15. QUALITY OF TWO TOMATO CULTIVARS GROWN UNDER DIFFERENT AGRONOMICAL CONDITIONS

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Abstract
Quality of two tomato cultivars ('Dundee' and 'V1') produced in greenhouses, under different agronomical conditions during a season, was studied. The main goal was to measure quality of tomato fruits produced under different environmental conditions, and to understand their influence on final quality. To achieve this objective several physical and chemical general quality parameters were evaluated and to study nutritional quality, antioxidants (lycopene, beta-carotene, vitamin C) and total sugars (fructose and glucose) were analyzed. Analyses of variance were performed considering the factors "Harvest time", "Cultivar" and "Agronomical conditions" that correspond to the different conditions inside greenhouses. The MANOVA statistical analysis revealed that all the factors considered were significant as well as their interactions. The factor "Harvest time" was the most important to explain the differences. The 'V1' fruits produced in the metallic greenhouse without additional CO_2 had higher and more homogeneous weight values and also higher skin firmness. The colour coordinate a* was generally lower for fruits grown in traditional greenhouse. 'Dundee' fruits reached the highest SST medium value of 6.37 °Brix. Biosynthesis of lycopene and vitamin C was affected by agronomical conditions and also predetermined by cultivars. 'Dundee' cultivar seems to be more sensitive to agronomical conditions than the 'V1'. Beta carotene content was mainly due to genetic factors. The 'V1' exhibited higher values of beta carotene for all the greenhouse conditions.
Keywords: antioxidants, physical-chemical analysis, quality parameters, tomato

Introduction
Traditionally fruit consumers prefer products that exhibit an adequate ripeness stage, freshness, good flavor and aspect, and after these aspects they consider nutritive value and price (Shewfelt 1993). However, nowadays consumers are becoming more informed about nutritional quality of food and its significance in health maintenance.

The importance of antioxidant intake on human diet as a prevention strategy of developing some types of cancer and coronary heart disease is a fact of common knowledge (Sabio *et al.* 2003). Tomatoes are consumed all over the world and can provide an important amount of total antioxidants in the human diet, mainly lycopene with unique antioxidant properties (Calvo & Santa-María 2008). The antioxidant content of tomato mostly depends on genetic, environmental and ripening factors (Martinez-Valverde *et al*. 2002).

Quality characteristics of tomato depend upon cultivar, agronomical conditions, ripening at harvest and storage conditions, mainly if considering sugar content, acidity and flavour used by consumers to define quality (Nuez 2000). However, colour and firmness are the characteristics more appreciated by consumers when buying tomato.

The interest of studying different agronomical conditions is due to technical changes introduced by growers from the south of Portugal, Algarve, in order to produce during all year: greenhouses of wood structure, covered with PE were changed by new greenhouses with metallic structures, equipped with heating and hydroponic systems. Sometimes, in order to improve yield, the addition of CO_2 in the inside atmosphere is also used (Islam *et al.* 1996; Reinert *et al.* 1997).

The main goal was to measure quality of tomato fruits produced under different environmental conditions, and to understand their influence on final quality. To achieve this objective were evaluated physical and chemical parameters and studied nutritional quality antioxidants (lycopene, beta-carotene, vitamin C) and sugars (fructose and glucose).

Material & Methods

Plant Material and Experimental Design

Two tomato (*Lycopersicum esculentum* Mill) cultivars, 'V1' (Hazera ©) and 'Dundee' (Ruitter Seeds ©) both suitable to hydroponic greenhouse cultivation, were grown in the region of Algarve under different greenhouses: A - traditional greenhouse with wood structure; B- metal greenhouse, with heating system (day temperatures of 25 ºC and night of 12 ºC), and C- metal greenhouse with the same temperatures and addition of CO_2 (500 to 700 ppm).

Fruits were harvested during the usual season at mature light red stage, considered adequate to commercial purposes. Five harvest dates were considered (2nd May, 17th May, 5th June, 19th June and 5th July), and 20 fruits of each modality were randomly picked up on each day. Tomatoes were carefully accommodated inside isothermal boxes and transported to the Post-harvest and Technology Laboratory at the University of Évora. For nutritional evaluation samples of 5 fruits of each modality were harvested at mature light red stage at middle season and kept at -80 ºC until analysis.

The experimental design was factorial: "Cultivar" ('Dundee' and 'V1'), "Agronomical conditions" (A, B and C), and "Harvest time" (1st, 2nd, 3rd, 4th and 5th harvest day).

Physical and Chemical Analysis

Samples of 10 fruits of each modality were submitted to physical analysis. Tomato weight was measured by using a centesimal balance (Mettler Toledo PB 1502). External color (L* a* b* coordinates color space) was measured using a colorimeter Minolta CR-300, and two measurements per fruit were made along the equatorial axis. Textural characteristics of epidermis (skin) and mesocarp (pulp) were evaluated with a Texture Analyser TA-HDi using a 3 mm diameter cylindrical probe until a maximum deformation of 10mm; each test was performed three times in the equatorial region of each fruit. To evaluate the epidermis, the maximum force (MFSkin) was considered and the firmness of the pulp was measured as the stable force after skin rupture.

Total soluble solids (TSS) was measured twice on juice from each tomato, using a digital refractometer Atago (ATAGO, Inc. Kirkland, WA, USA) and results were expressed as ºBrix. Titratable acidity (TA) was measured on juice from each tomato, using a Crison Compact Titrator, with NaOH 0.1N, to pH 8.2 (ISO 750 – 1981), and results were expressed as citric acid percentage.

Antioxidants (Lycopen, Beta-carotene and Vitamin C), Fructose, Glucose and Total sugars were determined at the laboratory of INTAEX (Junta de Extremadura) Three repetitions of each sample were performed.

The glucose, fructose and total sugar contents were measured according to the method described by Lozano *et al.* (2007) by making up 2 g of homogenate to 10 mL with deionised water, passing it through a 0.45 μm filter and injecting it into an HP 1050 chromatograph (Agilent Technologies, Inc., Palo Alto, USA) using a Zorbax NH2 5 μm 4.6×250 mm column and a refractive index detector. Calibrations were carried out for each sugar (D(+)-anhydrous glucose Merck 8337.0250, D(-)-fructose Fluka 47739, sucrose Sigma S5016).

The total amount of lycopene and beta-carotene were determined by high performance liquid chromatography (HPLC), using 5 g of fruit homogenate with an HP 1100 chromatograph, diode-array detector (DAD) (Agilent Technologies, Inc., Palo Alto, USA.) equipped with a 10-μm Lichrosorb RP-18 column (4.6×250 mm) and using acetone (solvent A, HPLC grade from Merck) and water (solvent B) as eluents. An isocratic elution was used: first, 10 min with a solvent composition of 75% A/25% B and, then, 20 min with 95% of solvent A/5% of solvent B. By comparing the retention times of the two pigments in the extract mixture with those of their respective standard compounds (Sigma), lycopene and beta-carotene were identified. Qualitative analysis of lycopene was also carried out by comparing the UV-visible spectrum of the obtained sample with that of the standard compound.

Vitamin C was extracted from 9 g of fruit homogenate with EDTA/H_3PO_4 (85%) solution, and was determined by HPLC in an HP 1050 chromatograph, diode-array detector (DAD) (Agilent Technologies, Inc., Palo Alto, USA), equipped with a 5 μm Agilent Zorbax SB-C8 column (4.6x250 mm) at 30 ºC. The eluent was 50 mM acetic/acetate pH=4.

Data Analysis

Data were analyzed by ANOVA (MANOVA), for physicochemical values considering three variables "Harvest time", "Cultivar" and "Agronomical conditions". When necessary mean comparisons were performed using Tukey test for $p<0.05$. For antioxidants and sugars, two variables, "Cultivar" and "Agronomical conditions", were considered. For all the statistical analysis Statistica 6.0 program was used.

Results & Discussion

Cultivars behaved differently under the different agronomical greenhouse conditions. However, 'V1' tomato fruits produced in the metallic greenhouse without added CO_2 showed higher and more homogeneous weight values and also better resistance to manipulation during postharvest, due to higher skin firmness values (Table 1).

Table 1. Analysis of variance of general quality parameters considering three factors "Harvest time", "Cultivar" and "Agronomical conditions" for $p<0.05$.

Parameters	Factors	F	p
Weight	Harvest time	*67.029*	0.000
	Cultivar	*19.732*	1.3E-05
	Agronomical conditions	*8.857*	0.0002
Colour a*	Harvest time	*49.227*	0.000
	Cultivar	*54.186*	2.21E-12
	Agronomical conditions	*71.026*	1.64E-25
Skin Firmness	Harvest time	*70.229*	0.000
	Cultivar	*35.149*	9.3E-09
	Agronomical conditions	*3.798*	0,024
Pulp Firmness	Harvest time	*74.487*	0.000
	Cultivar	*19.648*	1.36E-05
	Agronomical conditions	*42.134*	1.19E-16
TSS	Harvest time	*173,676*	0,000
	Cultivar	*9.741*	0.002
	Agronomical conditions	*13.248*	6.33E-06
TA	Harvest time	*50.102*	0.000
	Cultivar	*34.367*	1.3E-08
	Agronomical conditions	*33.220*	1.3E-13
TSS/TA	Harvest time	*70.221*	0.000
	Cultivar	*97.375*	8.2E-20
	Agronomical conditions	*19.279*	1.5E-08

The colour coordinate a* (green-red) was generally lower for those fruit grown in the traditional greenhouse.

The evaluation of quality was mainly supported by values of TSS, TA and TSS/TA. The ratio TSS/TA often had values higher than 10, referred by Kader *et al.* (1978) as an indicator of good quality. However 'V1' presented those values more often. Cultivar Dundee reached the highest medium TSS value of 6.37 °Brix. Results of TA were higher than that of 0.32%, referred by the same research team as a value of good quality.

In general, the results of Manova for all the instrumental parameters revealed that the factors considered were significant (Table 1), as well as their interactions (data not shown), and "Harvest time" was the one that most contributed to the differences in most cases.

Biosynthesis of lycopen and vitamin C in both cultivars were affected by agronomical conditions and also predetermined by genetic characteristics of cultivars. The 'Dundee' exhibited better results of these constituents, mainly for fruits produced inside metallic greenhouses (Fig 1). These greenhouses maintain

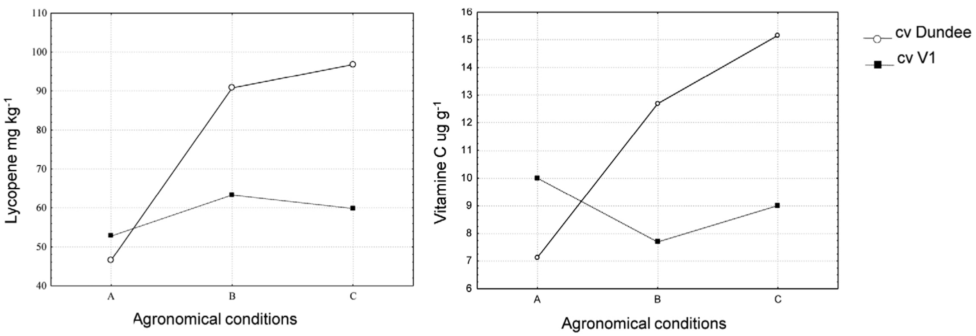

Fig 1. Means of lycopene and vitamin C content of 'Dundee' and 'V1' from different agronomical greenhouse conditions.

more stable and higher inside temperatures. According to Martinez-Valverde *et al.* (2002), lycopene synthesis is favoured at temperatures between 16 and 21 °C and inhibited at temperatures above 30 °C. On the other hand, Dumas *et al.* (2003) affirmed that since the antioxidant content of tomatoes may depend on genetics factors the choice of varieties cultivated may affect the results at harvest. The 'Dundee' seems to be more sensitive to agronomical conditions than the other cultivar.

Beta-carotene revealed a different behaviour than lycopene and vitamin C, being determined mainly by genetic reasons and not affected by agronomical conditions (Table 2). The 'V1' exhibited higher values of beta-carotene for all the greenhouse conditions. Both cultivars had a different response to temperature, light and CO_2. For instance 'Dundee' had higher Beta carotene content in fruits produced under metal greenhouse with CO_2 and 'V1' had better results without it (Fig 2).

Low values of vitamin C were obtained for fruits of both cultivars grown in the traditional greenhouse. Temperatures acted as a limiting factor on vitamin C production. Adequate regimes of temperatures allow reaching the potential level of vitamin C. Under greenhouse conditions, seasonal variation on vitamin C content of 'Jumbo' tomato ranged 70 to 230 mg kg^{-1} fwt at the mature-green stage, and was directly correlated with the temperature variations (Liptay *et al.* 1986). From the ANOVA results it can be said that vitamin C content is influenced by the cultivar, the agronomical conditions, and their interaction (Table 2).

Table 2. Analysis of variance of some chemical quality parameters considering two factors "Cultivar" and "Agronomical conditions" for $p<0.05$.

Chemical parameters	Factors	*F*	P
Lycopene	Agronomical conditions	*46.219*	0.000
	Cultivars	*50.102*	0.000
	Interaction	*22.729*	0.000
Beta-carotene	Agronomical conditions	*2.724*	0.106
	Cultivars	*12.082*	0.005
	Interaction	*0.140*	0.871
Vitamin C	Agronomical conditions	*6.888*	0.010
	Cultivars	*12.692*	0.004
	Interaction	*13.406*	0.001

The higher concentration of total sugars was found for 'Dundee' tomatoes produced in metallic greenhouse with CO_2. For cultivar V1 sugar concentration did not show any sensitivity to CO_2 level (Fig 2).

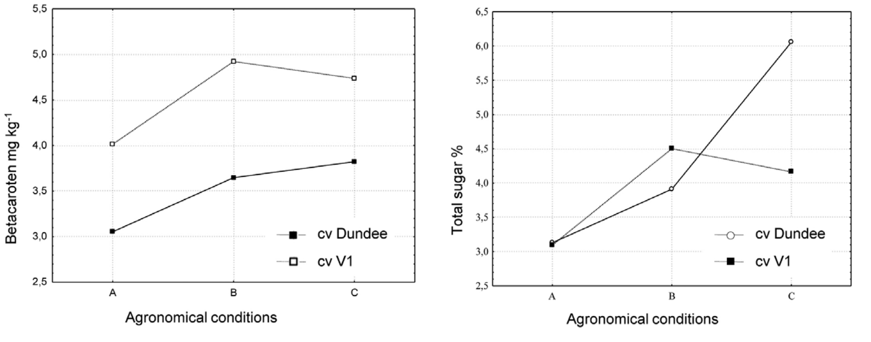

Fig 2. Means of beta-carotene content and total sugars of 'Dundee' and 'V1' obtained from different agronomical greenhouse conditions.

The lowest concentrations of antioxidants and sugars in the fruits produced under the traditional greenhouse can be justified by temperatures not properly maintained and less light intensity.

Excess of vegetative growth can cause a decrease on Beta carotene and vitamin C because it is necessary that radiation reaches the fruits to improve synthesis of these compounds (Dumas *et al*. 2003). Vitamin C produced in tomatoes 'V1' was higher in those from traditional greenhouse because plants had less leaves, so solar radiation could reach the surface of those fruits. The usual technique of taking off some leaves in order to promote aeration inside the plantation should be promoted to increase also the production of Beta-carotene and vitamin C, mainly with cultivars that tend to have too many leaves.

The different agronomical factors studied influenced the quality of tomato and both the metallic and heated greenhouses exhibited good conditions for improving quality.

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