DIFFERENTIATING BROAD SPECTRA

Substituting white light with red and/or blue light influences lettuce production.

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In the previous article, we compared warm-white light with red + blue light for indoor lettuce production. From an energy efficiency standpoint, warm-white light-emitting diodes (LEDs) had lower photon efficacy than red + blue LEDs. However, this alone did not mean warm-white LEDs were inferior. From a crop productivity standpoint, light-use efficiency of lettuce was higher under warm-white LEDs than under red + blue LEDs with 11% or more blue light. Therefore, warm-white LEDs can have a similar or higher crop yield per unit energy than red + blue LEDs. The take-home message was that fixture efficacy was not everything; crop responses under different light spectra should also be considered.

Unlike red + blue LEDs, broad-spectrum (white) LEDs can reveal the true colors of plants, which facilitates the inspection of crop growth, nutrient conditions, insects, and diseases in a visually pleasing environment. High color fidelity under broad-spectrum LED lighting can be desirable inside vertical farms and sunlight-limited greenhouses. A variety of broad-spectrum LED fixtures is available for indoor crop production, but not all of them have the same spectrum, output, or efficacy.

White LEDs are blue LEDs with a phosphor coating that converts some of the blue photons to photons at longer wavelengths (i.e., green, red, and far-red). Depending on the material and amount of phosphor coating, white LEDs create different hues, as indicated by the correlated color temperature (CCT). With a low percentage of blue light, warm-white LEDs have a low CCT of 2,500 to 3,500 K. In contrast, neutral-white (3,500 to 4,500 K), cool-white (4,500 to 5,500 K), and daylight (5,500 to 7,500 K) LEDs have higher percentages of blue light and higher photon efficacy.

These white LEDs also differ in how they reveal the true colors of plants, as indicated by the color rendering index (CRI, negative to 100) or the TM-30 fidelity index (R_f, 0 to 100). Higher indices mean higher color fidelity. Other specialized white LEDs also exist, such as mint-white (also known as EQ-white) LEDs. Developed by OSRAM Opto Semiconductors, these are blue LEDs with an efficient green phosphor coating that can be combined with red LEDs to create high-CRI white light.

Horticultural lighting companies often supplement white LEDs with monochromatic red and/or blue LEDs. First, this allows for spectrum customization to elicit specific plant responses (e.g., high yield, compact growth, and increased production of secondary metabolites). Second, including more efficient red and/or blue LEDs increases overall fixture photon efficacy while white LEDs provide acceptable color rendering and are low in cost.

Although there is a wide range of broad-spectrum LED fixtures on the market, it is unclear how different broad spectra with and without supplemental red and blue LEDs compare to each other in crop production. To address this, we conducted an experiment to evaluate how indoor hydroponic lettuce responded to four different broad spectra.

Experiment protocol

In an indoor growth room, we sowed seeds of red-leaf lettuce ‘Rouxai’ in 1-inch rockwool cubes soaked in deionized water and placed them in trays with transparent humidity covers. Seeds germinated under warm-white LEDs (CCT = 2,700 K) at a total photon flux density

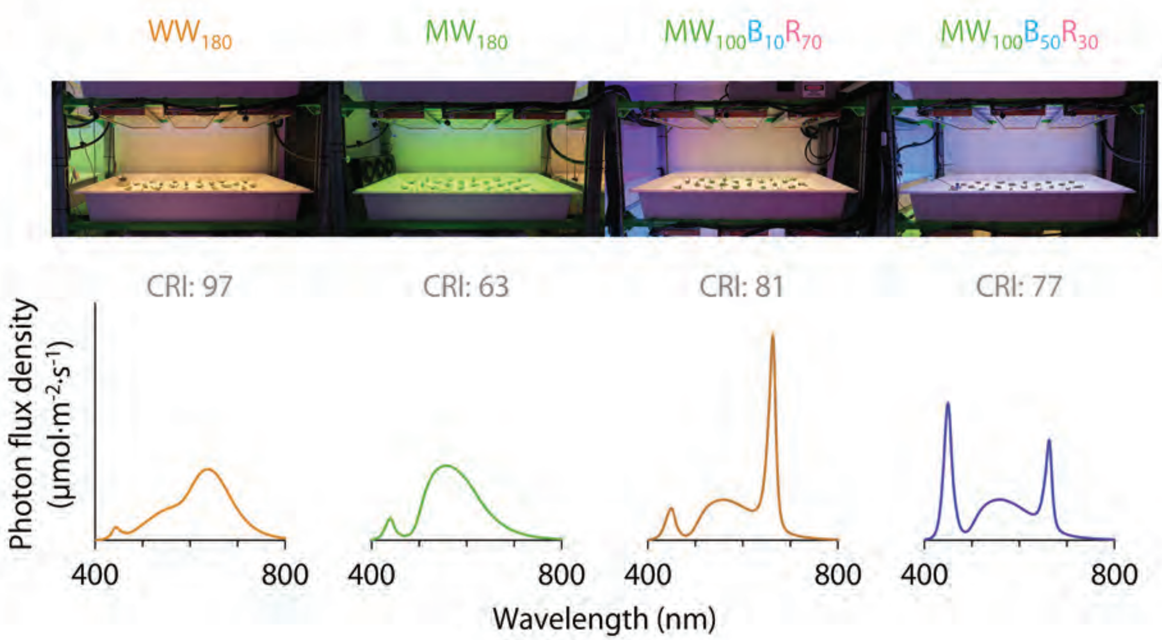

Fig. 1. Photos and spectral distributions of four indoor broad-spectrum LED lighting treatments. WW, warm white; MW, mint white; B, blue; R, red; CRI, color rendering index. The number after each LED type is the photon flux density in $\mu mol \cdot m^{-2} \cdot s^{-1}$.

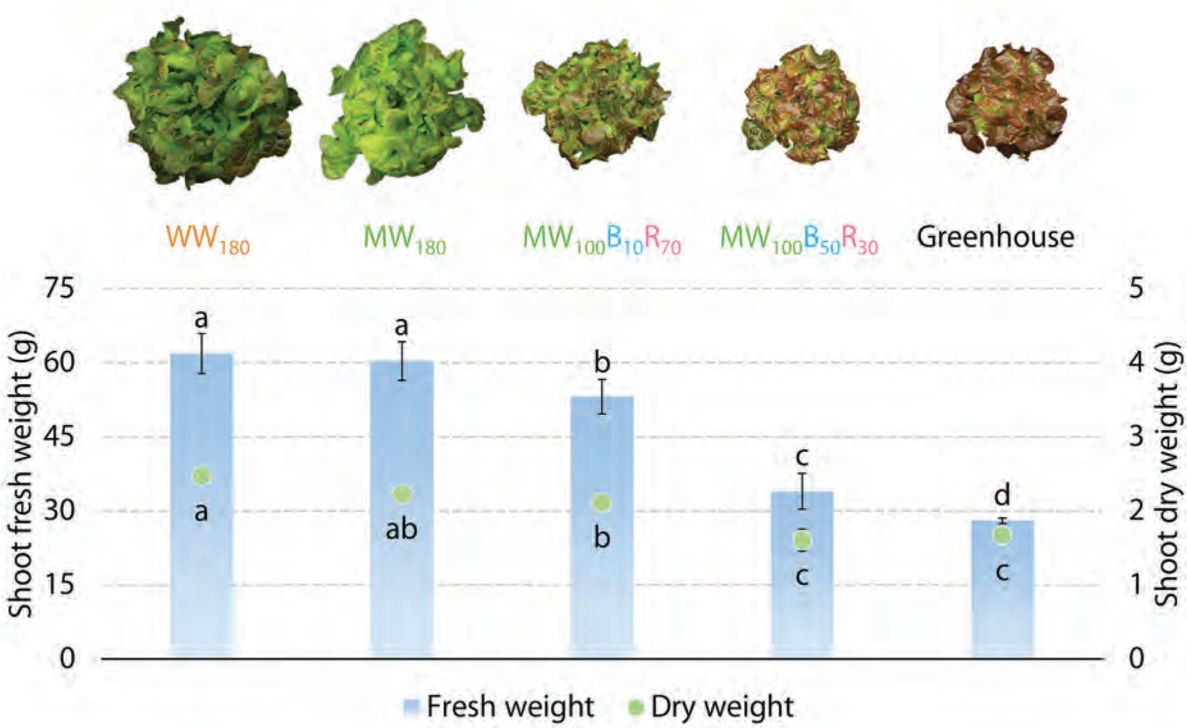

Fig. 2. Shoot fresh weight and dry weight of red-leaf lettuce 'Rouxai' grown under the four indoor LED lighting treatments in Figure 1 and in a greenhouse. For each parameter, values followed by different letters are statistically different (α= 0.05).

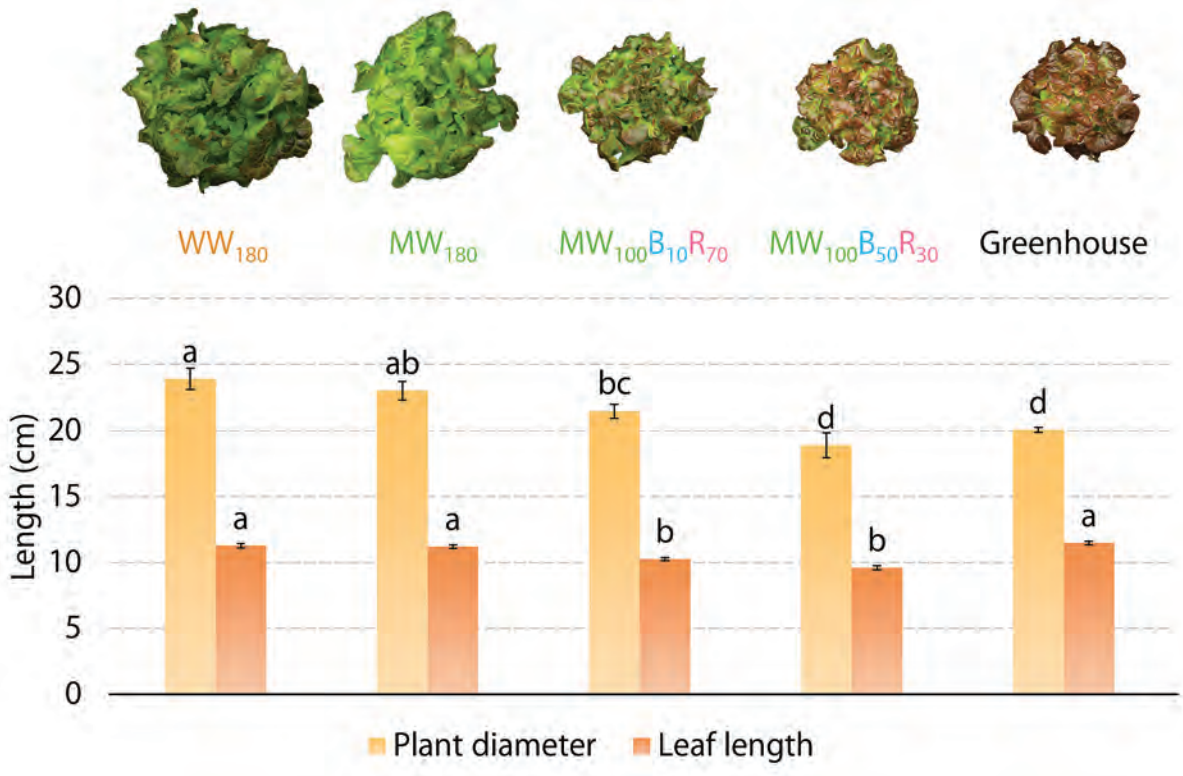

Fig. 3. Plant diameter and leaf length of red-leaf lettuce 'Rouxai' grown under the four indoor LED lighting treatments in Figure 1 and in a greenhouse. For each parameter, values followed by different letters are statistically different (a= 0.05).

of 50 µmol·m^{-2}·s^{-1} during the first 24 hours at an air temperature of 68°F (20°C). Next, we grew them under 180 µmol·m^{-2}·s^{-1} of warm-white light for 20 hours per day at 72 °F (22 °C). We sub-irrigated rockwool cubes with a nutrient solution made from a 12N–1.7P–13.3K fertilizer and magnesium sulfate (target nitrogen concentration = 125 ppm). The nutrient solution had a pH of 5.7 to 5.9 and an electrical conductivity of 1.2 to 1.4 dS·m–1.

On day 4, we transferred lettuce seedlings to four broad-spectrum treatments at the same total photon flux density of 180 µmol·m–2·s–1 under a 20-hour photoperiod:

1) warm white (WW180);
2) mint white (MW180);
3) mint white + blue + red (MW100B10R70);
4) mint white + blue + red (MW-100B50R30).

The number after each LED type is the photon flux density in µmol·m–2·s–1. The CRI and spectral distributions of the lighting treatments are in Figure 1. Warm white had 7% blue + 29% green + 54% red + 10% far-red photons, whereas mint white had 9% blue + 60% green + 28% red + 3% far-red photons.

On day 13, we transplanted lettuce seedlings in an indoor deep-flow hydroponic system. We grew plants at 72°F in recirculated and aerated nutrient solutions (initial nitrogen concentration = 150 ppm). For comparison, we transplanted additional lettuce seedlings in containers filled with a peat-based substrate in a greenhouse at 72°F. We performed the experiment twice in time. On day 30 or 33, we measured crop yield, shape, and coloration.

Results

Lettuce yield was the highest under warm white and mint white among all treatments (Figure 2). Although warm white and mint white had distinctly different spectra, lettuce grew similarly under these two LED types (Figures 2 and 3). With similar blue percentages (7% in warm white and 9% in mint white), these two white spectra had different green, red, and far-red percentages.

Low blue light was a strong signal to increase leaf area. In addition, the 10% far red in warm white and the 60% green in mint white also likely increased leaf expansion. The larger leaves under these two white spectra allowed plants to capture more light for photosynthesis. Therefore, the head size and yield of lettuce were the highest under these two white spectra. However, red-leaf lettuce appeared mostly green with a lack of red coloration because the red pigments, anthocyanins, were low under these low blue light treatments.

When mint white was partially substituted with blue + red light, lettuce growth depended on the blue-to-red ratio. Substitution with a low blue-to-red ratio (1:7) mainly decreased green light and increased red light, which decreased lettuce fresh weight and increased red coloration. Lettuce fresh weight and leaf length under MW100B10R70 were 12% and 8% lower, respectively, compared to MW180. On the other hand, substitution with a high blue-to-red ratio (5:3) mainly increased blue light and decreased green light, which also decreased lettuce growth and increased red coloration. Lettuce fresh weight, dry weight, plant diameter, and leaf length under MW100B50R30 were 44%, 28%, 18%, and 14% lower, respectively, compared to MW180.

Lettuce grown in the greenhouse had the lowest yield, smallest plant size, and reddest leaves among all treatments, even though the greenhouse had a higher daily light integral of 16 to 20 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ than indoor LED treatments (13 $mol{\cdot}m^{-2}{\cdot}d^{-1}$). High light in the greenhouse increased anthocyanin concentration and limited plant size. Nonetheless, the greenhouse treatment was for reference only in the same growing period because a number of environmental and cultural factors were different in the greenhouse versus indoors.

Take-home messages

Different white spectra, such as warm white and mint white, can have similar effects on plant growth and coloration, although other white spectra may have different effects. When a white spectrum is supplemented with blue and/or red light, the blue, green, red, and far-red photon flux densities determine plant responses. The amount and ratio of supplementary red and/or blue light can make a big difference in plant growth and coloration, even in the same white-spectrum background. Growers interested in broad-spectrum LEDs should conduct plant trials under different broad spectra at the same photon flux density to identify the desired spectrum based on production goals. **pg**

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