Optimizing light and temperature

Research reveals how far-red light and air temperature interact to regulate growth and quality in lettuce and basil.

By Jiyong Shin and Erik Runkle

This is part one of a two-part series on lighting leafy greens in CEA production.

Electric lighting plays a pivotal role in regulating crop growth, quality and yield, especially in indoor farms where electric lighting is the sole source of light. Temperature is another key environmental factor that regulates development, productivity and quality. Energy consumed for lighting and temperature management is one of the largest operational costs of indoor farming. Therefore, optimizing light and temperature conditions has important economic implications.

Most indoor farms use lighting fixtures with blue (400 to 499 nm) or white and red (600 to 699 nm) light-emitting diodes (LEDs). However, several recent studies have shown that incorporating low to moderate levels of far-red (700 to 750 nm) light can increase shoot growth in some species. In addition, far-red LEDs have a higher photon efficacy (how many photons are emitted per unit of input energy) than blue and white LEDs, and similar or slightly greater efficacy to red LEDs. Therefore, including far-red light can potentially increase yield and electrical efficacy and ultimately the economic viability of indoor farming.

Temperature and far-red light have been proposed to interact with each other to regulate plant growth in some species. Specifically, increasing temperature has been reported to amplify the growth-promoting effects of far-red light. However, whether this interaction occurs in diverse horticultural crops, many of which differ in their light and temperature sensitivity, remains largely unknown. Furthermore, the potential effects of such interactions on crop quality have received limited research.

The objective of this study was to investigate how far-red light and air temperature interact to regulate growth and quality. We

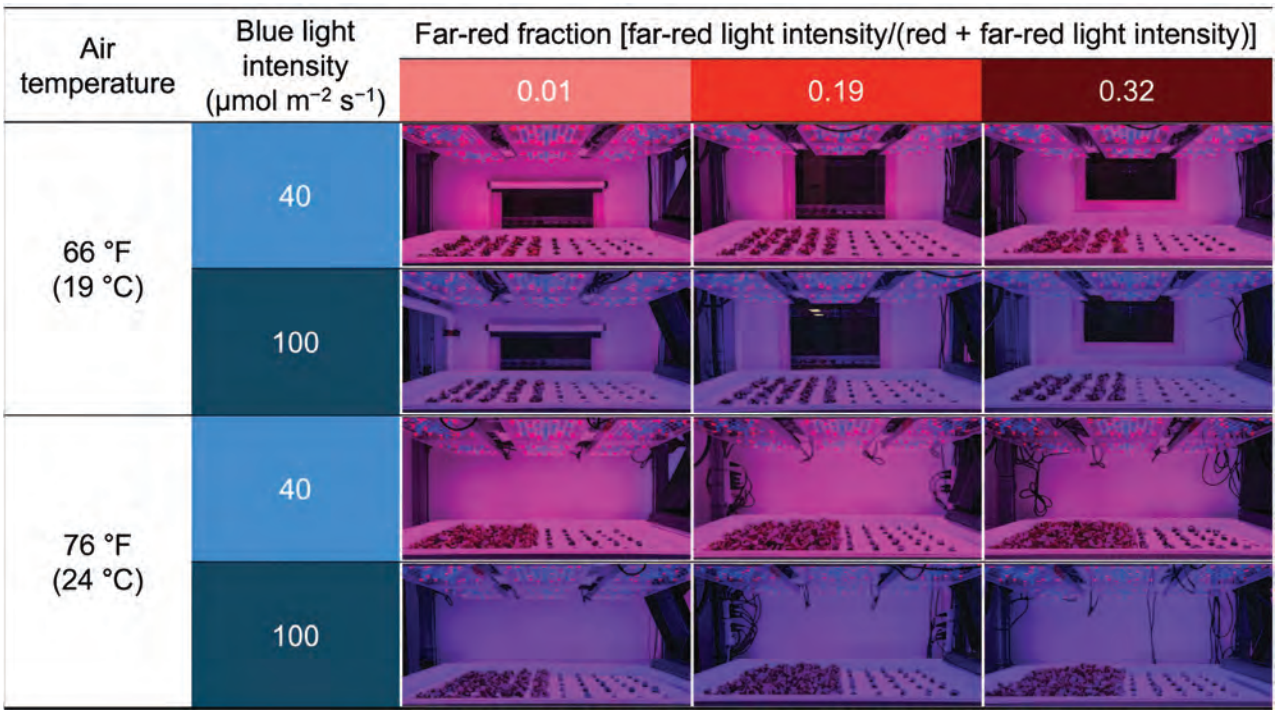

Figure 1. This graphic shows red oakleaf lettuce 'Rouxai' (left) and basil 'Prospera' (right) growing under six lighting and two temperature treatments in the Controlled Environment Lighting Laboratory (CELL) at Michigan State University.

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studied two commonly grown indoor crops with differing temperature sensitivity: cold-tolerant lettuce and cold-sensitive basil. We hypothesized that far-red light and air temperature would interdependently control growth and foliage coloration, the magnitude of which would vary among species.

Experimental protocol

We germinated seeds of red oakleaf lettuce 'Rouxai' and basil 'Prospera' using stonewool plugs under continuous sole-source lighting (without sunlight) from warm-white LEDs at 180 µmol·m^{-2}·s^{-1} of photosynthetically active radiation (photons with wavelengths between 400 and 700 nm). Eight days after seed sow, we transplanted seedlings into a vertical deep-flow hydroponic system that contained deionized water supplemented with water-soluble 12N-4P-16K fertilizer at an electrical conductivity of 1.6 mS·cm^{-1} and pH of 5.6.

During this time, we grew plants indoors under six lighting recipes with three far-red light levels and two blue light intensities (**Figure 1**). We describe the far-red light treatments based on the far-red fraction, which is the intensity of far-red light relative to the combined intensity of red + far-red light. For example, the far-red fraction of 0.01 means there was practically no far-red light, whereas 0.32 means there was about twice as much red light as far-red light.

The total light intensity (photons with wavelengths between 400 and 750 nm) was 270 µmol·m^{-2}·s^{-1} in all treatments. Therefore, the increase in blue light was offset by a decrease in red and far-red light. Lighting treatments were continuous (24 hours per day). The six lighting treatments were delivered in two different climate rooms with an air temperature of 66 or 76 °F (19 or 24 °C). We humidified the room with the higher air temperature to deliver a similar water vapor-pressure deficit at the two air temperatures.

We randomly selected and harvested 10 plants from each treatment on day 19 (lettuce) and day 32 (basil). We quantified shoot dry mass, shoot diameter (for lettuce) and first internode length (for basil). We also quantified foliage

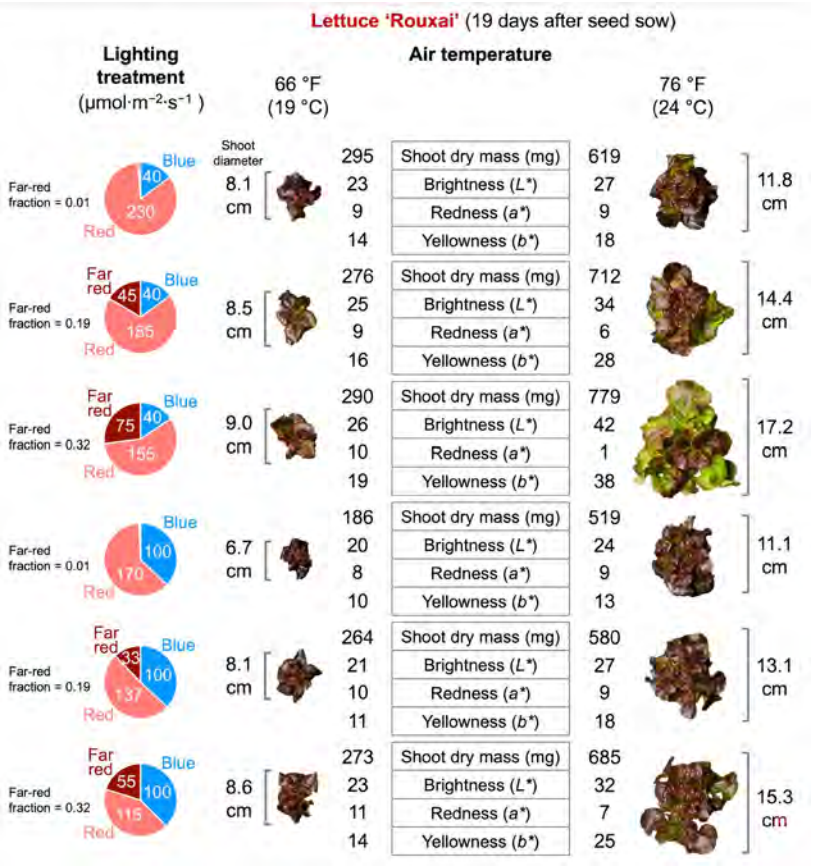

Figure 2. ***(top)*** This graphic shows the effects of six lighting and two temperature treatments on the growth and leaf coloration of red oakleaf lettuce 'Rouxai' grown indoors. All photos are to scale.

Figure 3. This graphic shows the effects of six lighting and two temperature treatments on the growth and leaf coloration of basil 'Prospera' grown indoors. All photos are to scale.

coloration by extracting color values from photographs and used International Commission on Illumination (CIE) $L^*a^*b^*$ as the color index. This indicates brightness-darkness (L^*; ranges from 0 to 100), greenness-redness (a^*; ranges from −128 to 127) and blueness-yellowness (b^*; ranges from −128 to 127) of leaves. We executed the experiment three times.

Higher temperature effects

Increasing far-red light (increasing the far-red fraction) increased lettuce shoot diameter (**Figure 2**) and basil internode length (**Figure 3**). The effects of far-red light on lettuce shoot expansion were more pronounced at 76 °F than at 66 °F. In contrast, increasing far-red light similarly extended shoot growth of basil at the two temperatures. These results indicate that a higher air temperature can amplify the effects of far-red light on shoot expansion in some species. However, this phenomenon did not occur in shoot dry mass.

As expected, increasing the air temperature appreciably increased the shoot dry mass of lettuce and basil across lighting treatments. For example, increasing the temperature at day eight from 66 °F to 76 °F more than doubled the biomass of lettuce when measured on day 19, and in some cases more than tripled the growth of basil. The effects of far-red light on shoot dry mass were less consistent than those of temperature and were only clear in two cases: (1) at 66 °F with a blue light intensity of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and (2) at 76 °F with a blue light intensity of 40 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Amplified shoot expansion sacrificed foliage coloration

Far-red light often altered foliage coloration in lettuce but had little to no effect in basil. In lettuce, increasing far-red light generally increased brightness, decreased redness and increased yellowness of leaves. These coloration responses were more pronounced at 76 °F than at 66 °F, coinciding with the greater shoot expansion observed at the higher temperature. This indicates a trade-off exists between shoot expansion and foliage coloration in lettuce. Combinations of far-red light and air temperature should be selected based on targeted crop attributes.

Blue light suppressed the interaction between far-red light and temperature

At 40 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of blue light, increasing far-red light had relatively strong negative effects on lettuce foliage (brighter, less red and more yellow) at 76 °F. In contrast, at 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of blue light, these effects on leaf coloration were substantially less pronounced. This indicates that increasing blue light can help preserve lettuce visual quality under conditions of high far-red light and temperature. Although modest, higher blue light also negated the enhancement of lettuce shoot expansion caused by far-red light at the warmer temperature.

Take-home messages

Findings indicate that lighting and temperature management in indoor farms should be considered together. Ideally, combined management strategies should also be tailored to the specific crops grown. In addition, potential trade-offs between shoot growth and crop quality can arise from individual environmental factors as well as their interactions. This is important for lettuce, considering its strong responsiveness to the light spectrum.

Although far-red light generally promoted shoot extension growth, its effects on shoot dry mass were less consistent. Results suggest that extension growth induced by far-red light does not always translate into increased shoot biomass. Further research is therefore needed to determine the conditions under which far-red light enhances biomass accumulation. This will help optimize the use of far-red LEDs in indoor farms. **pg**

Jiyong Shin is a postdoctoral scholar and Erik Runkle is a professor and extension specialist in the Department of Horticulture at Michigan State University. Contact Runkle at **runkleer@msu.edu**.