Far Red is the New Red

Adding far red to red and blue light from LEDs brings control of plant growth to the next level.

by **QINGWU (WILLIAM) MENG & ERIK RUNKLE**

Indoor farms are burgeoning in the United States and Asia as growers and entrepreneurs find niche markets for year-round production of high-value specialty crops. According to a recent survey conducted by Agrilyst, leafy greens, herbs and microgreens are the most popular crops grown in vertical and container farms. The survey also reveals operating costs as the biggest challenge for indoor growers and that 28% of participants expressed interest in adding light-emitting diodes (LEDs) in the next year.

Aside from benefits, such as energy savings, LEDs allow for customized lighting to achieve specific crop characteristics. Light quality, intensity and duration can be manipulated to elicit desired attributes of leafy greens, including leaf shape, leaf color, nutrition, flavor, texture and aroma.

Most LED fixtures used in the horticulture industry look purplish because they primarily emit red (600 to 700 nm) and blue (400 to 500 nm) light. It's no secret that red and blue light are effective in driving photosynthesis and LEDs of these colors are efficient in converting electrical energy into light. Other LED arrays combine red, green, blue and/or white LEDs to generate a broad spectrum that appears more white.

Regardless of the spectrum, the intensity of photosynthetically active radiation (PAR, 400 to 700 nm) is crucial for plant growth. Plants not only convert PAR into chemical energy for photosynthesis, but also use light as a signal that elicits adaptive responses to the environment. Radiation outside the PAR range, such as ultraviolet (UV, 300 to 400 nm) and far red (700 to 800 nm), regulates numerous signaling pathways in plants. For instance, UV signals plants to commence protective mechanisms against stress.

Far red is best known for its role in the shade-avoidance response, which is mediated by phytochrome photoreceptors. A low ratio of red to far red is indicative of shade that triggers elongation growth, upward leaf orientation and reduced branching. The potential of using far red to obtain desirable morphological traits merits consideration in horticultural lighting. Although the dynamics between red and far red is fairly well understood, how far red interacts with both red and blue isn't clear. We investigated the value of adding far red to red and blue LEDs for indoor production of leafy greens and herbs.

EXPERIMENTAL DETAILS

We grew Rex green lettuce, Cherokee red lettuce and Genovese basil from seed in a peat-based substrate. After germination under fluorescent lamps, we started treating the plants with six different spectral combinations using red, blue and far-red LEDs (Figure 1). The photosynthetic photon flux density was maintained at 180 $\mu mol \cdot m^{-2} \cdot s^{-1}$ across all light treatments. Two ratios of blue to red (blue:red), 30:150 and 90:90 (in $\mu mol \cdot m^{-2} \cdot s^{-1}$) were delivered with and without 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of far red. The same amount of far red was also added to 180 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of red or blue alone. The spectral distributions of the light treatments were measured at the plant canopy using a spectroradiometer.

Lettuce and basil were grown at 72F (22C) under a 24-hour photoperiod for nine and 13 days, respectively, before data collection. We weighed the shoots and roots on a fresh and dry basis, and measured hypocotyl length, leaf length, chlorophyll content and leaf color indices. Relative chlorophyll content was measured using a SPAD-502 chlorophyll meter. Leaf colors were quantified in a *Lab* color space using a tristimulus colorimeter.

RESULTS

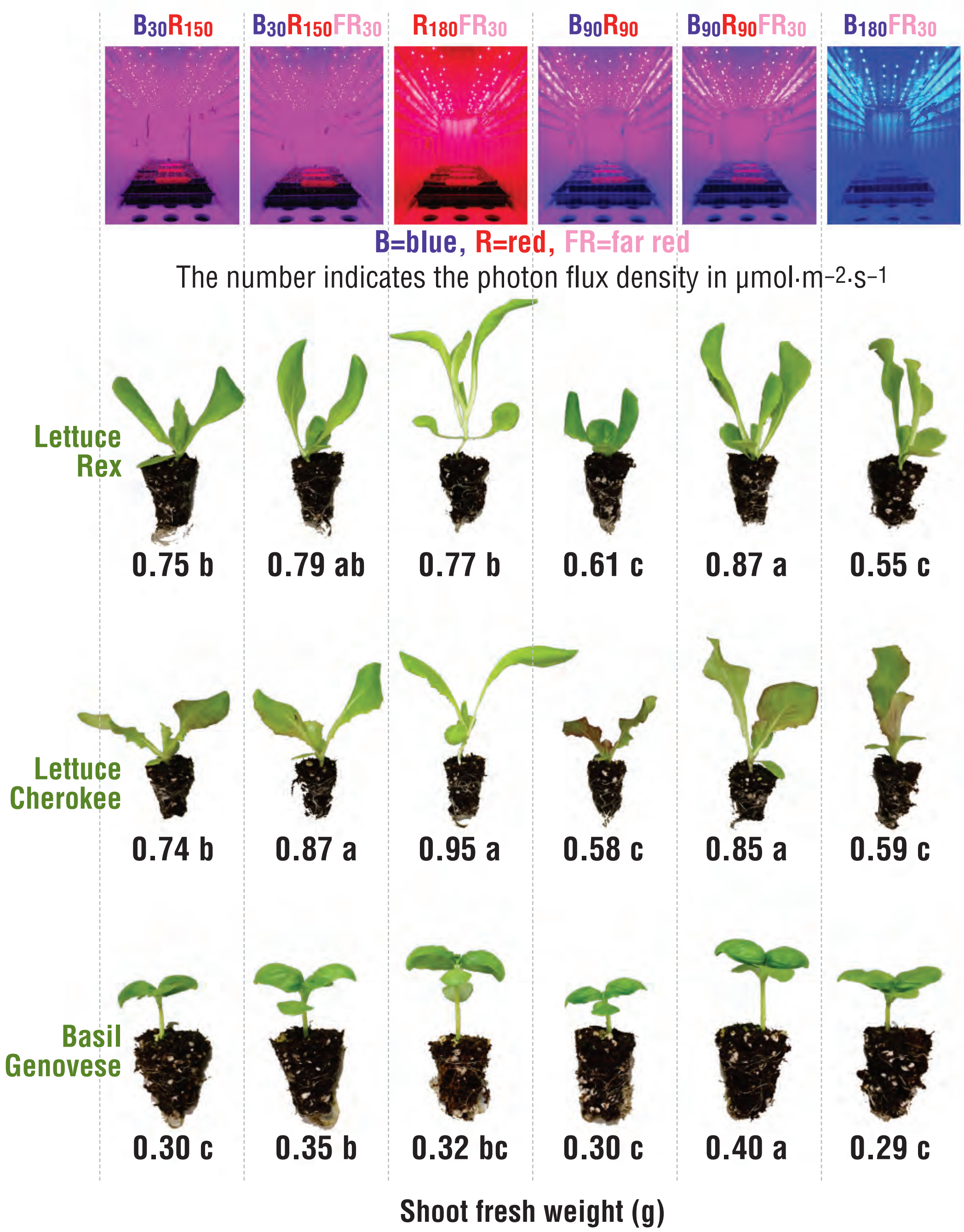
Biomass. The two lettuce cultivars responded to the light treatments similarly. Without far red, increasing blue:red from 30:150 to 90:90 reduced shoot fresh and dry weight by 17% and 22% for Rex and Cherokee lettuce, respectively (Figure 2). However, blue:red did not influence the biomass of basil. On the other

Figure 1. Plants were grown in a growth room housing six LED chambers with different spectral distributions.

hand, adding far red to red and blue increased the shoot fresh/dry weight of both lettuce and basil, especially when blue:red was 90:90. For example, the addition of 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of far red increased the fresh weight of Cherokee lettuce by 17% when blue:red was 30:150 and by 48% when blue:red was 90:90 (Figure 2).

The mixture of blue, red and far red resulted in the greatest shoot dry weight, regardless of blue:red. In comparison, the treatments that lacked either blue or red generally produced low shoot biomass. As for root growth, adding far red to red and blue increased the root dry weight of basil by 18% to 26%, but generally didn't affect that of lettuce. The added far red increased the lettuce shoot-to-root ratio when blue:red was 90:90, but had no influence when blue:red was 30:150.

Figure 2. The shoot fresh weight of three crops grown at 72F (22C) under six different LED treatments. Means followed by different letters are different based on Tukey's HSD test (α = 0.05).



■ **Elongation.** Hypocotyl length of Cherokee lettuce and basil increased by 33% to 37% when far red was added to the 90:90 blue:red treatment. For basil grown in the absence of far red, increasing blue:red from 30:150 to 90:90 reduced hypocotyl elongation by 19%. Adding 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of far red to red and blue increased the leaf length of both lettuce and basil irrespective of blue:red. However, the percentage increase was greater when blue:red was 90:90 than 30:150. Without far red, increasing the proportion of blue decreased lettuce leaf length by 12 % to 20%.

■ **Pigmentation.** Without far red, the relative chlorophyll content of lettuce increased by 10% as blue:red increased from 30:150 to 90:90. The addition of far red to red and blue reduced the relative chlorophyll content of lettuce by 10% to 19% in some cases, but didn't affect that of basil. In the absence of blue, lettuce and basil grown under red and far red had pale green leaves with the lowest relative chlorophyll content.

The redness of Cherokee lettuce leaves indicates the anthocyanin concentration. Adding far red to red and/or blue reduced their red pigmentation (Figure 3). In contrast, plants grown without far red appeared reddest in a blue-rich environment.

INTERPRETATIONS

Our results show that supplemental far red at a moderate intensity is a viable tool to manipulate extension growth. When added to red and blue, far red can increase leaf size, and thus, fresh weight, but at the expense of pigmentation. As leaf area increases from more far red, the plant captures more radiation that can be used for whole-plant photosynthesis. Moreover, recent research at Michigan State University indicates that far red can—to some extent at least—promote instantaneous photosynthesis.

Blue, red and far red have antagonistic effects on biomass accumulation, extension growth and pigmentation. For instance, blue inhibits leaf expansion, but promotes pigmentation, whereas far red does the opposite. The spectral distribution for plants should have an appropriate balance in these three wavebands. Because different crops often have ▶

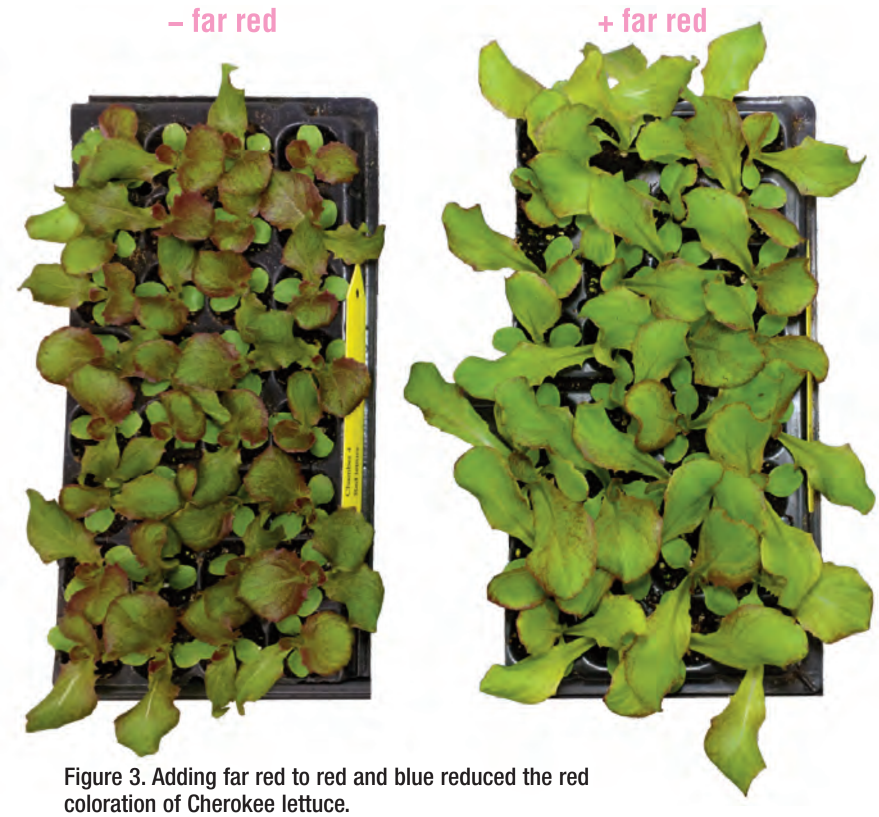


Figure 3. Adding far red to red and blue reduced the red coloration of Cherokee lettuce.

unique responses to light quality, it would be ideal to develop and use crop-specific light recipes. However, there's no such thing as a "perfect" spectrum, even for the same crop, because the desired crop traits often vary among growers and markets. To complicate the issue, light quality also interacts with other environmental factors, such as light intensity and temperature.

The "best" spectrum is what produces the crop characteristics growers want for their customers in their particular growing environments. Some lighting companies have already included far red in some of their commercial LEDs for horticultural production. Growers can take advantage of far red to increase yield and extension growth, but should keep in mind that the effects of far red often depend on blue:red and species. In some cases, far red can cause unwanted responses, such as reduced plant pigmentation and compactness.

Regardless, far red opens the door to more sophisticated control of plant growth. It's the new kind of red that can be valuable to indoor farming. IG

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A video presentation of this research is available at https://youtu.be/WX90R_dmEIM.