Impacts of the substrate medium on tomato yield and fruit quality in soilless cultivation

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ABSTRACT: The performance and suitability of different substrates for the soilless culture of tomato plants (*Lycopersicum esculentum* Mill., cv. Belladona) were studied over a 5-month period in a closed soilless culture system employing five different substrates (perlite, pumice or maize and their mixtures with 50% shredded maize stems in an unheated glasshouse). Plants grown in a maize stem-containing medium produced earlier fruits, followed by pumice. Plants grown in pumice and perlite substrates obtained lower total yield; a higher yield was associated with the addition of maize shredded stems. Pumice + 50% maize and 100% maize produced higher total number of fruits per plant. Fruit quality parameters such as mean fruit weight, fruit firmness, total soluble solids, titratable acidity, ascorbic acid and carotenoids were influenced by the treatment, while EC, pH and dry matter content were not. The results suggest that the addition of maize in perlite and pumice could improve inorganic substrates properties for tomato soilless culture, leading to higher yields and better fruit quality.

Keywords: earliness; fruit quality; organic materials; perlite; pumice; carotenoids; soilless culture; tomato; yield

Soilless culture avoids problems associated with decreasing fertility of natural soils, due to disease limitations and the increase in salinity (Verdonck 1975). Problems associated with the needs of growers to improve the efficiency and quality of the products, by means of a better control of production through technological innovations in the nursery, are also avoided. A number of problems such as material disposal and raising cost limit the development of soilless culture in Greek conditions. A major factor that might help to solve these problems is a possibility of using different substrate materials, locally available and less costly than those imported, with no pollution limitations, but with adequate physical and chemical properties.

Nowadays, there is a great interest in the changes in fruit quality that take place during ripening. Customer tests indicate that firmness and flavour are important criteria for high tomato quality; the typical tomato flavour depends on the ratio between sweet and acid tastes (Vesseur 1990). Moreover, an increased consumption and interest in tomato products has been associated with the reduced risk of some types of cancer (Clinton et al. 1996). In this regard, tomato antioxidants are believed to contribute to the disease prevention, particularly lycopene and β-carotene, which accumulate in plasma and tissues in relation to dietary intake (Oshima et al. 1996).

Worldwide, 12% of the hydroponic industry uses organic media as substrate and/or as compost (Donnan 1998). Maize stems constitute a readily available organic material that can be used in soilless cultivation as substrate (Tzortzakis, Economakis 2005) because of its low cost and lightweight. In the present work, the suitability of some local materials for soilless cultivation was studied, comparing the influence of inorganic and organic mixtures (perlite:maize and pumice:maize) on tomato yield and fruit quality.

MATERIALS AND METHODS

The present study was carried out in an unheated glasshouse with a North-South orientation at the Institute of Olive Tree and Subtropical Plants of Chania, Greece, located at the latitude of 35.35°N, longitude 24.02°E and altitude 8 m a.s.l. The tomato cultivar used was Belladona (HAZERA, Brurim, Israel), which has an extended self-life and large fruits (180–220 g). Seedlings were purchased from a nursery at the stage of the first truss appearance and placed in the appropriate substrate. Three main substrates, perlite, pumice and maize shredded stems and their selected mixtures were used, resulting in five substrate treatments: (1) perlite, (2) 50% perlite + 50% maize, (3) 50% pumice + 50% maize, (4) pumice, (5) maize. Photosynthetically active radiation (PAR) was monitored by a Delta-T Millivolt integrator (Delta-T Devices Ltd, Burwell, Cambridge, UK) equipped with an energy sensor (quantum sensor QS-4698); temperature as well as air relative humidity were recorded every 30 min by a data logger (Escort data logging system LTD, Escort Messtechnic AG, Aesch, Switzerland).

Substrates were applied on a row on greenhouse troughs, consisting of nine 16 l capacity bags (each with two plants), 18 plants per row with the spacing of 1.2 m between rows and 0.4 m among the plants in the row as described previously (Tzortzakis, Economakis 2005). Before transplanting, the bags were soaked with full strength nutrient solution, supplemented with N/P/K (1.44/0.25/1.00) by using the suitable commercial fertilizers. Perlite and pumice were the commercial products (Lava, Yali, Greece). Shredded maize stems were selected after field harvest of an abundant organic culture of maize in which no fertilizer or pesticides were used. Physicochemical properties of the substrates and composting procedure for maize shredded stems were presented in the previous studies (Tzortzakis, Economakis 2005).

A close soilless culture system adopted for the experiment with nutrient solution (1:100) consisted of the following concentrations of nutrients: $N0_3$-N = 9.6 mmol/l; K = 6.8 mmol/l; PO_4-P = 1.7 mmol/l; Ca = 4.0 mmol/l; Mg = 2.8 mmol/l, Fe = 73 μmol/l; Mn = 17 μmol/l; Cu = 3.6 μmol/l; Zn = 6.6 μmol/l; Mo = 1.2 μmol/l; B = 27 μmol/l; Na = 1.3 mmol/l; these were applied with a drip irrigation system, via drippers to the individual plants and by means of pressure pumps. Target pH and electrical conductivity (EC) values of the nutrient solution were 6.0 and 2.15–2.40 dS/m, respectively. Fertigation was applied through a timer 5 min/hr, every 0.5 hr after fruit setting, at a flow rate of 100 ml/min only during daytime. The actual pH values of the nutrient solution collected in the catchment tanks during the cultivation period fluctuated between 6.7 and 7.8 while those of the EC were between 1.77–2.72 dS/m.

The harvesting period lasted for approximately 60 days. During this period, up to thirteen harvests were performed. Total yielding period was divided into three sub-periods: a) 20/3–6/4 (early-yield), b) 6/4–4/5 (mid-yield), c) 4/5–20/5 (late-yield). Fruits were evaluated for their quality characteristics, including fruit weight, flesh firmness, pH and EC of the juice and dry matter content, total soluble solids (TSS), titratable acidity (TA)*, carotenoids, and ascorbic acid* (vitamin C) content (*fruits obtained from the 5^{th} truss). Fruits at the pink stage were weighed immediately after the harvest. Fruits with homogeneous colour development were selected for further studies of qualitative parameters. Fruit firmness was measured by a Bishop FT Oil model pressure tester (probe 7.9 mm). TSS, pH and EC of the extracted fruit juice were measured by a hand refractometer, a pH meter and an EC meter, respectively. TA was measured by titration with 0.1N sodium hydroxide and expressed as a citric acid percentage. Ascorbic acid in tomato juice was determined by the 2,6-dichloroindophenol titrimetric method (Helrich 1990).

Dry matter content of fruits was calculated as % of fresh weight (following drying at 80°C for 48 hours) of samples of 6 fruits from each substrate from the 3^{rd}, 4^{th} and 5^{th} truss. Fruits (4^{th} truss) were used for the determination of β-carotene, lutein and lycopene contents by HPLC analysis on a RP18 Lichrospher 100 (Merck) 250 × 4 (5 μ) column and DAD detection. Eluent used were (A) acetonitrile:water (9:1) containing 0.1% triethylamine and (B) ethyl acetate, and the flow rate was 1 ml/min. The elution programme was used as follows: from 100% A to 0% A in 25 min (total run time 35 min). The temperature of the column was kept at 40°C and monitoring was performed at 450nm (β-carotene), 447nm (lutein) and 471nm (lycopene).

Data were analyzed using the SPSS (SPSS Inc., Chicago, USA) and first tested for normality and subjected to univariate analysis of variance on multiple factors (ANOVA) followed by analysis of mean (one-way ANOVA), investigating significant differences between substrates.

RESULTS AND DISCUSSION

Effect of substrate on fruit yield and fruit number

During the early yield period, 35% of the total yield was achieved with plants grown on maize followed by pumice with 31%. No differences were obtained during the mid-yield period, whereas during the late yield period, the greatest yield was obtained from perlite + 50% maize as well as from pumice + 50% maize, i.e. 27% followed by maize with 19% (data not presented). The fact that early yield of plants grown on maize was higher than in the other substrates could be attributed to the higher substrate temperature recorded; on average by 1.6°C and 2°C higher during day and night, respectively. The increased temperature of the organic substrate should be caused by the microbial

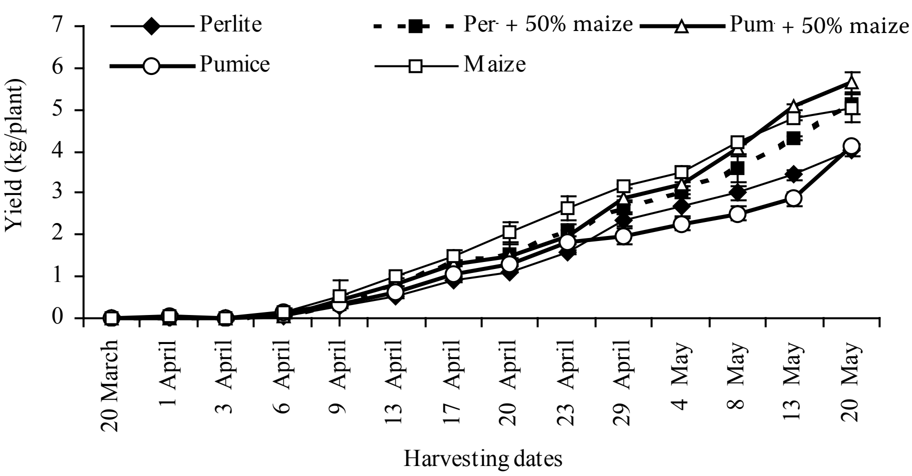

Fig. 1. Influence of different substrates on cumulative yield (kg/plant) per harvest date. Each point is mean ± standard error of cumulative yield per harvest date (values of error bars that are less than the symbol size are not visible)

decomposing activities. Similarly, the highest early yield was observed in pepper plants grown on the peat medium compared with perlite, pumice, sand and soil (Padem, Alan 1994).

Even though plant growth on maize presented a higher yield (kg/plant) per harvest date, till the beginning of May, a decline in productivity was noticed, resulting in a lower total yield (Fig. 1). The decline in yield on maize should be attributed to the reduction in volume of this material due to decomposition. Pumice presented higher yield than perlite until the 29th of April, and then the opposite phenomenon took place, till equilibrium of yields. Pumice + 50% maize, perlite + 50% maize and maize resulted in significantly higher total yield/plant than pumice and perlite (Fig. 1). The fact that perlite and pumice alone gave lower yields than maize-containing substrates suggested better nutritional conditions in the latter being in accordance with Padem and Alan (1994) in pepper cultivation. However, Bohme et al. (2001) reported no differences between organic (coconut-fibre) and inorganic (perlite and rookwool) substrates on yield of cucumber plants. Leoni et al. (1988) comparing perlite and pumice as substrates in tomato cultivation reported no significant difference in yield between them, which is in accordance with the present results.

The total number of fruits/plant harvested from each treatment varied and probably affected fruit quality characteristics of plants grown on perlite producing significantly lower numbers compared to those on pumice + 50% maize and maize (Table 1). Plants grown on pumice and perlite produced significantly lower total number of fruits/plant than on maize shredded stems, which contrasts with the previous findings stating that organic substrate (peat, bark and straw) produced significantly lower or insignificant (hortifibre) number of cucumber fruits/plant compared with the inorganic substrate (rockwool; Hardgrave, Hariman 1995). It is worth to mention that maize substrate volume reduced because of the proceeding decomposition. This resulted in plant growth (vegetative, flowering and fruiting) reduction compared with the other substrates, during the last 3–4 weeks, especially because of the lack of porosity and/or inadequate water availability to the roots in the middle of the day when plant wilting occurred.

Effect of substrate on fruit quality

An increase in fruit size was associated with improved climatic conditions (PAR, temperature), especially after the 23rd of April for the majority

Table 1. Effects of different substrates on fruit weight (g) in tomato grown hydroponically (total fruit number n^* = 1,607). In each column, values followed by the same letter are not significantly different at P = 0.05 according to Duncan's MRT

Substrate	Early period (20/3–6/4)	Mid period (6/4–4/5)	Late period (4/5–20/5)	Whole period* (20/3–20/5)	Fruits per plant
Perlite	147 b	190 a	210 b	196 b	20.3 b
Per + 50% maize	281 a	205 a	234 ab	216 a	23.7 ab
Pum + 50% maize	149 b	194 a	244 a	212 a	26.6 a
Pumice	145 b	188 a	212 b	192 b	21.1 b
Maize	162 b	207 a	169 c	192 b	25.9 a

Table 2. Effect of the harvesting time on mean fruit weight (g) during the cultivation period as affected by the substrate media. In each column, values followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's MRT

Harvesting time	Perlite	Per + 50% maize	Pum + 50% maize	Pumice	Maize
20 March	–	–	–	–	197 ab
1 April	–	–	–	–	153 b
3 April	–	–	–	142 c	–
6 April	147 c	281 a	149 c	146 c	160 b
9 April	160 bc	197 c	168 bc	149 c	174 ab
13 April	138 c	181 c	164 bc	143 c	175 ab
17 April	160 bc	193 c	164 bc	167 bc	221 ab
20 April	207 ab	192 c	179 bc	236 a	218 ab
23 April	235 a	207 bc	231 ab	238 a	218 ab
29 April	211 ab	263 ab	230 ab	176 abc	203 ab
4 May	206 ab	202 bc	213 abc	228 ab	257 a
8 May	188 abc	247 abc	253 a	224 ab	188 ab
13 May	215 ab	243 abc	250 a	202 abc	160 b
20 May	222 a	220 abc	222 ab	215 ab	142 b

Table 3. Effects of different substrates on fruit firmness (kg), on total soluble solids (Brix), pH, EC (dS/m), titratable acidity* (TA; % citric acid), ascorbic acid* (mg/g fresh fruit) and on TSS/TA* in fresh fruit in hydroponically grown tomato. In each column, values (n = 85 replicates/substrate; n* = 10 replicates/substrate) followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's MRT

Substrate	Firmness	TSS	pH	EC	TA*	Ascorbic acid*	TSS/TA*
Perlite	1.12 b	3.96 ab	4.10 a	3.28 a	3.32 ab	0.15 bc	1.19
Per + 50% maize	1.21 ab	3.89 ab	4.10 a	3.23 a	3.85 a	0.14 c	1.01
Pum + 50% maize	1.15 b	3.75 b	4.14 a	3.16 a	2.92 b	0.18 ab	1.28
Pumice	1.15 b	4.01 a	4.06 a	3.17 a	3.25 ab	0.18 ab	1.23
Maize	1.27 a	3.91 ab	4.06 a	3.18 a	2.95 b	0.20 a	1.32

of the substrates (Table 2). Mean fruit weight was affected significantly by the time of harvest, resulting in improvement of the mean fruit weight (after 23rd of April) (Table 2). During the early period, perlite + 50% maize showed significantly higher mean fruit weight compared with the other substrates. Mean fruit weight was not differentiated during the mid period. However, during the late yield sub-period, pumice + 50% maize revealed the highest mean fruit weight, maize presented significantly lowest mean fruit weight, whereas perlite, pumice and perlite + 50% maize did not differ statistically (Table 1). Maize-containing inorganic substrates significantly improved mean fruit weight over the whole yielding period, whereas no differentiation was observed in unmixed substrates. These results are in accordance with previous studies reporting insignificant differences between pure organic and inorganic substrates on mean fruit weight (g) of cucumber and tomatoes plants – Hardgrave and Hariman (1995) and Islam et al. (2002), respectively.

Maize resulted in greater fruit firmness compared with perlite, pumice and pumice + 50% maize, whereas no differences were observed with perlite + 50% maize (Table 3); this contradicts the findings reported by Traka-Mavrona (2001). TSS (°Brix) content of the fruit was found to differ significantly between substrates. Pumice compared with pumice + 50% maize produced a higher value of TSS, whereas no differences in TSS content were revealed with the other treatments (Table 3). Plants grown on pumice + 50% maize produced low TSS values in fruit juice, inevitably because they also had high number of fruits/plant. Higher sugar and organic acid content improves the quality of tomato fruits (Davies, Hobson 1981). Considering the ratio

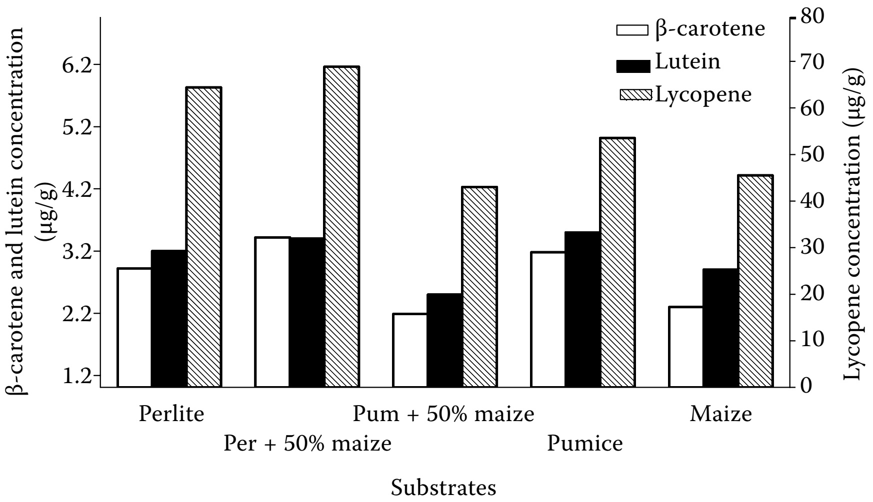

Fig. 2. Influence of different substrates on β-carotene, lutein and lycopene concentrations in fresh tomato fruits grown hydroponically

TSS/TA as an expression of fruit sweetness, maize gave the sweetest fruits. The TSS content of the fruits was inversely related to the total fruit yield per plant; the higher the yield, the lower the TSS (Table 3 and Fig. 1). In accordance with the present study, Islam et al. (2002) recorded no differences between organic and inorganic substrates in TSS in tomato fruit juice. The pH and the EC of the tomato fruit juice were not significantly different in tomato cultivation with different substrates, which is in accordance with Islam et al. (2002). Low pH is associated with high fruit quality (Davies, Hobson 1981) and was recorded in the substrates that produced early yield (maize and pumice). The TA of the fruit juice was significantly higher in perlite + 50% maize than in maize and pumice + 50% maize, and was expressed as a percentage of citric acid (Table 3).

Plants grown on maize produced fruits with higher amounts of ascorbic acid than the perlite and perlite + 50% maize but no differences were observed in pumice-containing substrates (Table 3). Padem and Alan (1994) and Islam et al. (2002) reported no significant differences in ascorbic acid content between the substrates in hydroponically grown pepper and tomato, respectively; this is in contrast with the present study.

Perlite-containing substrates enhanced lycopene content compared to pumice-containing substrates, whereas no differences were revealed in β-carotene and lutein content (Fig. 2). Pure perlite and pumice substrates gave higher contents of the above-mentioned substances than maize substrate, however the other fruit quality characteristics as well as fruit yield were better in the latter (Tables 1 and 3, Fig. 1). The increased EC [and pH] of the nutrient solution (data not presented) did not significantly result in reduced tendency among treatments after linear regression analysis for β-carotene and EC ($y = -0.61x + 4.24$) [and pH ($y = -2.22x + 18.4$)], lutein and EC ($y = 0.46x + 2.02$) [and pH ($y = -0.84x + 9.01$)] and lycopene and EC ($y = -30.73x + 126.9$) [and pH ($y = -73.9x + 574.1$)]. However, the findings of De Pascale et al. (2001) and Petersen et al. (1998) reported a significantly increased tendency of the above carotenoids, since the observed EC was lower than 4 dS/m (De Pascale et al. 2001), whereas the opposite tendency occurred at higher EC values (> 4dS/m).

No significant differences in the dry matter content of fruits were observed between the treatments (data not presented) similarly as in Islam et al. (2002). However Xu et al. (1995) reported that rockwool (inorganic) substrate produced significantly lower fruit dry weight of tomato plants than peat-bag substrate.

CONCLUSIONS

The results of this study indicate that the substrates used in the experiment had an effect on earliness, total yield, number of fruits and fruit quality. Maize and pumice produced remarkable early yield. The highest total yield was obtained on pumice + 50% maize, followed by perlite + 50% maize, maize and lastly on pumice and perlite. Total number of fruits per plant was greater on plants grown on pumice + 50% maize followed by maize substrate. Certain fruit quality characteristics, i.e. mean fruit weight, fruit firmness, TSS, TA, carotenoids and ascorbic acid, were differently affected by substrate. Adding maize shredded stems in perlite and pumice led to higher yields and better fruit quality.

Maize is a low cost, worldwide available and effective organic material that should be used for tomato growing as substrate more efficiently in a condensed form (compressed) because of quick decomposition under the Mediterranean conditions. The overall effect of the type of substrate on tomato growth and yield in the present experiment suggests that the examined materials are suitable substrates for tomato soilless cultivation. Further investigation is however needed to determine if the presence of maize in pumice and/or perlite could promise the prolonged reuse of the mixture. Moreover, more studies are necessary to specify the point of condensation (compression) of maize stems in order to assure their successful use (biostability) as substrate as well as the alternative use of maize substrate on soilless culture introducing plants with shorter life-cycle i.e. lettuce and spinach.

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Vliv substrátu na výnos a kvalitu plodů při pěstování rajčat bez půdy

ABSTRAKT: V průběhu pěti měsíců jsme studovali vhodnost a reakce různých substrátů při pěstování rajčat (*Lycopersicum esculentum* Mill., cv. Belladona) bez půdy. Experiment probíhal v uzavřeném pěstebním systému v nevyhřívaném skleníku za použití pěti různých substrátů (perlit, pemza, nasekané kukuřičné stonky, směs perlitu a pemzy s 50 % nasekaných kukuřičných stonků). Rostliny pěstované na médiu obsahujícím kukuřičné stonky plodily dříve, následovala pemza. Rostliny v pemzovém a perlitovém substrátu měly nižší celkové výnosy, vyššího výnosu bylo dosaženo po přidání kukuřičných stonků. Vyššího celkového počtu plodů připadajícího na rostlinu bylo dosaženo ve směsi pemzy a perlitu s 50 % kukuřice a rovněž na 100% kukuřičném substrátu. Kvalitativní parametry plodů, jako jsou průměrná hmotnost, pevnost, obsah refraktometrické sušiny, titrační kyselost, obsah kyseliny askorbové a karotenoidů, byly ovlivněny použitým substrátem, zatímco elektrická vodivost, pH a celkový obsah sušiny ovlivněny nebyly. Tyto výsledky naznačují, že obohacení perlitu a pemzy kukuřičným odpadem může vylepšit vlastnosti anorganických substrátů při bezpůdním pěstování rajčat a umožňuje dosažení vyšších výnosů a zlepšení kvality plodů.

Klíčová slova: ranost; kvalita plodů; organické materiály; perlit; pemza; karotenoidy; bezpůdní pěstování; rajče; výnos

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