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Acclimatisation of greenhouse crops to differing light quality

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ABSTRACT

High-intensity discharge (HID) and light-emitting diode (LED) lights have been widely compared for use in greenhouse plant production but the results are contradictory. In order to obtain more data on the effects of different light sources on plant growth, growth chamber experiments with high pressure sodium (HPS) or LED light and one treatment with alternating HPS and LED light (three days each) were carried out using tomato and rose as model plants. The LED lamps used were composed of blue (B, peak emissions 402, 419, and 445 nm) and red/far red (R/FR, peaks in 663 and 737 nm) LEDs. Plant growth parameters were recorded, as were photosynthesis, chlorophyll fluorescence, chlorophyll content, leaf temperature, leaf spectral properties and light penetration into the canopy. In roses, stem elongation and leaf area were generally lower for plants grown under LED light while fresh and dry weight was unaffected by the lamp type. For tomato, plants grown in alternating LED and HPS lamps had lower fresh weight as compared with HPS. Specific photosynthetic capacity (A_{max}) and maximum quantum yield of PSII (F_v/F_m) were higher in leaves developed under LED light than HPS. Leaf transmittance and reflectance were higher for leaves grown in HPS light, which also gave better penetration of light into the canopy. Plants subjected to alternating light regimes generally resembled LED treatment plants more than HPS plants. Leaf temperature was higher under HPS (0.9–1.3 °C) favouring plants growing in chambers with HPS light. Leaf temperature and the amount of blue light supplied were concluded to be key factors for plant performance.

1. Introduction

The use of solid-state technology light sources (e.g. light-emitting diodes, LED) for providing light in horticultural production systems has attracted great interest in recent years. It was suggested already in 1966 that the artificial lighting used for plants should be adapted to the peaks in sensitivity of the photosynthetic apparatus (Hårdh, 1966). A generalised action spectrum for photosynthesis was suggested by McCree (1972). With lighting sources based on LED technology, it is possible to tailor the spectral composition of the light in a way that is not possible with commonly used high intensity discharge (HID) lamps. Thus, it has been suggested that using LED-based light sources matching the spectral output of the lamps to the light response curve of photosynthesis could improve growth and reduce the energy needed for assimilation lighting (Pinho, 2008; Deram et al., 2014). However, few studies have reported an unambiguous positive growth response when comparing LED lighting to HID lighting at the same PAR light intensity. Dueck et al. (2012), Hernández and Kubota (2015) and Hao et al. (2012) observed reduced growth when using LEDs, which they attributed to lower leaf temperature due to low radiant heat from LED light sources. Bergstrand and Schüssler (2013) also observed lower biomass production when using LED light sources compared with HID lighting. However, Currey and Lopez (2013) reported increased leaf- and root mass for *Petunia*, but not for *Impatiens* or *Pelargonium*, when cultivated using a combination of red and blue LEDs, compared with HPS.

Warrington et al. (1976) concluded that the efficiency of the light source is more important than the quality of the spectrum for a system's light use efficiency. They also showed that long-term biomass production is not as strongly influenced by light quality as

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short-term photosynthesis. Similar results were reported by Terfa et al. (2013). Acclimatisation of the plants to the light conditions is a plausible explanation for this and probably part of the explanation for the relatively poor results often obtained when using 'optimised' spectra for plant lighting. Such acclimatisation may be of various forms, e.g. changes in leaf size (Islam et al., 2012), leaf thickness (Chabot et al., 1979), pigment content (Paradiso et al., 2011), number of stomata (van Ieperen, 2012; Terfa et al., 2013) and leaf positioning (Paradiso et al., 2011). In order to get data on the acclimatisation effects due to different light sources, in this study we performed a series of growth chamber experiments with differing light quality. The aims of the study were to: i) investigate the importance of plant physiological acclimatisation to their light environment and ii) evaluate alternating light quality as a way to counteract acclimatisation and thus improve light use efficiency.

2. Materials & methods

2.1. Plant material

Stem cuttings of *Rosa* × *hybrida* 'Toril' were rooted in 12-cm plastic pots with a peat-based growth medium (Degernes Torvstrøfabrikk AS, Degernes, Norway) and seeds of *Solanum lycopersicum* 'Espero' were sown in pots similar with the ones used for *Rosa*. Before starting the different treatments, the plants were kept in a greenhouse (heating temperature 18 °C, ventilation temperature 22 °C, misting if relative humidity was below 70%). Supplemental lighting, a mixture of high-pressure sodium and high-pressure mercury lamps (HPS + HPI ratio 2:1, Gavita 400 W, Gavita AS, Andebu, Norway) at a photon flux density (PFD) of 100–120 μmol m^{-2} s^{-1} was supplied for 16 h day^{-1} when natural outside irradiation was below 200 Wm^{-2} (corresponding to ~460 μmol m^{-2} s^{-1}).

2.2. Experimental conditions

The experiment was performed in controlled climate chambers (2 m^2) at the Centre for Plant Research in Controlled Climate (SKP), Ås, Norway. Three-week-old plants grown as above were transferred to the climate chambers. At the time of transfer, the shoot of the rose plants was pinched over five nodes. The tomato plants were at stage 103 according to the BBCH scale (Feller et al., 1995) at the start of the experiment (the third fully developed true leaf on the main stem), with an average plant height of 51 ± 20 mm.

The climate in the chambers was set to 20 °C and 70% RH. The CO_2 concentration was ambient (380 ± 20 ppm). The plants were irrigated manually with respect to depletion using a nutrient solution composed of Kristalon Indigo (N-P-K 9-5-25 + micronutrients) and $Ca(NO_3)_2$ (Yara, Oslo, Norway) in the ratio 1:1 w/w, at conductivity 2.5 mS cm^{-1}. Three different lighting regimes were provided: A) HPS light (R:FR (660/730 nm) ratio ~5); B) LED light (Heliospectra L4A, Heliospectra AB, Gothenburg, Sweden. Spectrum: R:FR-ratio ~6, R:B ratio 2:1) (Fig. 1); and C) alternating HPS and LED light, with three days of each. A PFD of 200 ± 20 μmol m^{-2} s^{-1} (measured with a Li-Cor Li 250, Li-Cor, Lincoln, NE, USA) was supplied for 16 h day^{-1}, corresponding to a total daily light integral of 11.5 mol m^{-2} day^{-1}. The plants were redistributed within each chamber once a week to compensate for any irregularities in light distribution. The plants were grown in the climate chambers for 55 (rose) or 23 (tomato) days.

2.3. Biometric analysis

At the end of the experiment, plant height, width (plant diameter), number of lateral shoots, internode length (calculated as total shoot length/number of nodes), number of leaves and leaf area (Li-Cor LI-3100, Li-Cor, Lincoln, NE, USA) were measured. The chlorophyll content of the leaves was measured at the end of the experiment using a chlorophyll meter (Hansatech CL-01, Hansatech Instruments Ltd, King's Lynn, UK). The first fully expanded leaf, as well as the lowest leaf (for tomato) was used for measurements. Leaf and stem fresh weight was measured at the end of the experiment. The dry weight was determined after 48 h of drying at 60 °C.

The photosynthetic capacity (A_{max}) of the leaves was measured two weeks after start of the experiment using a leaf chamber photosynthesis meter (LC Pro, ADC Bioscientific, Hoddesdon, UK). The capacity was measured at six different PFD levels in the range 0–1000 μmol m^{-2} s^{-1} using a light source composed of red and blue LEDs (R:B ratio 5:2). Measurements were taken on the second fully expanded leaf below the apex. The leaf temperature was adjusted to 20 °C during the measurements.

In addition, for roses, the photosynthetic capacity was measured for leaves exposed to full light level in the growth chamber (200 μmol m^{-2} s^{-1}) and for leaves where the light was filtered through one leaf, to simulate conditions in the lower part of the canopy. In this case, the lamp type used for the treatment was used. The values presented are the mean of 10 measurements.

2.4. Physical analysis

The spectral output of the light sources used in the experiment was measured using a spectroradiometer (StellarNet Epp 2000, Apogee Instruments, Inc., Logan, UT. USA). Based on the measurements, the phytochrome photostationary state was calculated as described by Sager et al. (1988). The temperature and relative humidity in the chambers were logged every 5 min (Priva Office, Priva, de Lier, the Netherlands). Leaf temperature was measured regularly during the experiments using an IR thermometer (Raytek Raynger ST, Raytek Corporation, Santa Cruz, CA, USA). The spectral properties (transmittance and reflectance) of detached leaves were measured (Ocean Optics SD2000, Ocean Optics, Dunedin, FL, USA) on the third fully developed leaf below the apex using the method described by Solhaug et al. (2010). Briefly, the leaf was illuminated with light from a standardized light source (Halogen lamp) through an optical fibre, and the transmitted/reflected light was analysed with respect to its spectral composition.

Chlorophyll fluorescence was measured using a chlorophyll fluorescence meter (PAM-2500, Heinz Walz GmbH, Effeltrich, Germany) on dark-adapted leaves (basic fluorescence, F_0, maximal fluorescence, F_m, and PS II Yield, F_v/F_m) and in the presence of light (maximal fluorescence, F_m', and incident fluorescence, F_t). Chlorophyll fluorescence was measured on the second fully expanded leaf below the apex.

2.5. Statistics

The experiment was run in duplicate, with 10 plants from each species per repetition. Two-sided analysis of variance (ANOVA) with Tukey's multiple comparison test was used for data analysis (Minitab 16, Minitab Inc., State College, PA, USA). A value of $P \leq 0.05$ was considered significant. For leaf spectral property measurements, data were analysed at 20-nm intervals from 400 to 800 nm.

3. Results

3.1. Plant growth parameters

Rose and tomato plants grown under LED light were generally more compact, with lower plant height and shorter internodes (Table 1). Compared to plants grown with HPS-lamps, plant height