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Responses of supplemental blue light on flowering and stem extension growth of cut chrysanthemum

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ABSTRACT

To determine the effects of blue (B) spectrum supplemental lighting on flower bud formation and stem elongation growth of cut chrysanthemum, plants of 'Zembla' cultivar were grown for 42 days under 4 different light treatments. Treatments comprised: RB (11 h of mixed red and blue [RB] light), RB + B (11 h of mixed RB light and then 4 h of supplemental B light), LRB + B (15 h of mixed RB light and then 4 h of supplemental B light) and RB + LB (11 h of mixed RB light and then 13 h of B light) by using light-emitting diodes. Diurnal patterns in the net assimilation rate were observed, depending on light-quality combinations. Under mixed RB light, the net assimilation rate increased rapidly, then slightly decreased under B light, and finally dropped to negative values during darkness. Final stem length was the highest in plants grown under RB + LB, followed by LRB + B, RB + B and then RB treatment. The stem lengths under RB + B, LRB + B and RB + LB were 1.3, 1.5 and 1.7 times longer than that of RB treatment, respectively. However, fully developed flower buds were formed under RB and RB + B treatments only. The extended final stem length of RB + B plants was determined by internode extension. Overall, our results indicate that supplemental B light, at least in part, may promote stem and internode elongation growth without any inhibitory effect on flower bud formation. The results of this study present a useful practical technique for optimizing cut chrysanthemum production in greenhouse horticulture.

1. Introduction

In photoperiod-sensitive plants, flower induction is primarily regulated by light duration (photoperiod). Chrysanthemums are the most important ornamental crop worldwide. They are quantitative short day plants (SDP) that flower uniformly when critical day-length photoperiod is ≈13.5 h or less, but fails to flower under the longer critical photoperiods (McMahon, 1999). At northern latitudes, chrysanthemums are grown in greenhouses year-round. In terms of floriculture, photoperiod control should focus on minimizing the number of days to flower induction. In cut chrysanthemum production, artificially long days (LDs) are maintained routinely for 2–3 weeks before the onset of short day (SD), because of the required stem length specification (Hisamatsu et al., 2008). Although the number of LDs guarantees a sufficient stem length, it delays the transition to flowering in cut chrysanthemum.

The growth and development of ornamental plants are also influenced by light intensity and quality. Of these 2 parameters, the importance of light quality for morphogenesis has been reported in many plant species. Plants sense light quality via photoreceptors categorized as phytochromes, cryptochromes and phototropins, and these photoreceptors are in charge of a wide spectrum of morphogenesis (Lin, 2000; Takemiya et al., 2005). Among them, phytochromes are red and far-red light-sensitive but cryptochromes and phototrophins absorb blue (B) light (Lin, 2000). Extended stem length has been shown to occur as a part of a phytochrome-mediated response (Patil et al., 2003). In chrysanthemums, extended stem length is promoted under a low ratio of red to far-red light conditions (Rajapakse et al., 1993; Khattak and Pearson, 2006) or supplemental far-red light irradiation (Lund et al., 2007; Hisamatsu et al., 2008). Hisamatsu et al. (2008) found that, compared to controls, irradiation with far-red light reduces flowering transition when close to critical day length threshold, and suggested that it is involved in the photo-conversion of phytochromes. Thus, far-red light affects stem length extension and/or flowering transition in chrysanthemums. However, far-red light has not been shown to affect either plant-mass accumulation (Lund et al., 2007) or to stabilize the flowering transition depending on photoperiod (Hisamatsu et al., 2008).

In contrast to phytochromes, B light related-photoreceptors have also been suggested to be involved in the flowering process (Hirose et al., 2006; Fankhauser and Ulm, 2011). It has been

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previously reported that supplemental B light induces the flowering response of chrysanthemum more than critical day-length (Stack et al., 1998; Jeong et al., 2012). Thus, it is likely that supplemental B lighting has important functions in the flowering process. The application of supplemental lighting also allows greenhouse crops to promote biomass accumulation by increasing photosynthetic carbon assimilation (Hao and Papadopoulos, 1999). Therefore, using a B light supplementation may be a useful practical technique for optimizing cut chrysanthemum cultivation. However, there is limited literature on the effects of supplemental B light on the stem elongation of cut chrysanthemum. Despite this deficiency, there are several reports about the effects of monochromatic B light and B light containing irradiance on the morphogenesis and/or physiology of plant species (Heo et al., 2002; Kim et al., 2004; Hirai et al., 2006; Hogewoning et al., 2010). Furthermore, since the effect of B light in relation to photoperiod length remains unknown, more knowledge is required about this phenomenon.

The objectives of the current study were to reveal the flowering responses and stem elongation growth of cut chrysanthemum to supplementary B lighting under different photoperiods. Therefore, in this study, we analyzed the influence of supplemental B lighting on photosynthetic functioning, flower bud formation and growth characteristics in cut chrysanthemum by using light-emitting diodes (LEDs).

2. Material and methods

2.1. Plant material and growth conditions

Block-rooted cuttings (8 ± 1 leaves per plant) of chrysanthemum (*Chrysanthemum morifolium*) 'Zembla' (Deliflor, The Netherlands) were planted in plastic pots (diameter, 14 cm) containing a peat-based commercial potting compost (Lentse potground nr. 4; 85% peat, 15% clay) and acclimated under artificial LD conditions (15 h photoperiod, 100 ± 5 μmol m^{-2} s^{-1} LED irradiance of combined 80% red and 20% blue light [mixed RB light]) in a climate chamber (Unifarm of Wageningen UR, The Netherlands). After 5 days, the 30 plants were grown under individual light treatments for 42 days. To avoid light interference among each light treatment, we used customized fabric tents. The tents were continuously ventilated to ensure no variation in growth conditions. The day and night temperature was 22 ± 0.2 °C, relative humidity was 65 ± 2%, and the CO_2 concentration was ambient. Water was supplied daily via overhead irrigation, and nutrient solution (Hoagland, pH = 5.9 ± 0.2, EC = 1.2 mS cm^{-1}) was provided every 4 days. The plants were rearranged every 4 days to minimize edge or position effects in the climate tents.

2.2. Light treatments

Light treatments (Table 1) included: (1) RB, 11 h of mixed RB light and then 13 h of darkness; (2) RB + B, 11 h of mixed RB light, then 4 h of B light and 9 h of darkness; (3) LRB + B, 15 h of mixed RB light, then 4 h of B light and 5 h of darkness; and (4) RB + LB, 11 h of mixed RB light and then 13 h of B light. Mixed RB light was turned on at 09:00 with a digital timer, and was followed with B light or darkness, according to the specified time schedules. An illumination system was used for all light treatments, consisting of a mixture of red and blue LEDs arrays (Lumileds Lighting Company, San Jose, CA, USA). The LEDs were equipped with lenses (6° exit angle), and the arrays were suspended ~1 m above the canopy; hence, irradiance from the 2 LED types was well mixed. All mixed RB and B lighting was maintained at 100 ± 5 μmol m^{-2} s^{-1} LEDs irradiance above the plant canopy (Fig. 1). Irradiance was measured routinely by using a quantum sensor (LI-COR, LI-191, Lincoln, NE, USA), but was verified with a spectroradiometer (USB2000 spectrometer, Ocean Optics, Duiven, The Netherlands). The phytochrome photostationary state was calculated according to the method of Sager et al. (1988) and was 0.89 for mixed RB light and 0.51 for B light in this study.

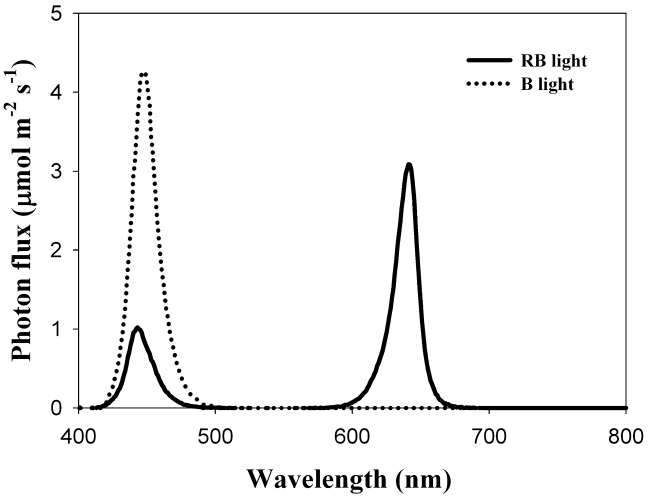

Fig. 1. Spectral photon distribution of (A) mixed RB light (80% R and 20% B) and (B) B light (100% B) measured at plant canopy level.

2.3. Leaf net assimilation rate and stomatal conductance measurements

The net assimilation rate and stomatal conductance were measured from day 15 to day 20 after the onset of light treatments by using a Li-6400 photosynthesis system with a leaf chamber (LiCor Inc., Lincoln, NE, USA). Fully expanded leaves at an identical location on the plant (4th leaf from the apical terminal) were used for the measurements. During the measurements, the light condition (light intensity and quality) of the leaf chamber was calibrated to comparable real-time light conditions by adjusting the LED back panel. The CO_2 concentration of the air entering the leaf chamber was adjusted to 400 μmol mol^{-1} by using a CO_2 gas container, and leaf temperature was maintained at 22 °C. The data were logged at every 30 s for 30 min.

2.4. Flower bud observation and plant growth measurements

We recorded the date when the flower buds became visible with naked eye, and the percentage of bud formation was investigated until 42 days. After 35 days from the start of treatments, apical dissection was performed under a binocular microscope, and images were taken with a digital camera connected to the microscope (Fig. 4). For growth property measurements, 15 plants per treatment were harvested on the 42nd day. The plants were dissected into two parts: leaves and stem. The plant parts were imaged together with a ruler and a digital photo camera in order to determine the area of the fully developed leaves, as previously described (http://rsbweb.nih.gov/ij/docs/pdfs/examples.pdf), and the length of the stem and the internodes. Image analysis was performed using the imaging software Image J (http://rsbweb.nih.gov/ij/). After imaging, all plants were oven dried at 70 °C for 72 h to obtain the dry weight (DW).

2.5. Statistical analysis

All statistical analyses were performed using SAS version 9.1.3 (SAS Institute, Cary, NC, USA). Results with P value at or below ($P \leq 0.05$) were considered significant.