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UV radiation as a tool to control growth, morphology and transpiration of poinsettia (*Euphorbia pulcherrima*) in variable aerial environments

Sheona N. Innes[a], Knut Asbjørn Solhaug[b], Louise Elisabeth Arve[c], Sissel Torre[a,*]

[a] Faculty of Bioscience, Department of Plant Science, Norwegian University of Life Sciences, 1430 Ås, Norway
[b] Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, 1430 Ås, Norway
[c] Norwegian Food Safety Authority, 1430 Ås, Norway

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ABSTRACT

Greenhouse production of poinsettia calls for strict control of morphological parameters, which may be achieved through the use of chemical growth retardants. Use of such chemicals is becoming restricted thus alternative methods for growth control are needed. Here the effects of UV radiation were tested on *Euphorbia pulcherrima* (Willd ex. Klotzch) in controlled environment under moderate (60%) and high (90%) relative air humidity (RH), to determine the potential to control plant morphology. Vegetative plants ('Christmas Feelings') received UV during the dark period, while two generative cultivars, one strong growing phenotype 'Infinity Red' ('IR') and one more compact phenotype 'Bravo Bright Red' ('BBR'), received UV at the end of the light period (EOD). The morphology of vegetative plants was mainly affected by RH rather than UV radiation. Generative plants were also strongly affected by RH, though both cultivars showed reduced plant diameter, shoot biomass, leaf area, and bract area when exposed to UV, as well as increased leaf chlorophyll content, though responses to UV were stronger in moderate RH compared to high RH. Transpiration of leaves and bracts was mainly affected by RH not UV, and photosynthesis and production time were not affected by either RH or UV. We conclude that UV radiation is a potential tool to grow more compact plants, though its effects are partially determined by the aerial environment.

1. Introduction

Poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) is an important ornamental potted plant species produced in greenhouses for the Christmas season and valued for its intensely coloured bracts. Plant growth control is important in poinsettia production and may be accomplished using chemical growth retardants (Alem et al., 2015). While non-chemical production methods and climate manipulation for growth control are in wide use in production today, further investigation into novel techniques is required as chemical restrictions and environmental protection become increasingly important (De Castro et al., 2004; Sørensen & Danielsen, 2006). Methods such as diurnal temperature drops, lower day- than night- temperature (negative DIF) regimes (Myster & Moe, 1995) and light quality manipulation using light emitting diodes (LEDs) (Islam et al., 2012; Islam et al., 2014) have been found to prevent excessive elongation in poinsettia. Light quality manipulation is increasingly used as a means of minimising chemical growth retardants in production systems, and the potential use of UV radiation in the same way remains little investigated. In a previous study on the effects of UV radiation on poinsettia, Torre et al. (2012) found a reduction in internode elongation and an increase in branching in response to a low dose of UV-B radiation given during the dark period. The study was performed on vegetative plants under long day (LD) conditions, yet testing the influence of UV on generative plants under SD conditions is important to evaluate its effect on production time, as it has previously been shown that UV-B can affect flowering (Martínez et al., 2004).

UV radiation, as UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (< 280 nm), has pleiotropic effects on plant growth and development (Frohnmeyer & Staiger, 2003; Mackerness et al., 1998; Strid et al., 1994; Wargent et al., 2009). Plant morphological responses to UV-B radiation have been thoroughly investigated for a large range of species under field-, greenhouse- and controlled environment conditions, as reported in several reviews. Despite variations in study conditions and species, 'keystone' UV radiation responses have been identified, such as plant height and leaf area reductions, and increased content of UV screening phenolic compounds (Wargent, 2016). Further commonly reported responses to UV radiation include increased leaf thickness, reduced plant biomass, reduced chlorophyll content, and visible damage such as leaf curling and bronzing (Baroniya et al., 2011; Deckmyn

* Corresponding author.
E-mail address: sissel.torre@nmbu.no (S. Torre).

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Table 1
Experimental growth chamber setup for experiments 1 and 2, "/" indicates experiment 1 and 2 respectively, where differences occurred. Chambers were set up in a factorial design, with plants grown in either moderate (60%) or high (90%) RH and either not exposed (−UV) or exposed (+UV) to 0.15 W m^{-2} UV radiation for 40 min per day (time of day differs between experiments).

	Temperature (°C)	RH (%)	PAR irradiance (μmol m^{-2} s^{-1})	UV radiation (W m^{-2})	UV duration, time of day	Absolute UV dose (W m^{-2} d^{-1})	Photoperiod (h)	Daily light integral (mol m^{-2} d^{-1})
Chamber 1 (60 − UV)	21/22	60 %	150 ± 10	0	NA	NA	20 h/10 h	10.8/5.4
Chamber 2 (60 + UV)	21/22	60 %	150 ± 10	0.15	40 min, Night/EOD	360	20 h/10 h	10.8/5.4
Chamber 3 (90 − UV)	21/22	90 %	150 ± 10	0	NA	NA	20 h/10 h	10.8/5.4
Chamber 4 (90 + UV)	21/22	90 %	150 ± 10	0.15	40 min, EOD	360	20 h/10 h	10.8/5.4

et al., 1994; Frohnmeyer & Staiger, 2003; Nogués et al., 1998).

Several studies have focused on the effects of UV-B radiation on stomatal behaviour, with often contradictory results, though the greater consensus report stomatal closure upon plant exposure to UV-B radiation (He et al., 2005; Negash & Björn, 1986; Nogués et al., 1999; Tossi et al., 2009; Tossi et al., 2014). Jansen and Van Den Noort (2000) attribute the disagreement in reported findings to the initial metabolic state of the guard cells when UV-B radiation is applied, reporting that in their study UV-B radiation served to enhance the initial state of the guard cells, that is, either enhance stomatal opening or closing. Stomatal behaviour and plant water relations are important in plant production systems, as control of water relations contributes to minimising production expenses, as well as optimising post-harvest quality (Arve et al., 2013).

High relative air humidity (RH) regimes are often employed in the greenhouse plant production industry, most notably in Northern climates where, in winter, there is a trade-off between ventilating to dissipate humid air and using closed systems to reduce heat loss (Mortensen, 2000). A diverse range of morphological responses to high RH has been shown in controlled environment studies, such as increased stem elongation and increased leaf area (Hovenden et al., 2012; Jeon et al., 2006; Leuschner, 2002; Torre et al., 2003). Increased leaf area in plants grown at high RH has been associated with changes in photosynthesis and carbon metabolism (Grange & Hand, 1987; Jeon et al., 2006). Thinner leaves at high RH reported by Torre et al. (2003) was attributed to a reduction in epidermis thickness along with smaller spongy- and palisade mesophyll cells. Tall plants with thin leaves are undesirable in commercial plant production, where compact and robust plants are required. Additionally, production in high RH can have a direct negative effect on post-harvest keeping quality due to high postharvest water loss and lower stress tolerance, as seen in ornamentals and cut flowers (Mortensen & Fjeld, 1998; Mortensen & Gislerød, 1999; Mortensen, 2000; Torre & Fjeld, 2001; Torre et al., 2003).

The aim of the study was to investigate the responses of poinsettia to artificial UV radiation grown in moderate and high humidity for the purpose of exploring potential improvement of production methods. Since many greenhouses have cladding or glazing material that does not transmit UV radiation and natural UV radiation is low during the period when poinsettias are produced, the use of UV lamps forms an alternative means of providing UV radiation in commercial production. We investigated the hypotheses that exposure of the plants to UV radiation would a) combat the morphological impacts of high RH and induce a more compact, robust growth form and b) improve plant water relations during production in a high RH environment.

2. Materials and methods

2.1. Experiment 1: vegetative growth of poinsettia

Cuttings of poinsettia 'Christmas Feelings', rooted in Jiffy-7 (Jiffy International AS, Kristiansand, Norway) were obtained from Ljones Gartneri AS in December 2013 and potted in 12 cm pots with Sphagnum peat growth medium, 6% ash, pH 5.0–6.0 (Degernes Torvstrøfabrikk AS, Degernes, Norway). The rooted cuttings were placed in a greenhouse compartment at 21 °C, 70% RH and ambient CO_2, controlled using a PRIVA system (Priva, De Lier, The Netherlands), for an initial growth period. In addition to natural light, the plants received 100 μmol m^{-2} s^{-1} PAR from high pressure sodium (HPS) lamps (Osram NAV T-400 W, Munich, Germany), measured using a Li-Cor quantum sensor connected to a Li-Cor Model L1-250 light meter (Li-Cor Inc., Lincoln, NE, USA). The plants were pinched over 3–4 leaves and two weeks later, when the new shoots were approximately three centimetres, the plants were moved to controlled environment growth chambers for UV exposure.

The plants were subjected to long day (LD) treatment, with a 20/4 h light/dark photoperiod regime receiving PAR radiation at 150 ± 10 μmol m^{-2} s^{-1} from HPS lamps. This gave a daily light integral (DLI) of 10.8 mol m^{-2} d^{-1}. Temperature was maintained at 21 °C ± 1 °C and ambient CO_2 (approximately 400 ppm) in all chambers by a PRIVA system. The plants were grown in a factorial design using four growth chambers (Table 1). Two levels of RH treatment, moderate (60%) or high (90%) RH, and two levels of UV treatment, either not exposed (−UV) or exposed (+UV) to 0.15 W m^{-2} UV radiation (at plant height) for 40 min in the middle of the dark period, were combined to create four treatment combinations (Table 1). The Green weighting spectrum for DNA damage (Green et al., 1974), normalised to 1 at 300 nm, was used to estimate biologically effective UV-B at 0.22 W m^{-2}. Individual plants were the unit of replication within each treatment ($n = 5$ per treatment). The plants were rotated in the chambers once a day.

UV radiation was provided by unscreened fluorescent tubes (Q-panel UV 313, Q-Lab Corporation, Ohio, USA), and measured using a Skye SKU 430/SS2 UVB Sensor connected to a Skye SpectroSense2 Meter (Skye Instruments Ltd., Llandrindod Wells, Powys, UK). The UV sensor was calibrated using an Optronic OL756 Spectroradiometer (Optronic Laboratories, Inc., Florida, USA). The lamps produced mostly radiation in the UV-B range (280–315 nm) with some radiation in the UV-A (315–400 nm) and the UV-C (< 280 nm) ranges (Fig. 1).

Cellulose di-acetate is often used to block wavelengths below 295 nm to simulate solar UV-B. However, unscreened fluorescent lamps were chosen for this investigation as the study was not geared to simulate solar UV, and was rather to investigate the practical potential of such a light source in commercial poinsettia production.

The plants were watered three times a week with 50/50 mixture of YaraLiva® Calcinit™ calcium nitrate solution (14.4% NO_3, 1.1% NH_4, 19.0% Ca, Yara Norge AS, Oslo, Norway) and Kristalon™ Indigo (7.5% NO_3, 1% NH_4, 4.9% P, 24.7% K, 4.2% Mg, 5.7% S, 0.027% B, 0.004% Cu, 0.06% Mn, 0.2% Fe, 0.004% Mo, 0.027% Zn, Yara Norge AS, Oslo, Norway), EC level 1.5 m S cm^{-1}.

The plants were pinched again when the shoots were approximately 10 cm long, and four shoots were allowed to develop per plant. After 56