantity in the first vegetation months (May, June, July) was the air temperature in glasshouse (fig. 3). The lowest yield was obtained in May (fig. 1). The air temperature in glasshouse in that month frequently exceeded 40°C, and in such conditions the pollen dries out and there was less fruit. The contents of mineral nitrogen and potassium, very important nutrients in this period was in the optimal range (fig. 2).

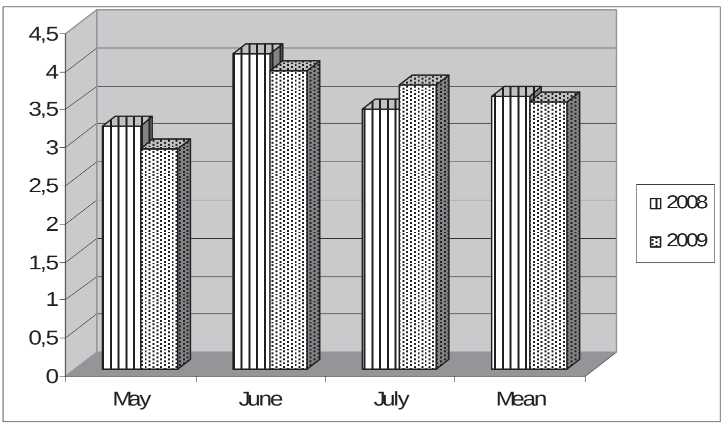

Fig. 1. Yielding of tomato (kg·plant^{-1}) in May, June, July 2008 and 2009 (means for substrates)
Ryc. 1. Plonowanie pomidora (kg·plant^{-1}) w maju, czerwcu i lipcu 2008 i 2009 (średnie z podłoży)

Table 2. The effect of substrate on the yield (kg·plant^{-1}), dry matter (%), vitamin C (mg·100 g^{-1} fr.w.), sugars (% fr.w.) in year 2008 and 2009.

Tabela 2. Wpływ podłoża na plon owoców (kg·roslina^{-1}), oraz zawartość w nich suchej masy (%), witaminy C (mg·100 g^{-1} św.m.), cukrów (% św.m.) w roku 2008 i 2009

Substrate – Podłoże	Yield – Plon				Dry matter Sucha masa		Vitamin C Witamina C		Total segars Cukry ogółem	
	2008		2009							
	tota ogólny	marketable handlowy	total ogólny	marketable handlowy	2008	2009	2008	2009	2008	2009
Triticale straw Słoma pszenżyta	16.54a	14.55a	16.19a	14.25a	5.68b	5.78b	16.10b	24.73c	3.57c	2.82a
Triticale straw + peat Słoma pszenżyta + torf	16.66a	14.66a	16.50a	14.52a	5.67b	5.18a	15.50a	24.70c	2.94b	2.69a
Triticale straw + pine bark Słoma pszenżyta + kora sosnowa	17.26a	15.20a	15.62a	13.74a	5.38b	5.83b	16.55b	20.23a	2.50a	2.56a
Rockwool – Wełna mineralna	16.68a	14.67a	15.97a	14.05a	5.08a	4.90a	17.76c	22.48b	2.90b	2.39a
$\bar{x}$	16.78	14.77	16.07	14.14	5.45	5.42	16.48	23.03	2.98	2.61

Note: means in each column followed by some letter are not significantly different P = 0.05
Średnie w kolumnach oznaczone tą samą literą nie różnią się istotnie przy P = 0,05

Table 3. The effect of substrate on the nutrients content of tomato fruit (% d.m.) in year 2008 and 2009

Tabela 3. Wpływ podłoża na zawartość składników pokarmowych w owocach pomidora (% s.m.) w roku 2008 i 2009

Substrate – Podłoże	N- total – N-ogółem			P			K			Ca			Mg		
	2008	2009	$\bar{x}$	2008	2009	$\bar{x}$	2008	2009	$\bar{x}$	2008	2009	$\bar{x}$	2008	2009	$\bar{x}$
Triticale straw Słoma pszenżyta	1.79	2.01	1.90a	0.49	0.41	0.45a	4.91	3.93	4.42b	0.11	0.12	0.12a	0.14	0.13	0.14a
Triticale straw + peat Słoma pszenżyta + torf	1.99	2.14	2.06a	0.46	0.42	0.44a	4.14	2.95	3.54a	0.10	0.12	0.11a	0.10	0.14	0.12a
Triticale straw + pine bark Słoma pszenżyta + kora sosnowa	2.20	2.32	2.26a	0.48	0.43	0.45a	4.04	3.00	3.52a	0.09	0.11	0.10a	0.09	0.14	0.12a
Rockwool – Wełna mineralna	1.96	2.19	2.07a	0.46	0.46	0.46a	4.13	3.14	3.63a	0.09	0.13	0.11a	0.09	0.17	0.13a
$\bar{x}$	1.98a	2.16a		0.47a	0.43a		4.30b	3.25a		0.10a	0.12a		0.10a	0.14a	

Note: see Table 2 – Patrz Tabela 2

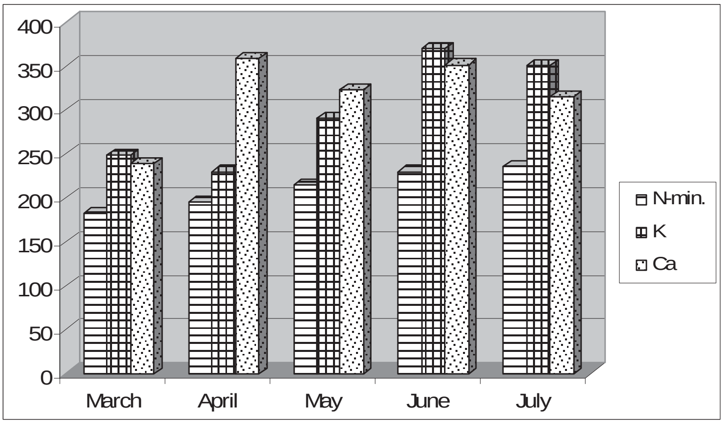

Fig. 2. The N-mineral (N-NH_4+N-NO_3), K and Ca content in substrates (solution from the root environment) in cultivation period (mean from years and substrates in mg·dm^{-3})
Ryc. 2. Zawartość N-mineralnego (N-NH_4+N-NO_3), K i Ca w podłożach (roztwór ze strefy korzeniowej) w okresie wegetacji (średnio z lat i podłoży w mg·dm^{-3})

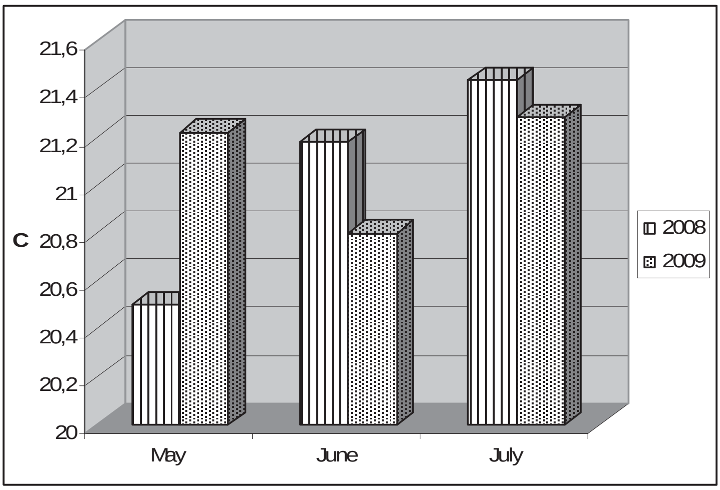

Fig. 3. Average daily air temperature (ºC) in the greenhouse during the period research
Ryc. 3. Średnia dobowa temperatura powietrza w szklarni w okresie badań

In the period of high air temperatures in the glasshouse plant fertigation was activated more frequently (11–13 times a day), but because of ca. 20% effect of the nutrient solution from rhisosphere, nutrient concentration in substrates changed in a very small range.

Irrespective of tomato yielding assessment the contents of dry matter, vitamin C, sugars, as well as N, P, K, Ca and Mg in fruit are important (tab. 2 and 3). More dry matter was contained in fruit grown in organic substrates, compared to rockwool. Such dependence occurred in both study years. As it has already been remarked, when comparing the yield of fruit with plants grown in particular substrates no significant differences were found. Mean yield from both study years, for instance from growing in a substrate made of straw only and in rockwool substrate was the same, whereas if expressed in fruit dry matter the differences are significant (0.93 and 0.81 kg from a plant) against rockwool.

Vitamin C content with reference to the examined substrates changed in fruit to a small extent. Only higher content was demonstrated, on average by 40%, in the year 2009, compared to 2008. However, in the year 2009 there were fewer sugars in fruit. Comparing the effect of particular substrates, fruit of plants grown in rockwool contained significantly less sugars compared to organic substrates (tab. 2).

The results of chemical analyses of fruit for contents of N, P, K, Ca, Mg show significant amounts of nitrogen, phosphorus and potassium in dry matter. On average they contain as much potassium and phosphorus as in the leaves, and nitrogen – a half less (tab. 3). These are good indicators of nutritional value. The effect of examined substrates and the years upon the contents of these nutrients was slight, only the fruit comprised more potassium in the year 2008 compared to 2009.

An important issue is the contents of calcium in fruit, and there is very little of it. At values below 0.06% Ca in dry matter there is blossom-end rot disease on the fruit. Such fruit is not suitable for consumption. In the presented studies the fruit contained 0.10–0.12% Ca in dry matter and this disease did not occur. It should be emphasized that the calcium contents in substrates (fig. 2) was in the optimal interval (240–360 mg $Ca \cdot dm^{-3}$).

DISCUSSION

High position of expenditures in glasshouse plant growing is occupied by the costs of substrates purchase and management as post-production waste. Verdonck [2007] calculated on the basis of talks given at the International Symposium on substrates in Parnu (Estland) that in Europe 16 million m^3 of substrates are used, including 3.5% pre-shaped products (rockwool and different foam products), as well as 2.3% of mineral materials (sand, clay, perlite, vermiculite). In hydroponical growing with fertigation 600 000 m^3 of pre-shaped materials are consumed, as well as about 30 000 m^3 of minerals. Also about 100 000 m^3 coconut fiber should be added. In total there are about 950 000 m^3 of substrates used in hydroponical plant growing, which can be referred to the surface of about 8500 ha.

The second issue concerns the problem of rockwool and perlite recycling, as well as management of these materials as post-production waste [Domeno et al. 2009]. During vegetation each substrate is infected by disease causing factors. Reusing rockwool and perlite as substrates for plant growing in the second and third year usually causes growth deterioration and low yielding [Fernandes et al. 2007, Borosic et al. 2009, Abukhovich and Kobryń 2010]. Therefore, there is the necessity of conducting studies on using various materials for the preparation of a good substrate. These materials should be easily accessible, cheap and, as a post-cultivation waste, they should not destroy the natural environment.

In the presented paper the usability of cut triticale straw was examined as a substrate for glasshouse tomato growing. Also included is a substrate with addition (25%) to straw peat and pine bark. Rockwool was as a reference object. Growth of plants grown in straw was normal, the yield of fruits (average 39.4 kg of 1 m^2) high. Comparing the yields obtained from cultivation in various media, no significant differences were observed. It should be emphasized that adding peat or pine bark to straw was advantageous, because during vegetation straw is mineralized in about 70%. Straw mineralization is an advantageous phenomenon, because then CO_2 is released, which is used by plants in the process of photosynthesis. The increased CO_2 concentration in the air in glasshouse causes yield increase. In the atmospheric air the concentration of CO_2 equals about 350 ppm, in a glasshouse it should be 900–1000 ppm [Elings et al. 2007, Hao et al. 2008, Stanghellini et al. 2009]. Schroeder and Knaack [2007], examining gas concentration in the rhisosphere of cucumber growing in various substrates emphasized that the inappropriate O_2 concentration in rhisosphere weakensplant growth, especially in hydroponical cultivation system, where the space for roots is limited. Therefore CO_2 contributes to maintaining gas balance. In the substrates (rockwool, phytocell foam) the concentration of CO_2 ranged from 2000 to 16 700 ppm.

Tomato, regardless of the kind of substrate where it grows, must obtain all the nutrients to the optimal extent. Besides, some of the nutrients are contained in the substrate, which, after decomposition during vegetation, become assimilable for plants. This concerns organic [Domeno et al. 2009, Nichualain et al. 2011, Raviv 2011], organic-mineral [Choi et al. 2007, Lopez et al. 2008] and mineral substrates [Nurzyński 2005, Bernardi et al. 2007, Miccolis et al. 2007, Parra et al. 2009]. Therefore, the chemical composition of the nutrient solution should be prepared separately for particular groups of substrates.

In the presented studies the obtained results concerning dry matter and chemical composition of fruit are interesting. The dry matter contents should be emphasized, which was lower in the fruit grown in rockwool. The contents of vitamin C, sugars, as well as N, P, K, Ca and Mg were in a similar range. Good quality of fruit grown in organic substrates is also confirmed by other authors [Nurzyński 2006, Jankauskiene and Brazaityte 2007, Kowalczyk et al. 2011]. Besides, the costs of substrate should be emphasized. Rockwool is a very expensive substrate compared to organic substrates. Comparing rockwool, perlite and pine bark [Hanna 2009] the lowest bark cultivation costs were demonstrated, in spite of the fact that tomato fruit yields (three cultivars) were similar.

The effect of organic substance upon the growth of plants is direct and indirect. Many studies have been conducted on the subject. In the experiments with cucumber [Olfati et al. 2010] positive effect of humus substances was demonstrated upon the uptake of nutrients by plants. Borowski and Nurzyński [2007], examining the photosynthetic activity of tomato leaves that grew in cut wheat and rye straw substrates, as well as in rockwool, demonstrated lack of significant differences the water potential in the leaves was also similar.

The correct growth of tomato on triticale straw substrate and on the substrate with peat and bark addition, high yield, as well as its quality, did not significantly differ compared to growing in rockwool substrate. Achieving so good results is possible on condition that boxes for the cut straw will be about twice as high as wide. This is connected with fast mineralization of straw during vegetation (about 70%). Placing the cut straw in the foil, shaping it like a rockwool mat (20 cm wide and 7,5 cm high) gives definitely worse conditions for the development of roots and overground parts, and the yield will always be lower compared to growing in other substrates [Nurzyński 2002, Kaniszewski et al. 2010]. As it has already been remarked, the plant roots, besides water, also need air. That is why the well-manufactured pots have correct dimensions, i.e. their height is twice as large as the bottom diameter.

Triticale straw is a very cheap, easily accessible material. Plastic boxes are very light, easy to clean and disinfect after plant growing. They can be used for many years.

CONCLUSIONS

1. Full usability of triticale straw as substrate for tomato grown in a glasshouse was demonstrated. Higher yield was obtained from growing in the substrate of triticale straw + pine bark and triticale straw + peat compared to rockwool, but these differences were not statistically significant.

2. The highest quantity of dry matter in fruit was found from growing in substrates of straw, the lowest – in rockwool.

3. No significant differences were demonstrated in the contents of N, P, K, Ca, Mg in fruit with reference to the examined substrates.

4. After 33 weeks of vegetation (end of studies) about 70% of straw were mineralized.

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PLONOWANIE I SKŁAD CHEMICZNY OWOCÓW POMIDORA SZKLARNIOWEGO UPRAWIANEGO W SŁOMIE ORAZ WEŁNIE MINERALNEJ

Streszczenie. Badania przeprowadzono z pomidorem odmiany Admiro F_1 uprawianym w szklarni w roku 2008 i 2009. Zastosowano cztery podłoża: 1) słoma pszenżyta, 2) słoma pszenżyta + torf wysoki (3:1 v:v), 3) słoma pszenżyta + kora sosnowa (3:1 v:v), 4) wełna mineralna (100 × 20 × 7,5 cm = 15 dm^3). Słomę pociętą na kawałki (2–3 cm) umieszczono w skrzynkach plastikowych (wysokość skrzynki ok. dwa razy większa od szerokości) o pojemności 15 litrów. W każdej skrzynce/macie rosły dwie rośliny. Doświadczenia przeprowadzono metodą kompletnej randomizacji w siedmiu powtórzeniach. Stosowano fertygację kroplową w układzie zamkniętym, bez recyrkulacji pożywki. W okresie wysokich temperatur zużycie pożywki na dobę wynosiło jednorazowo 4,2 dm^3 w 10–12 dawkach z około 20% przelewem. W przeprowadzonych badaniach wykazano pełną przydatność słomy pszenżyta jako podłoża dla pomidora uprawianego w szklarni. Wyższe plony otrzymano z uprawy w podłożu słoma pszenżyta + kora sosnowa oraz słoma pszenżyta + torf w porównaniu z wełną mineralną, przy czym różnice nie były statystycznie istotne. Najwięcej suchej masy w owocach stwierdzono z uprawy w podłożach ze słomy, najmniej z wełny mineralnej. Nie wykazano istotnych różnic w zawartości N, P, K, Ca i Mg w owocach w odniesieniu do badanych podłoży. Po 33 tygodniach wegetacji roślin (zakończenie badań) około 70% słomy zostało zmineralizowane.

Słowa kluczowe: słoma pszenżyta, plon, sucha masa, witamina C, cukry

ACKNOWLEDGEMENTS

The study was financed by the Ministry of Science and Higher Education, Poland, under project No NN 310147935.

Accepted for print – Zaakceptowano do druku: 25.01.2012