Research paper

Spectral quality of supplemental LED grow light permanently alters stomatal functioning and chilling tolerance in basil (Ocimum basilicum L.)

Nikolaj Bjerring Jensen, Morten Rahr Clausen, Katrine Heinsvig Kjaer

ARTICLE INFO

Keywords:
- Chilling injury
- Shelf life
- Stomatal density
- Abscisic acid
- Light quality
- Fatty acid
- LOX

ABSTRACT

The spectral qualities of light contain environmental information used by plants as cues to modify their biology in order to adapt and survive. LED based lamps, with their highly definable spectral properties, thus hold great perspectives for use in greenhouse production. The effects of the spectral qualities of light on plant physiology is still not fully understood, and a great fraction of the current knowledge further comes from studies looking at short term effects or using monochromatic light treatments in enclosed growth chambers, thus far from the light conditions of greenhouse production. The objective of this study was to determine whether spectral modifications to the supplemental LED lighting in greenhouse production could modify post-cultivation performance of basil, which is prone to chilling injuries (CI). We cultivated basil under greenhouse conditions using four different supplemental LED light treatments; 80%Red/20%Blue, 80%Red/20%Blue + UV-A, 40%Red/60%Blue and 80%Red/20%Green, followed by a post-cultivation shelf life simulation including a chilling treatment. Stomatal anatomical features and levels of hormonal regulators, abscisic acid (ABA) and ABA glucosylester (ABA-GE), along with soluble sugars, fatty acids and lipoxygenase activity (LOX) were determined at the end of the growing period. Without compromising grow rates, the light treatments showed marked effects on the chilling tolerance and shelf life performance with increasing ratios of blue light having negative effects, and green light having positive effects on chilling tolerance. Differences in shelf life performance seemed mediated solely by factors related to stomatal functioning. Stomatal density (number of stomata per leaf area, SD) increased with increasing ratios of blue light whereas green light showed indications to decrease SD. [ABA-GE] showed positive correlation to SD, whereas the ratio of [ABA-GE]/[ABA] conversely correlated negatively with increased SD. Our results thus suggest an important relationship between leaf water retention and post-cultivation chilling tolerance in basil.

1. Introduction

In northern latitudes, the use of electric light sources is a necessity in greenhouse production in order to provide crops with sufficient energy for sustainable rates of growth and development in periods with low levels of natural daylight (Mitchell et al., 2012). Light-emitting diodes (LED) have surpassed high-pressure sodium lamps (HPS) on the electrical cost per photon and continues to take rapid leaps forward in terms of energy efficiency (Nelson and Bugbee, 2014; Pimputkar et al., 2009). Contrary to HPS lamps, which emit light over a broad, un-modifiable spectrum of wavelengths, LED lamps can be designed to emit light with highly defined spectral properties from 250 nm up to 1000 nm (Bourget, 2008). The LED technology provides a possible solution for a more sustainable greenhouse production, not only because it reduces the carbon footprint of the individual light photon, but also because plants are highly responsive to changes in light quality. If used in the right way, the LED technology can be used to enhance plant traits related to post-cultivation performance thereby reducing waste.

Basil is a commonly produced fresh herb in greenhouse industry. It is prone to postharvest spoilage during transport and storage when cold storage is used. Temperatures below 12 °C induce chilling injuries (CI) such as discoloration in interveinal areas of leaves, wilting and leaf abscission (Aharoni et al., 2010). This is considered to be caused by transitions in cellular membranes from liquid crystalline to gel phase resulting in loss of membrane integrity, ion leakage, loss of compartmentalization, lipid degradation and generation of Reactive Oxygen Species (ROS).
Species (ROS) (Aghdam et al., 2014; Campos et al., 2003; Zhu et al., 2013). Therefore, we expect that reduced susceptibility towards CI in chilling sensitive plants could be achieved through a number of factors associated with membrane stability. Factors include a higher ratio of unsaturated fatty acids to saturated fatty acids (Kodama et al., 1994; Uemura and Steponkus, 1994), reduction of lipoxigenase (LOX) activity (Aghdam et al., 2014; Pongprasert and Srilaong, 2007; Wongsheere et al., 2009) and accumulation of sugars with stabilizing effects on membranes (King et al., 1988; Yue et al., 2015). Further, adequate hydration of membrane layers is important for the stability of membranes (Wolfe and Bryant, 2001). Higher leaf water content to leaf dry weight (LWC/DW) of plants subjected to 4 °C for 72 h, was shown to correlate with improved chilling tolerance in different genotypes of Ocimum basilicum (Ribeiro and Simon, 2007). Furthermore, Cucumis sativus and Phaseolus vulgaris grown at elevated CO2 had lower leaf transpiration and less visual leaf damage after exposure to chilling temperatures compared to plants grown at ambient CO2 (Boese et al., 1997). This suggests that water retention in the leaf tissue by the control of stomatal conductance (gs), could be an important factor for maintaining cellular water balance and preventing CI.

Stomata are small pores in the plant epidermis, bordered by two guard cells with the ability to regulate pore area, in response to environmental cues and hormones. Abscisic acid (ABA) is considered the key regulator of stomatal aperture (Acharya and Assmann, 2009). ABA levels can be controlled through conjugation with glucose to form abscisic acid glucosylester (ABA-GE) which has no biological activity. ABA-GE is processed by β-glucosidase upon stress conditions in order to rapidly release free ABA to induce physiological responses (Burla et al., 2013; Nambaran and Martin-Poll, 2005). Properties of stomatal anatomy such as stomatal size and pore depth affects gs of the pore. Furthermore, stomatal density (number of stomata per leaf area, SD) also affects the general rate of gas exchange pr. leaf area (Fanourakis et al., 2015). The development of stomatal traits is regulated by various environmental factors such as CO2, relative air humidity (RH) and light (Casson and Gray, 2008).

The spectral quality of light can affect the differentiation of protoderm cells into stomata through the photoreceptors Cry1, Cry2, PhyA and PhyB mediating the effect of blue, red and far-red light (Casson and Hetherington, 2014; Kang et al., 2009). Long-term application of red/ blue LEDs in mono- and dichromatic light treatments of Cucumis sativus showed synergistic effects of red and blue light on stomata development with the blue light treatment having higher SD than the red light treatment, and the dichromatic red/blue treatment being even higher (Savvides et al., 2012). Further, the dynamic regulation of the stomatal aperture can transit into long term patterns of altered SD. A high gs in mature leaves induce higher SD in developing leaves, whereas low gs inhibit stomatal development (Miyazawa et al., 2006). In a review by Chater et al. (2014), it was argued that ABA might be the central signalling component acting by transcriptional control linking the dynamic regulation of stomatal aperture to stomatal development. Dependent on its wavelength, light influence on the dynamic regulation of stomatal aperture both through ABA dependent and independent mechanisms. That blue light cause stomatal opening through Phototropin (Phot) mediated activation of H’ ATPasses in stomatal guard cells is well established (Shimazaki et al., 2007). In contrast, UV-A and green light has shown to reverse blue light activated stomatal opening (Eisinger et al., 2003). Spectral quality of light can also interact with the signalling of endogenous ABA on stomatal function. Blue light activation of CRY might reduce concentrations of ABA as cry1cry2 double mutants of Arabidopsis thaliana show increased ABA levels (Boccandalro et al., 2012). On the other hand, red light activation of PhyB increase the sensitivity to ABA levels, possibly by promoting the transcription of an ATP-binding cassette influx transporter transporting ABA over the plasma membrane or through a soluble ABA binding PYL-type receptor (González et al., 2012).

The spectral quality of light thus interacts with the development of stomata both through direct interaction with the photoreceptor involvement in the developmental control, and by the regulation of the stomatal aperture from effects on ABA metabolism.

The aim of this study was to test the hypothesis that modifications of the spectral environment by LED supplemental lighting on the background of natural daylight in the greenhouse could alter stomatal patterns in basil leaves, inflicting effects on chilling tolerance and post-cultivation shelf-life of basil.

2. Materials and methods

2.1. Light treatments

Four different light treatments were used, aiming to supply the same amount of photosynthetically active radiation (PAR) to the plants. For the treatment “R80/B20” (80%Red/20%Blue PAR), “R80/B20 + UVA” (80%Red/20%Blue PAR + UV-A) and “R40/B60” (40%Red/60%Blue PAR) combinations of Fionia Lighting FL300 and Fionia Lighting costumer made “red”, “red with UV-A” and “blue” lamps (Senmatic A/S, Søndersø, Denmark) were used. For the treatment “R80/G20” (80%Red/20%Green PAR), Heliospectra L4A lamps (Heliospectra AB, Göteborg, Sweden) were used. Adjusting the spectra of the lamps, the light intensity was measured for each color individually using a Walz ULM-500 light meter equipped with Mini Quantum LS-C Sensor (Heinz Walz GmbH, Effeltrich, Germany). The photons of the different wavelengths were weighted for their photosynthetic activity according to the Yield Photosynthetic Photon Flux Density (YPFD) curve (McCree, 1972). The spectral distribution under the lamps within the plots was further evaluated by spectral irradiance measurements using a Jaz spectroradiometer (Ocean optics, Dunedin, USA) measuring at 20 cm height above the greenhouse house (see Fig. 1 and Table 1).

2.2. Plant material and growing conditions

Sweet Basil (Ocimum basilicum L.) seedlings (~ 20 seedlings pr. pot, 1 cm height) in 9 cm pots in a peat substrate were obtained from Rosborg Kryderurter A/S, (Odense, Denmark), and placed in a growing bench under greenhouse conditions at Aarhus University (Årølev, Denmark 55°22′N) in late winter (9 February – 22 March 2016). For each light treatment two plots of ~1m² were made, each containing 25 plants placed at uniform density. In order to minimize position effects in relation to the used lamps and north-south effects in relation to the natural daylight, plants were rearranged within and between the plots within each treatment twice a week. Nutrition (macronutrients: N 159 μmol mol⁻¹, P 28 μmol mol⁻¹, K 254 μmol mol⁻¹, and Mg 30 μmol mol⁻¹, Ca 124 μmol mol⁻¹, SO₄ 62 μmol mol⁻¹; micronutrients: Cl 41 μmol mol⁻¹, Fe 1,65 μmol mol⁻¹, Mn 0.62 μmol mol⁻¹, B 0.22 μmol mol⁻¹, Cu 0.11 μmol mol⁻¹, Zn 0.38 μmol mol⁻¹ and Mo 0.08 μmol mol⁻¹; additional elements: Na 67 μmol mol⁻¹) was provided mixed with irrigation water, and automatically supplied as ebb- and flood irrigation once a day during the first ~ 3 weeks, and twice a day during the last ~ 2 weeks of the experiment in order to keep the plants well-watered at any time. The plants were grown in a 20 h/4 h, day/night cycle. During the day period the supplemental light was switched on with a set point of 150 μmol s⁻¹ m⁻² or less of natural daylight. The intensity of the supplemental light measured at the top of the plants for all treatments was 120 μmol m⁻² s⁻¹ PAR at the start of the experiment, and increased to 190 μmol m⁻² s⁻¹ PAR at the end, as the plants grew taller towards the lamps. The set points for air temperature and CO2 was 22±8 °C (Average temperature during the growth period was 22.4 °C), and 600 μmol mol⁻¹ respectively. Climate data was tracked continuously using LI-190SA Quantum sensors (Lincoln, USA) to measure light intensity received by the plants, IR/1.01 Exergen infrared sensor (Massachusetts, USA) to measure leaf temperature and a Pt 100
دریافت فوری

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات