The Influence of Photo-selective Shade Nets on Quality of Tomatoes Grown Under Plastic Tunnels and Field Conditions

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Abstract

The growth environment of a tomato affects its composition. The quality of tomatoes is affected by environmental factors (light and temperature) and agronomic techniques used (open field or plastic tunnel production). The photo-selective netting concept (screenhouse) and colour nets, integrated with plastic tunnels, were studied in a tomato 'Vedeta' cultivation in the south part of Serbia (Aleksinac) during summer months, using four different colour shade-nets (pearl, red, blue and black) with relative shading (40% PAR). Exposure to full sunlight and plastic tunnels was used as a control. Fruits produced in an open field were more acidic and had greater titratable acidity (0.37% citric acid) compared to fruits from a plastic greenhouse (0.34% citric acid). In addition, fruits grown in the field had greater TSS content (5.42°Brix) than tomatoes grown in a protected environment (5.10°Brix). Moreover, fruits produced in the field had greater TSS:TA ratios than those produced in a protected environment. Significantly higher lycopene content was observed in plastic-house tomatoes integrated with red shade netting technologies (64.9 μg g⁻¹) than in field-grown tomatoes (48.1 μg g⁻¹). By contrast, shaded fruits had lower content of β-carotene. The results of the present study provide useful data for detecting differences among environment variation in tomato composition and colour shade nets.

Key words: dry matter, soluble solid, pH-values, total acid, lycopene, β-carotene

Introduction

The tomato (Solanum lycopersicum L.) is one of the world's most important vegetables, with an estimated total production of about 141.40 million tonnes in 2009 (FAOSTAT 2009). It is the second most widely consumed vegetable after the potato (Gastélum-Barrios et al., 2011). Tomatoes find numerous uses in both fresh and processed forms (Kacjan-Maršić et al., 2010) in the human diet and it is an important source of micronutrients, notably lycopene, β-carotene, α-tocopherol, phenolic compounds, certain minerals (notably potassium) and carboxylic acids, including ascorbic, citric, malic, fumaric and oxalic acids (Caputo et al., 2004; Hernandez Suarez et al., 2008; Sgherri et al., 2008). They have beneficial effects on human health (Franceschi et al. 1994). Friscianite et al. (2000) reported that the consumption of tomatoes and its subproducts (i.e., ketchup, paste) is negatively correlated with the development of tumours in the digestive tract and the prostate.

Tomato quality is influenced by genetic and environmental factors such as climatic conditions; temperature and light (Dumas et al. 2003; Caliman et al. 2010) and cultural practices; soil type (Papadopoulos, 1991), nutrient and water supply, harvesting method, maturity stage at harvest (Kader, 1986) and postharvest handling (Dorais et al., 2001). In traditional vegetable-producing regions, tomato cultivation in a protected environment has expanded to prevent seasonality in the availability of fruit (Andriolo et al. 2000). Alterations in light intensity, temperature and relative humidity occur in protected environments and can affect the production and the partitioning of photo-assimilates in the plant and, consequently, the composition of the produced fruit (Martinez, 1994; Bakker, 1995).
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In Serbia shading is usually applied on greenhouses in summer (Ilić et al., 2012) in order to reduce the solar radiation and air temperature and consequently minimize fruit physiological disorders (Milenković et al., 2012). The benefit of shade on tomato quality in this case was due to less blossom end rot and cracked skin (Lorenzo et al. 2003). Netting is frequently used to protect agricultural crops from excessive solar radiation, improving the thermal climate (Kittas et al., 2009), sheltering from wind and hail, and exclusion of bird and insect-transmitted virus diseases (Teitel et al., 2008). It is either applied by itself over net-house constructions, or combined with greenhouse technologies (Shahak et al., 2004). Movable shade, applied only during sunny periods, is less deleterious than constant shade (Adams et al., 2001). Shade netting not only decreases light quantity but also alters light quality to a varying extent and might also change other environmental conditions (Shahak et al., 2004). It is well known that shading decreases the sugar content (Davies and Hobson 1981), ascorbic acid (Giovanelli et al., 1999) and pigments (carotenoids) (Davies and Hobson (1981) of tomato fruit. The maturity index (ratio of TSS to titrable acidity-TA) is a good indicator of tomato ripeness (Gonzalez-Cebrino2011). Kader et al. (1978) suggest that high quality fruits should have TSS:TA ratios of 10, thus being adequate for fresh consumption. Fruits produced in the field have higher TSS:TA ratio, acidity, as well as more reducing sugar, ascorbic acid, and TSS compared to fruits produced in protected conditions (Caliman et al., 2010).

Over the past 10 years many studies have been undertaken to improve the carotenoid content in tomato fruits through modification of cultivation practice (Hirschberg, 2001; Bramley, 2002). As many authors have reported, various biotic and abiotic factors, such as genotype, fruit maturity level (Dumas et al., 2003), cultivation practice (Abushita et al., 2000; Kuti and Konuru, 2005), plant nutrient status (Abushita et al. 2000; Binoy et al., 2004) and environmental conditions (Kuti and Konuru, 2005; Raffo et al., 2006) influence the content of carotenoids in tomato fruits. According to some authors (Farkas, 1994; Dumas et al., 2003; Lumpkin, 2005), lycopene production is inhibited when the environmental temperature is above 32°C. Consequently lycopene accumulation is inhibited, mostly because of the conversion of lycopene into β-carotene (Dumas et al., 2003). Although the formation of carotenoids in mature fruits does not require induction by light, shaded fruits have lower content of carotenoids (Dorais et al., 2001). The aim of this work was to study the tomato fruit quality in fruits from screenhouses (only colour shade nets) and plastic houses (integrated with colour shade nets) during the summer in south Serbia.

Material and methods

Tomatoes (Solanum lycopersicum L. cv. Vedeta) were tested in greenhouse production (plastic tunnels - 2.5 m high, covered by termolux 150 μ) during 2008-2010. The experiments were performed in an experimental garden located in the village of Moravac near Aleksinac, (longitude: 21°42’ E, latitude: 43°30’ N, altitude 159 m) in the central area of south Serbia. The shade nets were applied at the start of warm weather in early June. The houses were shaded for the rest of the summer and vegetables were harvested until late August. A completely randomized block design was used, with four blocks assigned to each of four treatments (black, pearl, blue and red net) plus control. Each treatment and block consisted of four rows of 20 plants.

Plant material. The plants were grown following the technique usually implemented by the local producers. Seedlings were transplanted on 5 May (planting density was 2.6 plants m⁻²), the shading nets were subsequently installed above the crop on 10 June (35 days after transplanting) and the measurements were carried out until late August. All plants were drip irrigated. The tomatoes used in the study were harvested at the mature-pink stage.

Net characteristics. In order to test the effect of shading nets (colour and shading intensity), four different shading nets were used: the photo-selective nets including “coloured-ColourNets” (red, blue and black) as well as “neutral-ColourNets” (pearl) with shading intensity of 40% relative...
shading (photosynthetically active radiation (PAR). The shading nets were compared to the open field microclimate and production. The colour shade nets were obtained from Polysack Plastics Industries (Nir-Yitzhak, Israel) under the trade mark ChromatiNet. The shading nets were mounted on a structure about 2.0 m in height over the plants (screenhouse) or combined with greenhouse technologies.

**Light interception by nets.** The effect of nets on the interception of light was measured annually as a percentage of total PAR above canopy, using a Ceptometer mod. Sun Scan SS1-UM-1.05 (Delta-T Devices Ltd Cambridge, UK) with a 64-sensor photodiode linearly sorted in a 100 cm length sword. Readings were in units of PAR quantum flux (μ mol m\(^{-2}\) s\(^{-1}\)).

The Solarimeter- SL 100 is an easy-to-use portable autonomous solarimeter that measures the solar irrigation range from 1 W m\(^{-2}\) to 1300 W m\(^{-2}\). All spectral data were expressed as radiation intensity flux distribution in W m\(^{-2}\) nm\(^{-1}\).

**Table 1.** Reduction (%) of solar radiation (W m\(^{-2}\)) and photosynthetically active radiation (PAR) μmol m\(^{-2}\)s\(^{-1}\) of the control at noon of sunny day in July by different colour shade nets

<table>
<thead>
<tr>
<th>PH + colour-nets</th>
<th>Only colour nets</th>
<th>PH+ colour-nets</th>
<th>Only colour nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40% 50%</td>
<td>40% 50%</td>
<td>40% 50%</td>
</tr>
<tr>
<td>percent of the reduction in compared with the control radiation (Wm(^{-2}))</td>
<td>percent of the reduction in compared with the control PPFD* (μmol m(^{-2}) s(^{-1}))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>44.0 46.2</td>
<td>51.2 57.0</td>
<td>66.9 90.0</td>
</tr>
<tr>
<td>White</td>
<td>54.4 74.1</td>
<td>66.7 82.0</td>
<td>64.7 94.4</td>
</tr>
<tr>
<td>Blue</td>
<td>72.0 91.7</td>
<td>80.8 98.7</td>
<td>72.7 101.3</td>
</tr>
<tr>
<td>Black</td>
<td>108.0 107.0</td>
<td>101.7 125.0</td>
<td>90.9 143.8</td>
</tr>
<tr>
<td>Control PH+</td>
<td>857</td>
<td>OF++</td>
<td>1112</td>
</tr>
</tbody>
</table>

Control: PH+-plastic house; OF++- open field (exposure to full sunlight).

*PPFD - photon flux density

**Weather measurement.** Monthly meteorological data from May to September 2008 and 2009 from the meteorological station in Aleksinac were used (Table 2).

**Table 2.** Temperature (°C) and solar radiation (MJ/m\(^{2}\)) during the growing season (Aleksinac)

<table>
<thead>
<tr>
<th>Month</th>
<th>TS 2008</th>
<th>TOD 2008</th>
<th>TX 2008</th>
<th>TM 2008</th>
<th>MSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maj</td>
<td>18.4</td>
<td>18.7</td>
<td>2.1</td>
<td>25.1</td>
<td>11.8</td>
</tr>
<tr>
<td>Jun</td>
<td>22.6</td>
<td>20.9</td>
<td>1.4</td>
<td>29.2</td>
<td>15.6</td>
</tr>
<tr>
<td>July</td>
<td>22.9</td>
<td>23.3</td>
<td>1.6</td>
<td>29.9</td>
<td>15.7</td>
</tr>
<tr>
<td>August</td>
<td>23.5</td>
<td>23.5</td>
<td>2.4</td>
<td>31.3</td>
<td>15.6</td>
</tr>
<tr>
<td>Septem</td>
<td>16.6</td>
<td>19.0</td>
<td>0.6</td>
<td>22.7</td>
<td>11.1</td>
</tr>
</tbody>
</table>

TS-mean monthly air temperature (°C); TOD-temperature deviation from 1961-1990 average (°C); TX-mean daily temperature maximum for month (°C); TM-mean daily temperature minimum for month (°C); MSR, mean daily solar radiation (MJ/m\(^{2}\));

**Quality trail.** Tomato samples (20 fruits) were collected each year from June until August and were taken from the third to sixth floral branches.

Total soluble solids (TSS) were determined for each sample fruit in two replications using an Atago DR-A1 digital refractometer (Atago Co. Ld., Japan) at 20°C and expressed as °Brix. The titratable
acidity (TA) was measured with 5 ml aliquots of juice that were titrated at pH 8.1 with 0.1N NaOH (required to neutralize the acids of tomatoes in the presence of phenolphthalein) and the results were expressed as grams of citric acid per 100 g of fresh tomato weight. The TSS to TA ratio (ripening index) was also calculated. The pH of the extracted fruit juice was measured by a pH meter.

The content of total and reducing sugars was determined by the Luff–Shoorl method. The method is based on the reduction of copper salts by reducing sugars in a warm alkaline solution and on indirect titration of the formed copper oxide by sodium thiosulphate solution.

**Pigment extraction from tomato fruits.** Ground tomato fruit (8 g) was thoroughly mixed with 40 cm$^3$ of ethanol. The slurry was stirred until the tomato paste material was no longer sticky (about 3 min). Ethanol was removed by vacuum filtration. The retained tomato residue was mixed with 60 cm$^3$ of a mixture of acetone and petroleum ether (1:1). The extract was collected by vacuum filtration, and the filter residue was rewash with the solvent mixture (20 cm$^3$) in order to improve the yield. The filtrate was transferred to a small separatory funnel and mixed with 50 cm$^3$ of saturated NaCl solution. The organic layer was rewash twice, repeatedly, first with 50 cm$^3$ of 10% potassium carbonate and then with 50 cm$^3$ of water. Finally, approximately 1 g of anhydrous magnesium sulphate was added to dry the organic layer. After 10 to 15 minutes the solution was vacuum filtered to remove the drying agent (Cvetković and Marković, 2008).

**Carotenoid and lycopene content.** HPLC analysis of β-carotene and lycopene content was carried out with the Agilent 1100 Series system, Waldborn Gemany (pump, detector, software). The LC column Zorbax-Eclipse XDB-C18; 4.6 × 250 mm, 5 μm was used, with a mobile phase consisting of a mixture of acetonitrile: methanol: ethyl acetate, at a flow rate of 1 cm$^3$/min. The injection volume was 20 μl using the detector DAD Agilent 1200 Series at 470 nm wavelength.

**Preparation of extracts for analysis.** The extracts (1 cm$^3$) with different concentrations were evaporated to dryness with rotary vacuum evaporators at room temperature and the residues were dissolved in mobile phase (acetonitrile: methanol: ethyl acetate, 6:2:2 v / v) to a concentration of 1 mg/cm$^3$. Extracts were filtered through a 0.45 μm Millipore filter before the HPLC analysis.

**Calibration plots of standard components.** Standards of β-carotene and lycopene were dissolved in mobile phase (eluent: acetonitrile: methanol: ethyl acetate, 6:2:2 v / v) just before HPLC analysis. From these standards, a series of solutions of appropriate concentration for the calibration curve were made. The external standard method was used for the qualitative and quantitative determination of β-carotene and lycopene. A calibration curve representing the dependence of the peak area (of standard compound) in chromatograms on standard concentrations were made. Based on the obtained linear regression equation, the concentrations of the tested components in the extracts were determined.

In addition, a taste index and the maturity were calculated using the equation proposed by Navez et al. (1999) and Nielsen (2003) starting from the Brix degree and acidity values, which were determined in a previous paper (Hernandez et al., 2008).

\[
\text{Taste index} = \frac{\text{Brix degree}}{20 \times \text{acidity}} + \text{acidity}
\]

\[
\text{Maturity} = \frac{\text{Brix degree}}{\text{acidity}}
\]

**Chemicals.** All chemicals and reagents were purchased from Sigma Chemical Co. (St Louis, MQ, USA), Aldrich Chemical Co. (Steinheim, Germany) and Alfa Aesar (Karlsruhe, Germany).

**Data analysis.** All statistical analyses were performed using SAS procedure (SAS Institute, Cary, NC) for analyses of variance. Means were compared by Tukey’s multiple range test.
**Results and discussion**

**Total soluble solid (TSS).** The total soluble solids (TSS) content in tomatoes is mostly composed of reducing sugar. The TSS content observed in fruits analyzed in this work ranged between 4.55 – 5.43 ºBrix and were higher than the 3.57 - 3.75 range observed by Ferreira (2001). We found a TSS content of 5.43 and 5.10 ºBrix for tomatoes grown in the field and in a plastic house, respectively. Contrary to our results, Loures (2001) found a lower TSS content (4.77) for tomato grown in the field than for tomato grown in a protected environment (4.95). No significant differences were observed in the TSS values of fruits grown under control conditions (plastic house) and fruits grown in integrated plastic houses with different shade nets (Table 3).

<table>
<thead>
<tr>
<th>Plastic tunnels + Colour nets</th>
<th>Colour nets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour nets (40% shade)</td>
<td>Total acidity</td>
</tr>
<tr>
<td>Red</td>
<td>0.34±0.02b</td>
</tr>
<tr>
<td>Black</td>
<td>0.40±0.01a</td>
</tr>
<tr>
<td>White</td>
<td>0.38±0.01a</td>
</tr>
<tr>
<td>Blue</td>
<td>0.35±0.01b</td>
</tr>
<tr>
<td>Control</td>
<td>Plastic tunnels</td>
</tr>
<tr>
<td></td>
<td>0.34±0.01b</td>
</tr>
</tbody>
</table>

Table 3. The average total acidity and total soluble solids contents in tomato fruits from plastic house integrated with colour shade nets and only colour shade nets production system.

Only tomatoes grown under red shade nets had a significantly lower TSS value (4.81). Tomato fruits from different screenhouses (only colour nets) had significantly lower TSS values in comparison to open field tomatoes. Our data show that the TSS value was affected by shading. It was previously known that shading decreases the sugar content of tomato fruits.

**Total acidity TA (Citric acid).** The environmental effect on fruit acidity is complex, and some studies favour the hypothesis that organic acids are produced in the fruit itself from stored carbohydrates, although some of these acids may be translocated from the leaves and roots to the fruits (Bertin et al., 2000). We found that field-produced fruits were more acidic (greater TA - 0.37%) than fruits produced in a protected environment (0.34%). Thus, the lower acidity of the fruits grown in a protected environment may be a result of the lower photosynthetic activity of the plant (shading in protected environment) in this environment, and consequently a lower carbohydrate accumulation in the fruits. However, the effect of shading on the acidity was not clear in this experiment. Sakiyama (1968) reported that titratable acidity is increased by high air temperature but unaffected by shading, which is what we found as well. However, Yanagi et al. (1995) reported that also shading increases the titratable acidity. According to Mahakun et al. (1979), genetic factors are the major acid content determinants in tomato plant fruits, with great variation occurring between genotypes (Stevens and Rick, 1986). When evaluating the hybrid ‘Carmen’ Loures (2001) found fruit titratable acidities (% citric acid) of 0.46% and 0.49% under greenhouse and field conditions, respectively.

**TSS/TA ratio.** The taste index is calculated using the values of Brix degree and acidity and applying the equation performed by Navez et al. (1999). Fruits produced in the field had greater TSS/TA ratios than those produced in a protected environment. Tomatoes have a good flavour when presenting a TSS/TA ratio of 10 (Kader et al., 1978; Mencarelli and Saltveit, 1988). The genotype evaluated here had TSS:TA ratios from 11.63 to 14.94 (depending on light conditions), thus being adequate for fresh consumption. Kader et al. (1978) suggest that high quality fruits should have values of TA > 0.32% and TSS values > 3%.
We found significantly greater maturity index in control fruits, from open field (14.68) in comparison with fruits from colour shade nets. Significantly lower maturity index were obtained in fruits covered by black shade nets integrated with plastic tunnels (12.95) and with greenhouse (11.63) cultivated tomatoes covered by red colour nets.

**Table 4.** Index of maturity and taste index in tomato fruits as affected by light intensity using colour shade nets

<table>
<thead>
<tr>
<th></th>
<th>Index of maturity</th>
<th>Taste index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plastic house +</td>
<td>Colour nets</td>
</tr>
<tr>
<td></td>
<td>colour nets</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>14.15 b</td>
<td>11.63 c</td>
</tr>
<tr>
<td>Black</td>
<td>12.95 c</td>
<td>12.65 b</td>
</tr>
<tr>
<td>White</td>
<td>13.68 b</td>
<td>12.78 b</td>
</tr>
<tr>
<td>Blue</td>
<td>14.94 a</td>
<td>12.64 b</td>
</tr>
<tr>
<td>Control</td>
<td>15.00 a</td>
<td>14.68 a</td>
</tr>
</tbody>
</table>

The maturity indices in our study (in all treatments) were higher than those reported by Hernandez et al. (2007) and therefore it can be deduced that the maturity levels of the analyzed tomatoes were adequate for consumption (Nielsen, 2003). This ratio can also be affected by climate, cultivar and horticultural practices (Nielsen, 2003).

Another parameter related with the maturity index is the taste index, which is usually a better predictor of an acid's flavour impact than Brix degree or acidity alone. The plastic house and open field (control) tomato production had a taste index mean value of 1.09-1.10. This is significantly (p < 0.05) higher than the values determined for the treatments with different colour shade nets (table 4). No significant differences in the mean taste index were found between tomatoes from plastic houses integrated with colour shade, and colour shade nets (greenhouse) cultivated tomatoes. When using these data, the mean values of the taste index in tomatoes considered were higher than 0.85, which indicates that the tomato cultivars analyzed were tasty. If the value of the taste index is lower than 0.7, the tomato is considered as having little taste (Navez et al., 1999).

**pH value.** Fruit pH will increase with maturity, and generally has an inverse relationship with titratable acidity. Tomatoes are still classified as acidic fruits (pH <4.6) and in the presented experiment the pH values ranged between 3.94 and 4.21. No significant differences were observed in the pH values of tomato fruits grown under a protected environment (pH 4.05) and field conditions (pH 4.16). Moreover, we found that the pH value is unaffected by shading. The pH values (3.94 to 4.21) obtained in our experiments were lower when compared to the data of Stevens and Rick (1986), who reported a tomato fruit pH between 4.26 and 4.82 (Table 5).

**Table 5.** Coloured shade nets effects on tomato fruit quality

<table>
<thead>
<tr>
<th></th>
<th>Plastic house + colour nets</th>
<th>Colour nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>Dry matter %</td>
</tr>
<tr>
<td>Red</td>
<td>4.12±0.02a</td>
<td>5.92±0.19c</td>
</tr>
<tr>
<td>Black</td>
<td>3.97±0.05b</td>
<td>6.33±0.14b</td>
</tr>
<tr>
<td>White</td>
<td>3.96±0.11b</td>
<td>6.40±0.04b</td>
</tr>
<tr>
<td>Blue</td>
<td>4.07±0.08a</td>
<td>6.38±0.08b</td>
</tr>
<tr>
<td>Control</td>
<td>4.05±0.04a</td>
<td>7.17±0.02a</td>
</tr>
</tbody>
</table>

Low pH is associated with high fruit quality (Davies and Hobson, 1981). The pH of a tomato is also highly dependent on cultivar, maturity stage, cultivation practices, growing season and location; thus some variation will occur (Gould, 1992). The determination of fruit acidity at complete maturation, when acidity declines, is likely the reason for the low values.
**Sucrose content.** Regarding sucrose contents, no differences between fruits produced in the field and fruits produced in the protected environment were detected. The content of sucrose in the fruits was unaffected by shading. Also, no significant differences were seen between control and colour shade net fruits. Opposite to our results, Martins et al. (1999) and Beckmann et al. (2006) achieved lower reducing sugar content in fruits produced in the protected environment (may be related to lower light intensity, approximately 25% lower) than in the field. Thus, the greater sugar content in fruits produced in the field may be due, in part, to the greater light intensity in this crop environment and greater photosynthetic plant activity. Davies and Hobson (1981) reported reducing sugar contents around 2.05 g 100 g⁻¹ of fresh fruit for the protected environment and 2.93 g 100 g⁻¹ of fresh fruit for field cultivation. According to these authors, there may be a great variation in the content of reducing sugars (1.66 g to 3.99 g 100 g⁻¹) among genotypes, even when they are cultivated in the same environment.

**Lycopene and β-carotene content.** Most of the quality traits show a continuous variation, strongly influenced by environmental conditions. Stronger light irradiance (both intensity and duration) increases the transportation of photo-assimilates to the fruit and thus can have a large influence on tomato fruit growth and development, and fruit quality. No significant differences in lycopene contents were observed in tomatoes grown in plastic houses (48.9 µg g⁻¹ f.w.) compared to control, open field conditions (48.1 µg g⁻¹ f.w.). The highest concentration of lycopene was detected in tomatoes grown in plastic houses integrated with red colour nets (64.9 µg g⁻¹ f.w.), while tomatoes grown in fields covered with pearl nets had the lowest levels of lycopene (46.7 µg g⁻¹ f.w.) (Table 6). Similar results were found by López et al. (2007) who showed that the lycopene content of tomatoes grown under red and pearl frame nets were 51 and 37 µg g⁻³, respectively. These values are similar to those reported by Martínez-Valverde et al. (2002) in Spanish commercial tomato varieties. Only tomatoes grown under pearl net had lower lycopene content than those reported by Gomez et al. (2001) in field-grown tomatoes. This fact could be attributed to two reasons: temperature and light quality. Significant differences are found among cultivars, and within cultivars cultivated under red or pearl net (Thomas and Jen, 1975). As lycopene biosynthesis is mediated by phytochrome, slight variations in red light over mature-green fruit could stimulate lycopene accumulation (Alba et al., 2000), which may explain the different lycopene content obtained depending on the net (red or pearl) under which the tomatoes were grown. Lycopene is the most abundant carotenoid in the ripened tomato, accounting for approximately 80–90% of the total pigments (García-Valvedere et al., 2011). The degree of redness of the ripe tomato, mainly attributed to lycopene pigments, is important in determining the final quality of tomatoes (Nisha et al., 2011). Lycopene accumulates mainly in the final period of ripening, and its content is not linearly related to colour changes (Giovanelli et al., 1999). Tomatoes exposed to direct sunlight in the field often develop a poor colour, mainly because fruit exposed to high temperatures has low lycopene content. The deep-red colour of tomato is associated with high levels of lycopene, while high β-carotene content accounts for the orange colour (Brandt et al. 2003). In fresh tomatoes the rate of lycopene synthesis is completely inhibited at 32-35°C, but not that of β-carotene.

**Table 6.** The average content of lycopene and β-carotene in tomato fruits from plastic-house integrated with colour shade nets and screenhouse (only colour shade nets).

<table>
<thead>
<tr>
<th>Colour nets</th>
<th>Plastic house + colour nets</th>
<th>Colour nets</th>
<th>Plastic house + colour nets</th>
<th>Colour nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lycopene µg/g fresh weight</td>
<td>β-carotene fresh weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>64.89c</td>
<td>2.01c</td>
<td>1.67b</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>56.99b</td>
<td>1.25a</td>
<td>2.17c</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>57.91b</td>
<td>1.33a</td>
<td>1.73b</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>62.67c</td>
<td>1.53b</td>
<td>1.50b</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>48.89a</td>
<td>1.61b</td>
<td>2.25c</td>
<td></td>
</tr>
</tbody>
</table>

Different letters indicate significant differences at P < 0.05 (Tukey’s test)
The Influence of Photo-selective Shade Nets on Quality of Tomatoes Grown Under Plastic Tunnels and Field Conditions

It was postulated that high temperatures (35°C) specifically inhibit the accumulation of lycopene because they stimulate the conversion of lycopene into β-carotene (Dumas et al., 2003). The production of lycopene is inhibited by excessive sunlight (~2990 µmol m⁻² s⁻¹ for 1.5-4 h is harmful) (Brandt et al., 2006) and the best way to protect the fruit from direct exposure to the sun is the use of photo-selective colour shade nets. Tomato fruits grown in open field (control) and under pearl net had significantly more β-carotene 2.25 µg g⁻¹ and 2.17 µg g⁻¹ respectively, than fruits grown under blue nets (1.50 µg g⁻¹). Tomato fruits grown in a plastic house - control (1.61 µg g⁻¹) and under integrated plastic house with red net (2.01 µg g⁻¹) had significantly more β-carotene level than fruits grown under plastic house covered by black (1.33 µg g⁻¹) or pearl net (1.25 µg g⁻¹) (see Table 6).

Tomatoes harvested during the first four stages of ripening did not contain detectable quantities of β-carotene or lycopene. However, those harvested 50 days after flowering contained 1.2 µg g⁻¹ β-carotene and 58 µg g⁻¹ f.w. lycopene (Abushita et al., 2000).

The results of the present study should provide useful preliminary data for detecting differences among environment variation in lycopene and β-carotene content and colour shade nets.

Conclusions

Overall, fruits produced in a protected environment (plastic house integrated with colour nets) presented better quality than fruits produced in the field. Plastic house grown fruits integrated with colour nets were tastier (obtained higher maturity and taste index) and contained more lycopene than fruits grown in field conditions covered with colour nets. However, the data are preliminary and more research is required for understanding the physiological mechanisms behind the plant responses and for testing results with other crops and other environmental conditions.

References


