Impact of lighting conditions during forcing on flowering time, morphology and postharvest transpiration of *Hydrangea macrophylla*

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Abstract

In this study, the main objective was to evaluate the impact of lighting conditions and to test effects of continuous lighting and light quality on morphology, number of flowering shoots, flowering time and postharvest transpiration. *Hydrangea macrophylla* 'Clarissa' was forced in controlled climate chambers. Extending the photoperiod from 16 h to 24 h with high pressure sodium lamps (HPS) did not affect forcing time or morphology, but postharvest transpiration was more than 50% higher when the plants were forced at 24 h compared to 16 h lighting. Additional blue light (30% BL, 400-500 nm) in combination with HPS (HPS + BL) did not change the postharvest transpiration compared to HPS but resulted in more compact plants and one week earlier flowering. White light emitting diodes (LEDs) with 20% BL induced more compact plants, compared to HPS, but the flowering was delayed by one week, and postharvest transpiration increased compared to HPS.

Key words: Blue light, flowering time, photomorphogenesis, hydrangea (*Hydrangea macrophylla*), transpiration

INTRODUCTION

Hydrangea macrophylla is a popular ornamental plant widely used as a potted plant indoors and outdoors in gardens. Flower bud formation of *H. macrophylla* is controlled by moderate temperatures (15-18°C), and takes place in open fields during late summer/early autumn. Plants are transferred to cold storage (2-10°C) to release flower buds from dormancy before forcing to flower in greenhouses (Nordli et al., 2011). A short forcing time, and compact plants with many flowering shoots are desired (Litlere and Strømme, 1975; Nordli et al., 2011). Furthermore, hydrangeas have a high postharvest water usage, and drought during shipping and retailing is a common problem (Arve et al., 2015). Hence, insight into how environmental factors during forcing influence plant quality and postharvest behavior is important for choosing the right forcing strategy.

At Northern latitudes, early forcing of hydrangea starts when the natural solar radiation is low. In this period, supplementary lighting is required to accelerate production time and improve plant quality. Light climate is a strong tool to control flowering time, morphology, stress tolerance and postharvest transpiration (Terfa et al., 2012). Besides, almost all the energy used in the production is consumed during the forcing period. Hence, understanding and designing the lighting strategies during forcing are very important for the production efficiency and the possible energy savings as well as for the quality. However, very little knowledge is available on light responses of hydrangeas.

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The common lamp type used in greenhouses for plant production including hydrangeas is high pressure sodium lamps (HPS), which contain 5-8% blue light (BL). Development of novel energy efficient lighting technology like emitting diodes (LEDs) has increased the possibilities of manipulating light quality in controlled production systems. In pot plants like poinsettia and roses, LEDs with BL (20% B) and red light (80% R) resulted in up to 30% reduction in plant height compared to HPS, with little effect on flowering time (Islam et al., 2012; Terfa et al., 2012). However, the responses to BL seem to vary with species. In *Petunia x hybrida* additional BL increased stem elongation and delayed flowering (Gautam et al., 2015). Furthermore, BL has a well-documented effect on stomata movements and patterning, and thereby it could influence postharvest transpiration of hydrangeas.

Another lighting strategy claimed to be energy efficient is continuous lighting. Plants exposed to low photosynthetic photon flux densities (PPFD) are believed to accumulate more dry matter than plants exposed to shorter photoperiods at high PPFD at the same daily light integral (DLI) (CL) (Velez-Ramirez et al., 2011). Hydrangea is not dependent on a specific photoperiod for inflorescence development, and CL could be a strategy to save energy during forcing. On the other hand, CL is known to reduce stomata function and increase postharvest transpiration of ornamentals like *Rosa* x *hybrida* (Mortensen and Gislerød, 1999). However, the effects of CL on hydrangeas have not been studied previously. Thus, in this study, the main objective was to evaluate the impact of lighting conditions such as photoperiod and light quality, specifically BL, on morphology, and flowering time of hydrangeas. Further, the aim was to investigate how the lighting conditions during forcing affects plant quality and postharvest transpiration.

MATERIALS AND METHODS

Plant material and pre-cultivation

Hydrangea macrophylla‘ ‘Clarissa’ (Heuger, Glandorf, Germany) were grown outdoors in the field at a commercial nursery in Norway (Tretteteig nursery, Sandefjord, Norway). The pot size was 13 cm and the plants were grown in peat. Plants were transferred into cold storage when the buds reached floral stage 5-6 (according to Litlere and Strømme, 1975), and stored in darkness at 2-10°C for 10-12 weeks. Then, the plants were transported to the Norwegian University of Life Sciences (NMBU), Ås, Norway, and were forced to flower in controlled growth chambers. In all experiments, the plants were watered with a balanced fertilizer (Superba red with micronutrients and added calcium nitrate) with an electric conductivity (EC) of 2-2.5 mS/cm, at each watering. A PRIVA (Priva, The Netherlands) greenhouse computer was used for recording, controlling and storage of the climate data. In all experiments photosynthetic active radiation (PAR) was measured with a Li-Cor, Model L1-185, quantum sensor Li-Cor, Model L1-185, quantum sensor (Lincoln, Nebraska, USA).

Experimental set-up and climate during forcing

Experiment I: Effects of photoperiod with similar light sum

Plants were forced at 21°C, 70% relative air humidity (RH) and ambient CO_2 level (400 ppm). The light was provided by HPS lamps (HPS, Osram NAV T- 400W, Munich, Germany) either at 16 or 24 h photoperiods at a photosynthetic active radiation (PAR) of 150 and 100 µmol m^{-2} s^{-1} (±10), respectively, resulting in the same light sum for both treatments.

Experiment II. HPS lamp combined with blue LED

Plants were forced in controlled growth chambers at a temperature of 21°C, and a RH of 85%. Plants were exposed either to 150 µmol m^{-2} s^{-1} (±10) provided by HPS (Figure 1) or to 100 µmol m^{-2} s^{-1} (±10) HPS + 50 µmol m^{-2} s^{-}1 blue LEDs (400-500 nm, peak at 460, Philips green power LED, Eindhoven, The Netherlands) for 16 h daily and a 8 h dark period.

Experiment III. White LED compared with HPS

Plants were forced in a greenhouse during the darkest time of the year (November-January) in a commercial greenhouse (Gjennestad, Stokke, Norway). The greenhouse compartment was covered with energy curtains to avoid natural light coming into the greenhouse from the outside. The temperature and RH in the greenhouse during forcing were 22°C and 75% (± 10%), respectively. Light was supplemented with either 150 µmol m^{-2} s^{-1} HPS lamps (as described above) or 150 µmol m^{-2} s^{-1} White LED (Evolys, Norway) for 16 h daily and a 8 h dark period (Figure 1).

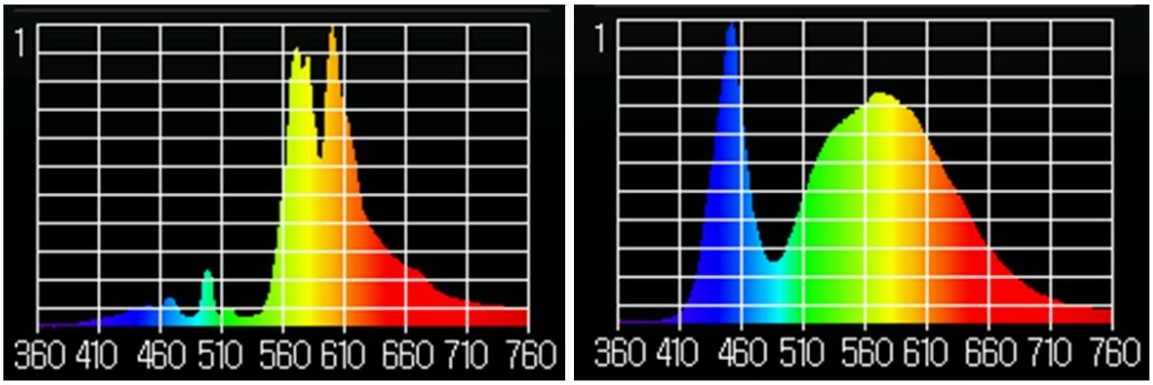

Figure. 1. Relative spectra of the lamps used in the experiments: High pressure sodium (HPS) lamps Osram NAV T-400W (left), White Light emitting diode (LED) lamps (right) (White LED, Evolys, Norway). In experiment II, HPS (left) was enriched with blue LED (400-500 nm, peak at 460).

Growth and production time measurements

The plants were harvested at a commercial marketing stage when 2-3 of the inflorescences were developed. Plant height was measured from the base of the shoot until the middle of the highest inflorescence. Plant diameter was measured by taking the average of two diameter measurements across the plant. The number of flowering shoots and vegetative shoots (< 10 cm in length) were counted. Relative chlorophyll content was measured on fully developed leaves with the use of a chlorophyll meter (Hansatech Instruments CL01 Chlorophyll, UK). In experiments I and II, the size of the inflorescences of two flowers per plant were measured every week from visible flower bud until harvest, to follow the increase in size.

Postharvest transpiration

Transpiration from whole plants during forcing was measured in experiment II by calculating the total plant water loss after placing the pots in plastic bags, weighing the plants and measuring the leaf area after the last weighing. Based on these data, the amount of water lost per time and leaf area was calculated (g cm^{-2} h^{-1}/g cm^{-2} day^{-1}). In experiments I, II, and III, postharvest transpiration was measured, using a porometer (AP4, Delta-T Devices Ltd, Cambridge, England) for three days. The first measurements were done 24 h after transferring plants from the growth chamber to the test room. The climate in the postharvest test room was 20°C, 50% RH and a photoperiod of 12 h provided by fluorescent tubes at an irradiance of 10-12 µmol m^{-2} s^{-1}. In experiments I, II, and III, the rate of water loss from leaves was measured, using the desiccation test method. Briefly, detached leaves from both cultivars and both treatments were weighted at different time intervals using an accurate scale in the same environment, as described for the postharvest test room.

Statistical analysis

Experiments I, and II were performed two times at different years, and the trends in the growth and morphology data was similar. Experiment III was performed once. Statistical differences between means were tested using the normally distributed general linear models (GLM) and Tukey's test.

Differences with $p < 0.05$ were considered as significantly different. All statistical tests were performed using Minitab 16.1.1 (Minitab 16.1.1, State College, Pennsylvania, USA).

RESULTS

Experiment I. Effects of photoperiod on growth, flowering and postharvest transpiration

Time to visible inflorescence was not significantly affected by photoperiod, and no difference in the time to marketing stage was found between plants forced at 16 or 24 h lighting (Table 1). Also, the inflorescence size, when comparing the two largest flowers per plant, was similar in both treatments (results not shown). Neither the plant height, plant diameter, number of flowering shoots nor the number of vegetative shoots were significantly affected by photoperiod (Table 1). Plants forced under 24 h lighting had 25% lower chlorophyll content compared to plants forced under16 h, but the data were not significant ($p = 0.056$). The main difference was found in the postharvest transpiration (Table 1). Plants forced at 16 h photoperiod showed about 50% lower postharvest transpiration compared to 24 h lighting. The large difference in postharvest transpiration was also confirmed by measuring the water loss from detached leaves. Thus, leaves from hydrangeas exposed to 24 h lighting showed a significant higher water loss, already 30 min after detachment, compared to leaves from 16 h lighting (Figure 2).

Table 1. Effect of photoperiod duration (16 h and 24 h) on morphology, flowering, relative chlorophyll content, and postharvest transpiration of *Hydrangea macrophylla* 'Clarissa' forced in growth chambers with artificial lighting provided by HPS; 5% BL lamps. Different letters between columns indicate significant differences at $p < 0.05$. n= 16.

Parameters	Light treatments	
	16 h	24 h
Plant height (cm)	31.6 a	31.7 a
Plant diameter (cm)	39.0 a	36.6 a
Number of flowering shoots	6.3 a	4.8 a
Number of vegetative shoots	2.4 a	3.4 a
Relative chlorophyll content	27.3 a	19.8 a
Postharvest transpiration (mmol m^{-2} s^{-1})	35.8 a	73.7 b

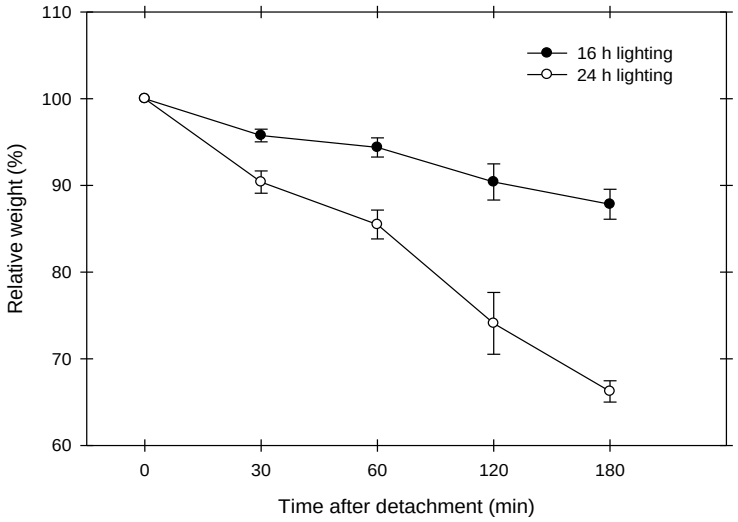

Figure 2. Change in the relative weight (%) of fully expanded detached leaves of *Hydrangea macrophylla* 'Clarissa' forced in growth chambers with 16 h or 24 h photoperiods provided by HPS lamps during 3 h of the desiccation test. Data points and error bars indicate means ± SE from two experimental repeats containing each eight replications (n=16).

Experiment II. Effects of additional BL combined with HPS

Time to visible inflorescence and marketing stage was significantly affected by the light quality, and plants forced with HPS+BL reached the marketing stage one week earlier compared to plants forced with HPS (Figure 3). In addition, plant height and plant diameter were reduced in plants exposed to HPS + BL compared to HPS, resulting in more compact plants (Figure 3). The relative chlorophyll content, number of flowering shoots or number of vegetative shoots were not significantly affected by the additional BL (Table 2). Furthermore, postharvest transpiration measurements were almost similar, when measured by whole plant transpiration using porometer measurements on single leaves (Table 2), or by the desiccation test of detached leaves (data not shown). During forcing, the measured leaf temperature was lower by 0.7°C in the HPS+BL compared to HPS.

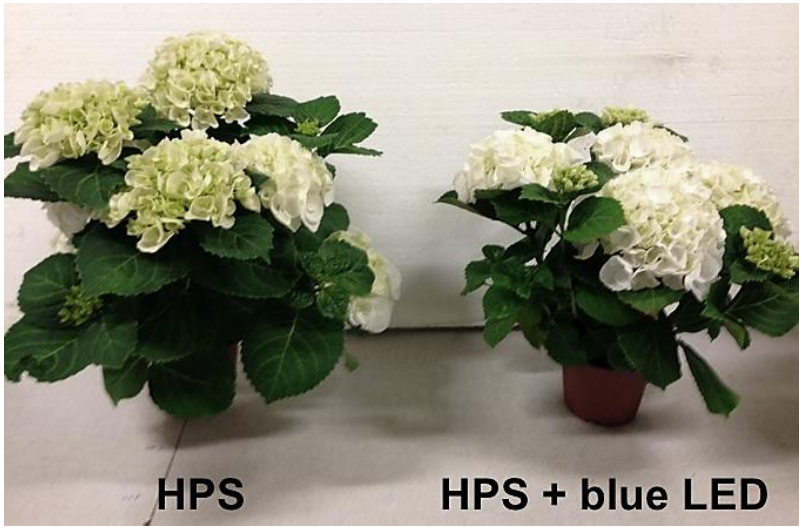

Figure 3. *Hydrangea macrophylla* 'Clarissa' appearance forced with HPS or HPS + blue LED.

Table 2. Effects of additional BL in combination with HPS, supplemented as 150 µmol m^{-2} s^{-1} (±10) HPS or 100 µmol m^{-2} s^{-1} (±10) HPS + 50 µmol m^{-2} s^{-1} blue LEDs, on morphology, flowering, relative chlorophyll content, and postharvest transpiration of *Hydrangea macrophylla* 'Clarissa' forced in growth. Different letters between columns indicate significant differences at $p < 0.05$ (n=16).

Parameters	Light treatments	
	HPS + BL	HPS
Plant height (cm)	28.4 a	32.3 b
Plant diameter (cm)	38.6 a	35.7 a
Number of flowering shoots	10.0 a	9.60 a
Number of vegetative shoots	3.90 a	5.00 a
Relative chlorophyll content	28.8 a	29.6 a
Postharvest transpiration		
- Conductance (mmol m^{-2} s^{-1})	48.8 a	46.0 a
- Whole plant transpiration ($grH_2O/cm^2/day$)	0.034 a	0.032 a

Experiment III. Effects of White LED compared to HPS

Time to the marketing stage was delayed by about one week when plants were forced with white LED compared to HPS (Table 3). Plant height and plant diameter were reduced in white LED, resulting in more compact plants than plants forced with HPS (Table 3). Meanwhile, the number of flowering shoots and total leaf area were not significantly affected by the light quality, except of the number of vegetative shoots (Table 3). Plants forced under white light had higher chlorophyll content compared to plants forced under HPS, but the postharvest transpiration was significantly higher (Table 3). The leaf temperature was lower by about 1.5°C in the white LED compared to the HPS (data not shown).

Table 3. Effect of White LED (150 µmol m^{-2} s^{-1}) compared to HPS (150 µmol m^{-2} s^{-1}) on morphology, flowering, relative chlorophyll content, and postharvest transpiration of *Hydrangea macrophylla* 'Clarissa'. Different letters between columns indicate significant differences at $p < 0.05$ (n=8).

Parameters	Light treatments	
	HPS	White LED
Plant height (cm)	25.3 a	22.3 b
Plant diameter (cm)	42.9 a	37.6 b
Number of flowering shoots	7.9 a	8.4 a
Number of vegetative shoots	0.8 a	1.9 b
Total leaf area (cm^2)	1331.7 a	1337.7 a
Relative chlorophyll content	25.0 a	30.2 a
Postharvest conductance (mmol m^{-2} s^{-1})	35.2 a	56.4 b

DISCUSSION

To improve compactness, potted hydrangeas are normally treated with plant growth regulators in the field during the first year of growing and during forcing (Bailey, 1989). However, other tools to suppress stem elongation have gained a lot of interest lately, and the present study shows that light quality can be a useful method. Plants exposed to HPS + BL LED (Exp. II) and white LED (Exp. III) increased compactness compared to HPS, by reducing shoot elongation and plant diameter without changing the number of flowering shoots. Thus, an increase in the proportion of BL could be a plausible strategy in controlling elongation of hydrangeas, as shown for poinsettia, roses and other greenhouse produced ornamentals (Islam et al., 2012; Runkle and Heins, 2001; Terfa et al., 2013).

The plant morphology did not change in response to photoperiod. However, hydrangeas are sensitive to CL, since it reduced both chlorophyll content and stomatal function. Plant species such as tomato and cucumber do not tolerate CL and develop chlorotic leaves after a short time (Haque et al., 2015). Other species such as roses, do not show chlorophyll degradation in CL, but have a high postharvest water loss due to dysfunctional stomatal behaviour (Mortensen and Fjeld, 1998). The postharvest transpiration increased by almost 50% when plants were forced at CL compared to 16 h. Hence, CL should be avoided during forcing of hydrangeas to control postharvest transpiration.

In addition to CL, light quality also significantly affected the transpiration rate during the postharvest storage, but the effect was much less severe than for CL (Table 3; Exp. III). This preliminary study shows that white LED increased postharvest transpiration of leaves. In a previous study with roses, it was shown that additional BL during growth reduced postharvest transpiration by improving the stomatal response to darkness and dry air as signals for closure (Arve et al., 2015; Terfa et al., 2012). In the study of Terfa et al. (2012), the extra BL was added in the background of red light (80% red and 20% blue), and compared with HPS. The white LED used in our study contained more green light (Figure 1), which could explain the lack of similar response. Green light can abolish the effect of BL, as discussed earlier (Smith et al., 2017). Addition of more BL with a background of HPS (Exp. II) did not affect postharvest transpiration. However, the RH in Exp. II was 85% compared to only 70% in Exp. III. The aerial environment can modify the effect of BL, and a stronger effect of BL might appear in a drier environment compared to more humid conditions (Innes, unpublished data). Thus, the effect of BL on postharvest transpiration requires more attention and further investigation to get concluding results.

Production time (time to the marketing stage) was rather robust in response to changes in the light climate. Photoperiod did not affect the time to the marketing stage. Forcing with HPS showed about one week earlier flowering compared with white LED. However, this effect was probably partly due to a higher leaf temperature. Plants exposed to white LED had a lower leaf temperature by about 1.5°C than plants exposed to HPS. On the other hand, additional BL combined with HPS accelerated production time compared to HPS. This cannot be explained by differences in leaf temperature, since only small differences in leaf temperatures were measured. Therefore, this indicates that more BL can increase production efficiency.

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