Use of sawdust, coco soil and pumice in hydroponically grown strawberry

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ABSTRACT

Strawberry (*Fragaria* × *ananassa* Duch.) plants were grown hydroponically in different ratio of sawdust (Saw-100), coco soil (Coc-100) and/or pumice (Pum-100) mixtures. Leaf number doubled in plants grown in Saw-100 while runners (stolons) number increased up to 70% in plants grown in Coc-100 compared with the control treatment (Pum-100). Fruit number increased (up to 50%) in plants grown in Pum-100. Leaf stomatal conductance, photosynthetic rate and internal concentration of CO_2 differentiated according to the plant vegetative or reproductive stage and/or substrate medium. Leaf and stem fresh weight as well as leaf area was increased (up to 32, 24 and 44%, respectively) in case of Coc-100 compared with the Saw-100 or Pum-100. Plant yield was doubled when Pum-Saw (50-50) was used compared with the Saw-100, which is due to the reduced fruit number produced rather than the difference in fruit fresh weight. Substrate affected fruit quality parameters. The present findings highlight the putative use of organic medium i.e. Sawdust on top of the widely used coco soil as substrate medium in strawberry culture.

Keywords: organic materials; plant growth; soilless culture; yield; marketability

Soilless culture under greenhouse conditions attracts scientific interest and increased in portions of the world where it has not been common practice. The occurrence of soil-limited factors (expensive chemical soil disinfection methods, low yields and possible plant residues, water shortage and increase in salinity of natural soils) has increased demand for a suitable technology adapted to soilless culture (De Rijck and Schrevens 1998) and exploitation of local materials for use as growing media with specific physicochemical properties (Ortega et al. 1996). Inorganic substrates such as perlite, sand and pumice, are chemically inert, making it possible to supply nutrients in a controlled manner (De Rijck and Schrevens 1998). Several studies reported the favorable effect that organic materials have on plant growth (Sawan and Eissa 1996, Tehranifar et al. 2007, Tzortzakis and Economakis 2008), as increased substrate porosity and water holding capacity (Hardgrave and Harriman 1995). Arancon et al. (2004) reported that organic matter (vermicompost) applications increased strawberry growth and yields significantly, including increases of up to 37% in leaf areas, 37% in plant shoot biomass, 40% in numbers of flowers, 36% in numbers of plant runners and 35% in marketable fruit weights.

Sawdust is widely used as a growth medium component in areas with wood processing industries, because of its low cost, high moisture retention, and high availability. Sawdust has been standard growing medium for the greenhouse industry in Alberta and Argentina for several decades (Sawan and Eissa 1996). Usually it forms a constituent (normally less than 50%) in mixtures rather than being used as a stand-alone growth medium. However, sawdust is prone to gradual decomposition which leads to unfavourable substrate physical properties converting it from 'dry' to 'wet' substrate with a higher volume of retained water and a deficiency of available oxygen. The air-to-water ratio in the root zone originating from differences in physical properties of the growing media is of great importance (Gizas and Savvas 2007). Despite perlite's (as inorganic substrate) higher stability, there was no improvement in productivity found for bell pepper or long English cucumber when compared to sawdust (Nichols and Savidov 2009). Indeed, coir was the better substrate when compared to sawdust for the long English cucumber crop, but sawdust was preferable substrate for the bell pepper crop (Savidov 2005).

The objective of the present study was to compare the performance of sawdust, coco soil and pumice, alone and in mixtures for strawberry (*Fragaria* × *ananassa* Duch.) cultivation.

MATERIAL AND METHODS

Experimental design. Strawberry (*Fragaria* × *ananassa* Duch. cv. San Andreas), plants were grown under natural light during spring in an unheated plastic greenhouse in Crete, Greece. Average minimum and maximum air temperatures during this period were 16°C and 32°C, respectively. Three substrates, pumice (Pum; as control treatment), sawdust (Saw), coco soil (Coc) and mixtures of these, were used to create six treatments which were: (1) Pumice (Pum-100); (2) Sawdust (Saw-100); (3) Coco soil (Coc-100); (4) Pum-Saw (50-50); (5) Coc-Saw (50-50); (6) Coc-Pum (50-50). Plants were obtained from California (US Davis), defrosted slowly in room temperature and directly transplanted in the substrates. Each substrate was filled (5 L) in multi-channels (POLYGAL Plastic Industries Ltd, Ramat Hashofet, Israel). The six substrate mixtures with four replications (multi-channel)/treatments (with 11 plants/replication) were arranged in single rows on a greenhouse trough. Rows were 1.0 m apart and plants were separated in multi-channel by 0.2 m. Drip irrigation emitters (four emitters/multi-channel) were placed at the top of each multi-channel which had slits in the bottom to allow drainage. Pumice and coco soil were obtained by local supplier and sawdust derived from Sweden pine (*Pinus sylvestris* L.) trees was obtained by a local furniture manufacture, while the wood was not treated with any chemicals. The soilless culture system was open with the excess nutrient solution drained away. A solution (1:100 v/v) in water containing the following concentration of nutrients: NO_3^--N = 14.29, K = 10.23, PO_4-P = 0.97, Ca = 3.74, Mg = 2.88, SO_4^{2-}-S = 1.56 and Na = 1.30 mmol/L, respectively; and B = 18.52, Fe = 71.56, Mn = 18.21, Cu = 4.72, Zn = 1.53, and Mo = 0.52 μmol/L, respectively. Fertigation was applied during the daytime through a timer (1 min every 1 h at a flow rate of 25 mL/min) with a drip irrigation system (via emitters) by means of pressure pumps. Nutrient solution target pH and electrical conductivity (EC) were 5.9 and 2.1 mS/cm, respectively.

Substrate properties. The physicochemical properties of pumice, coco soil and sawdust mixtures were examined in three replicants. Organic matter content was determined (ashed at 550°C/8 h) and the organic C was calculated. The EC and pH determined according to 1:2 dilution method. After a hydrochloric digestion of the sample ash, nutrients analysis for K and Na (photometric; JENWAY, PEP-7 Jenway, Dunmow, UK), P (spectrophotometric; Pye Unicam Hitachi U-1100, Tokyo, Japan) was determined while total N determined through Kjeldahl method. The main physical properties of the used substrates, determined according to De Boodt and Verdonck (1972). Particle size distribution values were determined by dry sieving with a mesh sizes of 8, 4, 2, 1, 0.5, 0.25 and 0.075 mm (Electromagnetic & Digital Sieve Shaker, TZBA200N, BWB Technologies Ltd, Berks, UK).

Plant growth and development. Beginning second week after transplanting, the impact of substrate medium on plant growth/development, yield and nutrient uptake in strawberry was studied. Biweekly, the following parameters were measured: the number of runners (stolons), leaf number, fruit number, fruit fresh weight, yield, fruit size, marketability (score 1–4; 1 – extra quality; 2 – good quality; 3 – medium quality; 4 – non marketable); total soluble solids (TSS); titratable acidity (TA); total phenolics (as described previously in Tzortzakis et al. 2007). Leaf chlorophyll (chl *a* and chl *b*) content was determined according to Porra (2002) while leaf fluoresces, photosynthetic rate (P_n), stomatal conductance (g_s) and internal leaf concentration of CO_2 (C_i) were determined using a portable infra-red gas analyser (model Li-6200; Li-Cor, Inc., Lincoln, USA). Measurements were carried out between 9:00–11:10 AM, the leaf temperature within the chamber was 28 ± 2°C, photosynthetic photon flux density of 1300 μmol/m^2/s was used at the ambient CO_2 concentration. The Li 6200 was equipped with a leaf chamber with constant area inserts (6.0 cm^2). All gas-exchange measurements started 3 h after the onset of the photoperiod and were replicated in nine plants in each treatment and on two fully expanded, healthy, sun-exposed leaves per plant.

In experiment completion, fresh weight and dry matter content (%) of stems and leaves and leaf area produced were measured. Leaf elemental analysis for K, Na (photometric), P (spectrophotometric; vanadomolybdophosphoric yellow colour method) and N (Kjeldahl) were determined in the end of the experiment.

Statistical analysis. Data were tested for normality, and then subjected to analysis of variance (ANOVA). Significant differences between mean values were determined using the Duncan's multiple range test ($P < 0.05$) following one-way ANOVA. Statistical analyses were performed using the SPSS (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

Substrate properties. The amount of pore space of media is critical physical characteristic which influences water and nutrient absorption and gas exchange by the root system (Sahin et al. 2002). For sufficient gas exchange, drainage, and water-holding capacity, the proper proportion of macropores is necessary. Several studies indicated that particle size and hydraulic properties of pumice affected growth and yield of greenhouse crops (gypsophila, rose, cucumber, lettuce) in soilless culture (Gizas and Savvas 2007). In the present study, organic matter (and as a consequence the organic carbon content) was increased in Saw-100 compared with Coc-100 (Table 1). The most substrates particle size was under 2 mm. Adding pumice into the sawdust substrate altered the negative properties of aeration and balance water content of the latter. In previous studies, physical analysis of substrates confirmed that particle size distribution was determined by the proportion of sawdust and sand. Dry and wet particle density increased while organic matter content and total porosity decreased with the addition of sand (Sodre et al. 2007). An increased EC (averaged 3.08 mS/cm) was observed in Coc-100 and affected substrate EC was reported in different mixtures. Saw-100 affected medium acidity (revealed – 4.71 pH) and contributed to the increased amount of N, K and P (Table 1), while no changes were revealed for Na content. Additionally, Coc-100 added nutrient amount of K and P, but also Na. Organic media improved total porosity when used alone or mixed with Pum-100. Oxygen deficiency may readily occur in media with relatively low air-filled porosity, especially if plants exhibit high growth rates, which demand intensive root respiration (as

Table 1. Physicochemical properties of different mixtures consisted of pumice, coco soil and sawdust

	Organic matter	Organic C	pH	EC	N	K	P	Na
	(%)			(dS/m)	(mg/g)			
Pum-100	–	–	7.87	0.45	0.01	~0.000	0.024	~0.000
Saw-100	92.6	54.8	4.71	0.74	10.80	0.032	0.055	0.006
Coc-100	89.2	52.6	5.46	3.08	0.01	0.119	0.219	0.175
Coc-Saw 50-50	91.2	53.1	5.37	1.59	9.06	0.136	0.082	0.042
Pum-Saw 50-50	47.5	23.7	6.13	0.53	5.49	0.011	0.034	0.005
Coc-Pum 50-50	43.4	22.3	6.65	1.41	0.10	0.082	0.054	0.041

	particle size distribution	bulk density (g/cm^3)	water content	air capacity	total porosity
			(%)		
Pum-100	< 8 mm	0.631	23.2	38.6	67.5
Saw-100	< 4 mm	0.117	33.0	13.2	89.8
Coc-100	< 8 mm	0.121	71.8	23.3	95.1
Coc-Saw 50-50	< 8 mm	0.168	47.8	18.0	91.3
Pum-Saw 50-50	< 8 mm	0.326	52.3	27.4	71.6
Coc-Pum 50-50	< 8 mm	0.349	42.6	29.1	73.9

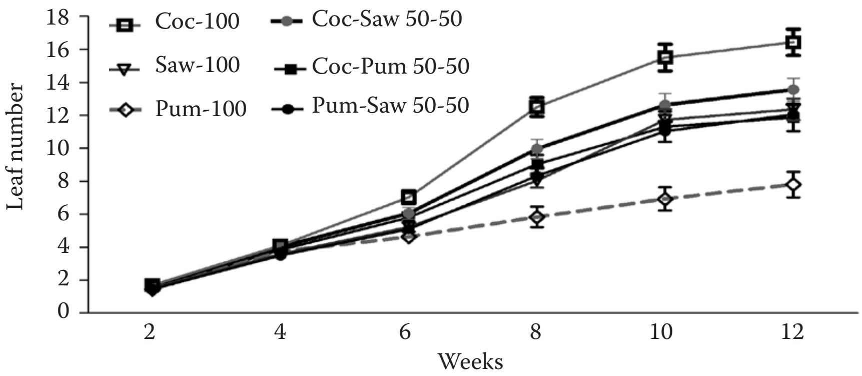

Figure 1. Effect of different substrate medium on the leaf number produced in hydroponically grown strawberry. Values are means ± SE according to the Duncan's multiple range test

reviewed by Gizas and Savvas 2007). Cultivation of bell peppers (cv. Sardana) performed better on perlite, a 'dry' substrate, than on coir which seems to have a higher demand for oxygen supply in the root zone, when grown at two levels of CO_2 (Savidov 2005).

Plant growth/yield. The number of leaves differed among plants growing in different substrates after the 6th week of plant culture (Figure 1). Leaf number increased up to 50% in plants grown in Saw-100 and up to 34% in plants grown in substrate mixtures compared with the control treatment (Pum-100), while no differences were observed among substrate mixtures. Similarly, leaf number was greater in strawberry plants grown in media containing peat rather than inorganic substrates, such as perlite or sand (Tehranifar et al. 2007). The number of stolons increased up to 70% in plants grown in Coc-100 compared with the respective plant grown in Saw-100 or Pum-100, yet no differences were observed in plants grown in substrate mixtures (in 50:50 ratio) (Figure 2), which is in agreement with previous findings in strawberry plant when grown in seven media. However, plants produced most runners in Coc-100 and the least in perlite (similar inorganic media as pumice) (Tehranifar et al. 2007). Guttrige (1985) also reported that number of runners of strawberry plants is different in different cultivars and under different growth conditions.

Fruit number increased (up to 50%) in plants grown in Pum-100 in comparison with plants grown in Coc-100 and all substrate mixtures, while no differences were observed among Pum-100 and Saw-100 (Figure 2). Fruit number produced in plants grown in Coc-100 did not differ with the equivalent number produced in Saw-100, and this is in agreement with previous studies when three tomato cultivars were grown in Saw-100 and Coc-100 (Sawan and Eissa 1996). Similarly, strawberry plants grown in sand 100% produced flowers earlier than in other growing media, including organic/inorganic mixtures with Cocopeat (Tehranifar et al. 2007).

Leaf and stem fresh weight increased (up to 32% and 24%, respectively) in case of Coc-100 compared with the Saw-100 or Pum-100 (Table 2). Additionally leaf area was markedly increased

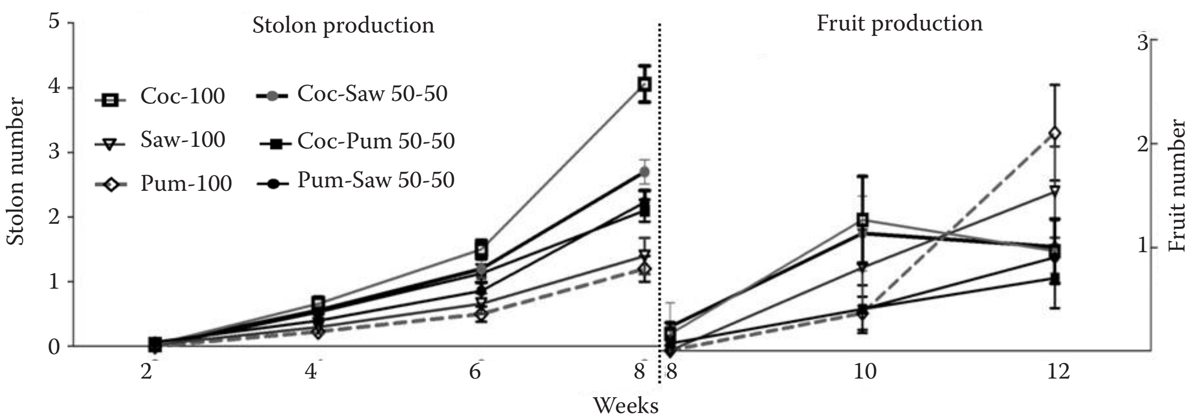

Figure 2. Effect of different substrate medium on the stolon (early stage) and fruit (late stage) production in hydroponically grown strawberry. Values are means ± SE according to the Duncan's multiple range test

Table 2. Effect of different substrate medium on the stem and leaf fresh weight (FW) and dry matter content (DM), leaf area, yield, fruit number and fruit fresh weight produced in hydroponically grown strawberry. In each column, mean values followed by the same letter do not differ significantly at P = 0.05 according to the Duncan's multiple range test

	Stem FW (g)	Stem DM (%)	Leaf FW (g)	Leaf DM (%)	Leaf area (cm^2)	Yield (g/plant)	Fruit number	Fruit FW (g)
Pum-100	20.7^{c}	20.6^{a}	25.9^{c}	29.3^{a}	828.2^{c}	32.9^{b}	2.6^{b}	14.6^{a}
Saw-100	25.7^{bc}	19.7^{a}	31.8^{b}	27.6^{a}	885.4^{c}	26.9^{b}	2.6^{b}	11.3^{b}
Coc-100	37.8^{a}	18.8^{a}	42.5^{a}	29.4^{a}	1641.1^{a}	34.8^{ab}	2.8^{b}	12.6^{ab}
Coc-Saw 50-50	29.6^{b}	17.7^{a}	36.4^{ab}	26.6^{a}	1120.3^{bc}	40.4^{ab}	2.6^{b}	15.6^{a}
Pum-Saw 50-50	22.1^{bc}	18.6^{a}	29.4^{bc}	26.9^{a}	887.5^{bc}	49.4^{a}	4.2^{a}	11.3^{b}
Coc-Pum 50-50	36.3^{ab}	16.6^{a}	37.7^{ab}	30.1^{a}	1185.6^{b}	29.3^{b}	2.8^{b}	10.6^{b}

(up to 44%) in case of Coc-100, i.e. 1641.1 cm^2, compared with the Saw-100 or Pum-100 (885.4 and 828.2 cm^2, respectively), while plants grown in substrate mixtures revealed intermediate values. Plant dry matter content did not differ among plants grown in different substrates.

The greatest fruit number harvested per plant was marked in plants grown in Pum-Saw (50-50) compared with others substrates (Table 2). When three strawberry cultivars grown in seven substrates – including peat, coco soil, perlite, sand and their mixtures of the higher plant yield fluctuated for the same substrates media and was cultivar dependent. Thus cv. Camarosa in cocopeat-perlite (40-60), cv. Gaviota in 100% peat and cv. Selva in 100% cocopeat produced higher yields (Tehranifar et al. 2007).

Plant yield increased in Pum-Saw (50-50) compared to Pum-100, Coc-Pum (50-50) and Saw-100. In more details, plant yield was doubled with Pum-Saw (50-50) used, compared with the Saw-100, which is rather due to the reduced fruit number produced than due to the difference in fruit fresh weight (Table 2). Similarly to the present study, tomato plant yield did not differ in plants grown in Coc-100 and in Saw-100 (Sawan and Eissa 1996). When sawdust, rockwool, coir and perlite were used for the production of bell pepper, long English cucumber and tomato, they showed a similar level of productivity in most applied conditions (Nichols and Savidov 2009), which contradicts the present outcomes regarding the impact of organic and inorganic medium on plant productivity but is in accordance with lettuce production in sawdust and/or perlite (Christoulaki et al. 2013). These may be due to different plant species and/or experimental treatments. Indeed, composted sawdust consists an alternative medium, and may substitute inorganic substrates with beneficial effects (Dorais et al. 2006). Yields in peat-bark substrates were similar to rockwool substrates during greenhouse tomato culture grown in plastic bags but were lower in sawdust (Allaire et al. 2005) being in agreement to some extent with the present study. Similarly, coir had no negative effect on the production of long English cucumbers during all three years of the experiments. Yield of the coir increased by up to 12.4% compared to sawdust. Thus, compared to sawdust, coir, with a flatter water retention curve, appears to be the most appropriate substrate for long English cucumber (Savidov 2005).

Leaf gas exchange. During stolon production (vegetative stage), the greatest leaf stomatal conductance was observed in plants grown in Coc-Pum (50-50), followed by Pum-Saw (50-50) while the least leaf stomatal conductance was observed in plants grown in Pum-100 (Figure 3). However, during the fruit production (reproductive) stage, Pum-100 and Coc-Saw (50-50) revealed significantly higher leaf stomatal conductance. Plants grown in substrate mixtures (Coc-Saw 50-50; Coc-Pum 50-50; Pum-Saw 50-50) revealed higher photosynthetic rate during vegetative stage compared with raw substrates (Figure 3), possible due to the better physiological status of plant development and/or improved media physicochemical properties. Moreover, plants grown in Coc-100 and substrate mixtures (Coc-Saw 50-50; Coc-Pum 50-50; Pum-Saw 50-50) had higher internal concentration of CO_2 in both vegetative and reproductive stage compared with Saw-100 and Pum-100 (Figure 3). Greater Sawdust content (75% or 100%) in sub-

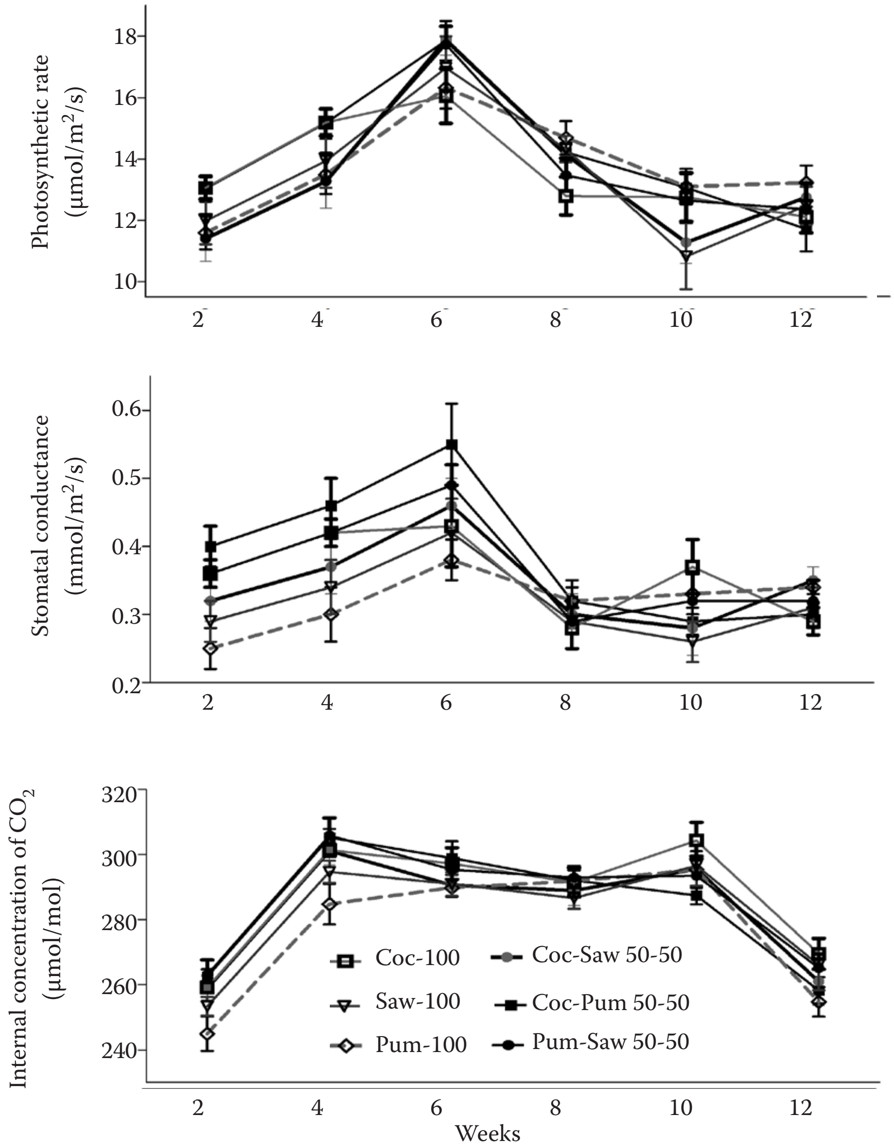

Figure 3. Effect of different substrate medium on leaf photosynthetic rate; stomatal conductance and intercellular CO_2 concentration of fully expanded leaves in hydroponically grown strawberry. Values are means ± SE according to the Duncan's multiple range test

strates reduced lettuce leaf photosynthetic rates as well as stomatal conductance in previous studies (Christoulaki et al. 2013). No differences were observed in leaf fluoresce and chlorophyll content among the different substrates (data not presented) being in accordance with previous studies in lettuce (Christoulaki et al. 2013). During plant growth, no symptoms of nutrient deficiency or toxicity observed optically. However, in previous experiments regarding seedling growth in different substrates, including sawdust, the F_v/F_m ratio was not a good indicator of the plant phytotoxicity (Dorais et al. 2006).

Fruit quality parameters. Examined fruit quality parameters as presented in Table 3; no differences were observed in fruit length while fruits derived by plants grown in Coc-Saw (50-50) and Pum-100 were wider than the equivalent fruits by Saw-100, Pum-Saw (50-50) and Coc-Pum (50-50). Fruit marketability revealed lower values in plants grown in Coc-Saw (50-50) and this might be due to substrate physicochemical properties alteration by mixing two organic substrates (i.e. sawdust and coco soil).

Mean fruit fresh weight increased in plants grown in Coc-Saw (50-50) and Pum-100 compared with

Table 3. Effect of different substrate medium on the fruit size, fruit marketability (1 – extra quality; 2 – good quality; 3 – medium quality; 4 – non marketable); total soluble solids (TSS); titratable acidity (TA) and total phenolics in hydroponically grown strawberry. In each column, mean values followed by the same letter do not differ significantly at $P = 0.05$ according to the Duncan's multiple range test

	Fruit length	Fruit width	Marketability (score 1–4)	TSS (Brix°)	TA (% citric acid)	Total phenolics (μmol GAE/g FW)
	(cm)					
Pum-100	3.2^{a}	3.0^{a}	3.03^{ab}	5.90^{a}	7.75^{ab}	3.91^{b}
Saw-100	3.1^{a}	2.6^{b}	3.11^{ab}	6.35^{a}	8.06^{a}	4.08^{ab}
Coc-100	3.2^{a}	2.9^{ab}	3.21^{a}	6.18^{a}	7.53^{abc}	4.88^{a}
Coc-Saw 50-50	3.4^{a}	3.1^{a}	2.77^{b}	6.56^{a}	7.11^{abc}	3.70^{b}
Pum-Saw 50-50	3.1^{a}	2.7^{b}	3.35^{a}	5.96^{a}	6.56^{c}	3.62^{b}
Coc-Pum 50-50	3.2^{a}	2.6^{b}	3.37^{a}	6.08^{a}	6.88^{bc}	4.17^{ab}

fruits harvested in plants grown in Saw-100, Pum-Saw (50-50) and Coc-Pum (50-50) (Table 2). Fruits obtained by Saw-100 substrate were more acid compared with fruits obtained by Pum-Saw (50-50) and Coc-Pum (50-50) as presented in Table 3. No differences observed in TSS among treatments, being in agreement with previous study in strawberry plant grown in cocopeat 100%, cocopeat-perlite (40-60), perlite 100% and sand 100% (Tehranifar et al. 2007). In previous studies, coco soil affected positively tomato fruit quality i.e. TSS while perlite mixtures with carbonized rice hull improved plant yield (Inden and Torres 2004). The content of total phenolics increased in fruits obtained by Coc-100 compared with fruits obtained by Pum-100, Coc-Saw (50-50) and Saw-Pum (50-50).

Nutrient concentrations in plant tissues. Examining nutrient status in leaves, there were no differences among basic nutrients such as K content (averaged 2.12 mg/g FW), Na content (averaged 0.089 mg/g FW), P content (averaged 0.53 mg/g FW) and N content (averaged 17.47 mg/g FW). Similarly, no main differences were observed on K, N and P lettuce leaf content when sawdust was added into perlite substrates (Christoulaki et al. 2013) as well as in tomato plants grown in rockwool or hinoki [*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.] bark fiber slabs (Yu and Komada 1999).

The increase in the production of potted plants and/or substrate culture, and thus the increase in demand for substrates, has focused worldwide horticultural research on the search for local materials which are readily available and affordable, with physical and chemical characteristics which make them likely to be suitable for use as growing medium. In most cases, these requirements have led to a concentration on by-products, the most important of which (by volume) are plant waste products, particularly from the forestry industry (sawdust, barks) and the food industry (grape and olive marc) (Ortega et al. 1996). Although agricultural re-use of plant wastes is well established, especially in the case of fertilizers, their use as substrates can involve problems of toxicity. These problems can have serious consequences owing to the direct contact with the plant in concentrated form. Methods such as composting, ageing, washing, mixtures or fertilization have been used to reduce or eliminate the negative impacts. Indeed, the determination of sawdust medium content that may be mixed with inorganic substrates is quite valuable.

In conclusion, the present findings highlight the putative use of organic medium i.e. Sawdust on top of the widely used coco soil as substrate medium in strawberry culture. The performance of plants grown on Pum-Saw (50-50), followed by the Coc-Saw (50-50) and then by Coc-Pum (50-50) is markedly influenced by the media and the alteration of physicochemical properties (such as porosity, water content and air capacity) of raw material and hence the air and water balance in the root environment. Further research study is necessary for the complete exploitation of the putative use of sawdust in substrate mixtures as pure or composted material and of its ability to improve physicochemical properties as substrate medium, indentifying the exact ratio mixed into substrates as well as appropriate container height (to improve hydraulic properties of the media), for hydroponically grown crops.

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