



Effects of LED supplemental lighting on yield and some quality parameters of lamb's lettuce grown in two winter cycles



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ABSTRACT

To date, little is known about the effects of different light emitting diode (LED) light spectra on the growth and quality of *Valerianella locusta* plants in greenhouse cultivation. The objective of our study was to evaluate the effects of LED and HPS lights (200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD; 16 h photoperiod) as a supplemental to solar radiation in winter growing. The effect of sole red (660 nm), combination of red (660 nm) and blue (430 nm) in different ratios (90R/10B, 70R/30B and 50R/50B), warm white LEDs and HPS lamps was investigated in two years of study. At harvest stage (after 60 days of supplemental lighting) fresh weight of rosettes, dry matter, soluble sugars, total phenols content and radical scavenging activity were the greatest under 90R/10B LED lamps in both investigated years. The least efficient in the enhancing of lamb's lettuce yield proved to be the supplemental lighting with white LED lamps. The lowest level of ascorbic acid content was shown in the case of the plants illuminated with HPS and 100% red light in successive years. The obtained results indicate the need for further, more comprehensive studies on the effects of LED supplemental lighting of horticultural plants in real greenhouse conditions.

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1. Introduction

Light is the primary environmental factor necessary for the growth and development of plants. At northern latitudes, supplemental lighting in greenhouse cultivation during the winter is necessary to obtain a commercial crop of many horticultural products. The most common light sources used for plant cultivation in greenhouses are still HPS (High Pressure Sodium) lamps (Pinho et al., 2007). Compared to HPS, light-emitting diodes (LEDs) have become a very promising light source in horticulture lighting. Owing to the development of new LED technologies (e.g. ability to control spectral composition, high light output with low radiant heat output), solid-state lighting light emitting diodes (SSL LED) systems are increasingly being used for plant cultivation and have found various applications in horticulture (Morrow, 2008; Yeh and Chung, 2009). Gupta and Jatothu (2013) presented a wide array of LED applications in *in vitro* plant growth and morphogenesis studies which led to many satisfactory results. Olle and Viršilė (2013) in their review article cited many recent studies which showed the

effects of LED lighting on photosynthesis, growth and the nutritional value of plants in greenhouse cultivation. The authors point out the usefulness of LED technology for greenhouse horticulture but they also consider that many questions are still open and more knowledge must be acquired on the effects of LED light (wavelength combinations, photosynthetic flux densities) on various vegetables (species, varieties) for larger scale applications.

It is worth noting that the first trials testing LEDs for plant growth and development were carried out, among others, with leafy vegetables like lettuce (Bula et al., 1991). In cited research red LED irradiation was supplemented with blue fluorescent lamps. The main conclusion of this study revealed that the growth of lettuce plants under LED irradiation was similar to growth under cool white fluorescent lamp but electrical energy conversion efficiency for LED lamps was more than twice higher. Subsequent studies have shown the effectiveness of the use of red and blue LED light (1:1 photon flux density) in increasing the development and rate of horticultural plants photosynthesis (lilium, chrysanthemum) compared to fluorescent or metal-halide lamps (Lian et al., 2002; Kim et al., 2004). Hogewoning et al. (2010) tested the leaf photosynthesis of *Cucumis sativus* under different blue LED light percentage supplemented with a red one, and showed, that in the blue range of 0–50%, photosynthetic capacity was gradually increasing. The absence of one of the two (red or blue) light

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wavelengths creates photosynthetic inefficiencies that affect plant growth and development. According to Wang et al. (2009), all *C. sativus* plants grown under monochromatic LED light had reduced growth, but purple (394.6 nm) and blue (452.5 nm) light increased stomatal conductance and the photosynthesis. Our earlier studies (Wojciechowska et al., 2013) documented that red + blue LED light (1:0.8) stimulated the high efficiency of *Valerianella locusta* photosynthetic apparatus (leaf Performance Index was the highest). In consequence, plants treated with red + blue LED lamp had higher yield in comparison to other treatments. Trouwborst et al. (2010) used red and blue LEDs for intracanopy lighting in cucumber cultivation during winter. In presented experiment cucumber plants were lighted with HPS lamps and additionally supplemental LED lighting was used. As compared to control plants illuminated only by HPS ($221 \mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD), interlighting treatment with LED lamps significantly increased photosynthetic characteristics in the leaves of lower layers.

There is a lot of research concerning the effect of LED light on plant growth and development in which the environmental conditions were strictly controlled and LED lamps were the sole source of illumination (for example Chang and Chang, 2014). But in horticultural practice the cheapest source of radiation is the Sun. The point is to supplement the solar radiation by other sources, but not to replace it. There has been little research carried out so far on the effects of using LED light on plants as supplemental radiation in greenhouse cultivation for commercial horticulture. Although some study focusing on the use of LED lamps as supplemental light source for natural radiation might be found. This kind of research was carried out by the group of Prof. Duchovskis (Samuolienė et al., 2012a,b, 2013a). In cited papers solar radiation of baby leaf lettuce plants was supplemented with HPS lamps with or without LED ones. The results clearly indicated a need of further studies in this range of horticulture practice.

Light affects the synthesis of many plant compounds which are important for the human diet (for example: ascorbic acid, sugars or phenolic compounds). Ascorbic acid is a molecule which occurs in different plant organs. It is considered that a lot of ascorbic acid is accumulated in photosynthetic tissues, but high content can also be found for example in fruit (Gest et al., 2013). The synthesis of ascorbic acid, followed by multiple pathways, usually starts from the sugars D-glucose and D-galactose (Loewus, 1999; Smirnoff et al., 2001). It was noted that ascorbic acid synthesis is stimulated by light (Smirnoff, 1996) and some of the enzymes involved in its synthesis are more active in higher intensity of light (Smirnoff et al., 2001). The question is whether the quality of light also affects the synthesis of this compound? Ascorbic acid has a number of functions in the plant cell; it is associated mainly with the role as antioxidant, but it is also a cofactor of many enzymes. This compound affects the course of processes, such as the synthesis of ethylene and gibberellins, growth or cell division, formation of hydroxyproline-containing proteins and other (Arrigoni and De Tullio, 2000).

Some studies indicate that LED light influenced the quality of horticultural products. For example Lin et al. (2013) demonstrated that soluble sugar content was higher and nitrate concentration was lower in lettuce grown under red–blue–white LEDs compared to red–blue LEDs and fluorescent lamp treatments. Wu et al. (2007) observed a significant β -carotene expression and antioxidant activity increase using red and blue LED lights in pea seedlings. In leafy radish, LED radiation with blue/red/far-red combinations reduced ascorbic acid and monosaccharide contents, however antioxidant activity and also concentration of phenolic compounds were promoted (Urbonavičiūtė et al., 2009a). Phenolics are an important group of substances with antioxidant properties, commonly occurring in plants. The key step in the biosynthesis of most plant phenolic compounds is the deamination of phenylalanine (L-Phe)

by phenylalanine ammonia-lyase (PAL; EC 4.3.1.24) resulting in trans-cinnamic acid formation, which is one of the precursors of plant phenols (Boudet, 2007). In many plants, PAL requires activation by a short impulse of red or blue light, or long-term light exposure. However, activation of PAL may occur differently in various plant species (Strack, 1997).

Due to the high energy costs there are few leafy vegetables produced in Poland in the winter season. It would be very desirable to produce green vegetables with a short vegetation period and simultaneously high nutritional value and also with a low energy input for its production in this period. For this purpose, a unique system for supplemental LED lighting in our greenhouse was implemented (described in detail by Grzesiak et al., 2014). Lamb's lettuce (*V. locusta* Laterr. Em Betcke) has been selected for this study because it is characterized by both high nutritional value and taste qualities, which is particularly valuable during the period of limited accessibility to fresh leafy vegetables. Owing to the high content of ascorbic acid, folic acid, phenolic compounds, and omega-3 fatty acids *V. locusta* is appreciated in numerous European countries (Ferrante and Maggiore, 2007).

Based on the effect of light on quantity and quality of plant yield and the need to increase radiation especially during light deficiency in winter, it is necessary to discover proper artificial light source for plant cultivation. Our hypothesis assumed that LED lamps might replace HPS ones in greenhouse plant cultivation mainly due to the regulation of emitted radiation. Because of it, in the presented study, the effects of sole red, red + blue in different ratios (90%, 70%, 50% to 10, 30, 50%, respectively), and white LED lamps in comparison to HPS ones on *V. locusta* growth were tested. Radiation emitted by the tested lamps was just supplementary for solar light and was used for the day enlargement. Our purpose was to determine the most effective light combination in increasing the weight of rosettes whilst simultaneously enhancing its nutritional value. Knowing that weather conditions are not repeatable, additional goal of the two year study was to find a spectral composition which will be beneficial irrespectively of winter solar radiation.

2. Materials and methods

2.1. Plant material and growth conditions

Experiments were performed in two winter seasons (2012/13 and 2013/14) in a high-tech greenhouse at the Agricultural University in Krakow (50°03'N, 19°57'E), Poland. The test plant was lamb's lettuce (*V. locusta* L.) 'Nordhollandse' (Floraland Distribution Sp. z o. o., Nieporęt, Poland). Seeds were sown in cell trays (7 × 8 × 8 cm, three seeds per tray, 24 trays in one plastic vessels) containing peat substrate (pH 5.5, Klamann KTS-2) on the 1st Dec 2012 and the 13th Dec 2013. The following amounts of nutrients were available in the substrate (mean for two years, mg L^{-1}): N 303, P₂O₅ 155, K₂O 461, Ca 1306, Mg 180, S 465, B 0.51, Cu 0.20, Fe 3.60, Mn 3.34, Zn 0.60. The plants were grown in a 16 h photoperiod to harvest time (16th Feb 2013 and 21st Feb 2014) under daylight with supplementary lighting which was implemented just after the seeds germinated (on the 18th and 23rd Dec, respectively, in 2012 and 2013). Plants were grown at density of 450 rosettes per square meter. In each light treatment, 320 plants were grown. The cultivation was carried out in quadruplicate, approx. 80 plants were grown in each replication. The relative humidity and ambient temperature levels were on average: $58 \pm 2\%$, $17 \pm 2^\circ\text{C}$ in 2012/13 and $54 \pm 2\%$, $16.3 \pm 2^\circ\text{C}$ in 2013/2014. The average natural solar radiation was $147.56 \text{ J cm}^{-2} \text{ d}^{-1}$ and $252.45 \text{ J cm}^{-2} \text{ d}^{-1}$ in successive growing cycles, respectively. Plants were watered when needed. Average CO₂ concentration was 380–400 ppm (CO₂ enrichment was not applied).

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