



## Impact of end-of-day red and far-red light on plant morphology and hormone physiology of poinsettia

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### ABSTRACT

Control of morphology is essential in greenhouse production of poinsettia, which is among the largest and economically most important ornamental pot plant cultures worldwide. Plant growth regulators are used to reduce shoot elongation but due to their potentially negative impacts on human health and the environment, it is highly desirable to replace these. Exploiting responses to light quality as an alternative has been investigated to a limited extent only in poinsettia and information about elongation-controlling hormones is scarce. In natural light an increased far-red (FR) proportion at the end of the day (EOD) is known to enhance shoot elongation in several species through action of phytochrome on hormone metabolism. The aim of this study was to assess the effect of manipulation of the phytochrome system at the EOD on elongation growth and hormone metabolism in poinsettia. Depending on cultivar, shoot elongation and internode lengths were reduced 34–54% by exposure to 30 min EOD-R compared to 30 min EOD-FR, both provided by light emitting diodes. The reduced elongation under EOD-R correlated with 29% and 21% lower levels of gibberellin and indole-3-acetic acid, respectively. Specific leaf and bract area were also significantly lower under EOD-R compared to EOD-FR. Bract formation and time to visible cyathia did not differ between the light treatments. In conclusion, manipulation of the phytochrome system by EOD-R in order to modulate the contents of the growth-controlling hormones can be a useful tool in control of shoot elongation in greenhouse-grown poinsettia in order to counteract the effect of the increased FR proportion at the EOD.

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### 1. Introduction

Poinsettia (*Euphorbia pulcherrima*) is among the economically most important ornamental potted plants worldwide (Ecke et al., 2004). Due to low natural solar radiation and low temperatures in northern areas during the autumn when poinsettia is produced in greenhouses, the use of supplementary light and heating is necessary. Control of plant height is then among the main challenges (Ecke et al., 2004; Lütken et al., 2012). In greenhouse culture of ornamental species such as poinsettia, lilies, geraniums and chrysanthemum, graphical tracking is a commonly used tool for

height management (Heins and Carlson, 1990; Moe et al., 1992). The graphical tracking method is based on a static sigmoid curve to determine the progress towards desired plant height. The actual growth is then compared with the predicted curves. Plant growth regulators (PGRs) such as chlormequat, daminozide or paclobutrazol are commonly used in this respect to control shoot elongation. However, due to the potentially negative effects of PGRs on human health and the environment (De Castro et al., 2004; Sørensen and Danielsen, 2006) their use is becoming restricted and desirable to phase out. In addition, application of PGRs is time-consuming. In northern areas temperature drop treatments in the morning are commonly used in combination with PGRs to reduce elongation growth. However, use of such temperature drops is limited by periods of high temperatures and high solar radiation in early autumn as well as energy-saving regimes in semi-closed or closed greenhouses. As an alternative, exploiting the responses of the plants to different light qualities provides an interesting possibility in greenhouse production of poinsettia.

**Abbreviations:** ABA, abscisic acid; EOD, end of day; FR, far-red; GA, gibberellin; IAA, indole-3-acetic acid; Pfr, far-red-light absorbing phytochrome form; PGR, plant growth regulator; Pr, red-light absorbing phytochrome form; R, red.

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In plants light quality is sensed by different photoreceptors, which are involved in a wide range of developmental processes. Red (R) and far-red (FR) light are sensed by phytochromes, which exist in two inter-convertible forms, the R-light absorbing inactive form ( $P_r$ ) and the FR-light absorbing active form ( $P_{fr}$ ) (Smith, 1995). Although the effect vary with species, the R:FR-ratio during the entire light phase or at a short duration (10–60 min) at the end of the day (EOD) has been shown to be very effective to control shoot elongation in a number of species, with FR and R enhancing and reducing elongation, respectively (Kasperbauer and Peaslee, 1973; Blom et al., 1995; Gilbert et al., 1995; Smith, 1995). Thus, the amount of  $P_{fr}$  relative to the total amount of phytochrome at the beginning of the dark period may regulate plant morphology and photosynthetic partitioning (Rajapakse et al., 1993). Furthermore, the phytochrome responses vary with other environmental conditions such as irradiance, other aspects of spectral quality and temperature (Smith, 1995).

Although effects of R:FR ratios have been studied to a limited extent in poinsettia, experiments where poinsettia plants were covered by selective films absorbing FR or R light, indicated that morphology is affected by the R:FR ratio (Clifford et al., 2004). Also, when a greenhouse-grown poinsettia cultivar was provided with a 30 min EOD-R treatment plant height was reduced compared to those where only high pressure sodium (HPS) lamps were used as supplementary light in addition to natural light (Islam et al., 2012). However, no systematic comparison of effects of EOD-R and FR on shoot elongation and involved hormones in poinsettia has been reported. In the poinsettia growing season in greenhouses (September–December) in northern areas, the R:FR ratio of natural sun light is decreasing at the EOD (Nilsen, 1985). Manipulation of the light quality at the EOD might thus provide an interesting, energy-efficient option for controlling shoot elongation in poinsettia.

Light-dependent changes of plant growth and development are known to be regulated by plant hormones. In investigated, responsive species internode elongation is influenced by the R:FR-ratio through modulation of the levels of hormones, especially gibberellin (GA) and auxin. In cowpea (*Vigna sinensis*) enhanced elongation in response to EOD-FR is apparently due to reduced inactivation of  $GA_1$  as a consequence of removal of the active phytochrome form  $P_{fr}$  (Martínez-García et al., 2000). In hybrid aspen (*Populus tremula* × *tremuloides*) phytochrome A (PHYA) over-expression resulted in decreased shoot elongation due to reduced cell numbers and cell lengths, and this was correlated with reduced GA and IAA levels (Olsen et al., 1997). However, after exposure of PHYA overexpressing lines and wild type plants to EOD-FR light, the plant length, cell lengths and cell numbers as well as GA levels were similar in both genotypes, indicating that phyA is not involved in the response to EOD-FR (Olsen and Junttila, 2002). As shown in a number of species, responses to different R:FR and EOD treatments appear to depend on the light stable phytochromes phyB, phyD and phyE (Devlin et al., 1999; Smith, 1995).

The biologically active GAs, such as the 13-hydroxylated  $GA_1$ ,  $GA_3$ ,  $GA_5$  and  $GA_6$  as well as the non-13-hydroxylated  $GA_4$  and  $GA_7$  are synthesised in the early 13-hydroxylation pathway and the non-13-hydroxylation pathway, respectively (Yamaguchi, 2008). In some species, such as the herbaceous pea (*Pisum sativum*), *Petunia*, cowpea and *Silene*, as well as woody species of the *Populus* and *Salix* genera,  $GA_1$  is dominating in vegetative tissues, whereas  $GA_4$  is dominating, e.g. in *Arabidopsis thaliana* and conifers like Norway spruce (*Picea abies*) (Olsen et al., 2004; Yamaguchi, 2008). In poinsettia, GA biosynthesis has not been characterised and information about hormone physiology in general is scarce.

Indole-3-acetic acid (IAA) is the predominant auxin in plants and an important determinant of phytochrome-mediated growth suppression during de-etiolation (Chory et al., 1996). Auxin is well

known to be implicated in developmental processes such as stem elongation, phototropism, gravitropism, vascular tissue differentiation and cell expansion. In pea endogenous IAA was increased under EOD-FR (Behringer and Davies, 1992). Up-regulation of auxin-induced genes under low irradiance and low R:FR ratio resulted in increased hypocotyl elongation in *A. thaliana* (Steindler et al., 1999; Vandebussche et al., 2003).

The role of cytokinins (CK) in mediating effects of light on stem elongation is unclear but they somehow appear to interact with other hormones (Miller, 1956; Thomas et al., 1997; Halliday and Fankhauser, 2003). CK can apparently promote stem elongation in light-grown *A. thaliana* either through blocking ethylene action or IAA transport (Smets et al., 2005). Furthermore, the effects of CK may vary in light- and dark-grown plants. In light-grown *A. thaliana* there was no effect of CK application on hypocotyl elongation but in the dark CK inhibited hypocotyl elongation (Su and Howell, 1995). Taken together, the role of CK in photomorphogenesis is still unclear.

The relationship between light and abscisic acid (ABA) levels is not clearly established (Kraepiel and Miginiac, 1997). The phytochrome chromophore-deficient mutant *pew1* in *Nicotiana plumbaginifolia* had higher levels of ABA compared to wild type plants (Kraepiel et al., 1994). In sunflower (*Helianthus annuus*) the R:FR ratio and ABA levels in leaves were correlated with internode length (Kurepin et al., 2007a). Similarly, FR-treated *Lemma gibba* showed higher ABA content compared to R light alone, whereas ABA levels decreased with decreasing elongation under R light (Weatherwax et al., 1996). Recently, reduced height was reported in an ABA deficient mutant in tomato (*Solanum lycopersicum*) (Nitsch et al., 2012).

In this study we aimed to investigate the effect of manipulation of the phytochrome status at the EOD on morphology and hormone metabolism in poinsettia by applying EOD-R or EOD-FR light treatments provided by light emitting diodes.

## 2. Materials and methods

### 2.1. Plant material

Two cultivars (cvs Christmas Spirit and Christmas Eve) of poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) were used to test the effect of red (R) and far-red (FR) end-of-day (EOD) treatments on plant morphology and hormone metabolism. Cuttings of poinsettia with 6–7 leaves were rooted in Jiffy-7 (G3 Ljones Gartneri AS, Tørvikbygd, Norway) and thereafter potted in *Sphagnum* peat (Veksttorv, Ullensaker Almennig, Nordkisa, Norway) in 13 cm plastic pots. The plants were kept for 6 weeks in a growth room at 20 °C with an average relative air humidity (RH) of 70 ± 5%, corresponding to an average of 0.7 kPa water vapour pressure deficit (VPD). Light at a photon flux density of 80–90  $\mu\text{mol m}^{-2} \text{s}^{-1}$  (Osram L 58 W/640 Cool White fluorescent tubes, Munich, Germany) was provided during an 18 h photoperiod. Plants were pinched above 3–4 leaves and three side shoots per plant were allowed to grow.

### 2.2. Growth conditions and light treatments

To induce flowering, all plants were then transferred to a growth chamber where plants were grown at 21 ± 2 °C under a 10 h photoperiod provided by high pressure sodium lamps (HPS, LU400/XO/T/40; General Electric Co., Fairfield, CT, USA) at an irradiance of 100  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . At the EOD, light emitting diode (LED) bars were used to provide 30 min of either R (peak 630 nm, Philips green power LED module HF deep red, 10W, Eindhoven, The Netherlands) or FR (peak 730 nm, Philips green power LED module HF far red, 10W) light at 10  $\mu\text{mol m}^{-2} \text{s}^{-1}$  was provided (measured

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