Using LEDs to manipulate red:far-red ratio and photomorphogenesis in controlled environments

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Introduction

Light signals play a crucial role in determining the architecture of individual plants and canopies. In dense stands of plants, reflected far-red light (wavelengths in the range 700-750 nm) signals lead to reductions in red:far-red ratio (R:FR ratio), which are perceived by the phytochromes, a family of reversibly photochromic regulatory photoreceptors.

$$Pr \underset{\text{far-red}}{\overset{\text{red}}{\rightleftarrows}} Pfr$$

Reductions in R:FR ratio, lead to reductions in Pfr levels and trigger shade avoidance reactions, resulting in increased elongation of internodes and petioles with a concomitant reduction in allocation of resources to harvestable components such as seeds, roots or tubers.

Our understanding of the perception of R:FR ratio signals and the roles of individual members of the phytochrome family, as well as efforts to experimentally eliminate shade avoidance responses in crop plants, has been dependent on the construction of controlled environments in which R:FR ratio can be manipulated. The conventional approach to manipulating R:FR ratio has been to create polychromatic light sources where white light is supplemented with high photon irradiances of far-red light, generated by filtering the output of high-energy incandescent lamps through appropriate filters. The use of high-energy incandescent lamps consumes significant amounts of energy and generates massive amounts of heat. The greatest challenge in constructing low R:FR ratio controlled environments has been the dissipation of excess heat, usually involving windows of flowing refrigerated water.

LEDs

LEDs (light emitting diodes), which generate virtually no heat, have very low energy consumption and estimated lifetimes of several years offer a simple and economic solution to the problem of creating controlled environments in which R:FR can be manipulated.

At least two companies manufacture LEDs that emit in the far-red region of the light spectrum (Fig. 1). The clear LEDs from Shinkoh Electronics have a high output and an emission spectrum (λmax 735 nm) that very closely resembles the absorbance spectrum of the Pfr form of phytochrome (Fig. 2).

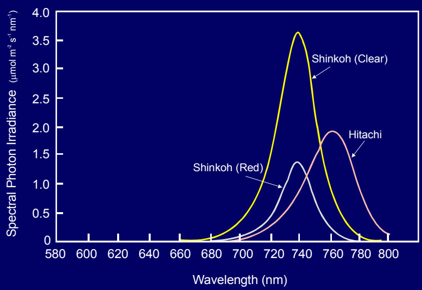

Figure 1. Spectral characteristics of far-red LEDs

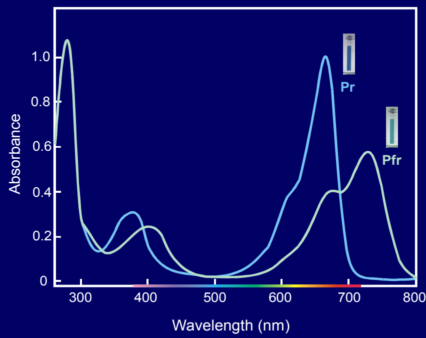

Figure 2. Absorbance spectra of the Pr and Pfr forms of phytochrome

Construction of LED arrays

Individual LEDs were mounted in polycarbonate as shown in Figs. 3 & 4. The arrays were placed inside 40 mm polycarbonate tubes and the tubes were mounted inside a controlled environment growth room (Fig. 5) or cabinet.

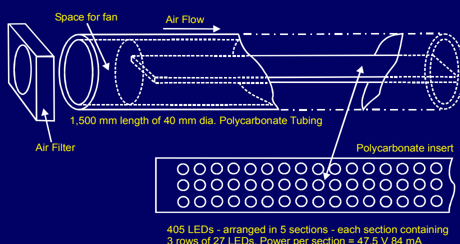

Figure 3. Design of far-red LED arrays

Figure 4. Close-up of LED array

Figure 5. LED arrays mounted inside a CE room

Performance

The spectral properties of the far-red supplemented growth rooms indicated that the LEDs did not contribute significantly to Photosynthetically Active Radiation (PAR: 400-700 nm) and were able to reduce the R:FR ratio to less than 0.1; a value typical of the light reflected from dense vegetation (Fig. 6).

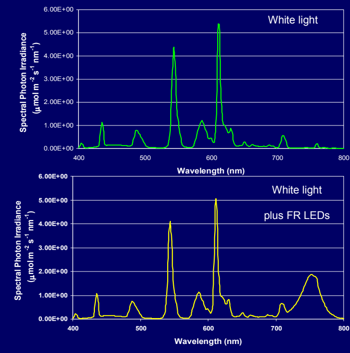

Figure 6. Spectral energy distributions of control and far-red-supplemented growth cabinets

Plants grown under light environments comprising white fluorescent light supplemented with the output of far-red LED arrays display classical shade avoidance responses (Figs. 7 & 8).

Figure 7. Seedlings of white mustard (*Sinapis alba*) growing in a modified Fisons growth cabinet

The plants on the left are receiving white fluorescent light only, whilst the plants on the right are receiving white fluorescent light supplemented with the output of far-red LED arrays.

Figure 8. Shade avoidance growth responses of mustard seedlings induced by supplementary light from far-red LEDs

Conclusions

Using far-red emitting LEDs it is possible to produce low R:FR ratio sources (or monochromatic far-red light sources) by a simple modification of existing controlled environment growth rooms or cabinets.

The LEDs, which generate essentially no heat and have very low energy consumption, have spectral characteristics that make them ideal for the manipulation of the phytochrome system and hence photomorphogenesis.