LEDs ON LETTUCE: WHITE LIGHT VS. RED+BLUE LIGHT

A closer look at a lighting debate from the crop production perspective

By Qingwu (William) Meng and Erik Runkle

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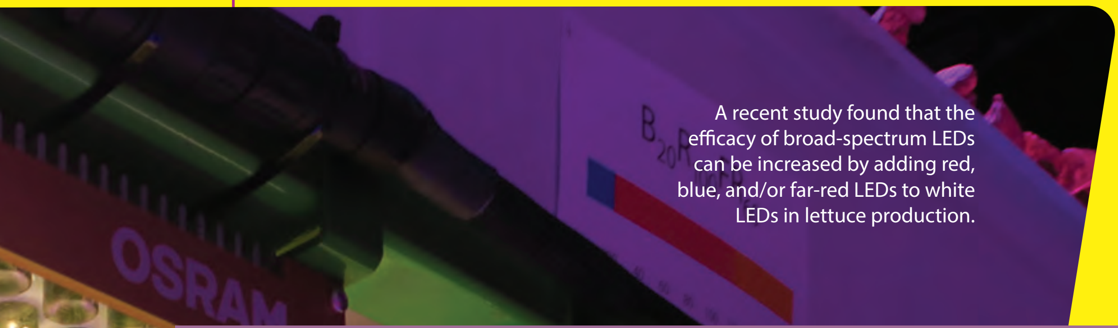

A recent study found that the efficacy of broad-spectrum LEDs can be increased by adding red, blue, and/or far-red LEDs to white LEDs in lettuce production.

In the last decade, lighting for controlled environment agriculture has evolved rapidly thanks to improved energy efficiency, spectral tuning and fixture design. These improvements helped to drive the commercial adoption of light-emitting diode (LED) fixtures, especially in indoor vertical farms.

Today, growers can choose from a wide range of LED fixtures with different specifications. The selection depends on factors including the fixture cost, efficacy (the photon output per unit energy), the light spectrum, the form factor, and the light responses of crops.

While it is straightforward to compare the fixture cost and efficacy, it is often unclear how different commercial light spectra compare in crop production. To further complicate matters, fixture efficacy is related to its light spectrum. These are the reasons behind a recurring debate within controlled environment agriculture on broad-spectrum (white) LEDs versus red + blue LEDs.

White LEDs

Commercial white LEDs are blue LEDs with phosphor coatings that distribute most of that light at longer wavelengths. The remaining blue fraction varies depending on the phosphor material. Warm-white LEDs emit a relatively small blue fraction (e.g., 7%), whereas cool-white and daylight LEDs emit larger blue fractions (e.g., 20% and 30%, respectively). White LEDs emit blue, green, red, and sometimes far-red light, thereby covering a broad range of photosynthetically active radiation.

Some broad-spectrum LED fixtures include additional blue and/or red LEDs alongside white LEDs to create distinct broad spectra. White LEDs create a visually pleasant environment for workers to inspect crops, unlike red + blue LEDs, which poorly render colors of objects.

Red + blue LEDs

Red + blue LEDs are common in horticulture primarily because of their higher efficacy than white LEDs.

Red and blue light are also perceived as the "optimal" wavebands for plant growth because: 1) in the lab, chlorophylls mainly absorb red and blue light, but not green light; and 2) the McCree curve shows high quantum efficiency of photosynthesis (on an instantaneous basis) under red and blue light.

However, these do not consider the roles that green light plays in plant growth. Green light drives photosynthesis and controls plant shape. Our previous research (**bit.ly/greenblueLEDs**) showed that the inclusion of 33% green light did not affect lettuce dry weight under low blue light (0 or 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$), although it decreased lettuce dry weight under high blue light (60 or 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$).

A missing link

There is no census on whether white light or red + blue light is better to maximize crop yield in indoor growing systems. Proponents of white light stress the usefulness of green light and higher visual quality for workers. In contrast, proponents of red + blue light emphasize higher efficacy and perceived advantages in instantaneous photosynthesis.

Whole-plant growth, however, is the product of instantaneous photosynthesis and the ability of plants to capture light, which is influenced by the light spectrum. Therefore, efficacy aside, a missing link in this debate is how crop yield, not just instantaneous photosynthesis, compares under white light and red + blue light in indoor growing systems.

Studies

To address this, we compiled the results from three of our studies. The studies included side-by-side comparisons of hydroponic lettuce yield under warm-white light or red + blue light at various ratios.

We grew red-leaf lettuce 'Rouxai' indoors with a deep-flow hydroponic system at an air temperature of 68° F (in study 1) or 72° F (in studies 2 and 3). After sowing seeds in 1-inch rockwool cubes, we grew seedlings for 13, 11 and 11 days in studies 1, 2 and 3, respectively, and then transplanted them in 2-feet × 4-feet floating rafts (36 cells in studies 1 and 3 and 72 cells in study 2). We continued to grow the plants for 19, 14 and 19 days before harvests in studies 1, 2 and 3, respectively.

Plants began to receive different lighting treatments 4, 0 and 11 days after seed sow for 20 hours a day in studies 1, 2 and 3, respectively. All treatments delivered the same total photon flux density of 180 μmol·m^{-2}·s^{-1}. The only variable was the light spectrum. The relative spectral distributions of the warm-white, blue, red and far-red LEDs in these studies are shown in Figure 1. The warm-white LEDs emitted 7% blue, 29% green, 54% red and 10% far-red light.

For each lighting treatment, we calculated light use efficiency (LUE) of lettuce, which is the harvestable shoot fresh weight produced (in grams) per mole of light.

Results

In study 1, lettuce LUE under warm-white light was 16% lower than under 100% red light, but 28% higher than under 89% red + 11% blue light (Figure 2). Compared to warm-white light, lettuce LUE was 29% lower under 67% red + 33% blue light, and 50% lower under 44% red + 56% blue light. In other words, LUE decreased as the blue fraction increased.

In study 2, lettuce LUE was similar under warm-white light and 100% red light. Compared to warm-white light, lettuce LUE was 26% lower under 89% red + 11% blue light and 63% lower under 100% blue light.

In study 3, lettuce LUE under warm-white light was 33% higher than under 67% red + 33% blue light. In addition, we substituted far-red light for part or all of blue light in 67% red + 33% blue light. Compared to warm-white light, lettuce LUE was 20% lower, similar and 45% higher when 11%, 22% and 33% far-red light were included, respectively.

Lettuce growth responses were generally similar in the first two studies, albeit minor differences due to different growing periods, treatment durations and air temperatures.

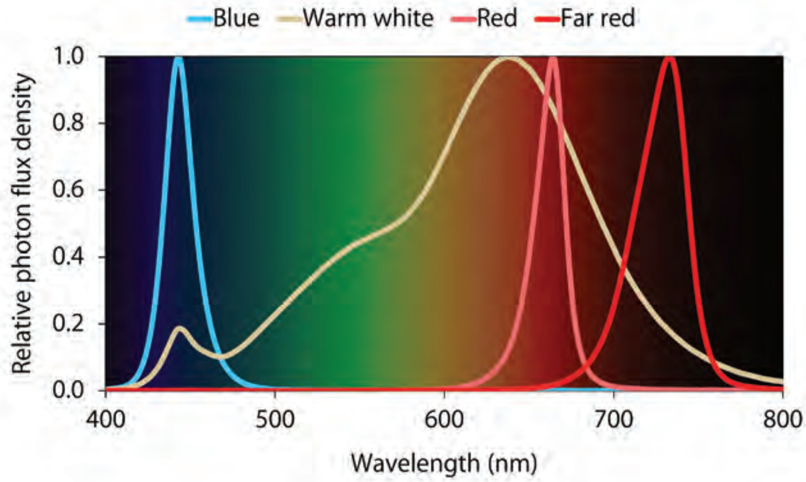

Figure 1: This graph shows the relative spectral distributions of blue (443 nm), warm-white (peak = 638 nm), red (peak = 664 nm), blue (443 nm), and far-red (733 nm) LEDs.

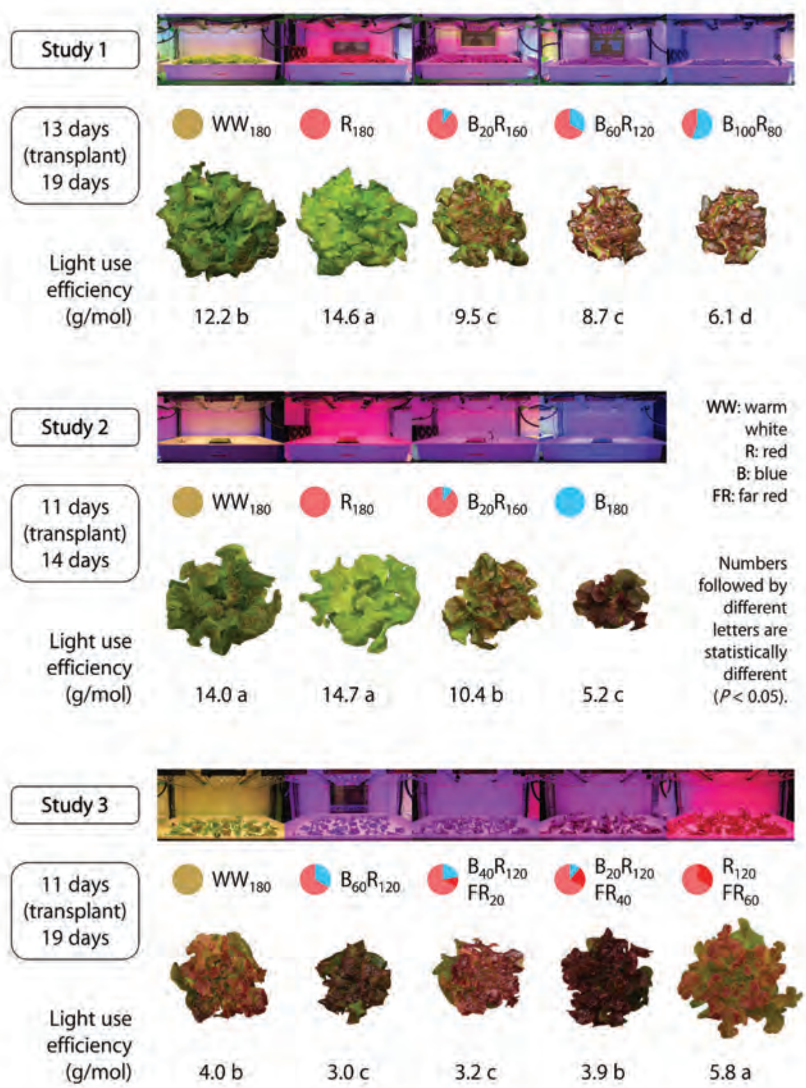

Figure 2: Light use efficiency of red lettuce 'Rouxai' grown under light quality treatments in three studies. The number for each color of light denotes its photon flux density in μmol·m^{-2}·s^{-1}.

However, we used a different fertilizer in study 3 that stunted lettuce growth and intensified leaf redness.

In the first two studies, lettuce leaves under warm-white light had a mildly red tint. The red leaf coloration under warm-white light was between that under 100% red and 89% red + 11% blue light. To maximize crop yield and intensify leaf redness, red lettuce can be grown under a low blue fraction (e.g., 5–10%) and then several days (e.g., 5 days) before harvest, grown under a high blue fraction (e.g., 30%).

Take-home messages

Red + blue light is not superior to white light for plant growth. To the contrary, the LUE of red lettuce 'Rouxai' under warm-white light was at least 26% higher than under red + blue light when the blue fraction was at least 11%. It was 33–40% higher compared to red + blue light when the blue fraction was 33%.

The high crop yield under warm-white light can be attributed to its low blue fraction and inclusion of far-red light, both of which promote leaf expansion and thus light capture for photosynthesis.

Not all white LEDs are the same. Not all red + blue LEDs are the same. Without the LED specifications or comparative plant responses, it is not fair to say which is better. Compared to red + blue light with at least 11% blue light, the higher LUE under warm-white LEDs can offset their lower efficacy to some extent.

The efficacy of broad-spectrum LEDs can be increased by adding red, blue, and/or far-red LEDs to white LEDs, which can further narrow the efficiency gap between broad-spectrum LEDs and some red + blue LEDs.

In our next article, we will compare different broad spectra with and without supplemental red and blue LEDs. **pg**

Dr. Qingwu (William) Meng (qwmeng@udel.edu) is an assistant professor of controlled environment horticulture in the Department of Plant and Soil Sciences at the University of Delaware. Dr. Erik Runkle (runkleer@msu.edu) is a professor of horticulture in the Department of Horticulture at Michigan State University.