Differences in the Spectral Output of Single- and Double-Ended High-Pressure-Sodium Lamps

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Differences in the spectral output of single- and double-ended high-pressure-sodium lamps

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Abstract:
High pressure sodium lamps have a low fraction of blue photons, and this fraction is reduced from 3.6% to 2.6% in the newer style double-ended bulbs. About half of the photons in the “blue” region (400 to 499 nm) are between 491 and 499 nm. These photons have low biological activity for cryptochrome activation.

Background:
High pressure sodium (HPS) lamps are commonly used in controlled environment agriculture (CEA). Compared to single-ended HPS bulbs, double-ended HPS bulbs do not have frame wire, which allows for a smaller diameter bulb. Double-ended HPS bulbs are more efficient at converting electricity to photons output than single-ended HPS bulbs and produce more photons with the same wattage. Double-ended HPS bulbs typically have longer life span than single-ended HPS bulbs, due to the slow start and the steady output of electronic ballasts (Johnson and Bugbee 2017).

Results:
The spectral output of double-ended HPS bulbs is different than their single-ended counterpart. We measured the spectral output from a single-ended HPS bulb (Gavita Pro Plus 1000W EL) and a double-ended HPS bulb (Philips #C400551/ALTO) from 220 to 1100 nm and present the data from 350 to 750 nm (Fig. 1, Table 1). The extended photosynthetically active radiation range or extended photosynthetic photon flux density (ePAR or ePPFD) is from 400 to 750 nm. Single-ended HPS emit 5.9% blue photons in ePAR (dashed red line in Fig. 1, Table 1). Double-ended HPS emit fewer blue photons at 4.0% (solid blue line in Fig. 1, Table 1). Spectral distribution of double-ended HPS is slightly wider than single-ended HPS spectrum in the green region (500-599 nm)(Fig. 1). The ePAR photon output of single- and double-ended HPS was 67.0% and 57.7% in green region, respectively (Table 1). Red photons make up for 25.1% and 35.5% of ePAR photons for single- and double-ended HPS bulbs, respectively (Table 1).

Fraction of blue photons. The blue waveband (400-499 nm) of both single- and double-ended HPS has a sharp peak at 498 nm (Fig. 1). Photons at this wavelength are much less efficient at activating cryptochromes and eliciting blue light response of plants than photons below 490 nm (Banerjee, Schleicher et al. 2007, Fraikin and Belenikina 2023). If we exclude this peak and only consider photons in the waveband of 400-490 nm as blue photons, the fraction of blue photons of single- and double-ended HPS lamps decrease significantly to 3.6% and 2.6%, respectively (Table 2). This low blue fraction in HPS spectra is important to explain morphology of crops grown under HPS lamps in sole-source lighting.

Fraction of UV photons. Both types of HPS bulbs produce less than 0.5% UV photons relative to ePAR photons (Fig. 1, Table 1). This is much less than the fraction of UV photons typically in sunlight (Gueymard, Myers, and Emery 2002). Single-ended HPS produce only 0.45% UV photons relative to ePAR photons, while double-ended HPS provide 0.23% UV photons (Table 1).
Fraction of far-red photons. Single- and double-ended HPS bulbs emit 2.0% and 2.8% far-red photons relative to ePAR photons, respectively. These numbers are lower than sunlight, which contains 16-18% far-red photons relative to ePAR photons. The calculated phytochrome photoequilibria (PPE) of single-ended and double-ended HPS bulbs are very similar, at 0.83. The internal PPE (iPPE), which take into consideration of spectral distortion within leaves, is a better parameter than PPE (Kusuma and Bugbee 2021). The calculated iPPE of both HPS types are also similar at 0.75. Whereas the PPE of sunlight and metal halide lamps are 0.70 and 0.82, respectively, higher than that of HPS lamps. This indicates that both sunlight and metal halide lamps would induce a reduced shade avoidance response of plants than HPS lamps.

Both types of HPS lamps have a sharp peak output in the near-infrared region at 819 nm. Photons in this waveband are unlikely to induce any physiological response and therefore are excluded from our discussion.

Table 1. Fraction of photons in five wavebands relative to ePPFD (400 to 750 nm). The phytochrome photoequilibria (PPE) and the internal PPE (iPPE) of single- and double-ended HPS output spectra are also shown.
<table>
<thead>
<tr>
<th>Waveband</th>
<th>Single-ended HPS</th>
<th>Double-ended HPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPFD 400-700 nm</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>UV/PPFD</td>
<td>0.46%</td>
<td>0.24%</td>
</tr>
<tr>
<td>% blue</td>
<td>6.1%</td>
<td>4.1%</td>
</tr>
<tr>
<td>% green</td>
<td>68.4%</td>
<td>59.4%</td>
</tr>
<tr>
<td>% red</td>
<td>25.6%</td>
<td>36.5%</td>
</tr>
<tr>
<td>Far-red/PPFD</td>
<td>2.1%</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

Table 2. Fraction of photons in five wavebands relative to PPFD (400 – 700 nm) of single- and double-ended HPS output spectra.

<table>
<thead>
<tr>
<th>Waveband</th>
<th>Single-ended HPS</th>
<th>Double-ended HPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-499 nm</td>
<td>5.9%</td>
<td>4.0%</td>
</tr>
<tr>
<td>400-490 nm</td>
<td>3.6%</td>
<td>2.6%</td>
</tr>
<tr>
<td>491-499 nm</td>
<td>2.3%</td>
<td>1.4%</td>
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</tbody>
</table>

Table 3. Fraction of photons in originally defined blue photons (400 to 499 nm), the re-defined blue photons (400-490 nm) and the percent photons between 491 and 499 nm of single- and double-ended HPS output spectra relative to ePPFD.

References


Johnson, J. and B. Bugbee (2017). Double-ended high pressure sodium fixtures decline less than 6% over 2 years and 5000 hours, DigitalCommones@USU.