BEYOND RED AND BLUE RADIATION

Explore the efficacy of LED supplemental lighting for high-wire vegetable transplants.

BY CHARLIE GARCIA & ROBERTO LOPEZ

FIGURE 1
Tomato transplants were grown under a low DLI, consequently the crops are leggy, have weak stems and large leaves and flowers have aborted.

FIGURE 2
Light-emitting diode (LED) and high-pressure sodium (HPS) lamp supplemental and photoperiodic lighting treatments at Michigan State University. From left to right: supplemental lighting providing $B_{25}R_{95}$, $B_{30}G_{30}R_{60}$, HPS_{120}, $B_{20}G_{10}R_{75}FR_{15}$, and photoperiodic lighting: HPS_{25}.

High-quality vegetable transplants for high-wire production are defined as having thick and straight stems, compact growth with short internodes, well-developed and deep-green leaves and shortened production times. A minimum daily light integral (DLI) of 13 mol·m^{-2}·d^{-1} or greater is required to achieve these desirable morphological traits. However, in greenhouses located in northern latitudes, the DLI can average between 1 to 5 mol·m^{-2}·d^{-1} during winter months. Under these low light intensities, plants have weak stems and large leaves, are leggy, flowers are aborted, and subsequently, fruit abortion can occur leading to economic losses (**Fig. 1**). Supplemental lighting is commonly used to increase the DLI within vegetable transplant greenhouses during light limited times of the year. High-pressure sodium (HPS) lamps have been the industry standard for greenhouse supplemental lighting. However, the availability of energy-efficient light-emitting diode (LED) fixtures for horticultural applications are a promising alternative.

FIGURE 3
High-wire pepper, cucumber and tomato transplants grown in rockwool cubes.

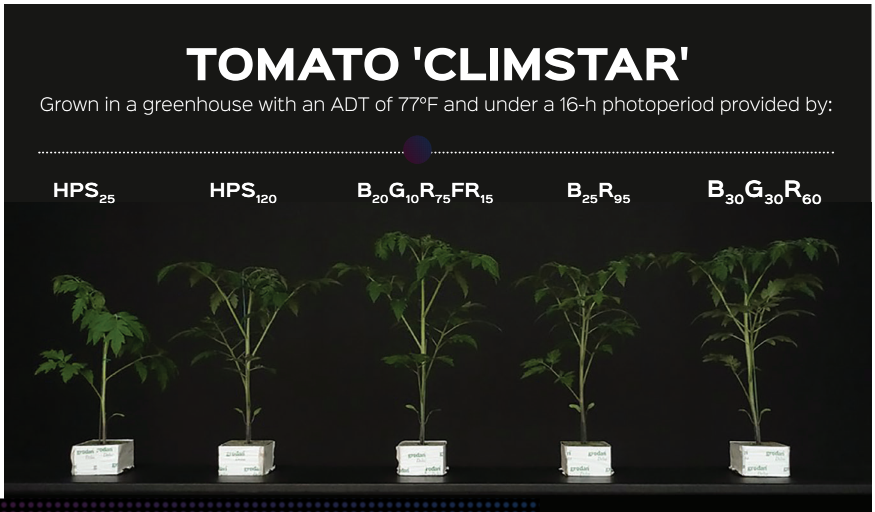

FIGURE 4
Tomato 'Climstar' transplants were grown in a greenhouse with an average daily temperature of 77° F and under a 16-h photoperiod provided by high-pressure sodium (HPS) lamps providing photoperiodic or supplemental lighting and light-emitting diode (LED) fixtures delivering supplemental lighting. Blue (B, 400-500 nm) represents the blue photon flux (PF), G (500-600 nm) the green PF, R (600-700 nm) the red PF, and FR (700-800 nm) the far-red PF from LEDs. Number subscripts after HPS denote the total photon flux density (TPFD) in $\mu mol\cdot m^{-2}\cdot s^{-1}$. Number subscripts in the LED treatments denote the photon flux density (PFD) in $\mu mol\cdot m^{-2}\cdot s^{-1}$ of B, G, R and FR.

Previous supplemental lighting studies conducted on vegetable transplants have primarily used fixtures containing blue (B) and red (R) LEDs. However, LED technology has evolved and fixtures that provide green (G) and far-red (FR) radiation among many others within and outside of the photosynthetically active radiation (PAR) range are now available. Additionally, the availability of LED fixtures with the ability for spectral quality manipulation, have created the opportunity to create "light recipes" for specific crops, which could be used to manipulate height, leaf area, foliage color and nutritional content of crops. Therefore, our objective was to quantify the influence of supplemental lighting radiation quality on high-wire tomato, pepper and cucumber transplant growth and development.

The study

Seeds of hybrid greenhouse cucumber 'Elsie', tomato 'Climstar' and pepper 'Kathia' were sown into 120-cell plug trays and covered with a thin layer of vermiculite. The trays were placed into a dark growth chamber until radicle emergence. Trays were then moved to one of five glass-glazed greenhouse compartments with an air average daily temperature set point of 77 °F (**Fig. 2**). After 10 and 14 days, cucumber and tomato and pepper seedlings, respectively, were transplanted into rockwool cubes (**Fig. 3**). Plants were irrigated once per day with a hydroponic ebb and flow system, using reverse osmosis water supplemented with a 12N-4P-16K water-soluble fertilizer and magnesium sulfate.

Four supplemental lighting treatments were delivered for 16 $h\cdot d^{-1}$ based on an instantaneous threshold (on from 6 a.m. to 10 p.m. when the outside light intensity was ≈440 $\mu mol\cdot m^{-2}\cdot s^{-1}$). HPS lamps or LED fixtures, provided a total photosynthetic photon flux density (*TPFD*; 400 to 800 nm) of 120 $\mu mol\cdot m^{-2}\cdot s^{-1}$. A photoperiodic lighting treatment (control; HPS_{25}) provided a *TPFD* of 25 $\mu mol\cdot m^{-2}\cdot s^{-1}$. The subscript number following each color waveband (B, G, R, FR), and for treatments labeled HPS indicate its photon flux density in $\mu mol\cdot m^{-2}\cdot s^{-1}$ at plant height. The treatments were:

- HPS_{25} (HPS photoperiodic lighting; control)
- HPS_{120} (HPS supplemental lighting)
- $B_{20}G_{10}R_{75}FR_{15}$ (LED supplemental lighting)
- $B_{25}R_{95}$ (LED supplemental lighting)
- $B_{30}G_{30}R_{60}$ (LED supplemental lighting)

What we learned

Not surprisingly, increasing the natural DLI from ≈5.8 to ≈11.8 $mol\cdot m^{-2}\cdot d^{-1}$ with supplemental lighting increased the shoot dry weight and stem diameter of tomato, pepper and cucumber transplants; indicating that plants were larger and sturdier. For tomato, shoot dry weight increased by 107 to 183% depending on the radiation quality provided by supplemental lighting (**Fig. 4**).

Plant responses to radiation quality were found to be genera-specific:

- Leaf area, and fresh and dry weight of tomato was greatest under LED supplemental lighting providing $B_{30}G_{30}R_{60}$ radiation.
- When G radiation replaced R or B radiation ($B_{30}G_{30}R_{60}$ vs $B_{25}R_{95}$), leaf area and fresh weight of tomato, pepper and cucumber was significantly greater (Figures 4 and 5).
- For example, leaf area and fresh weight of tomato, pepper and cucumber increased by 49, 22 and 33% and 56, 14 and 35%, respectively, for plants under LED supplemental lighting providing $B_{30}G_{30}R_{60}$ radiation compared to plants under $B_{25}R_{95}$ radiation.
- Stem diameter of cucumber, tomato and pepper was generally greatest when transplants were grown under either supplemental lighting providing $B_{30}G_{30}R_{60}$ radiation or HPS_{120} compared to the other treatments.
- Generally, $B_{25}R_{95}$ radiation was the most effective at reducing internode length of all three species (**Figures 4 and 5**).
- The tallest tomato transplants were those grown under LED supplemental lighting providing $B_{30}G_{30}R_{60}$, $B_{20}G_{10}R_{75}FR_{15}$ radiation, or HPS_{120} (**Fig. 4**).
- Stem elongation of cucumber was promoted under the low intensity control, while it was reduced for

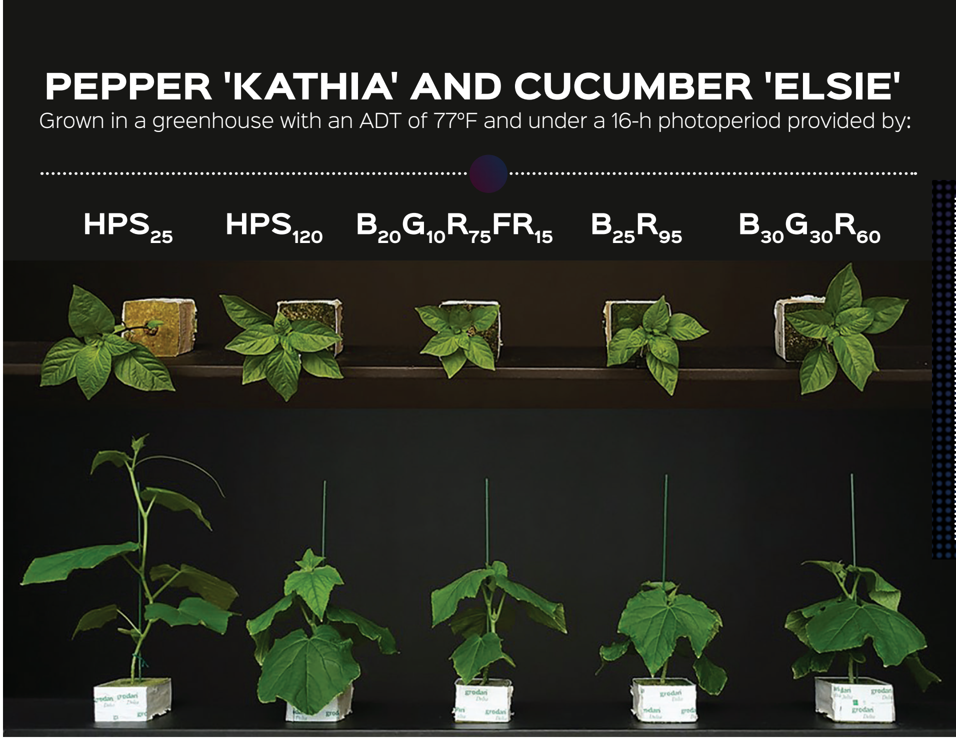

FIGURE 5
Pepper 'Kathia' and cucumber 'Elsie' transplants were grown in a greenhouse with an average daily temperature of 77 ºF and under a 16-h photoperiod provided by high-pressure sodium (HPS) lamps providing photoperiodic or supplemental lighting and light-emitting diode (LED) fixtures delivering supplemental lighting.

tomato transplants under the low intensity control (Figures 4 and 5).

- The inclusion of FR radiation reduced the incidence of tomato leaf necrosis.
- The lowest percentage of visible buds for tomato, pepper and cucumber was under the control, control and $B_{25}R_{95}$ radiation, respectively.

Take-home message

Beyond reducing the time to produce a high-quality vegetable transplant, the radiation quality (color) of LED supplemental lighting influenced the morphology and physiology of high-wire vegetable transplants when the natural DLI was low (≤7 $mol \cdot m^{-2} \cdot d^{-1}$). From previous MSU research we have concluded that LED supplemental lighting must contribute to greater than 40% of the total DLI to elicit morphological responses. Given this, supplemental lighting radiation quality could be used to elicit desired high-wire vegetable transplant morphological features as they can differ depending on the intended use. For instance, seedlings can be used as rootstocks, scions, or as non-grafted transplants. Grafted seedlings benefit from an extended hypocotyl [the part of the stem beneath the seed leaves (cotyledons) and directly above the root] length, since it helps to increase grafting success and hence survival rate, and reduce rooting from the scion after transplant. However, elongated hypocotyls are not desired for non-grafted seedlings, as it can lead to weak transplants and logistical challenges for shipping. Thus, a grower producing non-grafted transplants might utilize supplemental lighting providing $B_{25}R_{95}$ radiation as tomatoes, peppers and cucumber were the most compact under this treatment. However, they should also consider that parameters such as leaf area and fresh weight were negatively impacted under $B_{25}R_{95}$ radiation. Lastly, we have also determined that LED supplemental lighting providing $B_{30}G_{30}R_{60}$ radiation produces comparable quality high-wire transplants to those grown under HPS lamps. Therefore, we can conclude that LED supplemental lighting is an alternative to the current industry standard for high-wire transplant production. **pg**

Charlie Garcia is a former M.S. student and Roberto Lopez is Associate Professor and Controlled Environment/Floriculture Extension Specialist in the Department of Horticulture at Michigan State University (MSU). The authors gratefully acknowledge Nate DuRussel for assistance, Heliospectra for LEDs, JR Peters for fertilizer, Grodan for substrate, Syngenta for seeds and MSU AgBioResearch for support.