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Effect of light emitting diodes (LEDs) on postharvest needle retention of balsam fir (*Abies balsamea* L.)

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Abstract

Two experiments were conducted to understand the effect of light emitting diodes on postharvest abscission in balsam fir (*Abies balsamea* L.) branches. In one experiment, branches were pre-exposed to the fluorescent light, LEDs, or darkness for 1, 4, 8, 12, 24, or 48 h. In a second experiment, branches were constantly exposed to fluorescent lights, LEDs, or darkness. The response variable was needle retention duration (NRD). A 48-hour exposure time to red, white, or blue LEDs significantly ($P < 0.001$) increased NRD by approximately 75, 118, or 127%, respectively, compared to a cool white fluorescent lighting or darkness. Constant exposure to any LED significantly ($P < 0.001$) improved NRD compared to fluorescent lights or darkness, though white and red LEDs were most effective. It is speculated that LED-promoted needle retention could possibly be due to changes in carbohydrate synthesis similar to those observed during cold acclimation.

Key words: Abscission, *Abies balsamea*, balsam fir, conifer, light emitting diode, needle retention, postharvest, senescence

Introduction

Balsam fir is the principal Christmas tree species and specialty horticultural product grown in Nova Scotia. Balsam fir are grown on over 10,000 ha (25,000 ac) and approximately 1.5 to 2.0 million trees are harvested each year. Overall, the industry generates 72 million dollars annually in the Atlantic region and employs several hundred people (CTCNS, 2010). Postharvest needle drop is a significant challenge faced by the Christmas tree industry of Atlantic Canada. In recent years, the severity of needle loss has escalated to an extent that threatens the survival of Christmas tree and greenery industry, where the number of annual sales is starting to decrease (Chastagner and Benson, 2000). While needle losses occur during harvesting, handling, transportation, and at display stands to a certain extent, extensive needle loss after consumers' purchase has become a matter of great concern for the industry (Mitcham-Butler *et al*., 1988). The industry suffers huge economic losses due to the reduced marketability, as consumers no longer tolerate needle loss and there is an increasing trend towards purchasing artificial trees. While the exact reason for needle drop is yet to be determined, it is commonly believed that increased demand from foreign markets requires earlier harvesting. Harvesting balsam fir often begins in early October in Nova Scotia, which results in poor needle retention (MacDonald *et al*., 2010a; MacDonald and Lada, 2008). In addition, warmer fall temperatures in late October have reduced the needle retention capabilities of Christmas trees worldwide (Chastagner and Riley, 2003).

The use of LEDs in horticulture was originally presented as a potential technology for space-based plant research chambers or bioregenerative life support systems (Bula *et al*., 1991; Barta *et al*., 1992). Certain advantages that LEDs provide, such as small size, durability, long operational life, wavelength specificity, and relatively cool emitting surface, could be useful during transport and storage of Christmas trees (Li *et al*., 2010). In addition, LEDs are considered eco-friendly due to their low electricity requirements and long operational lifespan. Light spectra quality, intensity and duration at different wavelengths, particularly those at red or blue, influence plants by triggering physiological reactions including dormancy, photoperiodism, flowering, senescence, and abscission (Li *et al*., 2010, Okamoto *et al*., 1996; Tennessen *et al*., 1993; Yanagi *et al*., 1996). For example, red light is important in the development of the photosynthetic apparatus and starch accumulation (Saebo *et al*., 1995) while blue light is important in development of chlorophyll, chloroplast development, and enzyme synthesis (Senger, 1982). Light controls hypocotyls growth and activity of enzymes associated with nitrogen metabolism in Scots pine trees using a combination of phytochrome and blue/ultra-violet light. Other studies done on Scots pine trees showed that far red and red light invoke phytochrome system and induce cold hardening (Beck *et al.,* 2004).

Leaf senescence and abscission are affected by light. Leaves kept in the dark senesce faster compared to those exposed to light (van Lieburg *et al*., 1990). In contrast, certain spectra of light can delay abscission. For example, abscission resistance in mung bean leaves is enhanced with red light (Curtis, 1978) while red LEDs delayed postharvest senescence and abscission in ornamental flowers such as hibiscus and lillies (van Lieburg *et al*., 1990; van Meeteren and van Gelder, 2000). However, there is no information relating the role of LED's to postharvest abscission in balsam fir. The objective of this study was to understand the effect of certain spectrums (blue, red and white) of LED's on needle abscission in postharvest balsam fir.

Materials and methods

Sample collection: Balsam fir branches containing the two most recent years of growth were collected from mature grafted trees (approximately 17 years old) at the Tree Breeding Center, Department of Natural Resources, Debert, Nova Scotia, Canada (45° 25' N, 63° 28' W). A total of 112 trees were randomly selected for experiment 1 on August 11, 2009; another 28 trees were randomly selected for experiment 2 on September 24, 2009. In each experiment, one branch was cut from each tree from the south facing side at between 1.0 to 1.5 m above ground to serve as a sample. Cut branches were placed in distilled water and transported to a growth chamber with a day/night temperature regime of 18/10°C and 60% relative humidity. Light was provided using fluorescent lights at an intensity of 254 µmol m^{-2} s^{-1} for 16 hours each day. All branches were given a fresh cut 3 cm from the stem and weighed before they were placed in 250 mL flask of distilled water.

Short-term exposure to LEDs: Separate, but similar, experiments were conducted to determine the effect of short-term exposure to blue LEDs, red LEDs, white LEDs (LED wholesalers.com Burlingame, California, USA), fluorescent light, or darkness on postharvest needle abscission. Each experiment followed a completely randomized design using exposure duration (0, 1, 4, 8, 12, 24, or 48 hours) as a treatment. In each treatment, a branch was placed in a custom-built chamber and exposed to certain lighting or darkness for a specified length of time and then placed in growth chamber conditions (described above). This procedure was repeated 4 times for each exposure time, each with a separate branch. Fluorescent light and dark treatments each served as control, as they each simulate environments in storage and shipping. LED treatments involved exposure to a 30 x 30 cm LED panel. Light intensity in each chamber was measured using the LI-188B Integrating Quantum Photometer (LI-COR, Lincoln, NE, USA) and reported as the average of six measurements from random locations in each chamber (Table 1). Air flow was supplied to each chamber by forcing air into the bottoms of the chambers at a rate of 3 L min^{-1} using an Elite 802 air pump (Hagen, Truro, NS, Canada). The internal temperature of all LED chambers was monitored throughout the experiment and was consistent with growth chamber temperatures.

The response variable used was needle retention duration (NRD) defined by MacDonald *et al.* (2010a; 2010b), as the length of time to lose 50% initial fresh mass through needle abscission. To determine needle loss, all dropped needles were collected each day and weighed. Data were subjected to non-linear regression analysis (Sigma Plot 11, Systat Software Inc., Chicago, IL, USA), using the following general logistic equation:

$$y = \frac{a}{1 + e^{-\left(\frac{x - x_0}{b}\right)}}$$

In the above equation, y represents NRD while x represents light exposure time. The remaining variables a, b, and x_0 are constants determined by regression for each relationship. The numerator of the equation, a, is of particular interest because it represents the approximate limit of NRD as exposure time increases. A t-test at 5% significance was used to test for significant differences in a between treatments.

Constant exposure to LEDs: The second experiment investigated the effect of constant exposure to different sources of light on needle abscission in balsam fir branches. The experiment followed a complete randomized design with four replicates, where a single branch served as a replicate and each branch was placed in a separate chamber. Each light source (growth chamber fluorescent, blue, red, white, or dark) was a treatment. Flasks, with branches, were placed into trays at the bottom of the chamber to collect the needles that had fallen off. Needles were collected with growth chamber lights turned off; the only light was provided by the chamber LED panel to ensure that they were not exposed to any other light during the experiment. For the dark treatment, a lamp with a single 40-watt green incandescent bulb was turned on in the far side of the growth chamber to allow needle collection. After needle collection, branches were returned to their respective treatment.

Table 1. Summary of light sources used in this experiment. Light intensity is reported as the mean from six measurements ± standard deviation

Treatment	Peak wavelength (nm)	Light intensity (µmol s^{-1} m^{-2})
Fluorescent*	400 - 800	253.7 ± 4.5
Blue	465	17.0 ± 0.6
Red	650	17.0 ± 0.6
White**	465, 575, 650	20.0 ± 0.7
Dark	N/A	N/A

* Fluorescent lights have many peak wavelengths in the range of 400 -800 nm.

** White LEDs are considered 'multicolored' which uses a combination of red, green, and blue wavelengths to create white light.

The response variable was NRD (as described above). Data were subjected to an analysis of variance and means separation was performed using the least significant difference at 5% significance (SAS v9, SAS Institute Inc, Cary, NC).

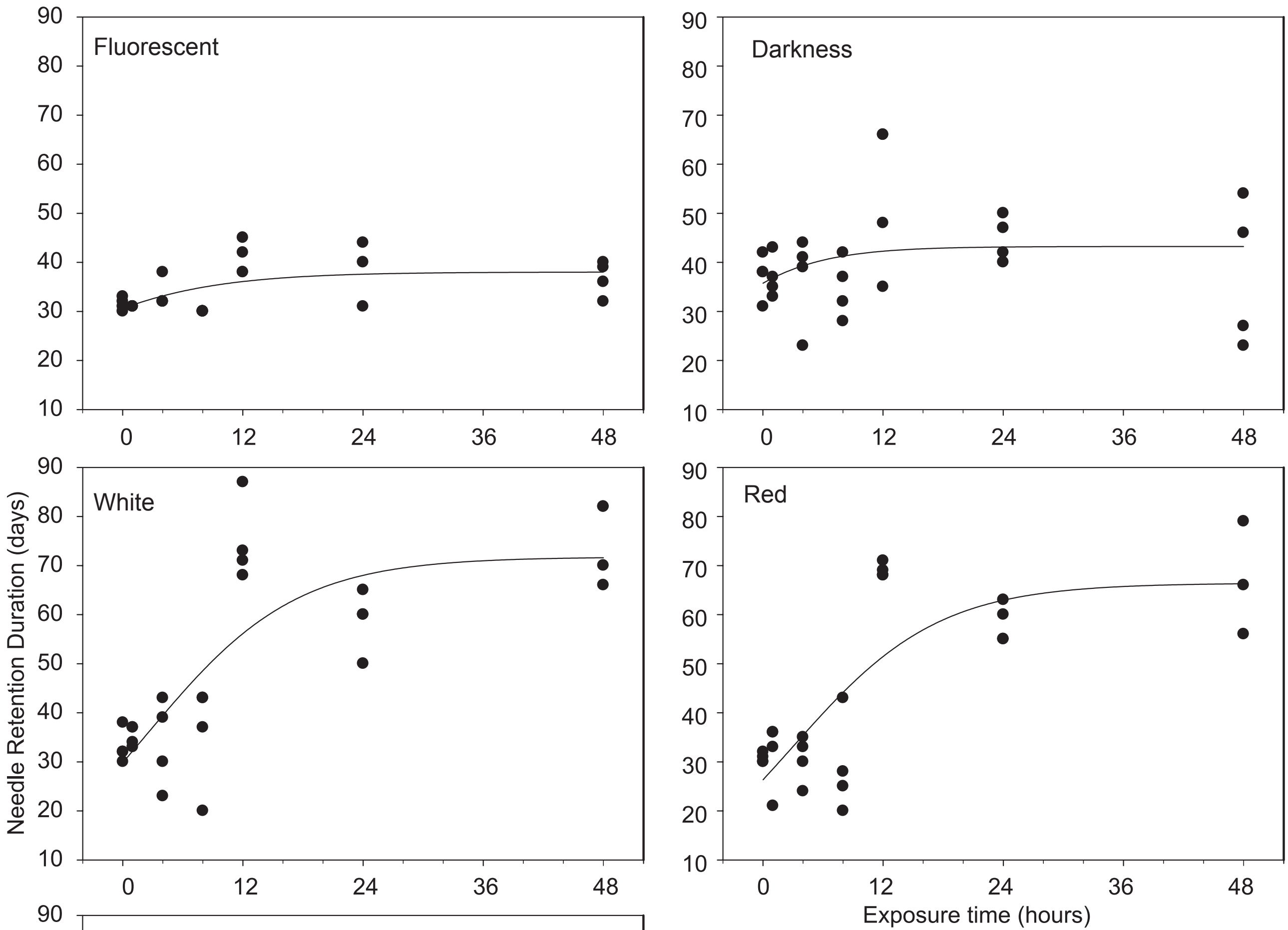
Results

Exposure to cool white fluorescent lights or darkness had no significant effect on NRD in balsam fir, with an average NRD of 31.5 days and 35 days, respectively. However, there were significant relationships between NRD and exposure duration to each of red, white, and blue LEDs (Fig. 1). A 48-hour exposure to red, white, or blue LEDs increased NRD by approximately 36, 42, and 25 days compared to their respective non-LED exposed treatments. The horizontal asymptote of each relationship represents the limit of effectiveness of each light exposure. A comparison of the horizontal asymptote of each relationship suggests that exposure to red, white, and blue LEDs have a significantly higher asymptote than fluorescent or dark treatments, but there is no significant difference among the three LED treatments (Fig. 2). A comparison of branch needle loss after 12-, 24-, or 48-hour exposure to each light source is shown in Fig. 3.

Continuous exposure to LEDs also had a significant effect on NRD. The fluorescent light and dark treatment each had an NRD of 62 days. However, exposure to red, white, and blue LEDs resulted in a significantly ($P < 0.01$) higher NRD of 68, 73, and 76 days, respectively (Fig. 4).

Discussion

Exposure to any LED spectra tested delayed needle abscission, while branches in the dark lost needles on an average 10 to 30 days earlier. The results are consistent with the literature as plants



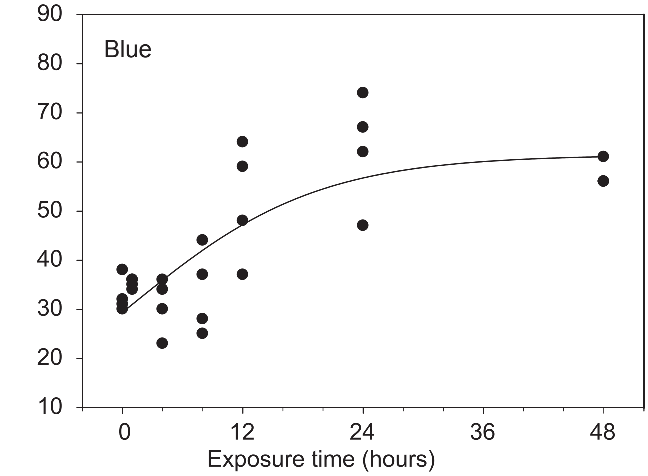


Fig. 1. Needle retention duration of different exposure times to fluorescent lights, darkness, white LEDs, red LEDs, or blue LEDs. A logistic curve is fitted to each set of data using exposure duration as the explanatory variable and needle retention duration as the response based on 28 observations.

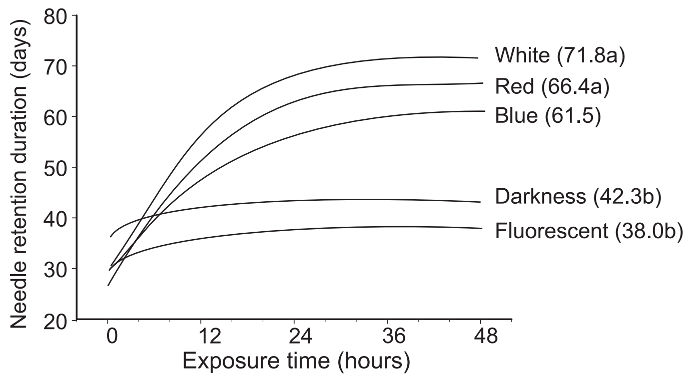


Fig. 2. Comparison of needle retention duration curve after exposure to fluorescent lights, darkness, blue LEDs, red LEDs, or white LEDs (as calculated from each regression in Fig. 1). Numbers in parentheses are the limit of needle retention (in days) for each relationship, based on regression analysis. Letter groupings were calculated from logistic regression coefficient and standard error and indicate a significant difference at $\alpha = 0.05$.

in the dark will induce senescence faster than those exposed to light (van Lieburg *et al.*, 1990). However, the branches in the dark treatment lost their needles at nearly the same time as the ones in the growth chamber exposed to fluorescent lighting. This suggests that there was no preconditioning effect due to short term dark exposure. The general response in NRD due to LED treatments was similar for all spectra tested. The improvement in NRD was minimal after short exposures of 1 to 8 hours, increased sharply after 12 to 24 hours of exposure, and then leveled off. Exposure to fluorescent lights or darkness had a similar trend, though the benefit to NRD was much lower or nonexistent.

Overall, after 48 hour exposure, the white and red LEDs had the greatest effect, delaying abscission for 75 days and 67 days, respectively. Although carbohydrate status was not analyzed in this study, it is possible that carbohydrate synthesis was altered when branches were exposed to LEDs compared to the fluorescent light or dark treatment and this may influence abscission. Changes in carbohydrate metabolism are associated with cold acclimation, which similarly alter abscission in balsam fir (Beck *et al.,* 2004; MacDonald and Lada, 2008). More specifically, in

Fig. 3. Comparison of balsam fir branches after exposure to fluorescent lights, darkness, blue LEDs, red LEDs, or white LEDs for 12, 24, or 48 hours. Photos were taken 60 days after the start of the experiment. The effectiveness of white LEDs is particularly evident from this photo.

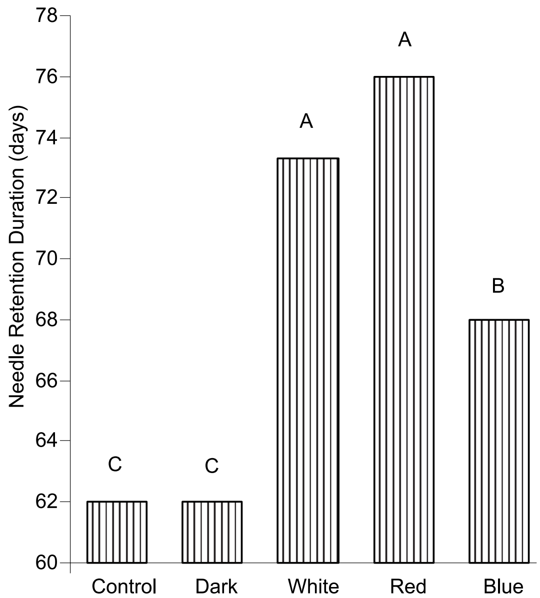


Fig. 4. Comparison of needle retention in balsam fir branches after constant exposure to different light sources. Different letters indicate significance at 5% significance as determined using LSD multiple means comparison. Means are calculated from four replicates.

several conifers sucrose and raffinose increased in the winter, strongly correlated with minimum temperatures (Hinesley *et al.*, 1992). Although photosynthesis (Tennessen *et al.*, 1993) and plant growth (Okamoto *et al.*, 1996; Yanagi *et al.*, 1996) are shown to occur under red LED light and may be enhanced with blue LED light, it is not clear that photosynthesis or its resulting carbohydrates played a major role in this study. It should be noted that the cool white light treatment resulted in a NRD similar to dark treatment, even though it provided a much higher quantity of light that could contribute to photosynthesis than any of the LED treatments. Thus any consideration of carbohydrate synthesis should focus on changes in individual sugars instead of overall carbohydrate status.

Constant exposure to red, white, or blue LEDs significantly delayed needle abscission compared to the fluorescent light or dark treatments, but the relative benefit was not as high as that observed with short-term exposure. This is largely due to a much higher NRD observed in this experiment. In experiment 1, the typical NRD of branches exposed to fluorescent lights was approximately 32 days, but in experiment 2 the same treatment had a NRD of 62 days. It is possible that the difference in NRD is due to differences in harvest time and dormancy status; branches in the experiment 2 were harvested 6 weeks later (at the end of September). Later harvests benefit balsam fir needle retention and diminish the effect of some abscission mitigating technologies (MacDonald and Lada, 2008; MacDonald *et al.*, 2010a).

LEDs have several unique advantage over conventional lighting systems used today in growth chambers and greenhouses. The potential use of LEDs as an eco-friendly postharvest treatment during storage and transport for the Christmas tree industry in Atlantic Canada is promising. The ability to control spectra, their small size, durability, and relatively long lifespan are all traits that growers could easily adapt into their current production practice. However, the biggest advantage is their relatively cool emitting surface and ability to match wavelengths to specific tree photoreceptors to provide optimal balance between plant morphology and metabolism (Bourget, 2008; Massa *et al.*, 2008; Morrow, 2008). LEDs are currently being used in several plant production systems, but are becoming more popular with micropropagation studies because they are more suitable than fluorescent lamps (Li *et al.*, 2010). The initial cost of installing custom lights may be high, but could be recovered in a relatively short time as LEDs are very energy efficient. For example, the 12 x 12 inch LED panels used for this experiment used only 13.8 watts of electricity and covered an area of two square feet (LED wholesalers, 2010). However, further study of the LED technology on full size balsam fir trees is needed before this technology can actually be implemented on large scale.

In conclusion, needle retention was significantly improved with the red, white, or blue LEDs. Needle abscission was delayed by 118, 127, and 75% after a 48-hour exposure to red, white, or blue LEDs, respectively, compared to fluorescent lights. In addition, constant exposures to red and white LEDs delayed abscission by 23 and 18%, respectively compared to fluorescent lights. The improvement in needle retention after LED exposure makes LEDs an interesting technology to explore for postharvest Christmas trees.

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References

Barta, D.J., T.W. Tibbitts, R.J. Bula and R.C. Morrow, 1992. Evaluation of light emitting diode characteristics for a space-based plant irradiation source. *Advances Space Res*., 12: 141-149.

Beck, E.H., R. Heim and J. Hansen, 2004. Plant resistance to cold stress: mechanisms and environmental signals triggering frost hardening and dehardening. *J. Biosci.,* 29: 449-59.

Bourget, C.M. 2008. An introduction to light-emitting diodes. *HortScience*, 43: 1944-1946.

Bula, R.J., R.C. Morrow, T.W. Tibbitts, D.J. Barta, R.W. Ignatius and T.S. Martin, 1991. Light emitting diodes as a radiation source for plants. *HortScience*, 26: 203-205.

Chanishvili, S.H. and M.D. Dolidze, 1974. The effect of light intensity on carbohydrate assimilation and distribution in the organic compounds of grapevine leaves. *Trudy Inst. Bot.,* 27: 315-326.

Chastagner, G.A. and D.M. Benson, 2000. The Christmas tree: tradition, production, and diseases. *Plant Health Progress*, DOI:10.1094/PHP-2000-1013-01-RV.

Chastagner, G.A. and K.L. Riley, 2003. Postharvest quality of noble and Nordmann fir Christmas trees. *HortScience,* 38: 419-421.

Christmas Tree Council of Nova Scotia, 2010, <http://www.ctcns.com/ab_industry.htm. Accessed 05 May 2010>.

Curtis, R.W. 1978. Phytochrome involvement in the induction of resistance to dark abscission by malformin. *Planta*, 141: 311-314.

Hinesley, L.E., D.M. Pharr, L.K. Snelling and S.K. Funderburk, 1992. Foliar raffinose and sucrose in four conifer species: relation to seasonal temperature. *J. Amer. Soc. Hort. Sci.,* 117: 852-855.

LED wholesalers, 2010. LED wholesalers.com. LED grow light [Online]: http://www.ledwholesalers.com/store/index.php?act=viewProd&productId=370 Accessed 07/11/2010.

Li, H., X. Zhigang and C. Tang, 2010. Effect of light-emitting diodes on growth and morphogenesis of upland cotton (*Gossypium hirsutum* L.) plantlets *in vitro*. *Plant Cell Tiss. Organ Cult.,* 103: 155-163.

MacDonald, M.T. and R.R. Lada, 2008. Cold acclimation can benefit only the clones with poor needle retention duration (NRD) in balsam fir (Abstr.). *HortScience*, 43: 1273.

MacDonald, M.T., R.R. Lada, M. Dorais, S. Pepin, Y. Desjardins and A.I. Martynenko, 2010a. Ethylene exposure duration affects postharvest needle abscission in balsam fir (*Abies balsamea* L.). *HortScience*, 46: 260-264.

MacDonald, M.T., R.R. Lada, A.I. Martynenko, M. Dorais, S. Pepin and Y. Desjardins, 2010b. Ethylene triggers needle abscission in root-detached balsam fir. *Trees,* 24: 879-886.

Massa, G.D., H.H. Kim, R.M. Wheeler and C.A. Mitchell, 2008. Plant productivity in response to LED lighting. *HortScience*, 43: 1951-1956.

Mitcham-Butler, E.J., L.E. Hinesley and D.M. Pharr, 1988. Effects of harvest date and storage temperature on the postharvest needle retention of Fraser fir branches. *J. Environ. Hort.,* 6: 1-4.

Morrow, R.C. 2008. LED lighting in horticulture. *HortScience,* 43: 1947-1950.

Okamoto, K., T. Yanagi, S. Takita, M. Tanaka, T. Higuchi, Y. Ushida and H. Watanabe, 1996. Development of plant growth apparatus using blue and red LED as artificial light source. *Acta Hort.,* 440: 111-116.

Saebo, A., T. Krekling and M. Appelgren, 1995. Light quality affects photosynthesis and leaf anatomy of birch plantlets *in vitro*. *Plant Cell Tissue Organ Culture*, 41: 177-185.

Senger, H. 1982. The effect of blue light on plants and microorganisms. *Phytochem. Photobiol.*, 35: 911-920.

Tennessen, D.J., E.L. Singsaas and T.D. Sharkey, 1993. Light emitting diodes as a light source for photosynthesis research. *Photosynthesis Res.,* 39: 85-92.

van Lieburg, M.J., W.G. van Doorn and H. van Gelder, 1990. Prevention of phytochrome-related postharvest loss of quality in ornamentals through red light emitted by diodes. *Acta Hort.,* 272: 347-351.

van Meeteren, U. and A. van Gelder, 2000. The role of leaves in photocontrol of flower bud abscission in *Hibiscus rosa-senesis* L. 'Nairobi'. *J. Amer. Soc. Hort. Sci.,* 125: 31-35.

Yanagi, T., K. Okamoto and S. Takita, 1996. Effects of blue, red, and blue/red lights of two different PPF levels on growth and morphogenesis of lettuce plants. *Acta Hort.,* 440: 117-122.

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