The Design and Production of a High-Intensity, Variable-Spectra LED Array for Plant Development in Challenging Environments

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ABSTRACT

Plant development can be dramatically influenced by the quality of light present in their environment. Many factors, such as rates of photosynthesis and dry-matter production, synthesis of specific compounds, or time of flowering can be manipulated through the use of specific wavelengths of light. Researchers at the Controlled Environment Systems Research Facility (CESRF) have developed a high-intensity, narrow-bandwidth LED array with nine distinct wavelengths, ranging from short-wavelength UV LEDs to relatively long-wave far-red LEDs. Individually, each wavelength present is sufficient in intensity to drive associated pathways in plants. The intended use for the array is to develop light “recipes” that maintain a plant’s optimum light environment for whatever developmental characteristic is desired. The short term goal at the CESRF is to optimize dry matter accumulation in lettuce, tomato, and pepper plants for food production in challenging environments. Design considerations for deploying LEDs in this study are presented.

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INTRODUCTION

Conventional lighting systems for plant development do not allow for fine control of the spectrum emitted. This often results in light qualities that are not optimal for stimulating the desired developmental characteristics of the species being grown.

Foremost of the many responses to light by plants is photosynthesis. In many species, previous studies have shown that a combination of red and blue light can effectively drive photosynthesis and fully develop a plant. More recent studies have begun to expand on this, supplementing red and blue with green light, or by adjusting the peak wavelengths of red and blue light.

Other light responses:
- Shorter wavelengths (UV / Blue):
  - Hypocotyl and petiole elongation
  - Cotyledon and leaf expansion
  - Stimulation of phenylpropanoid pathway
  - Plasma membrane depolarization
  - Circadian rhythm regulation
- Midrange wavelengths:
  - Increased electron transport rate
  - Effectively transmitted through canopies, lighting lower leaves
- Longer wavelengths (amber / red / far red):
  - Seed germination
  - Cell elongation
  - Nitrate reductase regulation
  - Flowering time

This aim of this study was to develop an array capable of emitting variable spectra using multi-coloured, narrow-bandwidth LEDs. The array would then be used to design high-resolution light “recipes” for eliciting targeted responses.

SELECTION OF LEDS

Seven colours of narrow-bandwidth LEDs were acquired from Philips. The emission peaks and relative intensity of each is summarized in figure 1 below.

![Emission spectra and relative PAR of seven Philips LEDs.](image1.png)

Table 1. Surface maps of light intensity ($\mu$mol/$m^2$/s) of each colour. Maps were created at 40 cm, 60 cm, and 100 cm away from the light source.

### ARRAY DESIGN

It was found that seven colours of light from the LEDs could be homogeneously distributed with the LEDs clustered in groups of seven, arranged in a hexagonal star. (figure 2a). Optics were fixed over the LEDs to focus light on the plants below (figure 2b). Twelve stars were then assembled into a “snowflake” design (figure 2c).

![Figure 2. (A) Seven clusters of seven different colours. (B) Optics applied to the LED stars. (C) Twelve stars arranged into one Snowflake array.](image2.png)

### EXPERIMENTS

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**Germination**

Germination tests of several species were performed under seven monochromatic light qualities, an HPS lamp, and in darkness. Species tested included wheat, barley, radish, lettuce, tomato, soybean, pepper, and kale. Seeds were plated in moist germinating pods, maintained at 22°C ± 0.5°C. The intensity of each light treatment was set at 280 $\mu$mol/$m^2$/s, with a photoperiod of 16 h. The number of seeds germinated was counted every 24 h, and germination rates under different light qualities were compared.

**Photosynthesis**

Photosynthesis of vegetative lettuce was measured in the previously described conditions under seven monochromatic light qualities on day 1 (initial). The plants were then “adapted” to a light quality for three 16 h days. On day 5 (final), photosynthesis was again measured under the initial seven light qualities.

### INTENSITY CALIBRATION

The intensity of each colour was mapped inside the single plant surface within the chamber. This was repeated at three fixed over the LEDs to focus light on the plants below.

![Surface maps of light intensity ($\mu$mol/$m^2$/s) of each colour. Maps were created at 40 cm, 60 cm, and 100 cm away from the light source.](image3.png)

### SUMMARY RESULTS

**Germination**

Some species showed a much greater sensitivity to light quality than others. Higher germination rates were achieved in some species using relatively long wavelengths, while in other species, this same treatment was completely inhibitory. Shorter wavelengths were generally inhibitory to germination, suggesting that there may be competition between photoreceptors in germination regulation.

**Photosynthesis**

In general, longer wavelengths were more effective in driving photosynthesis. However, other light qualities that included shorter wavelengths were shown to be equally effective in this regard. This may be useful in designing light qualities to elicit other responses while maintaining a high photosynthetic rate.

**Adaptation**

After adaptation, the photosynthetic capacity of plants under many light qualities was significantly impaired, indicating that there may be a necessary “recovery” period for plants in altering light qualities during their development.

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