



INTRODUCTION

Photobiology includes the study of the effects of radiation quality on photomorphogenesis and photosynthesis in plants. Photomorphogenesis is directly affected by three factors: light quality, light intensity, and photoperiod [1]. All three of these factors are perceived by a plant's light perception network, which is composed of primarily three types of photoreceptors: phytochrome, cryptochrome, and phototropin (for a review on photoreceptors see [2]).

Phytochrome is the most studied of the three photoreceptors and is the only one for which the absorption spectra has been measured (Fig. 1A). Because we have the absorption spectra, the phytochrome response to a light source can be predicted by calculating the fraction of P_{fr}/P_{total} (also known as phytochrome photoequilibrium; PPE). Note that the P_r and P_{fr} absorption spectra are not restricted to only red / far red wavelengths (Fig. 1A).

Cryptochrome is a blue light and UV-A receptor that, like phytochrome, controls many aspects of plant physiology and development. It strongly suppresses stem elongation and contributes to both leaf expansion and plastid processes. [1]

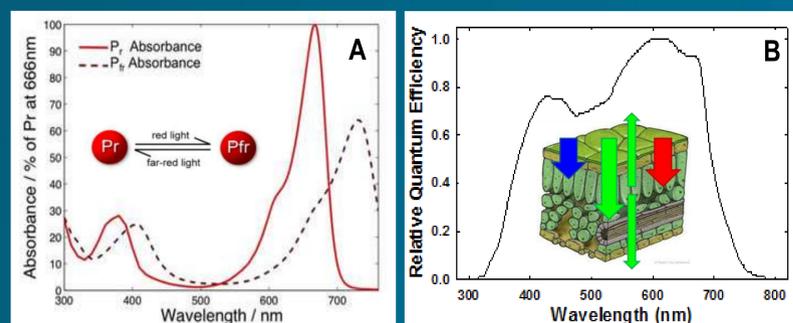


Figure 1. (A) The absorption spectra for P_r and P_{fr} from 300 to 750 nm (B) The relative quantum efficiency from 300 to 800 nm (adapted from [3]); blue, green, and red light leaf penetration is illustrated.

Photosynthesis is driven by the photosynthetic photon flux (PPF), which gives equal weight to all photons between 400 and 700 nm; however, not all wavelengths of photons are equally efficient in driving photosynthesis. Some photons are absorbed by inactive pigments, such as anthocyanins, which results in energy loss as heat and/or fluorescence [4]. This loss is indicated in the relative quantum efficiency (RQE) curve (Fig. 1B). The RQE of red light (600-700 nm) is 25 to 35% more efficient than blue light (400-500 nm) and 5 to 30% more efficient than green light (500-600 nm). For this reason, a theoretically more accurate measurement of PAR is the yield photon flux (YPF), which is derived from weighting each photon's wavelength using its RQE. Although red light has the highest quantum efficiency, most plant species require blue light for normal development [5]. Furthermore green light may increase plant growth [6] because it is transmitted more effectively through the leaf, thus illuminating lower plant leaves and potentially increasing whole-plant photosynthesis [4].

MATERIALS & METHODS

Light-emitting diodes (LEDs) are an extremely useful tool for studying photobiology because of their narrow spectral output [1]. We used LEDs (Fig. 2 and Table 1) to study the effects of light quality on photomorphogenesis and photosynthesis. Radish, lettuce, soybean, and wheat were all grown under cool, neutral, and warm white LEDs and combinations of RB and RGB LEDs or single colors of LEDs (Fig. 3). Two light intensities (200 and 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$) were used throughout the study to observe the effects of differing percentages of blue and green light. Environmental conditions and root-zone environment were uniformly maintained across treatments.

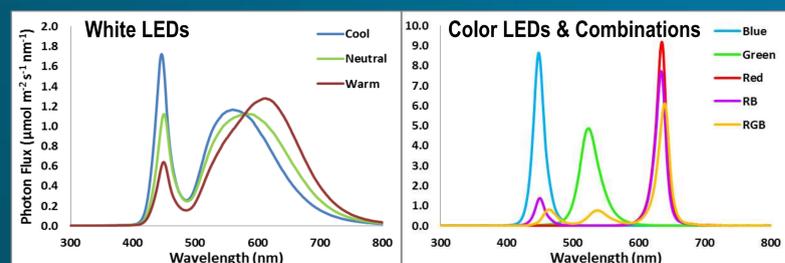


Figure 2. Spectral traces for all eight LED treatments used for the experiment. Note the color coordination of each spectra with its LED type in Table 1.



Figure 3. Experimental setup for LED treatments used for growing lettuce. (A) Green, Blue, Red, RB, and RGB LED treatments; (B) Warm, Neutral, and Cool White LED treatments.

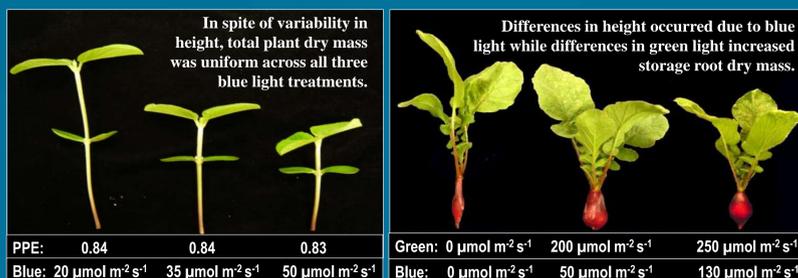


Figure 4. Soybean plants grown under various blue light levels.

Figure 5. Radish plants grown under varying blue & green light levels (PPF 500).

RESULTS

The effects of PPE (phytochrome) were far less significant than the effects of blue light (cryptochrome), which had a profound effect on radish, lettuce and soybean development but hardly affected wheat. An increase in the absolute amount of blue light ($\mu\text{mol m}^{-2} \text{s}^{-1}$) from 0 to 80 $\mu\text{mol m}^{-2} \text{s}^{-1}$ resulted in a decrease in stem elongation in soybean and radish, independent of the light intensity (Figures 4 and 5). This effect occurred despite comparable PPE. In lettuce, however, an increase in the relative amount (0 to 20%) of blue light caused a decrease in stem elongation (Fig. 6).

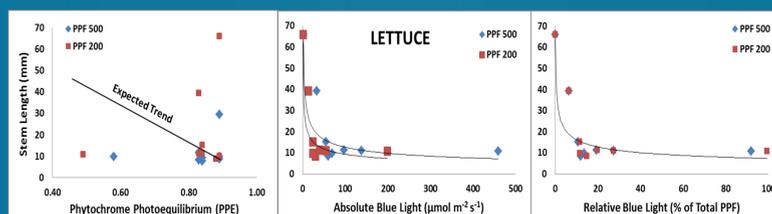


Figure 6. Comparison of the effects of PPE, absolute blue light levels ($\mu\text{mol m}^{-2} \text{s}^{-1}$) and relative blue light levels (% of total PPF) on stem elongation.

Light Quality Parameter	LED Type							
	Cool	Neut	Warm	Red	Green	Blue	RB	RGB
PPF =	500	500	500	500	500	500	500	500
YPF =	429	441	455	486	390	351	469	447
YPF/PPF =	0.86	0.88	0.91	0.97	0.78	0.70	0.94	0.89
% UV-A =	0.17	0.13	0.09	0.03	0.17	0.18	0.01	0.11
% Blue =	27.5	19.4	10.8	0.27	6.52	92.0	12.0	13.7
% Green =	37.8	34.5	29.0	0.39	91.1	7.77	0.71	21.6
% Yellow =	10.2	11.1	12.0	1.27	1.44	0.06	0.98	1.28
% Red =	24.5	35.0	48.3	98.1	0.96	0.22	86.3	63.4
PPE =	0.83	0.84	0.84	0.89	0.83	0.58	0.89	0.89
R/FR =	6.44	5.67	5.02	>999	0.4/0	0.1/0	>999	170.0/0

Table 1. Light quality parameters for the LED treatments used in this experiment.

DISCUSSION

These results are comparable to [7] and indicate that phytochrome and cryptochrome work synergistically to reduce stem elongation and specific leaf area, as discussed in [2]. Furthermore, using only PPE to predict photomorphogenesis is not sufficient; blue light levels also need to be determined.

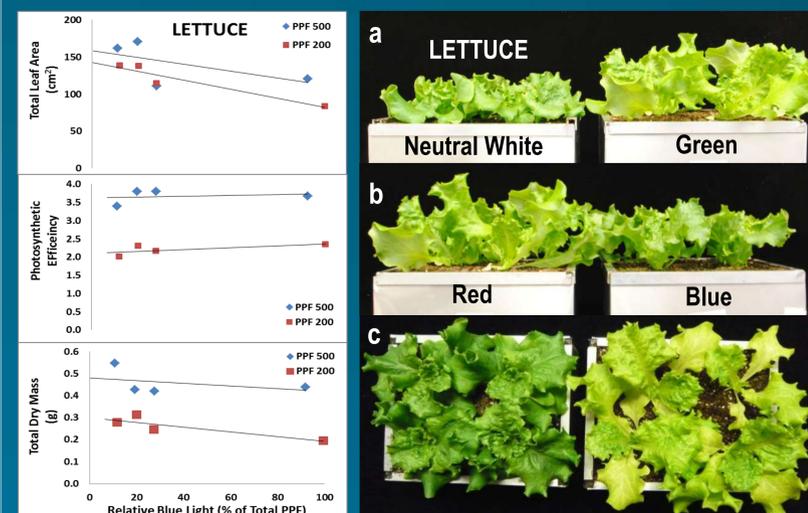


Figure 7. Effects of blue light on lettuce leaf area and dry mass.

Figure 8. Effects of phytochrome and cryptochrome on plant height (a,b) and chlorophyll concentration (c: left, warm white; right, green).

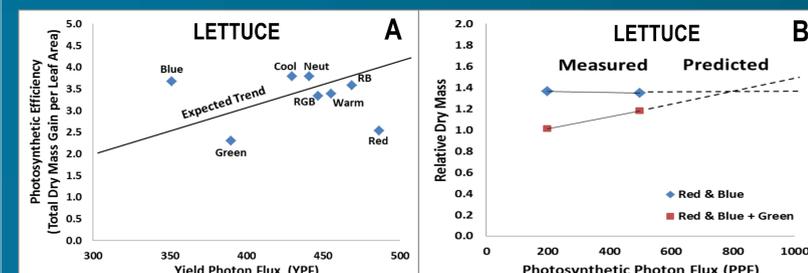


Figure 8. (A) A comparison of photosynthetic efficiency to the yield photon flux; and (B) A comparison of relative dry mass in RB and RGB treatments to increased PPF.

Our results indicate that YPF is poorly correlated with photosynthetic efficiency (Fig. 8A). Furthermore, addition of green light to a red and blue light source at a constant PPF increased growth as light intensity increased (Fig. 8B; compare to [8]). Kim et al. [6] observed similar effects.

CONCLUSIONS

- 1) Photomorphogenesis is the sum of the feedback provided by phytochrome and cryptochrome, which work synergistically to help the plant adapt to its light environment.
- 2) At high light intensities supplemental green light may increase whole plant photosynthesis.

REFERENCES

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