

## Countermeasure for Radiation Protection and Repair



Energy-Efficient  
Lighting Systems

Exposure to ionizing radiation during long-duration space missions is expected to cause short-term illness and increase long-term risk of cancer for astronauts. Radiation-induced free radicals overload the antioxidant defense mechanisms and lead to cellular damage at the membrane, enzyme, and chromosome levels. A large number of radioprotective agents were screened, but most had significant side effects. But there is increasing evidence that significant radioprotective benefit is achieved by increasing the dietary intake of foods with high antioxidant potential.

Early plant-growing systems for space missions will be limited in both size and volume to minimize power and mass requirements. These systems will be well suited to producing plants containing high concentrations of bioprotective antioxidants. This project explored whether the production of bioprotective compounds could be increased by altering the lighting system, without increasing the space or power requirements for production, and evaluated the effects of environmental conditions (light quantity, light quality, and carbon dioxide [CO<sub>2</sub>] concentration) on the production of bioprotective compounds in lettuce, which provide a biological countermeasure for radiation exposure.

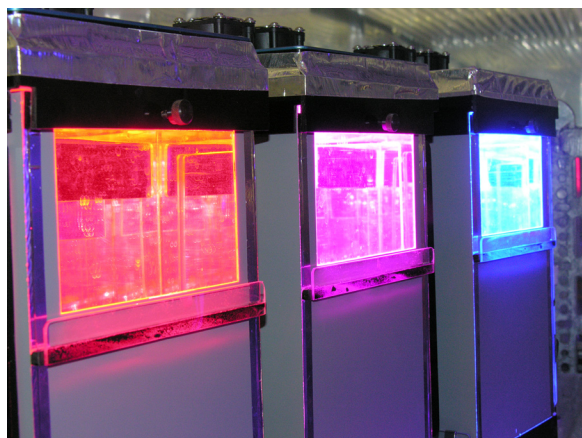
The specific deliverables were to

- develop a database of bioprotectant compounds in plants that are suitable for use on long-duration space missions,
- develop protocols for maintaining and increasing bioprotectant production under light-emitting diodes (LEDs),
- recommend lighting requirements to produce dietary countermeasures of radiation, and
- publish results in the *Journal of the American Society for Horticultural Science*.

Red leaf lettuce contains relatively high concentrations of bioactive pigments known as anthocyanins. These pigments, as well as other antioxidant molecules, have radioprotective properties. To determine if the concentration of these compounds could be increased, several red leaf lettuce cultivars were grown under either fluorescent lamps or LEDs at 300  $\mu\text{mol m}^{-2} \text{s}^{-1}$  of photosynthetically active radiation (PAR) of light intensity, 1,200  $\mu\text{mol mol}^{-1} \text{CO}_2$ , 23 °C, and an 18-hr light/6-hr dark photoperiod in controlled-environment chambers. The LED treatments were selected to provide different amounts of red (640-nm), blue (440-nm), green (530-nm), and far red (730-nm) light in the spectra. Total anthocyanin content and the oxygen radical absorbance capacity (ORAC) of the

tissue were measured at harvest. The results were compared with effects of light intensity under fluorescent lamps from 100 to 450  $\mu\text{mol m}^{-2} \text{s}^{-1}$  PAR and CO<sub>2</sub> concentrations of 400, 1,200, and 3,000  $\mu\text{mol mol}^{-1}$ . Bioprotectant concentration of red lettuce grown under red (640-nm) and blue (440-nm) light was comparable to plants grown under fluorescent lamps.

The source of light had a dramatic effect on both plant growth and production of radioprotective compounds. LEDs produced 50 percent more bioprotectant content per plant at the same light level than did conventional fluorescent lamps. The use of LEDs containing blue (440-nm) light in particular appeared to activate the pathways leading to increased concentration of bioprotective compounds in leaf tissue. LEDs provided a number of indirect effects that increased the bioprotective content. LEDs also allowed the ability to



High-output LED arrays provide the capability to define spectra to increase the concentration of radioprotective compounds.

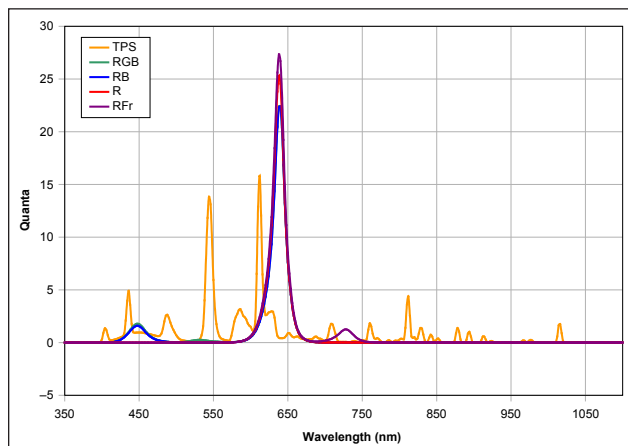
alter the spectral quality that can enhance leaf expansion and maximizes light interception. In addition, LED lighting systems minimized the use of nonphotosynthetic light and increased the photosynthetic efficiency of the lighting system.

Related research demonstrated photochemical regulation of the biochemical processes associated with the synthesis of bioprotective compounds in lettuce. These experiments showed the development of the bioprotective pigments (anthocyanin) and antioxidants (ORAC) is strongly affected by both light intensity and light quality. In particular, blue (440-nm) light seems to be necessary in order to maintain the bioprotective properties in lettuce.

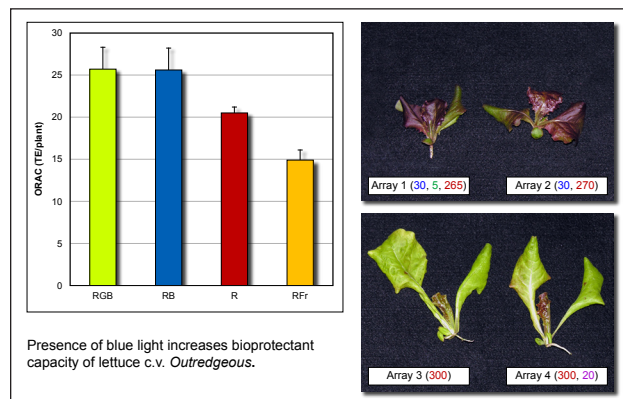
CO<sub>2</sub> enrichment had no direct effect on the regulation of the biochemical processes associated with synthesis of bioprotective compounds in lettuce. However, there was an indirect effect of increased growth rate at elevated CO<sub>2</sub> and thus greater bioproduction per plant.

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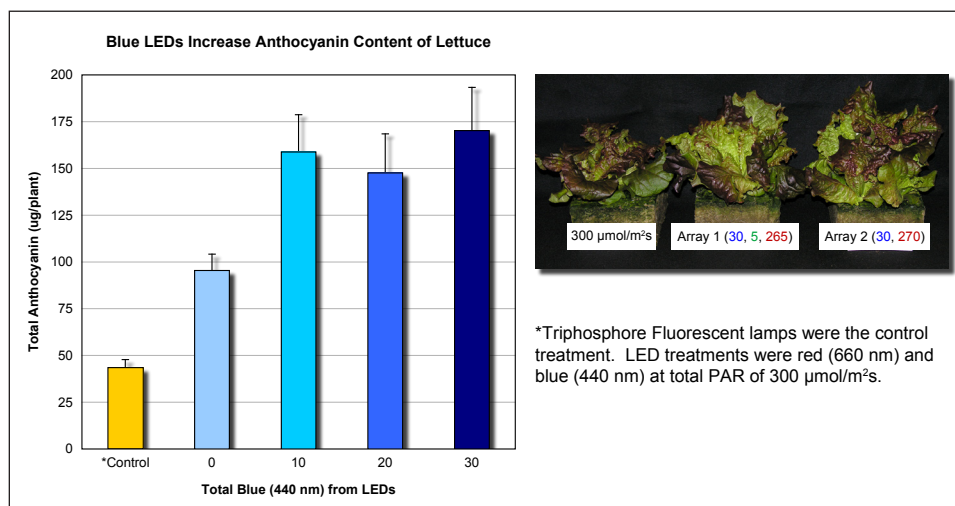


Spectroradiometric scans were used to set the light quantity and quality for growth of red leaf lettuce.



Presence of blue light increases bioprotectant capacity of lettuce c.v. *Outredgeous*.

Blue light was necessary in the spectra for anthocyanin production and to maximize antioxidant-potential tissue.



\*Triphosphore Fluorescent lamps were the control treatment. LED treatments were red (660 nm) and blue (440 nm) at total PAR of 300  $\mu\text{mol}/\text{m}^2\text{s}$ .

Plants grown under LEDs were 30 to 40 percent larger than plants grown at the same light under fluorescent lamps (see inset). The addition of 10  $\mu\text{mol}/\text{m}^2\text{s}$  of blue (440-nm) light nearly doubled the concentration of anthocyanin in the leaves.