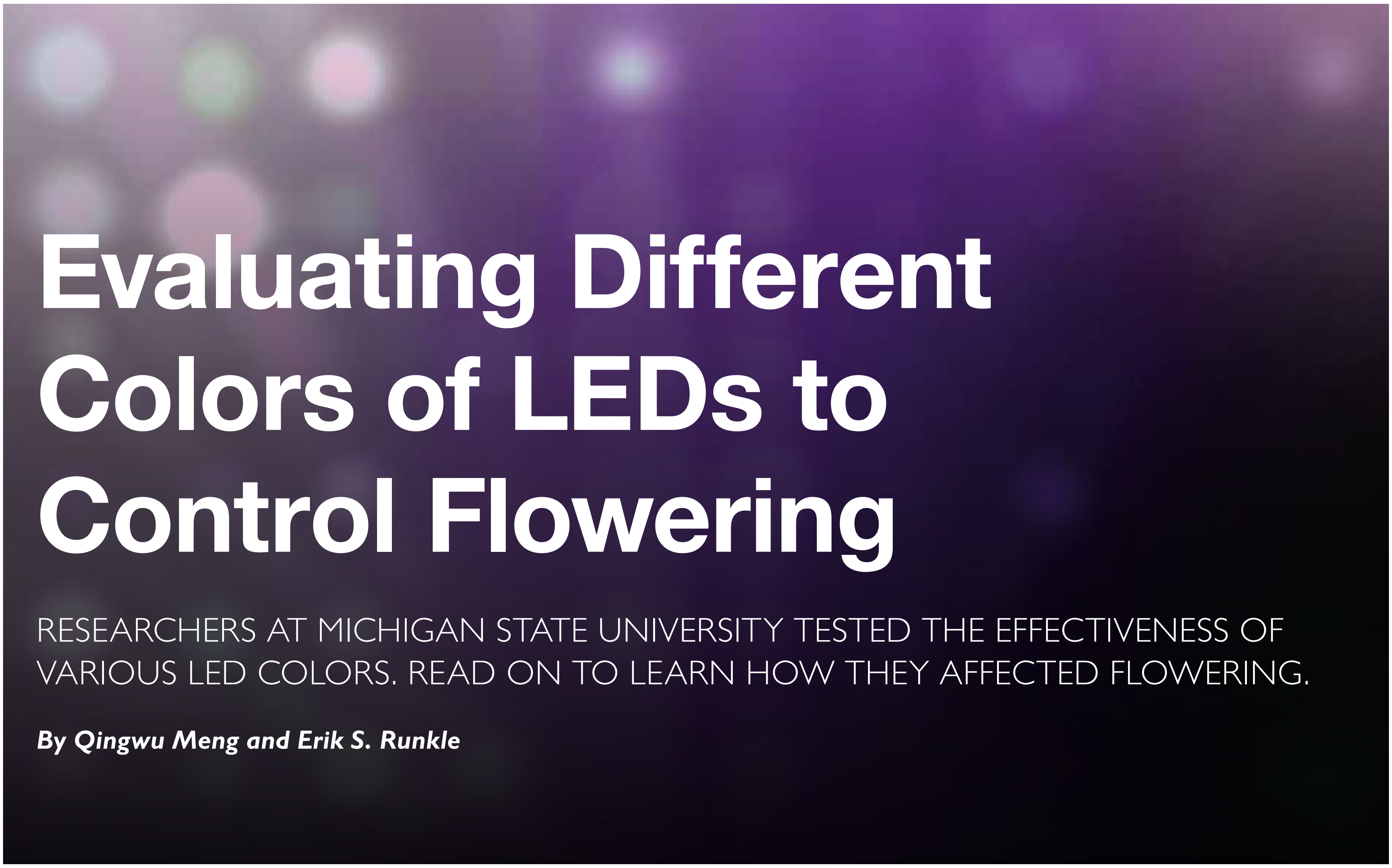

Evaluating Different Colors of LEDs to Control Flowering

RESEARCHERS AT MICHIGAN STATE UNIVERSITY TESTED THE EFFECTIVENESS OF VARIOUS LED COLORS. READ ON TO LEARN HOW THEY AFFECTED FLOWERING.

By Qingwu Meng and Erik S. Runkle

Flowering of a wide range of ornamental crops is influenced by the lengths of the day and night. Under natural short days, four hours of low-intensity (≈2 μmol·m^{-2}·s^{-1}) lighting during the middle of the night (night interruption or NI) can promote flowering of long-day plants. Traditional incandescent lamps effectively provide long days, but they are energy inefficient and have been phased out of production. Light-emitting diodes (LEDs) are emerging as an alternative light source because of their greater energy efficiency and long life span.

Previous studies performed at Michigan State University (MSU) showed that LEDs emitting similar amounts of red (R; 600 to 700 nm) and far-red (FR; 700 to 800 nm) light, such as the R+white+FR (R+W+FR) LED "flowering" lamp from Philips, were as effective as incandescent lamps at controlling flowering. The inclusion of FR light accelerates flowering in some crops, but also can lead to plant stretch. Compact fluorescent lamps emit little FR light and thus do not promote as much elongation, but they can be less effective for some crops such as petunia. White LEDs also emit little FR light, so we would predict similar flowering and elongation responses as compact fluorescent lamps. We performed an experiment to test the effectiveness of white LEDs, as well as other colors, at controlling flowering.

White LEDs are really blue (B; 400 to 500 nm) LEDs with a coating or cover that scatters most of the blue light into other colors, such as green and R, so that the colors combined appear white. There are many different types of white LEDs, such as cool white (or daylight), neutral and warm white. The differences are marked by the correlated color temperature on the Kelvin (K) scale. The correlated color temperature is not the actual temperature of a lamp, but the temperature of a black-body radiator, the color of which resembles the color of the lamp to human eyes. The higher the color temperature is, the cooler the color of a lamp appears. For example, a low color temperature of 2,700 to 3,000 K indicates warm colors (a softer, redder light), whereas a high color temperature of 4,000 to 5,000 K indicates cool colors (a bluer light). Therefore, the spectral distributions of cool-white and warm-white LEDs are characteristic of high and low ratios of B to R light (B:R), respectively.

We compared the efficacy of R, B+R, cool-white, warm-white, and R+W+FR LEDs in NI lighting at controlling flowering. We postulated that the R+W+FR LEDs would be more effective than the white LEDs for some FR-sensitive crops, and that the cool-white and warm-white LEDs would be similarly effective.

Experimental Protocol

We tested flowering responses of five long-day plants: calibrachoa 'Callie Yellow Improved', coreopsis 'Early Sunrise', petunia 'Wave Purple Improved', rudbeckia 'Indian Summer' and snapdragon 'Liberty Classic Yellow'. Young plants were obtained from C. Raker & Sons within one week of seed sow or as a nearly rooted liner. They were grown under a nine-hour short day until ready for transplant. Ten plants of each species were then transplanted and placed on each of six benches in a greenhouse at a constant 68° F. All plants were exposed to a nine-hour short day achieved by closing black cloth at 5 p.m. and opening it at 8 a.m. The four-hour NI lighting treatments were delivered by LEDs (see Figure 1) as follows:

- None (a short-day control);
- R only;
- B+R;
- Cool white (5,000 K color temperature);
- Warm white (3,000 K color temperature); and
- R+W+FR.

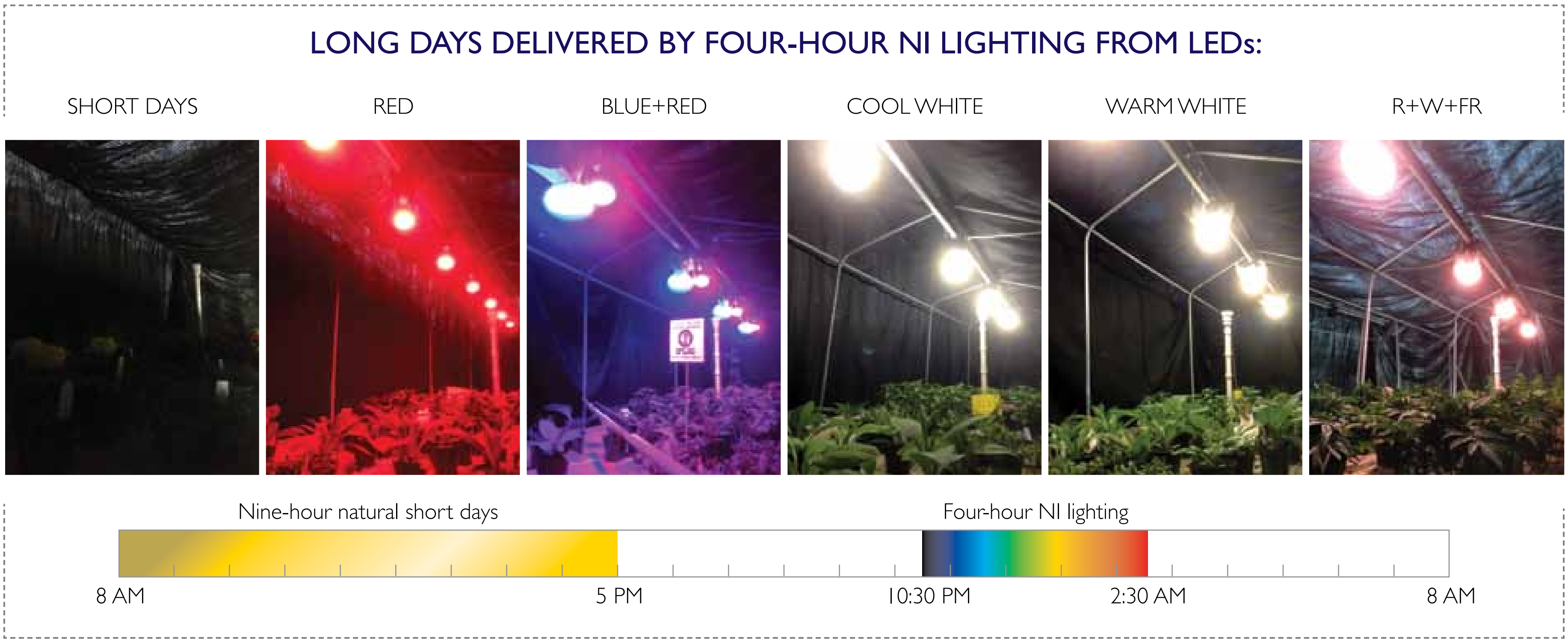

Figure 1. *Experimental setup of a short-day treatment and night-interruption (NI) lighting treatments provided by red, blue+red, cool-white, warm-white, and red+white+far-red (R+W+FR) light-emitting diodes (LEDs).*

The spectral distributions of the lighting treatments were measured by a spectroradiometer and are presented in Figure 2. Irradiance at plant height was adjusted to approximately 2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ between 400 and 800 nm.

Plants were grown following established floriculture research protocols at MSU. The experiment was performed twice. Date of the first visible flower bud or inflorescence (VB) and date of the first open flower were recorded. At flowering, main stem length, VB number, and increase in leaf number on the main stem were recorded. For petunia, the stem with the first open flower was measured for stem length and leaf number.

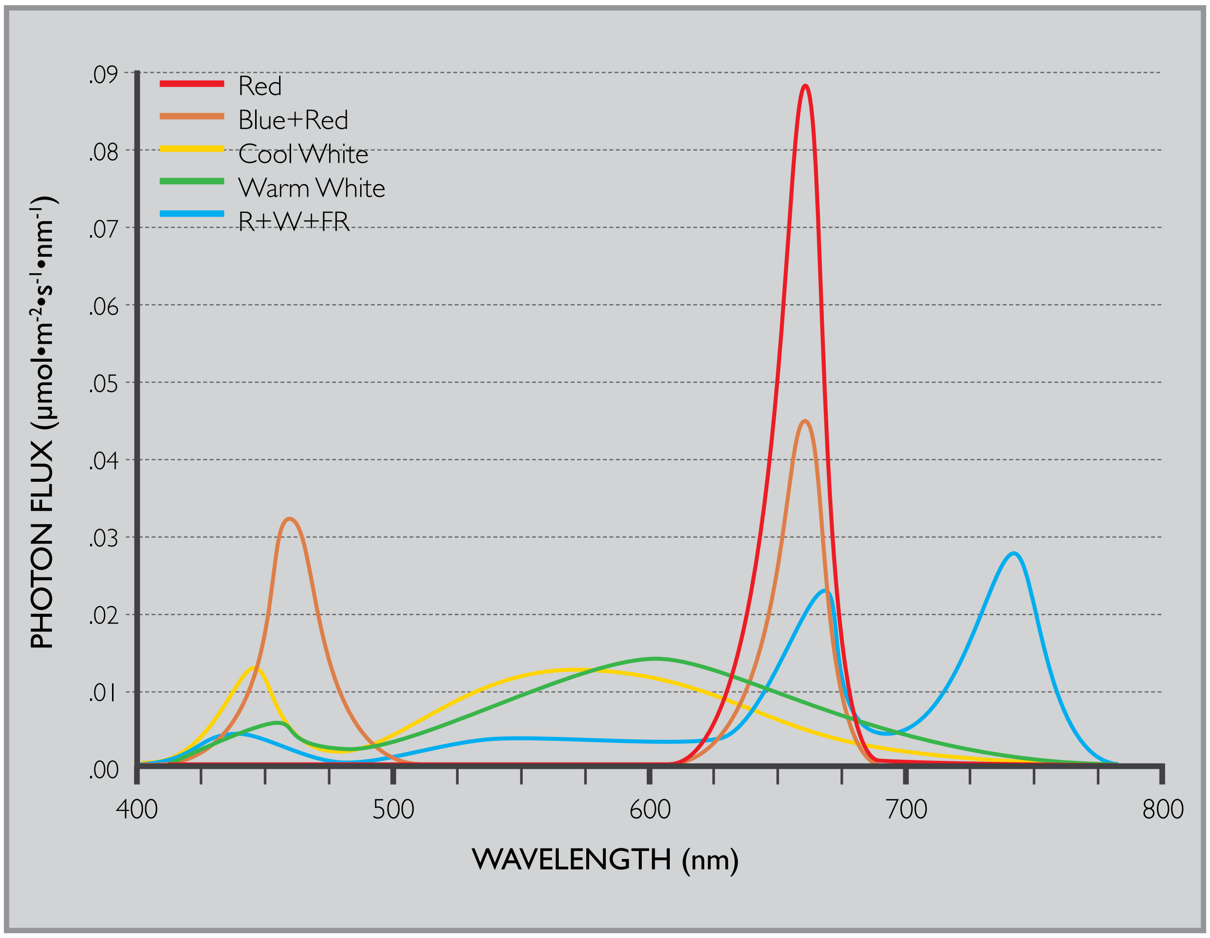

Figure 2. *Spectral distributions of night-interruption lighting treatments provided by red, blue+red, cool-white, warm-white, and red+white+far-red (R+W+FR) light-emitting diodes.*

Results

Flowering percentage. All plants of petunia and snapdragon flowered under all treatments, whereas calibrachoa, coreopsis and rudbeckia did not flower under the short day. All plants of calibrachoa and rudbeckia and at least 80 percent of coreopsis plants flowered under all NI lighting treatments.

Flowering time. Some crops, such as calibrachoa and rudbeckia, were not sensitive to FR light and flowered at the same time under all NI lighting treatments (Figure 3). Flowering time of snapdragon was similar under the short day and NI lighting treatments without FR light (the R, B+R, cool-white, and warm-white NI), but the R+W+FR NI accelerated flowering by 11 days. This indicates FR light was essential to promote flowering of snapdragon. Although NI lighting treatments without FR light promoted flowering of coreopsis and petunia, flowering was eight to 13 and five to seven days earlier, respectively, under the R+W+FR NI than under the other NI lighting treatments. This indicates that a combination of R and FR light accelerates flowering more than R or FR light alone, at least for some long-day plants.

Different fractions of B and R light in LEDs did not affect flowering time. For example, there were no differences between cool-white and warm-white LEDs at controlling flowering of all crops studied,

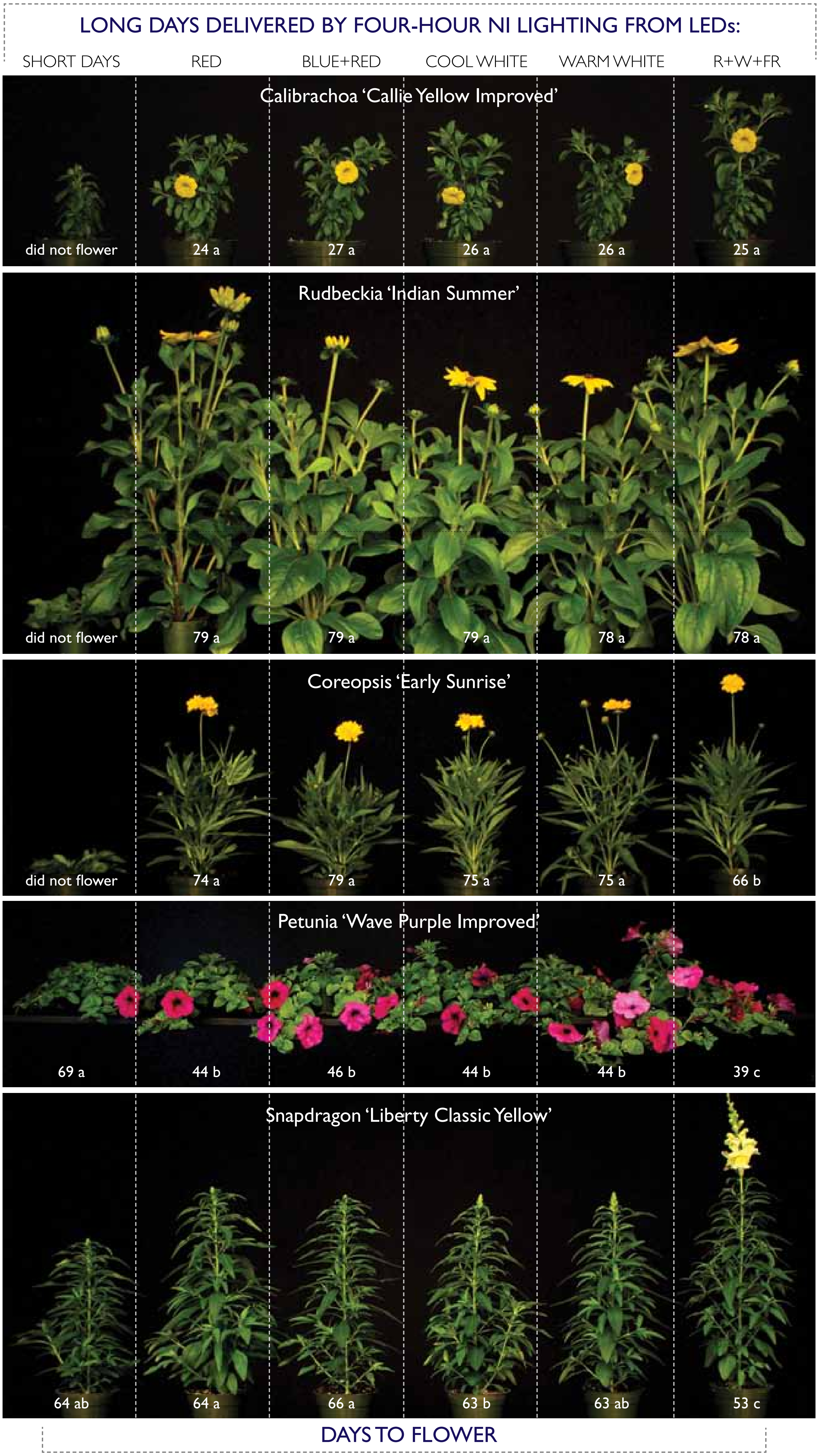

Figure 3. *Calibrachoa and rudbeckia flowered similarly under all five NI lighting treatments delivered by different LEDs. Coreopsis, petunia and snapdragon flowered earlier under an NI delivered by LEDs that emitted red, white, and far-red (R+W+FR) than other colors. Means followed by different letters within species are significantly different (P ≤0.05). Photos taken 29 days after transplant for calibrachoa and 86 days after transplant for rudbeckia. Photos taken 78, 53, and 45 days after transplant for coreopsis, petunia and snapdragon, respectively.*

showing the B:R of 0.67 and 0.27 were equally effective. Moreover, the B+R NI (B:R=0.83) was as effective as the R NI (B:R=0) for all crops studied, revealing that low-intensity B light did not influence flowering when added to R light.

Extension growth. At flowering, snapdragon under the short day was 2 to 3 inches shorter than plants under the NI lighting treatments. A low R to FR light ratio (R:FR) promoted stem elongation in some crops, but not others. For example, coreopsis was 1 to 2 inches taller under the R+W+FR NI (R:FR=0.81) than under the R (R:FR=1419), B+R (R:FR=1703), and warm-white NI (R:FR=7.18). In addition, the main stem of calibrachoa was one inch longer under the R+W+FR NI than under the R NI. Plant height of petunia, rudbeckia and snapdragon was similar at flowering under all NI lighting treatments.

VB number. VB number of calibrachoa, petunia, and rudbeckia was similar under all NI lighting treatments. Coreopsis had five to nine fewer VBs under the R+W+FR NI than under the R, B+R, and warm-white NI. Compared with the short day, snapdragon had similar VB number under NI lighting treatments without FR light and had three fewer VBs under the R+W+FR NI.

Increase in leaf number. The increase in leaf number before flowering was similar under all NI lighting treatments for coreopsis and rudbeckia. Compared with the short day, petunia had 21 to 22 fewer leaves under NI lighting treatments without FR light and had 25 fewer leaves under the R+W+FR NI. Compared with the short day, snapdragon had similar leaf number under NI lighting treatments without FR light and had 13 fewer leaves under the R+W+FR NI. Therefore, the FR light caused plants to flower earlier from a plant development standpoint.

Conclusions

Selection of appropriate light sources for NI lighting depends on specific species. The R+W+FR LEDs promoted flowering of coreopsis, petunia, and snapdragon more effectively than lamps that emit little or no FR light (i.e., the R, B+R, and white LEDs). In particular, snapdragon required FR light for early flowering. However, early flowering of calibrachoa and rudbeckia did not depend on delivery of FR light during the NI. In addition, the cool-white and warm-white LEDs caused very similar plant responses.

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