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Investigating the effect of different soilless substrates on strawberry productivity and fruit composition

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ABSTRACT

The effect of different soiless substrates (*viz.* agrotextile, coir fibre, perlite and rock wool) on strawberry productivity and fruit composition of three strawberry cultivars ('Camarosa', 'Candonga' and 'Festival') was investigated.

Plant productivity and berry composition was mainly affected by differences between cultivars rather than by the nature of the different growing substrates. However, regardless of the cultivar, plants grown on agrotextile-type substrate produced significantly more fruit (1018.2 g plant^{-1}) than those grown in other substrates (average 892.3 g plant^{-1}). In addition, accompanying greater fruit production, fruit from plants grown on agrotextile generally had the lowest concentrations of the main strawberry anthocyanins perlargonidin-3-glucoside (0.74-fold) and pelargonidin derivative 1 (0.85-fold). Nor sugars, organic acids or any other health-related compounds were significantly affected by the nature of the soilless substrate.

Overall, the present study demonstrates that despite some minor differences in fruit yield and the health-related composition of fruit grown on agrotextile, a number of different substrates with different physico-chemical characteristics may be employed during soilless cultivation of strawberry fruit without detrimentally affecting final fruit quality.

1. Introduction

Traditional commercial strawberry production is mainly based on replanting season after season plants in the same field plots. Under this production system and given the susceptibility of most available strawberry cultivars to soilborne pathogens (*viz. Phytophthora* spp., *Verticillium* spp., etc.) soil disinfestations need to be routinely applied (De Cal et al., 2005). Up to the year 2005, when it became banned due to its environmental hazards, methyl bromide (MB) was widely used as a soil fumigant in Spain and elsewhere in the Mediterranean area (Medina et al., 2009). Since then, numerous attempts involving new cultivation technologies have been studied as to maintain viable strawberry production and maximum yields (López-Aranda et al., 2009). Soilless cultivation systems, in all variations (*viz.* supported or suspended, open or closed, with or without substrate) are considered potential alternatives, whereby soil disinfestations are not an issue and where water and nutrients are used in a more sustainable manner (Hernanz et al., 2007, 2008). In the region of Huelva, where 94% of the Spanish strawberry production takes place, over 350 ha are currently designated for the production of strawberry fruits using soilless cultivation systems. Soilless production of strawberry fruits is expected to rise in the forthcoming years. Studies throughout the past decades have compared productivity and yield from plants grown under soilless cultivation and those grown in a more traditional manner without finding significant differences (Paraskevopolou-Paroussi et al., 1995; Tagliavini et al., 2005). Similarly, Recamales et al. (2007) compared the fruit quality (*viz.* soluble sugars, organic acids and mineral content) between soilless (open and close systems) and traditional cultivated strawberry plants and found that soilless production resulted in fruit with lower pH and soluble solids. Despite technological differences among soilless systems (open vs. close), the amount and nature of the substrates that can be employed is vast (*viz.* peat, sand, gravel, polyurethane foam, expanded polyestirene, geotex-

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tiles, perlite, rockwool, vermiculite, coconut fibre, grape debris, rice husks, solid urban waste, etc.) (Recamales et al., 2007; Ghazvini et al., 2007). In this context, efforts are being made proposing by-products from different industrial sectors to be employed as substrates in strawberry soilless cultivations, yet little is known about their impact on the final fruit quality.

Quality in strawberry fruits is a complex trait generally assessed in terms of the balance between sugar and acids within the fruit, which directly relates to taste and hence consumer acceptability (Cordenunsi et al., 2003; Terry et al., 2007; Giné Bordonaba and Terry, 2009, 2010), but also in terms of the concentration in bioactive compounds with known health-related properties (Terry et al., 2007; Giné Bordonaba et al., 2011; Manganaris et al., 2013). Several studies have assessed the role that different production systems, including irrigation techniques, organic and/or conventional cultivation methods have on overall strawberry fruit quality (Wang et al., 2002; Davik et al., 2006; Keutgen and Pawelzik, 2007a,b, 2008; Terry et al., 2007; Hargreaves et al., 2008, 2009). This said, no other studies have yet investigated the role that the substrate may have on the plant productivity and final fruit quality and/or composition. Given that the nature of the substrate may play a crucial role in determining water and nutrient availability for the plant and hence may affect the metabolic pathways involved in the synthesis of specific biochemical compounds, the present study was conducted to assess the effect four different substrates (*viz*. coir fibre, perlite, rock wool and agrotextile) on the final quality and composition of fruit from three different cultivars grown in the Spanish region of Huelva. Particular attention was given to quantify sugars and organic acids as main indicators of strawberry taste as well as to quantify the concentration of certain secondary metabolites (*viz*. anthocyanins and ellagic acid) intimately associated with the potential health-promoting properties (Giné Bordonaba and Terry, 2011).

2. Materials and methods

2.1. Plant material and experimental design

Commercial strawberry (*Fragaria* x *ananassa* Duch.) plants of short day cultivars 'Camarosa', 'Festival' and 'Candonga' of similar size and developmental stage were chosen for the experiment. Plants were planted (October 2008) in a high tunnel (350 m^2 using transparent polyethylene (PE) 200 μm) at the experimental orchard of Huelva University, Spain (Latitude: 37°12′N, Longitude: 6°54′W, Altitude: 6 m from sea level). High tunnels were built using semicircular steel bars that reached 3 m high on the tunnel apex and were 6.25 m wide. Each high-tunnel had six beds and was covered with translucent polyethylene plastic, which allowed in 60% of the photosynthetic active radiation. Strawberry plants inside the tunnels were grown in a simple and environmentally friendly soilless technique (Closed Soilless Growing System, CSGS) in PE bag (100 cm x 18 cm x 30 cm) containing either coir fibre (Pelemix Spain, S.L., Murcia, Spain), perlite (Otavi Ibérica S.L.u., Almería, Spain), rock wool (Grodan med S.A., Almería, Spain) or Agrotextile (Geotexan, S.A., Huelva, Spain) as substrates and planted in double rows separated 1.6 m from each other at a density of 10 plants m^{-2}. The nutritional solution was composed of KNO_3, $CaNO_3$, $Mg(NO_3)_2$, KH_2PO_4, P_2O_5, K_2O, H_3PO_4, and other microelements at standard concentration for hydroponic cultures during the crop cycle (mg L^{-1}): N 182, P 67, K 235, Mg 15, S 27, Fe 1.3, Mn 0.6, Cu 0.05, Zn 0.1, B 0.01 and Mo 0.05. pH and electrical conductivity of the nutrient solution were measured before each addition. Their values ranged from 5.6 to 6.4 for pH and around 1 dS/m for conductivity.

2.2. Fruit sampling

Yield per plant, determined as early fruit production (before the 31st March; early plant yield, g $plant^{-1}$) and total production over the experimental period were recorded (from 23st of January to 31st of May; total plant yield, g $plant^{-1}$). From each plant per cultivar and per treatment, *ca*. 150 g of fruits were harvest at fully ripe stage (April 2009), assessed for absence of physical damage and used for further analysis. Briefly, strawberry fruit without calyxes were weighed and cut in half longitudinally and were immediately snap frozen in liquid nitrogen. Samples were stored at −80 °C before being freeze-dried in a Telstar Cryodos freeze drier (Telstar Cryodos, Terrassa, Spain) for 4 days at 0.023 mBar and −82 °C. Lyophilized samples were then ground in a pestle and mortar, weighed, and returned to the freezer in plastic freezer bags until analysis.

2.3. Extraction and quantification of sugars and non-volatile organic acids

Sugars and organic acids were extracted and quantified as described elsewhere (Terry et al., 2007; Giné Bordonaba and Terry, 2008; Crespo et al., 2010; Giné Bordonaba and Terry, 2010). Sugar content in strawberry extracts was determined using an Agilent 1200 series HPLC binary pump system (Agilent, Berks., UK), equipped with an Agilent refractive index detector (RID) G1362A (Giné Bordonaba and Terry, 2010), whereas organic acid concentrations (*viz*. L;-ascorbic, malic and citric) were detected at 210 nm using an HPLC system comprising a P580 pump, Dionex STH column thermostat, GINA 50 automsampler and a UVD 170S/340S detector (Dionex, Sunnyvale, CA) (Terry et al., 2007; Giné Bordonaba and Terry, 2009). The sugar to acid ratio was then calculated as the total sugar content divided by the total acid content of the fruit. The sweetness index was calculated as described in Giné Bordonaba and Terry, 2010.

2.4. Extraction and quantification of health-related compounds

Individual anthocyanins were extracted as described elsewhere (Terry et al., 2007; Giné Bordonaba and Terry, 2008; Crespo et al., 2010; Giné Bordonaba et al., 2011) by mixing 150 mg of freeze-dried sample with 3 mL of 70% (v/v) methanol and 0.5% (v/v) HCl in HPLC-grade water. Briefly, the slurry obtained was held at 35 °C in a water bath with constant shaking for 1.5 h; mixing the samples every 15 min. Finally, the flocculate obtained was filtered through a 0.2 μm Millex-GV syringe driven filter unit (Millipore Corporation, MA) and the clear extract analyzed by HPLC coupled to Diode Array Detector (DAD) based on the acetonitrile-free HPLC method reported by Giné Bordonaba et al., 2011. Eluted anthocyanins were detected at 520 nm, the presence and quantity of each analyte were calculated by comparing peak area with standards of cyanidin-3-glucoside (Cya-3-gluc) and pelargonidin-3-glucoside (Pg-3-gluc) (Extrasynthese, Lyon, France). Free ellagic acid was directly quantified from the same extract as described for individual anthocyanins. Total ellagic acid concentrations were determined after an optimised acid hydrolysis method according to Vrhovsek et al. (2006) with some modifications. Briefly, 300 mg of strawberry freeze-dried extract were dissolved in 5 or 4 mL of 70% (v/v) aqueous methanol and 1 or 2 mL of 32% HCl (v/v), respectively, making a final extract volume of 6 mL. Extraction was performed in a water bath at 90 °C during different time intervals (0, 60, 90, 120 and 180 min). The flocculate obtained after acid hydrolysis was filtered through a 0.2 μm Millex-GV syringe driven filter unit (Millipore Corporation, MA) and the clear extract analyzed. Both free and total ellagic acid (EA) concentrations in fruits were determined using the same HPLC conditions as described for individual anthocyanins. Eluted EA concentrations were detected at 254 nm and