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Relationships between strawberry fruit quality attributes and crop load

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ABSTRACT

Crop load can influence fruit quality in several horticultural species. The aim of the present study was to determine the effect of different concentrations of calcium on crop quality traits in three short-day strawberry (*Fragaria × ananassa* Duch.) cultivars ('Ventana', 'Camarosa' and 'Candonga') and to assess the relationships between crop load and quality parameters. The studies were conducted using a hydroponic system in a greenhouse. Calcium was added as $Ca(NO_3)_2$ at 2 mM, 3 mM, 4 mM and 5 mM. A completely randomized block design (4 Ca concentrations × 3 cultivars) with three replicates was used. Each replicate consisted of 12 plants grown in polyethylene bags (100 cm × 18 cm × 3 cm) filled with coconut peat. Titratable acidity, total soluble solids and firmness were measured throughout the experimental period. Calcium application had no effect on fruit quality attributes but the genotype effect was clear. At the end of the experiment (28th May, 2008), titratable acidity was positively related to the fresh weight of above-ground biomass and number of leaves respectively in the 'Ventana' and 'Camarosa' cultivars. Higher values of total soluble solids were found at low crop load in 'Ventana' but in 'Camarosa' this relation was not found. In 'Candonga', higher total soluble solids were linked to crop load. In 'Ventana', titratable acidity significantly decreased as crop load increased, and in 'Camarosa' high values of titratable acidity were found at different values of crop load. 'Ventana' seemed to be more sensitive to the effects of crop load patterns. Genotype was an important factor in determining fruit quality parameters.

1. Introduction

Calcium (Ca) is a nutrient that differs from others as it appears in fleshy fruit only in small amounts, and far less than in leaves. The role of Ca in the regulation of fruit maturation and ripening processes is well-established (Ferguson, 1984). Ca is one of the most important nutrients involved in fruit ripening specifically because of its role in cell wall strengthening and membrane function (Poovaiah et al., 1988). Improving fruit Ca concentrations is often difficult to achieve. Attempts to increase Ca fruit levels have not always been successful and the results are often contradictory (Roy et al., 1999; Joyce et al., 2001). It is known that low fruit Ca content may lead to physiological and pathological disorders, and the fruits affected usually have a short shelf life (Fallahi et al., 1997). As a result, Ca is applied before and after harvesting to prevent physiological disorders, delay ripening and improve the quality of fruits crops, including the strawberry (Asrey et al., 2004; Dunn and Able, 2006; Hernández-Muñoz et al., 2006). However, while postharvest Ca treatments can be effective in raising fruit Ca levels in apples, the effectiveness of preharvest Ca sprays is less certain (Fallahi et al., 2010). In apples, sprays of soluble Ca reduce the incidence of bitter pit but do not always increase Ca concentration in cortical tissue (Fallahi et al., 2010). In strawberries, Ca is implicated in some fruit physiological disorders (Sharma et al., 2006) but Palencia et al. (2010) observed that the incidence of tipburn was also related to foliar K:Mg and K:Ca ratios.

It is well-known that consumers now pay much more attention to food quality traits. Nutritional value of strawberry fruits is demanded by growers and consumers for general health benefits and quality can be described by several parameters, including antioxidant capacity (Capocasa et al., 2008). Strawberry fruits is a source of micronutrients and phenolic compounds, most of which are natural antioxidants and contribute to a high nutritional quality (Roussos et al., 2009; Tulipani et al., 2011). Consumers also prefer sweet strawberries, and sweetness is positively correlated to soluble solid content. Fruit soluble solids and titratable acidity (TA) are quantitatively inherited (Shaw, 1990), and Keutgen and Pawelzik (2007) reported that decreasing soluble solid content in strawberries results in lower consumer acceptance of fruits.

Strawberry plant morphology is affected by cultivation practices, and plant size is related to fruiting potential. The stored assimilates in the crowns and roots have been reported to improve strawberry plant performance after a period in cold storage (Lieten

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et al., 1995). Whitehouse et al. (2009) proposed manipulating the production pattern of two strawberry cultivars by defoliating the plants, and therefore changing the normal course of source to sink pathways. The cropping pattern was changed, but cultivars respond differently to defoliation treatments.

Crop load (CL) may influence fruit quality in certain horticultural species. In apples cv. 'Jonagold', Stopar et al. (2002) found that lower CL (expressed as the number of fruits per crown) increased total polyphenols, but this response was not observed in other cultivars (Unuk et al., 2006). In peaches, increased CL negatively affected fruit soluble sugars and titratable acidity (TA), but the result was dependent on the scion/rootstock combination (De Salvador et al., 2007). It is possible to assume that any increase in the plant's biomass production (such as the number of leaves or fresh weight) may change the nutritional allocation patterns in fruits, with direct implications for crop quality. Therefore, quality parameters may change according to CL seasonal variations, an issue which, to our knowledge, yet to be studied in strawberries.

The aim of the present study was to determine the effect of different concentrations of Ca on fruit quality traits in three short-day strawberry (*Fragaria* × *ananassa* Duch.) cultivars ('Ventana', 'Camarosa' and 'Candonga') and to assess the relationships between CL and fruit quality parameters.

2. Materials and methods

The studies were conducted in a transparent polyethylene greenhouse measuring 160 m^2 at the Gambelas *Campus* of the University of Algarve, Portugal (7°58′W, 37°02′N) from October 2007 to May 2008. Three different short-day strawberry cultivars ('Ventana', 'Camarosa' and 'Candonga') were grown in polyethylene bags (100 cm × 18 cm × 3 cm) containing coconut peat (Pelemix Spain, S.L., Murcia-Spain), in an open soilless growing system. The polyethylene bags were mounted on support structures at a height of 100 cm and were watered by a drip irrigation system with one dripper per bag delivering 8 L h^{-1}. A complete concentrated fertilizer solution (without Ca) was injected into the irrigation system from a stock tank throughout the growing season. The nutrient solution consisted of (mg L^{-1}): N 271, P 702, K 586, Mg 207, S 414, Fe 8, Mn 4, Cu 0.3, Zn 0.8, B 0.7 and Mo 0.3, in accordance to the standard crop cultivation practices (Palencia et al., 2010).

Each cultivar was fed with four different Ca concentrations (2 mM, 3 mM, 4 mM and 5 mM) supplied as $Ca(NO_3)_2$. The smallest Ca concentration (2 mM) corresponded to that of the irrigation water. Additional Ca was applied using inverted glass bottles (1 L of calcium nitrate) placed 30 cm above the bags. These solutions were applied once per week and each bottle was replenished just before the next application.

Ripe fruits from each treatment (cultivar × Ca concentration) were harvested throughout the period of the experiment. Yield per plant were also calculated. Harvested fruits per bag were graded into two commercial classes: class-1 (fresh weight ≥22 g per fruit) and class-2 fruits (fresh weight <22 g per fruit). The first sampling was taken in February 2008 and the last in May. At each sampling date, all fruits from each bag and treatment were gathered for quality assessment and converted into pulp using a mixer. TA expressed as g of citric acid 100 g^{-1} (fresh weight) was measured in each treatment by titrating 10 g of the pulp plus 10 mL of H_2O with 0.1 mol L^{-1} NaOH up to pH 8.1. Total soluble solids (TSS, expressed as °Brix) was determined using an automatic temperature-compensated PR101 digital refractometer (Atago Pallette PR101). Firmness was evaluated in a sub-sample of 3–4 fruits from each treatment and in four sampling dates using a portable penetrometer. Results were expressed in g cm^{-2}.

The number of leaves (NL) was registered throughout the period of the experiment in previously selected plants from each treatment. CL was calculated as the ratio between yield and the NL per plant, registered on the same date or on the closest date. Since fruit thinning was not done, the patterns obtained correspond to natural crop behaviour. At the end of the experiment (28th May, 2008), plants from each treatment were removed from the bags and the total fresh weight of the above-ground biomass (leaves and crowns) was recorded.

The experimental design was a complete randomized block (3 replicates × 4 Ca concentrations × 3 cultivars). Each replicate consisted of one polyethylene bag with 12 plants. The main effects (Ca level and cultivar) on quality parameters were evaluated by variance analysis. Means were compared using Duncan's multiple range test with a significance level at 5%. Linear models were used to describe the relationships between vegetative (NL and biomass) and fruit quality parameters at the last harvesting date (28th May). The best-fitted models were chosen with regard to the variation of quality parameters due to CL values. All data analysis was carried out with the SPSS program version 17.0.

3. Results

At the end of the experiment, NL was similar in 'Camarosa' and 'Ventana'. Lower NL was found in 'Candonga' (Table 1) but with no statistical significance.

Total yield per plant was 172 g, 93 g and 130 g respectively for 'Ventana', 'Camarosa' and 'Candonga' (Table 1). The 'Ventana' cultivar had the highest accumulated production in cycle (24.8 kg). Also, a greater percentage of heavier fruits (class-1) were found in 'Ventana' compared to other cultivars.

TA was different between cultivars but similar between Ca treatments (Table 2). Lower values were obtained in 'Ventana' plants in February, March and May, compared to other cultivars. TA varied from 0.24 ('Ventana'-26th March) to 0.42 ('Camarosa'-28th May). The highest TA level was obtained from 'Camarosa' and 'Candonga' fruit. Regarding TSS, Ca application had no effect despite the small differences observed on the first sampling date (Table 3). 'Ventana' fruits had lower TSS values on several sampling dates compared to 'Candonga' and 'Camarosa' (Table 3). TSS ranged from 6.23 °Brix ('Ventana'-22nd February) to 10.35 °Brix ('Camarosa'-14th March). The effect of Ca treatments on fruit firmness remained unclear (Table 4). However, 'Ventana' fruits were less firm than 'Candonga' and 'Camarosa' fruits. It appears that the effect of genotype on fruit quality parameters is more important than Ca application.

In order to look if a relationship exists between fruit quality parameters and vegetative growth, several regression models were

Table 1
Number of leaves and yield per plant of three cultivars, pooling together the calcium treatments at the end of the experiment (28th May, 2008). Percentage of class-1 and class-2 fruits is also shown. SD: standard deviation.

Cultivar	Number of leaves (NL) ± SD	Yield per plant (g $plant^{-1}$)	Distribution of fruits per class (%)	
			Class-1	Class-2
'Ventana'	22.3 ± 2.8	172	26.0	74.0
'Camarosa'	22.3 ± 5.3	93	7.4	92.6
'Candonga'	21.8 ± 1.8	130	10.5	89.5