Article

Increasing the Yield of Lactuca Sativa, L. in Glass Greenhouses through Illumination Spectral Filtering and Development of an Optical Thin Film Filter

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Supplementary
Calibration of the Heliospectra LED Source

The Heliospectra LED light source was calibrated using the hand-held laser power meter LaserCheck (Coherent, Oregon, USA). It was set to a specific wavelength to be measured, then the Heliospectra was turned on at intervals of 100 ‘intensity’ readings, and the LaserCheck meter was used to measure the power density (Wm$^{-2}$) at 0.2 m height intervals from, directly under the LED source down to pot height. This was conducted to determine the power output required from the Heliospectra LED light source at plant height, in order to attempt to emulate the Heliospectra output to the output power from the sun, across an 18 hour day/6 hour night, time interval, as discussed in the literature to be an optimum daylight time interval for lettuce [1,2], within the constraints of the Heliospectra system.

The calibration utilized the following data constraints, not to scale.

![Figure S1. Schematic diagram of the Heliospectra LED source calibration setup.](image)

The calibration graphs were obtained for the range 1.4–0.6 m from the LED data (where the plants grew between 1.2–1.4 m from the LED source in height, growing closer to the source, i.e., closer to 1.2 m as growing). A linear regression line was fitted to the 1.4 m from the LED source data, which is approximately at pot height (the pot top being ~13 cm from the ground).
Blue Calibration: 448nm

Red Calibration: 666nm

(a)

(b)
Figure S2. The power density calibration plots of the Heliospectra LED source.

Photon Flux Density (PFD) Calibration to the Heliospectra ‘Intensity’ Reading

The photon flux density (PFD) is the number of photons in the wavelength regions under consideration (µmolm⁻²s⁻¹) [3]. The wavelength regions of interest are selected because of their relevance to either the photosynthetic response, and/or the plant production yield. Using the power density (W/m²), and the formula to convert the power density to PFD, as shown below [4].

\[ 1 \text{ Js}^{-1} = 1 \text{W} \]  \hspace{1cm} (1)

\[ \text{Photon Irradiance (mol.m}^{-2}\text{s}^{-1}) \text{ or Photon Flux Density (PFD)} = \frac{E}{(\frac{c}{h})N} \]  \hspace{1cm} (2)

where:
- \( E \) = Energy (J)
- \( c \) = Speed of light = \( 3.0 \times 10^8 \text{ms}^{-1} \)
- \( h \) = Planck’s constant = \( 6.63 \times 10^{-34} \text{Js} \)
- \( N \) = Avogadro’s number = \( 6.023 \times 10^{23} \text{ quanta mol}^{-1} \)
- \( \lambda \) = wavelength (m)

A linear regression was then applied to the 1.4 m results (measured from the LED down to the top of the pot).
Blue Calibration: 448nm

![Graph showing the relationship between PPFD (µmol/m²/s) and 'intensity' Heliospectra reading for different distances from the LED. The graph includes a linear trendline for 1.4m from the LED with an equation of \( y = 0.0044x + 3.9679 \) and an R² value of 0.7579.]

Red Calibration: 666nm

![Graph showing the relationship between PPFD (µmol/m²/s) and 'intensity' Heliospectra reading for different distances from the LED. The graph includes a linear trendline for 1.4m from the LED with an equation of \( y = 0.0845x + 15.042 \) and an R² value of 0.9972.]

(a) Blue Calibration: 448nm

(b) Red Calibration: 666nm
The photon flux density calibration plots of the Heliospectra LED source.

Figure S3. The photon flux density calibration plots of the Heliospectra LED source.

The PFD values determined were:
- Tent 1 — White at 1000 ‘intensity’: ~101 µmolm<sup>-2</sup>s<sup>-1</sup> (3 s.f.)
- Tent 2 — Blue at 1000 ‘intensity’, Red at 458 ‘intensity’: ~61.9 µmolm<sup>-2</sup>s<sup>-1</sup> (3 s.f.)
- Tent 3 — Blue at 1000 ‘intensity’, Red at 458 ‘intensity’, Far Red at 1000 ‘intensity’: ~70.6 µmolm<sup>-2</sup>s<sup>-1</sup> (3 s.f.)

**Wavelength Calibration of Ocean Optics Fiber Spectrometer**

Periodically, tests of the wavelength calibration accuracy of the fiber spectrometer instrument were made, using a range of diode-pumped solid-state, semiconductor, and gas (red He–Ne) laser sources of known wavelength.

The technical essence of the procedure is checking that a light source of a particular central wavelength, Full Width Half Maximum (FWHM) bandwidth, and spectral emission line shape, is measured with the spectrometer as a spectral distribution fitting these specifications, to an acceptable degree of error (usually being about ± 1 nm for most optical source measurements not requiring mode distribution analysis, or the characterization of longitudinal coherence properties).

It is necessary to check the wavelength calibration stability and accuracy across the entire spectrum range of the measurements required. Therefore, three solid-state laser sources were commonly used, a 473 nm blue laser, 532 nm green diode-pumped solid state (DPSS) laser (featuring frequency doubling of a stable 1064 nm radiation line from an Nd:YAG crystal pumped by an 808 nm semiconductor laser), a 635 nm red DPSS laser, and a 670 nm semiconductor laser. These sources covered the entire spectral range of interest where the broadest (white LED) Heliospectra source had any significant optical output. The maximum spectral drifts noted so far in the spectrometer wavelength calibration never exceeded about ± 1 nm, gauged from the spectral positions of the measured emission peaks with respect to the known wavelengths.

**Growth Results**

Photos of each plant were taken approximately at two week intervals during the experiment, specifically days 12/13, days 22/23 and day 34. Plant 8, from each grow tent, is shown in Figure 2 as a random sample from the 90 plant set. As can be observed, the growth characteristics over the 39d
growing period were visually similar, and this observation was confirmed by the average wet weights (g/plant) being very similar between the grow tents.

Figure S4. Growth of a randomly selected plant, the same plant number within each of the three different illuminated grow tents. (a–c) Grow Tent 1, Plant 8 growth from (a) day 12, (b) day 22 and (c) day 34. (d–f) Grow Tent 2, Plant 8 growth from (d) day 12, (e) day 23 and (f) day 34. (g–i) Grow Tent 3, Plant 8 growth from (g) day 13, (h) day 23, and (i) day 34.

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