Applications of Far-Red LEDs in Plant Production under Controlled Environments

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LEDs in Horticulture

• Increasing interest worldwide

• Challenges
  – High fixture costs
  – Limited information on optimization (light quality, design and application methods)

• Opportunities
  – Maximizing photosynthesis
  – Photomorphology or photoperiodic control
Incandescent Lamps

• 100-year old technology
• Rich in yellow, red, and far-red in addition to thermal radiation.
• Used in horticulture for photoperiodic as well as supplemental photosynthetic lighting.
• The only widely available light source containing far-red radiation.
• Currently horticulture use is exempt from the phase-out, but the limited access may increase the price.
Far-red LEDs

• Current LED market is for visible range (~380 – 680 nm), UV and NIR (>800 nm), leaving far-red (700 – 800 nm) without much development.

• Far-red (response peak at 735 nm) is a light quality relevant to plant growth/development.

• LED technology enables monochromatic far-red lighting.
Supplemental Far-Red Light Potential Applications

• Greenhouse conditions
  – Extending stem/hypocotyl of plants (cut flower and seedlings)
  – Expanding leaf and enhancing growth rate (leafy greens)

• Growth chamber (plant factory) conditions
  – Extending stem/hypocotyl of plants (seedlings)
  – Expanding leaf and enhancing growth rate (leafy greens)
End-of-Day Light Treatment

• Classic photobiology (phytochrome response)
• Light quality at the end of day (photoperiod) determines stem elongation during the successive night (dark period)
  – EOD red light $\gg$ shorter plants
  – EOD far-red light $\gg$ taller plants
• Effective at VERY low light intensity
• Responses are light quality dependent (i.e., $P_{fr}/P_{total}$)
• EOD-FR: Limited applications in the past (there was no pure FR light source).
• EOD-FR: Potential non-chemical control of stem or hypocotyl elongation
EOD-FR Application for Vegetable Rootstock

- Longer hypocotyls are needed in vegetable grafting
  - Greater grafting speed
  - Keeping grafted unions above the soil line.
End-of-day light quality treatment for controlling morphology of vegetable seedlings in greenhouse

Tomato rootstock seedlings

Squash rootstock seedlings

EOD Far-red Dose (0 – 9000 μmol/m²/d)

Squash hypocotyl (mm)

EOD Far-red Dose (μmol/m²/d)

(Chia and Kubota, 2010; Kubota et al., 2011)
Indoor Grafted Seedling Production

- Technology widely used in Japan
- However, application for cucurbitis is limited (i.e., plants become too short)

Figure. Typical light quality of T5 white fluorescent lamps. 
\[ \frac{P}{P_{total}} = 0.807 \ (R/FR = 10.2) \]

[Sunlight \( \frac{P}{P_{total}}: \sim 0.7 \ (R/FR: \sim 1) \]
End-of-day FR Light Treatment for Cucurbit Seedlings Grown under Artificial Lighting

*Preliminary Experiment*

**Plant species:**
*C. maxima x C. moschata* ‘Tetsukabuto’

**Main light source:**
Cool White fluorescent lamp
PPF: 150 μmol m$^{-2}$ s$^{-1}$ (400-700 nm)
Photoperiod: 12 hours

**EOD FR treatment:**
Intensity: 4 μmol m$^{-2}$ s$^{-1}$ (700-800 nm)
Duration: 30 min EOD for 3 days
FR Dose: 7200 μmol m$^{-2}$ d$^{-1}$

![Control vs EOD-FR plants](image-url)
Moving Far-Red Lighting

New application method

- End-of-Day FR light dose response showed saturation at around 4000 μmol m⁻² d⁻¹ (700-800 nm)
- There was also reciprocity (intensity vs. duration) demonstrated for tomato and squash rootstock seedlings.

<table>
<thead>
<tr>
<th>FR light intensity (μmol/m²/s)</th>
<th>FR light duration (min)</th>
<th>FR light dose (μmol/m²/d)</th>
<th>Hypocotyl (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>24</td>
<td>1800</td>
<td>72a</td>
</tr>
<tr>
<td>2.7</td>
<td>12</td>
<td>1900</td>
<td>76a</td>
</tr>
<tr>
<td>0 (Control)</td>
<td>0</td>
<td>0</td>
<td>55b</td>
</tr>
</tbody>
</table>

(Squash result after Chia (2009))

- Prototype of moving Far-Red LED lighting was designed and tested.
Moving Far-Red Lighting

New application method

Figure. FR photon flux distribution at the horizontal plane 5 cm below the light source.

Collaboration with Dr. Murat Kacira (UA, ABE)
# End-of-Day FR Treatment with Moving fixture vs. Stationary fixture

<table>
<thead>
<tr>
<th>Main factor</th>
<th>Hypocotyl (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EOD FR treatment and LED fixture type</strong> (dose = 4000 ( \mu \text{mol/m}^2/\text{d} ))</td>
<td></td>
</tr>
<tr>
<td>Moving fixture</td>
<td>82.2 a</td>
</tr>
<tr>
<td>Stationary fixture</td>
<td>89.6 a</td>
</tr>
<tr>
<td>Non-treated control</td>
<td>53.0 b</td>
</tr>
<tr>
<td><strong>Traveling speed (application times) of moving fixture</strong></td>
<td></td>
</tr>
<tr>
<td>0.8 mm/s (one application per EOD)</td>
<td>73.6 a</td>
</tr>
</tbody>
</table>
| 3.1 mm/s (four applications per EOD)                                        | 90.9 a         

Yang et al. (submitted)
Supplemental FR Lighting for Baby Leaf Lettuce under Artificial Lighting

- Supplemental far-red light significantly increased the biomass of baby lettuce plants by 28%.
- This was due to the increased light interception caused by enhanced leaf elongation.
- Similar observation by Stutte et al. (2009).

(Li and Kubota, 2009)
End-of-Day FR Light Treatment for Baby Leaf Lettuce in Greenhouse

Preliminary Experiment

Non treated control

EOD FR light treatment
Intensity: $46 \, \mu\text{mol m}^{-2} \, \text{s}^{-1} (700-800 \, \text{nm})$
Duration: 3.3 min at EOD for 10 days
Dose: $9,200 \, \mu\text{mol m}^{-2} \, \text{d}^{-1}$
Conclusions

• Far-red light is a well-studied light quality in relation to phytochrome responses with limited applications in the past.

• We successfully demonstrated the applications of far-red LED lighting for seedling production (as EOD lighting) as well as lettuce production (supplemental or possibly, EOD lighting).

• However, wider applications will be dependent on availability and costs of far-red LEDs. We will continuously develop new applications (part of USDA SCRI LED project).
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