EFFECT OF SHORT-WAVELENGTH LIGHT ON PLANT PHYSIOLOGY

Light is one of the most important environmental factors, acting on plants not only as the sole source of energy, but also as the source of external information, affecting their growth and development. Plants are empowered with an array of photoreceptors controlling diverse responses to light parameters, such as spectrum, intensity, direction, duration etc. These photoreceptors include the red and far-red-absorbing phytochromes, the blue and UV-A light absorbing cryptochromes, phototropins, and other implied photoreceptors, absorbing in UV-A and green regions. Spectral changes of illumination evoke different morphogenetic and photosynthetic responses, which can vary among different plant species.

What is the good of it?

The photoresponse is of importance in agrotechnology, since feasibility of tailoring illumination spectra enables one to control plant growth, development, and nutritional quality. optimization of lighting system is of especial importance for plant cultivation in greenhouses and phytotrons. First of all, suitably selected lighting spectrum ensures normal plant growth. Moreover, using purposefully designed lighting spectrum enables one to regulate flowering time, the balance between growth and development processes, biomass accumulation, stem elongation, and to impact plant primary and secondary metabolism, directly associated with the food quality of vegetables.

How to employ the light?

It is generally accepted, that optimal plant illumination spectrum should contain 90% of red light component and 10% of blue component. Meanwhile, plants representing different life strategies and different life forms require different lighting conditions. The conventional high pressure sodium lamps have the highest intensity in red/orange spectral region. Such light, affecting phytochrome reversibility, is the most important for photosynthesis, flowering and fruiting regulation. Nevertheless, the other spectral components can also be employed when seeking for desired effect. The recent progress in solid-state lighting, based on light-emitting diodes (LEDs), facilitated and expanded the research in this field and created an outset for new progressive plant cultivation technologies. Thus, what about other light colors? What is the influence of short-wavelength light? Therefore, our joint research supported by EU-Asia Link project ENLIGHTEN was aimed at study of the effect of supplemental short-wavelength light on plant growth and development.

Fig. 1 Lettuce plants, grown under red and blue light emitting diodes.

Fig. 2 The wheat, grown under the light emitting diode illumination.

What did we do?

Our researche was carried out by joint efforts of professors and students at the Lighting Laboratory of Helsinki University of Technology, Institute of Materials Science and Applied Research of Vilnius University, and Lithuanian Institute of Horticulture. The reserach was targeted on evaluation of the effect of short-wavelength light on growth and development of lettuce. LED-based luminaries consisting of high flux of red light and additional short wavelength light in combination with high pressure sodium lamps were designed and fabricated by Project participants. Using this facility, we performed growth treatments of lettuce, radish and other plants and estimated the effect of such lighting on growth parameters, photosynthetic system, phytohormone contents and sugar, nitrate and vitamin C metabolism. We can summarize our results as follows.

The blue light

Blue light is favorable for growth of many plants, including lettuce, spinach, wheat, radish and other. It affects the chlorophyll formation; photosynthesis processes, stomata opening, and through cryptochrome and phytochrome system raises the photomorphogenetic response. In our study, we observed that the blue light (450 nm) promotes dry matter production and inhibits cell elongation in stems and leaves. The optimal flux of blue light for leafy plants is about 10-15% of the total photosyntheticaly active radiation. Moreover, the higher flux of blue light is essential for radish (for normal carbohydrate metabolism and photosynthetic assimilate transport from leaves to the storage organs, thus assuring tuber formation). Also it has a slight effect on primary and secondary metabolite synthesis, indicating light-dependent metabolism.

The green light

Plants are green because they reflect light in this spectral region; the green light is more efficiently transmitted through the plant body and acts as a signal to tissues not directly exposed to the light environment. Therefore, the supplemental green light enhances biomass accumulation in the above-ground part of the plants, and also affects chlorophyll and carotenoid synthesis, thus improving the color of leaves. Phytochromes, principally thought of as red/far-red reversible pigments, are extremely sensitive to the entire illumination spectrum and even small variations in the spectrum initiates responses in the phytochrome system.

The cyan light

There are no solid scientific evidences on the effect of the cyan light on plants. However, it is possible, that cyan light, being close to the green region, has the same positive biological effect. According to our results, supplemental lighting with cyan light emitting diodes (505 nm) significantly affected carbohydrate and nitrate metabolism in lettuce and slightly improved radish growth.

The near UV light

Though overexposure to UV light is dangerous for the flora, small amounts of near-UV light can have beneficial effects. In many cases, UV-light is a very important contributor for plant colors, tastes and aromas. This is an indication of near-UV light effect on metabolic processes. According to our results, the UV light (385 nm) promotes the accumulation of phenolic compounds, enhances antioxidant activity of plant extracts, but do not have any significant effect on growth processes.

In summary

Exploitation of purposefully designed LED-based luminary for cultivation of lettuce and radish plants under different combinations of red and short-wavelength components and high pressure sodium lamps enabled us to elucidate the influence of light in short-wavelength visible and near-UV regions on growth and development of the plants under study.

Combination of red and blue components was found to be favourable for growth and nutritional quality of lettuce. The most striking sensitivity to illumination spectrum was observed for production of carbohydrates. In respect to the reference plants, content of nitrates in lettuce grown under the bicomponent illumination in red and short-wavelength region was by 15-20% lower, with no significant difference among treatments, where the short-wavelength component was cyan, blue or UV.

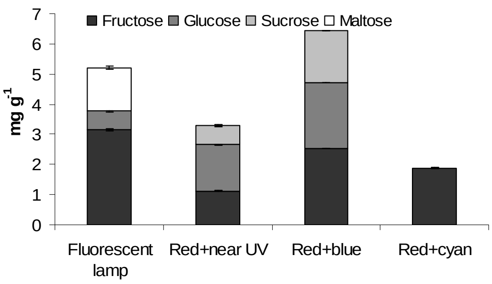

Fig. 3 Carbohydrate contents in lettuce grown under red light illumination supplemented with short-wavelength LED emission.

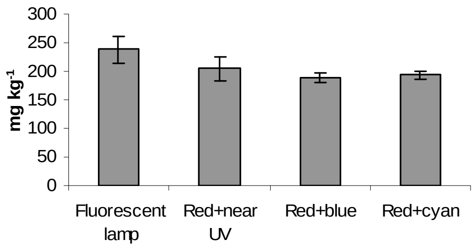

Fig. 4 Nitrate contents in lettuce grown under red light illumination supplemented with short-wavelength LED emission

Introduction of short-wavelength components into the spectrum of illumination for radish cultivation is insufficient to compensate the stress caused by excessive illumination in photosynthetically active red region. Spectral position of the short-wavelength component in the region from 385 to 505 nm has no crucial influence on radish development, though illumination in cyan region (505 nm) is more favorable for biomass accumulation than illumination at shorter wavelengths. Such lighting conditions are more suitable for cultivation of leafy vegetables.

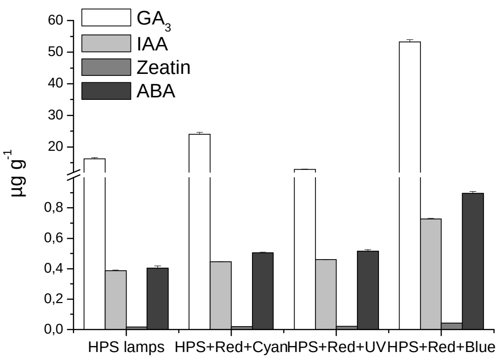

Fig.5 Phytohormone contents in radish, grown under illumination by HPS lamps supplemented by emission of red and short-wavelength LEDs.

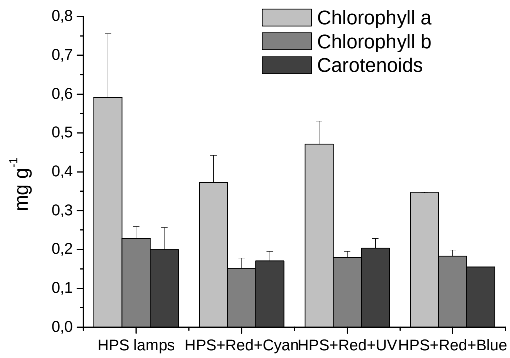

Fig. 6 Photosynthetic pigment contents in radish, grown under illumination by HPS lamps supplemented by emission of red and short-wavelength LEDs.

The results of our study confirm that plant growth can be modulated by employing tailored spectrum provided by emission of different LEDs. Even illumination with spectrum, consisting of two components (one in red region and another in short-wavelength region), when properly selected, can be beneficial in respect to illumination using conventional lamps.

Publications:

- Urbonavičiūtė A., Pinho P., Samuolienė G., Duchovskis P., Vitta P., Stonkus A., Tamulaitis G., Žukauskas A., Halonen L. 2007. Influence of Bicomponent complementary illumination on development of radish. Sodininkystė ir Daržininkystė, 26 (4): 309-316.
- Urbonavičiūtė A., Pinho P., Samuolienė G., Duchovskis P., Vitta P., Stonkus A., Tamulaitis G., Žukauskas A., Halonen L. 2007. Effect of short-wavelenght light on lettuce growth and nutritional quality. Sodininkystė ir Daržininkystė, 26 (1): 157-165.

References:

- Devlin P.F., Christie J.M., Terry M.J. Many hands make light work // Journal of Experimental Botany. 2007. Vol. 58. P. 3071-3077.
- Drozdova I. S., Bondar V. V., Bukhov N. G., Kotov A. A., Kotova L. M., Maevskaya S. N., Mokronosov A. T. Effects of light spectral quality on morphogenesis and source-sink relations in radish plants // Russian journal of plant physiology. 2001. Vol. 48. P. 415-420.
- Folta K. M., Maruhnich S. A. Green light: a signal to slow down or stop // Journal of Experimental Botany. 2007. Vol. 58. P.3099-3111.
- Franklin K. A., Whitelam G. C. Light signals, phytochromes and cross-talk with other environmental cues // Journal of experimental botany. 2004. Vol. 55. P. 271-276.
- Kim H.H., Goins G.D., Wheeler R.M., Sager J.C. Green-light supplementation for enhances lettuce growth under red- and blue- light-emitting diodes // HortScience. 2004. Vol.39. P.1617-1622.
- Matsuda R., Ohashi-Kaneko K., Fujiwara K., Goto E., Kurata K. Photosynthetic Characteristics of Rice Leaves Grown under Red Light with or without Supplemental Blue Light // Plant Cell Physiol. 2004. Vol. 45. P. 1870-1874.
- Spalding, E.P., Folta, K.M. Illuminating topics in plant photobiology // Plant Cell Environ. 2005. Vol.28. P. 39-53.
- Yorio N.C., Goins G.D., Kagie H.R., Wheeler R.M., Sager J.C. Improving spinach, radish and letuuce growth under red light emitting diodes (LEDs) with blue light supplementation // HortScience. 2001. Vol.36. P.380-383.