Optimizing Lettuce Quality, Taste and Morphology with LED Lighting

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Introduction

Lettuce grows remarkably well under LED lighting. Today's LED lighting is an effective, productive and energy-efficient tool to consistently increase production. Furthermore, varying light intensity and wave length has been shown to direct nutrition and flavor in crops ranging from broccoli to blueberries.

Light can increase levels of health-promoting phytochemicals like anthocyanins. Light can also regulate production by giving a stretched or more compact plant depending on the consumer demands. Finally, light can elicit different tastes and aromas to achieve the desired product.

Materials & Methods

In studies done at LumiGrow, we examined the effects of varying light ratios on two lettuce varieties: the classic loose-leaf lettuce, Black Seeded Simpson, and the head variety, Salinas lettuce. We used LED lighting as the sole source of light. Using LumiGrow fixtures we grew lettuce under 5 different light treatments and analyzed the differences in plant flavor, yield and morphology.

In each light treatment we grew plants under a total PAR of 250 µmol•m-2•s-1. The percentage of blue light increase from 0, 20, 40, 60 to 80 µmol•m-2•s-1 respectively in the five different treatments. White light was maintained at a constant 20 µmol•m-2•s-1 in each treatment and red light was added to bring the final PAR to 250 µmol•m-2•s-1 for each trial. By exploring how various ratios of blue, white and red light influence lettuce growth, we want to inform growers on the use of LED light spectrums to steer plant growth, flavor and nutrition.

FIGURE 1. Black Seed Simpson grown under 0, 40 and 80 µmol•m^{-2}•s^{-1} of blue light 34 days after planting.

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Light treatment	Blue ($\mu mol \cdot m^{-1} \cdot s^{-2}$)	White ($\mu mol \cdot m^{-1} \cdot s^{-2}$)	Red ($\mu mol \cdot m^{-1} \cdot s^{-2}$)
0% Blue, 0B:20W:230R	0	20	230
8% Blue, 20B:20W:210R	20	20	210
16% Blue, 40B:20W:190R	40	20	190
24% Blue, 60B:20W:170R	60	20	170
32% Blue , 80B:20W:150R	80	20	150

FIGURE 2. Photosynthetic Photon Flux Density (PPFD) values for blue, white and red channels of five light treatments.

Conclusions

Conclusions from the Black Seeded Simpson experiment are summarized below. Salinas lettuce yields very similar results. The experiment demonstrates the effects of different light ratios on lettuce production, morphology, flavor and aroma. Biomass of the lettuce increased with increasing levels of blue light up to 60 μmol•m-2•s-1. However, at 80 μmol•m-2•s-1 plant biomass dropped in half as seen Figure 3.

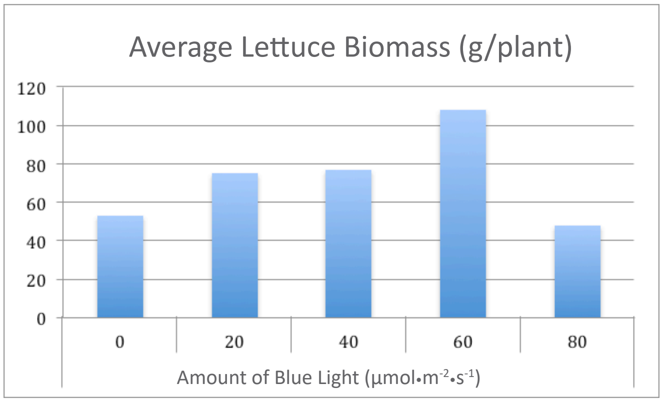


FIGURE 3. Histograph showing the change in Black Seeded Simpson lettuce biomass yield at 32 days after planting when plants were grown under increasing levels of blue light.

The influence on morphology was illustrated in the variation in plant height seen in Figures 4, 5 and 6.

FIGURE 5. Black Seeded Simpson lettuce grown under 0, 40 and 80 μmol•m6.2•s-1 of blue light 13 days after planting.

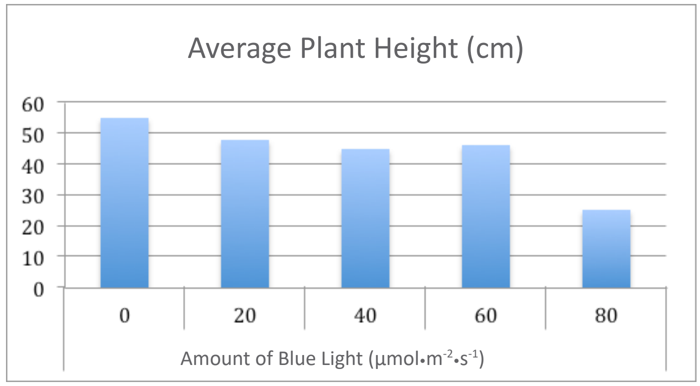


FIGURE 4. Histograph showing the change in Black Seeded Simpson lettuce plant height at 32 days after planting when plants were grown under increasing levels of blue light.

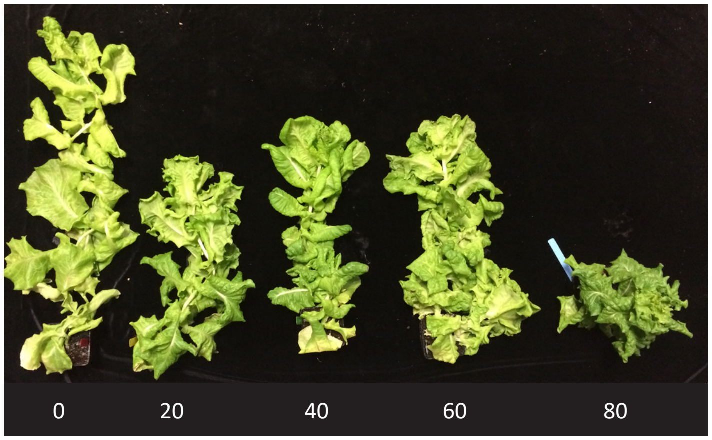


FIGURE 6. Photograph showing the change in lettuce plant height at 32 days after planting when plants were grown under increasing levels of blue light.

Taste & Flavor

Our tasting panels demonstrated the wide range of consumer preferences with half our panel preferring lettuce grown with no blue light, resulting in a mild taste, and aroma with smooth leaves, while half the panel preferred the spicy, curly leaf lettuce that grew under the 80 μmol•m-2•s-1 blue light treatment. Given the desired outcomes and unique flavor profiles produced by each treatment, growers can develop their own custom light programs to meet their customer needs.

In addition to the in-house work at LumiGrow other scientists working on lettuce are publishing definitive results that show how readily lettuce with desired traits can be grow using spectral variation.

Below are a few select publications illustrating the recent progress.

Published Research

End-of-Production Supplemental Lighting from Red and Blue Light-emitting Diodes Increases Leaf Pigments of Lactuca sativa L. 'Cherokee' and 'Vulcan' in the Greenhouse. W. Garrett Owen and Roberto Lopez. 2014. Presented at American Society of Horticultural Science Meeting

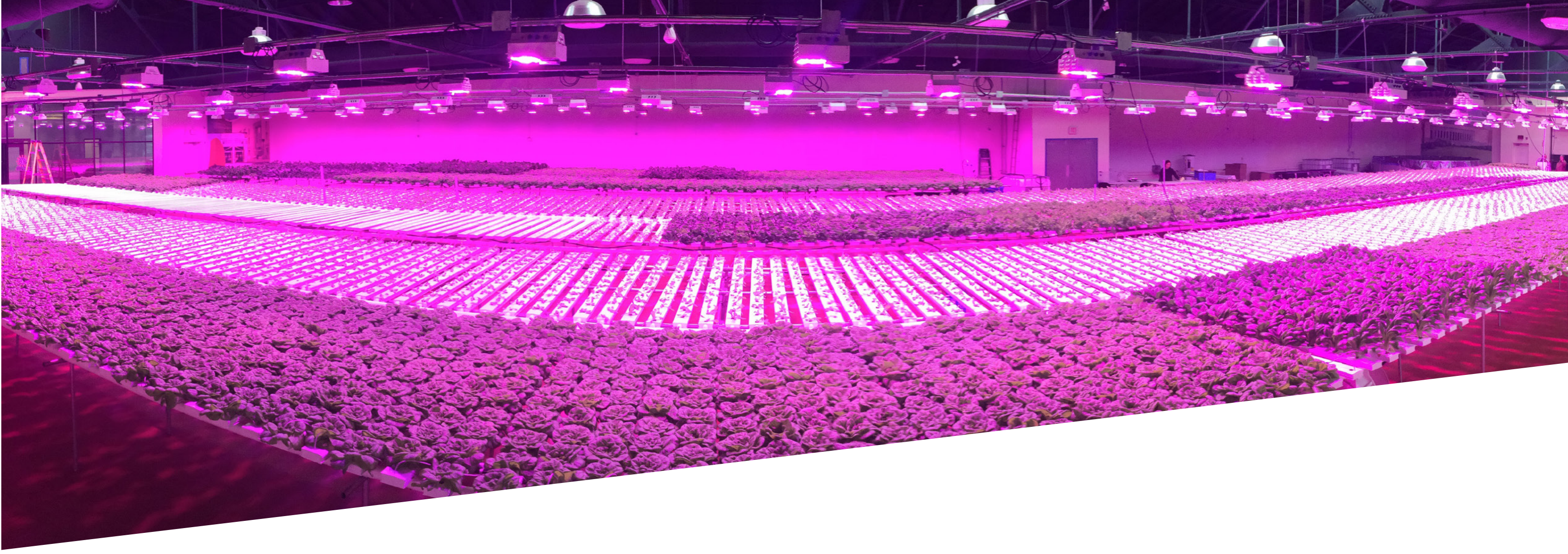
Under low-light greenhouse conditions, such as those found in northern latitudes, the foliage of red-leaf lettuce (Lactuca sativa L.) varieties is often green and not aesthetically appealing to consumers. Our objective was to quantify the effect of end-of-production supplemental lighting (SL) of different intensities and sources on foliage color of two red leaf lettuce cultivars, 'Cherokee' and 'Vulcan'. Plants were grown for 5 weeks at 20 °C and under a daily light integral (DLI) of 8.3 mol·m−2·d−1. Two weeks prior to being marketable, plants were placed at 18 °C and under an ambient DLI of 6 mol·m−2·d−1 and provided with a 16-h photoperiod from low-intensity LED lamps providing 4.5 μmol·m−2·s−1 (control), or 16-h of SL from high-pressure sodium (HPS) lamps providing 70 μmol·m−2·s−1, or high-intensity LED arrays providing 25, 50, or 100 μmol·m−2·s−1 blue light, 100 μmol·m−2·s−1 red light, or 100 μmol·m−2·s−1 50:50 (%) red:blue light. Chromametric and relative chlorophyll content (SPAD) values of 'Cherokee' and 'Vulcan' foliage were significantly different among all treatments after 3, 5, 7, and 14 days of SL. For example, after 14 days 'Cherokee' and 'Vulcan' plants grown under 100 μmol·m−2·s−1 red:blue light were the darkest in color with an L* (lightness) value of 31.01 and 33.97, respectively. Chromametric a* (change from green to red) and b* (change from yellow to blue) values increased with 100 μmol·m−2·s−1 red, blue, or combination of red:blue light. Chromametric a* and b* values of 'Cherokee' were 4.61 and -1.63 and 3.42 and -1.33 when plants grown under 100 μmol·m−2·s−1 red:blue and blue light, respectively. Under the same lighting treatments, chromametric a* and b* values of 'Vulcan' were 4.46 and 11.11 and 5.15 and 12.08, respectively. Our data suggests that as little as 7 days of end-of-production SL of 100 μmol·m−2·s−1 red:blue or blue LED light promotes enhanced red pigmentation of L. sativa 'Cherokee' and 'Vulcan' foliage when the crop is grown under a low greenhouse DLI.

Growth and Phytochemical in Lettuce as Affected by different Ratios of Blue to Red LED Radiation. Jae Su Lee, Tae Gyu Lim, and Yong Hyeon Kim. 2014. Acta Hort. 1037:843-848

Light-emitting diodes (LED) lamps have been widely used to promote the growth and quality of horticultural crops. Five ratio levels of red 100% (red only), red 90% + blue 10%, red 80% + blue 20%, red 70% + blue 30% and blue 100% (blue only) radiation in a closed plant production system (CPPS) were provided to analyze the effect of combination of red and blue LED on growth and phytochemicals in lettuce (Lactuca sativa L. 'Jeokchima'). Photoperiod, air temperature, photosynthetic photon flux, relative humidity, and CO2 concentration in CPPS were maintained at 16/8 h, 22/18°C, 230 μmol m-2 s-1, 70%, and 800 μmol mol-1, respectively. Nutrient solution with temperature 22°C, electric conductivity 1.5-1.8 mS cm-1, and pH 5.5-6.0 was circulated from a nutrient solution tank to growing beds. Growth and phytochemicals in lettuce was significantly affected by the different ratios of blue to red LED illumination. Lettuce grown under red light showed the greatest number of leaves, leaf area, leaf fresh weight and dry weight. Maximum ascorbic acid in lettuce was found under RB91 treatment (red 90% + blue 10%). Anthocyanins increased with theincreasing addition of blue light.

Leaf Shape, Growth, and Antioxidant Phenolic Compounds of Two Lettuce Cultivars Grown under Various Combinations of Blue and Red Light-emitting Diodes. Ki-Ho Son and Myung-Min Oh. 2013. HortScience. Vol 48. 8:988-995.

Light-emitting diodes (LEDs) of short wavelength ranges are being developed as light sources in closed-type plant production systems. Among the various wavelengths, red and blue lights are known to be effective for enhancing plant photosynthesis. In this study, we determined the effects of blue and red LED ratios on leaf shape, plant growth, and the accumulation of antioxidant phenolic compounds of a red leaf lettuce (Lactuca sativa L. 'Sunmang') and a green leaf lettuce (Lactuca sativa L. 'Grand Rapid TBR'). Lettuce seedlings grown under normal growth conditions (20 °C, fluorescent lamp + high-pressure sodium lamp 177 ± 5 μmol·m−2·s−1, 12-hour photoperiod) for 18 days were transferred into growth chambers that were set at 20 °C and equipped with various combinations of blue (456 nm) and red (655 nm) LEDs [blue:red = 0:100 (0 B), 13:87 (13 B), 26:74 (26 B), 35:65 (35 B), 47:53 (47 B) or 59:41 (59 B)] under the same light intensity and photoperiod (171 ± 7 μmol·m−2·s−1, 12-hour photoperiod). Leaf width, leaf length, leaf area, fresh and dry weights of shoots and roots, chlorophyll content (SPAD value), total phenolic concentration, total flavonoid concentration, and antioxidant capacity were measured at 2 and 4 weeks after the onset of LED treatment. The leaf shape indices (leaf length/leaf width) of the two lettuce cultivars subjected to blue LEDs treatment were similar to the control, regardless



of the blue-to-red ratio during the entire growth stage. However, 0 B (100% red LED) induced a significantly higher leaf shape index, which represents elongated leaf shape, compared with the other treatments. Increasing blue LED levels negatively affected lettuce growth. Most growth characteristics (such as the fresh and dry weights of shoots and leaf area) were highest under 0 B for both cultivars compared with all other LED treatments. For red and green leaf lettuce cultivar plants, shoot fresh weight under 0 B was 4.3 and 4.1 times higher compared with that under 59 B after 4 weeks of LED treatment, respectively. In contrast, the accumulation of chlorophyll, phenolics (including flavonoids), and antioxidants in both red and green leaf lettuce showed an opposite trend compared with that observed for growth. The SPAD value (chlorophyll content), total phenolic concentration, total flavonoid concentration, and antioxidant capacity of lettuces grown under high ratios of blue LED (such as 59 B, 47 B, and 35 B) were significantly higher compared with 0 B or control conditions. Thus, this study indicates that the ratio of blue to red LEDs is important for the morphology, growth, and phenolic compounds with antioxidant properties in the two lettuce cultivars tested.

Effects of supplemental light quality on growth and phytochemicals of baby leaf lettuce. Qian Li and Chieri Kubota. 2009. Environmental and Experimental Botany. Vo.67. 1:59-64.

Using UV-A, blue (B), green (G), red (R), and far-red (FR) light-emitting diodes (LEDs), we investigated the effects of different supplemental light qualities on phytochemicals and growth of 'Red Cross' baby leaf lettuce (Lactuca sativa L.) grown at a high planting density under white fluorescent lamps as the main light source inside a growth chamber. Photon flux added by supplemental LEDs for UV-A, B, G, R and FR were 18, 130, 130, 130 and 160 μmol m−2 s−1, respectively. Photosynthetic photon flux (PPF, 400–700 nm), photoperiod, and air temperature (day/night) was 300 μmol m−2 s−1, 16 h, and 25 °C/20 °C in all treatments including white light control. After 12 days of light quality treatment (22 days after germination), phytochemical concentration and growth of lettuce plants were significant affected by light treatments. Anthocyanins concentration increased by 11% and 31% with supplemental UV-A and B, respectively, carotenoids concentration increased by 12% with supplemental B, phenolics concentration increased by 6% with supplemental R while supplemental FR decreased anthocyanins, carotenoids and chlorophyll concentration by 40%, 11% and 14%, respectively, compared to those in the white light control. The fresh weight, dry weight, stem length, leaf length and leaf width significantly increased by 28%, 15%, 14%, 44% and 15%, respectively, with supplemental FR light compare to white light, presumably due to enhanced light interception by enlarged leaf area under supplemental FR light. Although the mechanisms of changes in phytochemicals under different supplemental light quality are not well known, the results demonstrated that supplemental light quality could be strategically used to enhance nutritional value and growth of baby leaf lettuce grown under white light.

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