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Nocturnal low irradiance pulses improve fruit yield and lycopene concentration in tomato

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ABSTRACT

Light is one of the most important factors modulating processes and sequences in plants life, like fruit ripening and the concentrations of water and lipid soluble antioxidants. The aim of this work was to evaluate the most effective frequency of low irradiance light pulses (LP) during the night and to analyze its effect on plant and fruit growth, as well as on modifications of concentrations of soluble sugar, amino acids, antioxidants and organic acids. LP of 15 min each were applied over the plants in a temperature controlled greenhouse after fruit set till they turned to mature red, with a frequency of 2 and 4 h. LP induced no changes in the typical maturation indexes such as soluble solid, total acidity, pH or firmness; meanwhile there was an 18% increase in fruit yield when plants were exposed to 15 min LP every 2 h during the night. Furthermore, by analyzing the tomato cluster receiving this LP treatment separately, the biomass of the fruit was found to have increased by 28% compared with the same cluster in control plants. In coincidence with this, fruit treated with a frequency of 2 and 4 h LP showed an increase in lycopene concentration, concomitantly with a rise in the proportion of red mature fruit harvested from the whole plant. On the other hand, there was a drop in the concentration of soluble sugars and free amino acids, possibly conducing to a decrease in water soluble antioxidants (ascorbic acid and glutathione) and citric and malic acids concentration. Overall, these results showed that nocturnal LP treatments improved fruit yield in tomato plants with higher amounts of lycopene, which indicate earlier fruit ripening.

1. Introduction

Fruit growth and ripening are complex issues for plants. As plants develop, light plays a key role in carotenoid accumulation in tomato (Giovannoni, 2004), which is a phytochrome-mediated effect (Alba et al., 2000). During fruit maturation, several processes, such as pigment synthesis (Bramley, 2002; Alba et al., 2005), cell wall metabolism (Vicente et al., 2007), carbohydrate metabolism (Carrari et al., 2006) and antioxidants synthesis (Jimenez et al., 2002) are interconnected.

Plants perceive the interruption of dark periods when they receive a brief red light treatment modifying flowering (Salisbury and Bonner, 1956) or germination (Benech-Arnold et al., 2000). Furthermore, plants exposed to a light pulse (LP) before dawn alter their circadian rhythm which leads to changes in growth, enzyme activity, photosynthesis and other physiological processes (McClung, 2006 and references therein). In addition, treatments with LP extend postharvest life of spinach leaves stored in darkness improving their antioxidant concentration (Gergoff et al., 2013). In spite of this, the effect of nocturnal LP treatment in tomato fruit and the consequences for their ripening such as changes in lycopene concentration and in other quality parameters have not been addressed.

A previous work has demonstrated that LED can improve tomato quality, however, the treatments were done with different LED and for long periods of time. Those authors found a rise in glucose and ascorbic acid (AA) when applying blue and white LED treatments (Xu et al., 2012). On the other hand, as demonstrated by Massot

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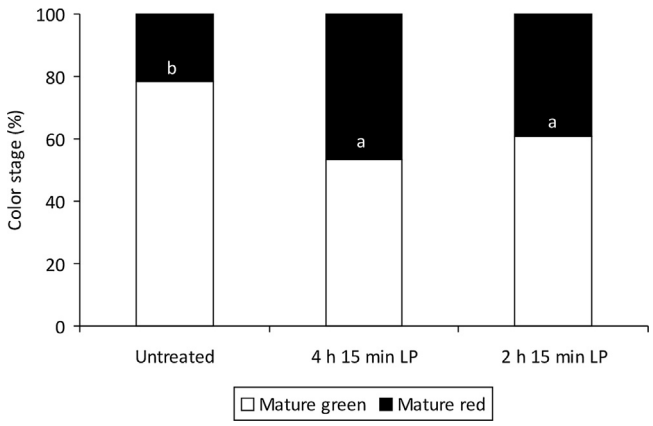

Fig. 1. Percentage of mature green and mature red tomato fruit in untreated plants and in plants treated with 4 h LP and 2 h LP during the night. Results were analyzed by ANOVA ($P \leq 0.05$) to refuse the null hypothesis and multiple test range (LSD test) was performed to detect the differences among means. Letters denote statistical differences.

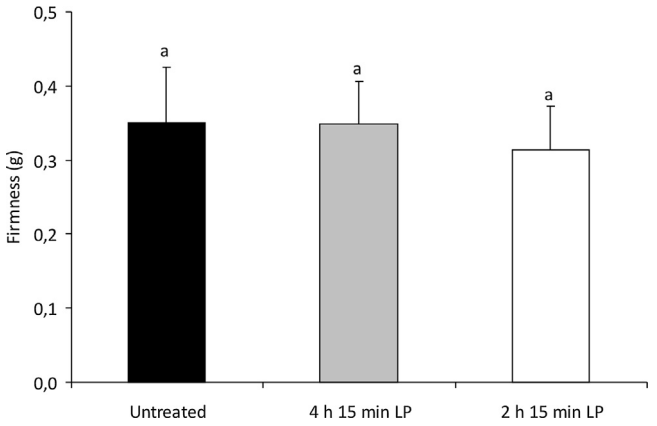

Fig. 2. Firmness of mature red fruit in untreated plants and in plants treated with 4 h LP and 2 h LP during the night. Results were analyzed by ANOVA ($P \leq 0.05$) to refuse the null hypothesis and multiple test range (LSD test) was performed to detect the differences among means. Error bars represent standard deviation and letters denote statistical differences.

et al. (2012), light produces a higher effect in AA content in leaves than in tomato fruit, when plants are shaded for a long time. Both light intensity and quality have a strong relation to AA content and synthesis in leaves (Bartoli et al., 2006, 2009) and determinate plant growth (Fan et al., 2013). In model organisms, light has proved to regulate the expression of L-galactono-1,4-Lactone Dehydrogenase (GLDH) mRNA, the last enzyme in the AA synthesis pathway (Tanaka et al., 2015). Also, there are many changes in the GLDH and AA concentrations along one day, in a cycle regulated by irradiance rather than by circadian rhythm (Tamaoki et al., 2003).

Tomato fruit is a remarkable source of vitamin C (AA and dehydroascorbic acid) and carotenoids for human diet (García-Closas et al., 2004) and it is the most important fruit worldwide (FAO, 2013). The aim of this work was to determine the effect of nocturnal application of short and low irradiance LP on the ripening of the fruit, its antioxidant concentration and plant growth.

2. Materials and methods

2.1. Plant material and treatments

Tomato plants (*Solanum lycopersicum* cv Elpida) were cultured in 10 L pots inside a greenhouse of the Institute of Plant Physiology (CCT CONICET La Plata—UNLP) during four consecutive years (2011–2014) from 1st September till the middle of December, when the fruit were harvested. The temperature at different heights (0.0, 0.5, 1.0 and 2.0 m) and photosynthetic photon flux density (PPFD) were controlled and measured during the period of plant growth with a Licor LI-1400 data logger (equipped with a 1400–101 air temperature sensor and a LI-190SA quantum sensor) every half hour. Temperature and PPFD data are shown in supplementary Fig. 1. Ten plants were analyzed for each treatment and experiment. The LP treatment consisted of 15 min of 30 $\mu mol\, m^{-2}\, s^{-1}$ PPFD every 2 or 4 h during the night (From 6 pm to 6 am). The light source consisted in 20 W fluorescent tubes (OSRAM®) placed at an approximate distance of 15–20 cm from the fruit. LP were applied directly to the first inflorescence after fruit set (around 1st November) until harvest (around 15th December), when fruit turned to red stage (at least 90% of surface red). After harvest, fruit were immediately taken to the laboratory for the analytical determinations and extra samples were frozen in liquid nitrogen and stored at −80 °C until used.

2.2. Fruit weight, plant yield and chlorophyll concentration

After harvest, fruit weight and yield per plant and per inflorescence were recorded. Ten replicates were used for each of the four years of tomato cultivation. Apart from the fresh and dry fruit yield, plant height, dry stem and dry leaves were measured. Leaf chlorophyll concentration was estimated with a SPAD-502 Chlorophyll meter (Minolta, Japan) and results were expressed in Spad Units.

2.3. Total soluble solids, titratable acidity, pH and color

Twenty g of fruit tissue were processed with mortar and pestle and a few drops of the juice were placed in a refractometer to determinate total soluble solids (TSS) (Milwaukee MA871, Rocky Mount, USA) expressing results as °BRIX. Then 100 mL of distilled water were added to the juice. pH was potentiometrically measured and total titrable acidity (TTA) was determined titrimetrically with a 0.1 N solution of NaOH until pH 8.2 was reached (AOAC, 1980). Results were expressed as grams of citric acid per 1000 g of fresh fruit weight.

Fruit were classified under the USDA ripening stages, as described by Tu et al. (2000).

2.4. Firmness

Fruit firmness was determined with a texture analyzer (T.A., Exponent lite Texture Analyzer TA.XT.PLUS from Stable Micro Systems™ Goldalming, Surrey, UK). T.A. was equipped with a 25 mm diameter flat probe. The fruit was deformed for a distance of 0.5 mm at a speed of 0.25 mm/s. and a 5.9 g trigger force. Twenty fruits were analyzed for each treatment and harvest season. Results are expressed in force g, representing the maximum force developed during the test.

2.5. Concentrations of free amino acids and total and reducing sugars in fruit

The concentration of total free amino acids was determined according to Rosen (1957). Standard curve was made with glutamic acid at 570 nm in a UV–vis spectrophotometer (Shimadzu UV-160A, Shimadzu Corporation). Concentrations of free and reducing sugars were determined using the Somogyi–Nelson method with modifications according to Nelson (1944) and Somogyi (1952). The measurements were carried out in the UV–vis spectrophotometer at 520 nm. Standard curve was developed with sucrose.