Customizing Crop Foliage Color With LEDs: Red Leaf Lettuce

In the first of a four-part series highlighting the multiple uses of light-emitting diodes (LEDs), researchers share how end-of-production supplemental lighting with LEDs enhances red leaf lettuce color prior to harvesting and shipping.

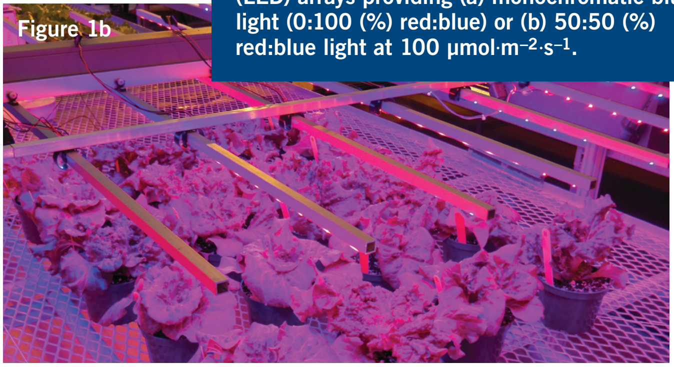

Figure 1. **Lettuce under light-emitting diode (LED) arrays providing (a) monochromatic blue light (0:100 (%) red:blue) or (b) 50:50 (%) red:blue light at 100 μmol·m^{-2}·s^{-1}.**

by **W. GARRETT OWEN** and **ROBERTO G. LOPEZ**

THIS is the first of a four-part series highlighting the multiple uses of high-intensity light-emitting diodes (LEDs) for greenhouse and indoor multilayer crop production of ornamentals, leafy greens and microgreens. In this first article, we will discuss our research methodology and findings for enhancing the color of red leaf lettuce with end-of-production supplemental lighting.

Many of the ornamental crops greenhouse and nursery growers produce vary in size, shape and color. These are aesthetic qualities that are important to consumers. Additional indicators of leafy green quality include flavor, freedom from defects, nutritional value and texture.

Leaf color (intensity, distribution or both) in greens such as lettuce is particularly important because it often influences consumer purchasing behavior (impulse purchases) and perceptions of freshness and quality. Red leaf lettuce varieties have become increasingly popular in packaged salad mixes due to their unique colors and textures and can often command a higher price compared to green leaf lettuce.

Anthocyanin pigments (flavonoids) are responsible for the red, purple and blue colors of many fruits, vegetables and flowers. Their concentration in foliage is dependent on environmental conditions such as the light quality and intensity that we often struggle to maintain during the winter in greenhouses. Research has shown that the synthesis and accumulation of anthocyanins are induced at high light intensities. Additionally, ultraviolet (UV-B and UV-A), blue, red and far-red light are responsible for stimulating anthocyanin production. Therefore, light can influence the amount and distribution of these pigments that contribute significantly to lettuce leaf color.

Red leaf lettuce producers often find that their crop is not as colorful (eg., green or light red/purple) during the winter and early spring due to low-light greenhouse conditions such as those found in northern latitudes. What if they had the ability to customize the color of leaves quickly and without the use of fertilizers or low production temperatures? For instance, what if they could quickly enhance and darken the color of red leaf lettuce with supplemental light in as little as five days? With the use of high intensity LEDs, our objective was to quantify the effect of end-of-production (EOP, prior to harvest or shipping) supplemental lighting (SL) of different sources and intensities on foliage color of four commercially available red leaf lettuce varieties.

Methods For Lettuce Production

Seeds of red leaf varieties 'Cherokee,' 'Magenta,' 'Ruby Sky' and 'Vulcan' were sown into 72-cell plug trays filled with a commercial soilless medium and were irrigated as necessary with acidified water supplemented with water-soluble fertilizer to provide 100 ppm nitrogen (N). After 21 days, seedlings were transplanted into 5-inch diameter containers filled with a commercial soilless medium and were irrigated as necessary with acidified water supplemented with a combination of two water-soluble fertilizers to provide 200 ppm N. Plants were grown in a glass-glazed greenhouse at Purdue University, West Lafayette, Ind., with a day and night air temperature set point of 68°F/65°F (12 h/12 h). The photoperiod was a constant 16-hours consisting of natural day lengths with day-extension lighting from high-pressure sodium (HPS) lamps that delivered a supplemental photosynthetic photon flux (*PPF*) of ≈70 μmol·m^{-2}·s^{-1} at plant height. The daily light integral (DLI) and average daily temperatures (ADT) were 8 mol·m^{-2}·d^{-1} and 67°F ± 1.6°F, respectively.

End-Of-Production Supplemental Lighting

After 35 days from sowing seed, plants were finished under a DLI of 7 mol·m^{-2}·d^{-1} and ADT of 65°F ± 0.9°F. Five plants of each variety were placed under a 16-hour photoperiod consisting of either ambient solar light plus day-extension light (control; no EOP SL) or EOP SL. Day-extension lighting consisted of two [7:11:33:49 (%) blue:green:red:far-red] low intensity LED lamps providing 4.5 μmol·m^{-2}·s^{-1}. Supplemental light was delivered from 150 W high-pressure sodium (HPS) lamps providing 70 μmol·m$_{-2}$·s^{-1} or one of five LED arrays providing either 100 μmol·m$_{-2}$·s^{-1} of monochromatic red [100:0 (%) red:blue] or 25, 50 or 100 μmol·m$_{-2}$·s^{-1} of monochromatic blue [0:100 (%) red:blue; Figure 1a], or 100 μmol·m$_{-2}$·s^{-1} of a combination of red and blue [50:50 (%) red:blue; Figure 1b] light. End-of-production SL occurred for up to 14 days.

Figure 2. **The colorimeter is a non-destructive instrument used by the U.S. food industry for measuring and tracking color changes of fruits and vegetables during processing and storage. In our study, we used the colorimeter to determine and track lettuce leaf color without damaging leaves or plants.**

At 0, 3, 5, 7 and 14 days after initiating EOP SL, relative chlorophyll content (RCC) was estimated using a SPAD chlorophyll meter by measuring two recently matured leaves of each plant under each lighting treatment. Measuring RCC is an important parameter because we can determine the greenness of the plant and figure out the transmittance of light through the leaf. As a result, the amount of chlorophyll present in the leaf or leaf greenness can be quickly estimated.

Additionally, leaf color of the same two recently matured leaves was measured using a portable tristimulus colorimeter (Figure 2). Portable tristimulus colorimeters are used by the U.S. food industry for measuring surfaces and tracking color changes of fruits and vegetables during processing and storage. These instruments estimate chlorophyll content by measuring spectral reflectance properties such as lightness and chromaticity of fruit and leaf color without destruction or damage of leaves or plants.

For our study, we calibrated the portable tristimulus colorimeter analyzer to a standard white reflective plate (L* = 97.5, a* = 0.40, b* = 1.90) using the CIE (Commission Internationale de l'Eclairage) 1976 (L*a*b*) color coordinates. The L* value indicates darkness and lightness (black: L* = 0; white: L* = 100). Chromametric a* value is the ratio between greenness and redness (green: a* = –60; red: a* = +60) and chromametric b* value is the ratio between blueness and yellowness (blue: b* = –60; yellow: b* = +60). On a circular scale, hue angle (*h*°) or tone indicates redness (0°), yellowness (90°), greenness (180°) or blueness (270°) and were calculated.

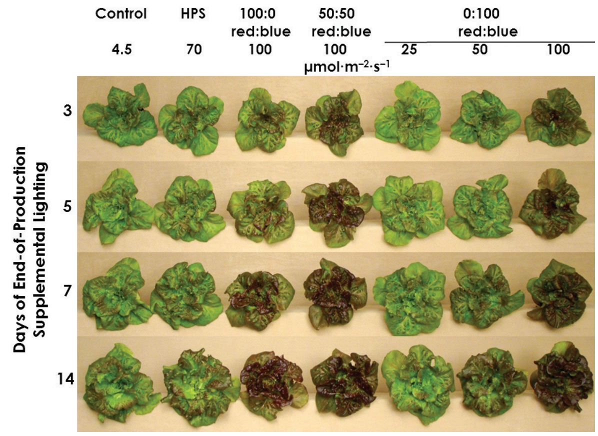

Figure 3. **Leaf color of 'Cherokee' lettuce finished under three to 14 days of day-extension lighting (control) or end-of-production (EOP) supplemental lighting (SL) from high-pressure sodium lamps or light-emitting diodes (LEDs) providing monochromatic red, blue and red:blue light at either low or high intensities.**

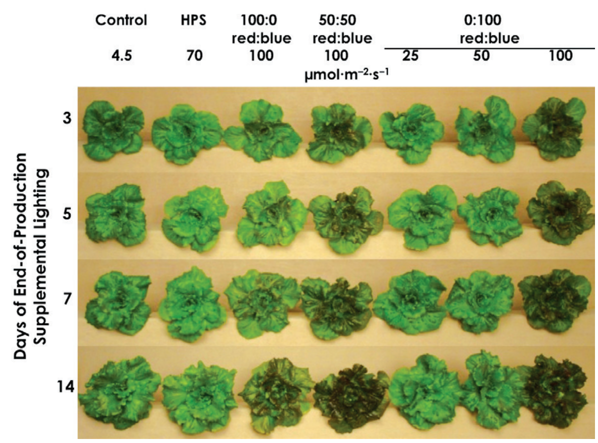

Figure 4. **Leaf color of 'Magenta' lettuce finished under three to 14 days of day-extension lighting (control) or end-of-production (EOP) supplemental lighting (SL) from high-pressure sodium lamps or light-emitting diodes (LEDs) providing monochromatic red, blue and red:blue light at either low or high intensities.**

EOP Supplemental Lighting Effects On Chlorophyll And Foliage Color

Relative chlorophyll content and foliage L* (lightness) and chromametric a* (change from green to red) and b* (change from yellow to blue) values were significantly influenced by EOP SL and days of exposure. Generally, RCC of all varieties increased from day three to 14 when provided with EOP SL from the HPS lamps and LEDs delivering 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$. End-of-production SL providing 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of 100:0, 0:100 or 50:50 red:blue light for ≥5 days resulted in increasing a* (red) and decreasing L* (darker foliage), b* (blue) and *h*° for all varieties. For example, 'Cherokee' at five days of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of 100:0, 0:100 or 50:50 red:blue EOP SL resulted in a* values (red) of -1.5, 0.5 and 2.9 CIE lab units, respectively (Figure 3). Therefore, foliage color of plants under 50:50 red:blue EOP SL were more red. Leaf L* (darkness) and b* (blueness) values of ‘Cherokee’ at five days of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of 100:0, 0:100 or 50:50 red:blue EOP SL were 38.1, 32.1 and 35.5 and 14.0, 6.3 and 10.7 CIE lab units, respectively (Figure 3). Based on our results, the red leaf lettuce varieties varied in color, from dark vivid red to candy-apple red (Figures 3 and 4). Our data suggests that a minimum of five days of EOP SL providing 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of 100:0, 0:100 or 50:50 red:blue light enhanced red pigmentation of ‘Cherokee,’ ‘Magenta,’ ‘Ruby Sky’ and ‘Vulcan’ leaves when plants are grown under a low greenhouse DLI <10 $mol \cdot m^{-2} \cdot d^{-1}$.

Figure 5. **End-of-production supplemental red and blue LEDs can be used in the last stage of production for five to seven days to darken lettuce foliage before plants are harvested and prepared for packaging and shipping.**

EOP Supplemental Lighting For Customizing Lettuce Color

End-of-production SL demonstrates an alternative, practical and cost-effective greenhouse SL practice for increasing red and purple pigments of lettuce crops produced during the winter and early spring. The novel concept of EOP SL can allow growers to manipulate leaf color in as few as five to seven days prior to harvest or shipping, thus increasing aesthetic appeal, quality and market value without negatively affecting growth or morphology of the crop.

Now you are probably thinking that this production practice is out of your price range because of the cost of LEDs. Unlike a traditional SL installation of HPS lamps to increase greenhouse DLI, EOP SL with red and blue LEDs is much more affordable as only a small area of LEDs are required to light the crop prior to harvest or shipping (Figure 5). Furthermore, growers can provide EOP SL with commercially available high-intensity LEDs. **GG**

W. Garrett Owen (**owenw@purdue.edu**) is a greenhouse technician and graduate research assistant and Roberto Lopez (**rglopez@purdue.edu**) is an associate professor and floriculture Extension specialist at Purdue University.
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