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Evaluation of different lighting sources on the growth and chemical composition of lettuce

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Abstract. Experiment were carried out in Latvia University of Agriculture in plant growth room. Lettuce *Lactuca sativa* L. var *foliosum* cv. 'Dubacek' and *L .sativa* L. cv. 'Michalina' were grown under 4 types of lights (luminescence lamps, commercial light emitting diodes (LED) lamps (V-TAC premium series – for plant growing) and two different Lumigrow LED strips - dominant wavelength- blue or red with 14 h photoperiod and total photosynthetic active radiation (PAR) 100 µmol m^{-2} s^{-1} in all variants. Plant weight, length, amount of leaves were measured. Content of chlorophylls, carotenoids, phenols, flavonoids in lettuce was determined three times per vegetation period. In experiments were found that higher lettuce yield was under commercial LED (V-TAC premium series), but these plants contain less soluble sugars, pigments and phenols. Better plant quality was obtained with luminescence lamps. These lettuces have higher sugar, phenols and flavonoids content. Lettuce growth under blue dominate LED (LEDb) was delayed, but these plants contain higher chlorophylls content. The differences in plant growth, response to light and biochemical content between cultivars were detected.

Key words: LED lamps, *Lactuca sativa*, pigments, phenols, flavonoids.

INTRODUCTION

Light is one of most important factor in plant life what can affect their growth and development in a complicated manner. Plant response to the light is made by interaction of many different responses (Hogewoning et al., 2010).

In controlled environments growers use electric lamps such as fluorescent, high-pressure sodium and metal halide (Wheeler, 2008). The light emitting diodes (LED) becomes popular among growers due to spectral output matched to plant photoreceptors (Dougher & Bugbee, 2001). LEDs turn on instantly and do not need warmup time. They are easily integrated into digital control system (Morrow, 2008). Small lighting elements gives more uniform distribution of lighting than use of few larger such as incandescent and fluorescent lamps, that allows to get maximum production without wasting energy

(Yano & Fujiwara, 2012). LEDs are environmentally friendlier than other currently used lamps in horticulture (Dougher & Bugbee, 2001; Morrow, 2008).

Traditional light sources create light with an ionized gas, superheated element or arc discharge. LEDs create light through a semiconductor process. Material which are used to form the semiconductor junction determined by the wavelength of the emitted light. LEDs can give the light with wavelengths from 250 nm (ultraviolet) to 1,000 nm (infrared) and even more (Bourget, 2008).

If plants were grown in greenhouses light effect on the plants are complex and caused by mixed with natural and supplemental light.There for results from greenhouses and growing room by using same lightening source can give different results.

The spectral composition of LEDs light is extensively studied, but due to no systematic research approach, the results sometimes are contradictory (Viršile et al., 2017).

Red and blue light are the major energy source for the photosynthetic CO_2 assimilation in plants. Therefore influence of the red and blue light on plant physiologic processes gives easily noticeable changes (Lin et al., 2013). Red light is necessary for normal plant growth and photosynthesis. Red light with different wavelengths can effect plants uneven. Lettuce biomass yield increased if LED wavelength was increased from 660 to 690 nm. Red light gives positive impact on antioxidant system (Olle & Viršilė, 2013).

Blue light (440–476 nm) stimulated biomass accumulation in lettuce (Johkan et al., 2010), promote lettuce growth after transplanting,increased concentration of carotenoids and anthocyanins, enhanced antioxidant status (Olle & Viršilė, 2013).

Combination of blue and red light reduced nitrate content and significantly increased soluble sugar content (Viršile et al., 2017).

Understanding of wavelengths effects on the plant will allow researchers to develop specific lighting systems for the current plant species with changeable light spectrum and intensity during plant development (Massa et al., 2015).

The aim of the study is to evaluate lettuce growth, yield and its chemical composition to improve plant nutrition quality with the use of different lighting sources.

MATERIALS AND METHODS

Lettuce *Lactuca sativa* L. var *foliosum* cv. 'Dubacek' and *L.sativa* L. cv. 'Michalina' were used in experiments. 10 plants per pot were grown in 3 L vegetation pots filled with commercial peat substratum (Kekkila – peat fraction > 25 mm, EC – 25 mS m^{-1}, pH_{H2O} 5.6, N – 80 mg L^{-1}, P – 30 mg L^{-1} K – 200 mg L^{-1}).

Experiments were arranged in growing room without natural lighting.. Plants were grown under 4 different lighting sources- luminescence lamp (OSRAM, Cool-white, 36 W), commercial LED (V-TAC premium series – for plant growing, 18 W, 1,530 Lm) and two different Lumigrow LED strips – dominant wavelength- blue (LEDb) or red (LEDr). In all variants plants were grown in 14 h photoperiod with total PAR 100 μmol m^{-2} s^{-1}. Light spectrum of used illumination sources were shown in Fig. 1. Relative spectral distribution 440 nm : 660 nm are: luminescence lamp (LL) 79 : 21, commercial LED (LEDc) 50 : 50, LEDb 77 : 23, LEDr 15 : 85. Temperature in plant growth room during day and night time were 22 ± 2 °C.

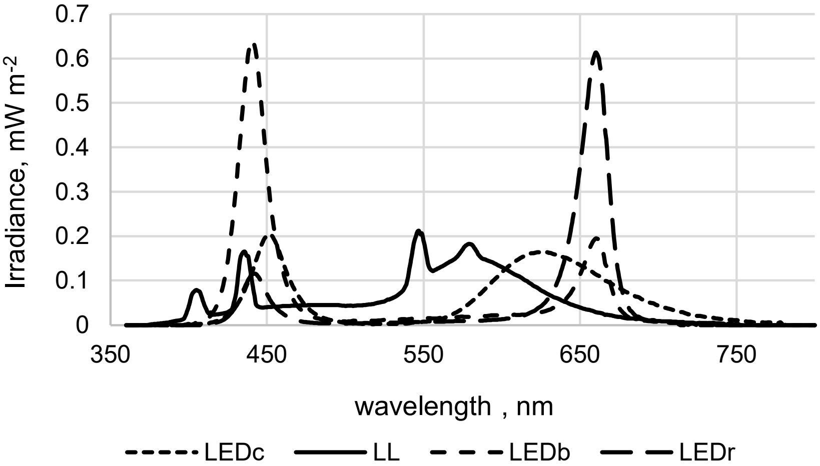

Figure 1. Spectrum of used lighting sources (determined with Gigahertz-Optic MSC15).

All plant analyses were made three times during the plant vegetation with two week interval. Plant weight, dry weight, dry matter content (dried at 60 °C for 24 h), number of leaves, and plant biochemical parameters was detected.

Phytochemical extraction and determination

All the chemicals used were with the analytical grade. For absorbance measurements UV spectrometer UV-1800 Shimadzu Corporation, Japan was used.

Chlorophylls and carotenoids content was analysed spectrophotometrically in ethanol extract according to the method described by Duma et al. (2014) and results were expressed as mg g^{-1} fresh matter (FM).

Total phenolics in lettuce leaves was extracted with methanol- distilled water- hydrochloric acid solution (79 : 20 : 1 v/v/v). Total phenolics content was determined with Folin- Ciocalteu reagent. Absorption was measured at 765 nm and results was expressed as mg g^{-1} gallic acid equivalent (GAE) (Duma et al., 2017).

Flavonoids were extracted with ethanol. Total flavonoid content was determined by method described by Duma et al. (2016). Absorption was measured at 506 nm and results were expressed mg rutin equivalent (RE) 100 g^{-1} FM.

The total soluble solids content (°Brix) from lettuce leaf juice was determined with Refractometer DR301-95 made by company A.KRÜSS Optronic.

Biochemical analyses were performed in three replicates. Two-way analyses of variance (ANOVA) was used. Fisher LSD post-hoc test were made to determine significance of differences. For mathematical data processing $p < 0.05$ was regarded as statistically significant. Data were expressed as means ± standard deviation.

RESULTS AND DISCUSSION

Plant growth significantly depends on used illumination source, plant cultivar and development stage. Tallest plants were obtained under LEDr illumination. Under that illumination atypical stem elongation for the rosette type plants was observed and decrease of leaf number by 10–17% for cv. 'Michalina' and 10–21% for cultivar

'Dubacek' was stated. Similar results are reported also by Lin et al. (2013) and Chen et al. (2014). Till the 4th week of plant growth there are no significant differences in plant weight grown under LEDr and other lighting sources, but at the end of experiment this variant and LEDb were the worst. The decrease of plant biomass by 7–49% for cv. 'Dubacek' and 3–49% for 'Michalina' was observed in comparison with other lighting sources (Fig. 2). It is contrary to Son & Oh (2013) results. They reported the highest lettuce weight under monochromatic red light. The next best result was observed in variant illuminated with light in relative proportion 13% of blue light and 87% of red light (Son & Oh, 2013). Similar positive effect of red light was reported by Bian et al. (2016), Viršilė et al. (2017). That is completely opposite to ours LEDr, were plant weight was one of the lowest (Fig. 2).

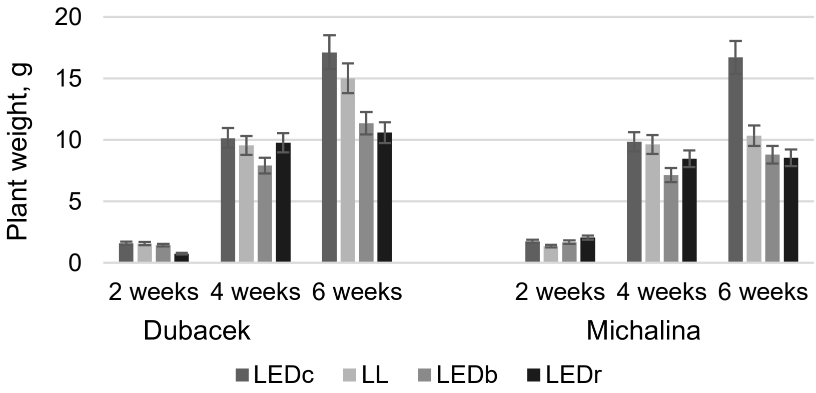

Figure 2. The lettuce weight during vegetation period.

Under LEDc, LL light sources plant growth was harmonious. The largest and vigorous plant was obtained under LEDc. At the 6th week of cultivation lettuce of cv.'Dubacek' weighted 14.1%, but cv.'Michalina' 61.6% more in comparison with plants grown under luminescent lamps. Retarded growth was observed under dominant LEDb. (Figs 1 and 3.) It corresponds to the results of other authors (Li & Kubota, 2009, Stutte et al., 2009, Lin et al., 2013, Chen et al., 2014).

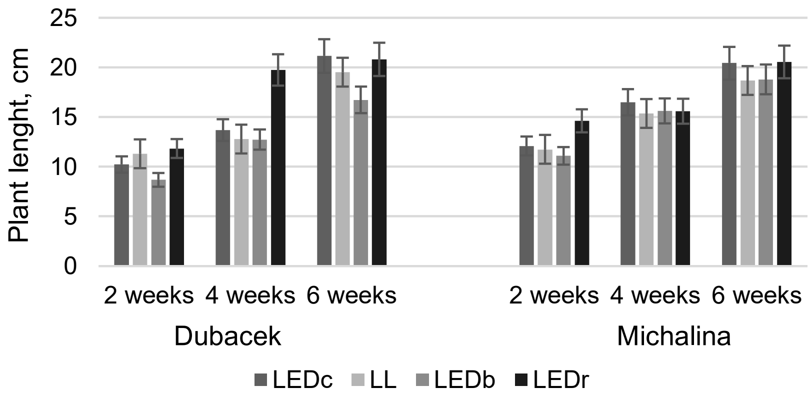

Figure 3. The lettuce length during vegetation period.

The impact of illumination source on the dry matter content significantly depended on cultivar and sampling time. (Fig. 4) For cv. 'Dubacek' significant differences as result of light source was observed only at the 4th week of vegetation, but cv. 'Michalina' after 4 and 6 weeks of cultivation. The highest content of the dry matter was in variant with commercial LED. Knowing that the dry matter content in plants increases with the plant age, it can be hypothesized that commercial LED stimulates plant aging.

Results corresponds to Son & Oh (2013) data where also the highest dry matter content was observed in variants with blue and red light proportion close to 50 : 50 calculated from.

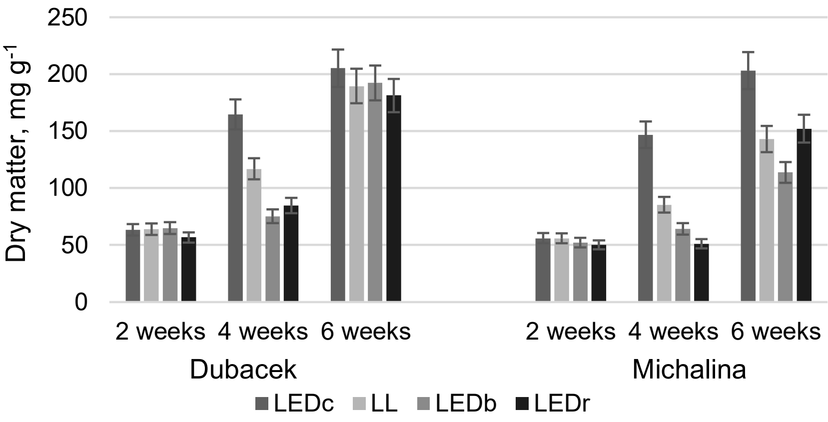

Figure 4. Dry matter content in the lettuce plants during vegetation period.

The content of soluble solids (°Brix) depended on cultivar. Slightly higher content was observed in cv. 'Dubacek'. Significantly higher soluble solids content was detected in lettuce grown under LL, the less one- under LEDr (Fig. 5). The decrease of soluble sugar content by adding red light is reported also by Lin et al. (2013). Soluble sugars are main product of photosynthesis and effects lettuce nutrition quality as well as together with other compounds- plant taste. Higher soluble sugar content by luminescence lamp use in comparison with LED is reported also by Chen et al. (2014).

Plant pigments have specific wavelength absorption patterns and LED lamps are manufactured taking into account these spectrums. In average higher chlorophyll content was in the lettuce grown under LEDb. After 2 weeks of cultivation the highest content of total chlorophyll (0.827 mg g^{-1}) and carotenoids (0.190 mg g^{-1}) was detected in the leaves cv. 'Dubacek' under the LEDb. Higher chlorophylls content in cv. 'Michalina' leaves was detected at 4th week 0.685 mg g^{-1} under the same – LEDb light. Difference in pigments content as result of lighting increased with the plant aging (Table 1). The impact of light spectrum on the chlorophylls content is reported also by other researchers. Son & Oh (2013) detected higher chlorophylls value in red: blue light proportion 50:50. Increase of red wavelength proportion leads to decrease of chlorophyll content, but there is no significant positive effect of blue light reported (Son & Oh, 2013). Lin et al. didn't find significant differences in chlorophylls and carotenoids content due to different light spectrum (Lin et al., 2013).

Table 1. The effect of light source on the biochemical content of lettuce plants

	Dubacek					Michalina				
	LEDc	LL	LEDb	LEDr	$LSD_{0.05}$	LEDc	LL	LEDb	LEDr	$LSD_{0.05}$
Chlorophylls'content, mg g^{-1}										
2 weeks	0.678	0.662	0.827	0.656	0.101	0.564	0.496	0.598	0.560	0.039
4 weeks	0.582	0.712	0.706	0.648	0.073	0.654	0.674	0.685	0.664	0.037
6 weeks	0.557	0.531	0.663	0.584	0.108	0.206	0.345	0.561	0.402	0.066
Carotenoides content, mg g^{-1}										
2 weeks	0.119	0.154	0.190	0.154	0.035	0.128	0.109	0.136	0.128	0.015
4 weeks	0.129	0.151	0.151	0.156	0.035	0.142	0.150	0.146	0.144	0.012
6 weeks	0.123	0.114	0.145	0.136	0.031	0.057	0.082	0.123	0.098	0.015
Phenols content, mg g^{-1}										
2 weeks	1.381	0.732	2.050	1.311	0.010	0.687	0.840	0.872	0.849	0.012
4 weeks	2.840	2.865	3.242	1.395	0.024	2.316	3.413	1.844	1.761	0.031
6 weeks	6.340	3.112	4.002	3.133	0.003	4.451	3.960	1.568	2.959	0.003
Flavonoids content, mg 100 g^{-1}										
2 weeks	4.918	5.136	6.211	5.648	0.199	3.980	4.130	5.220	4.390	0.139
4 weeks	6.462	7.021	6.801	6.109	0.494	5.740	5.300	5.450	4.800	0.250
6 weeks	6.743	5.967	8.396	6.601	0.350	6.430	6.280	4.310	5.310	0.384

Results showed that phenols and flavonoids content in lettuce leaves significantly increased with the plant age. Larger phenol and flavonoids content was detected in cv. 'Dubacek'. After 6 weeks of cultivation highest phenol content was in variant with LEDc – 6.340 mg g^{-1} FM for 'Dubacek' and 4.451 mg g^{-1}FM for 'Michalina'. The smallest amount of phenols at 4^{th} week of vegetation was in variants with LEDr (Table 1, Fig. 5). Opposite results were obtained in experiments with lettuce made by Li & Kubota (2009) and Zukauskas et al. (2011) – phenol content under red light wavelengths increased. Taulavuori et al. (2017) reported that accumulation of phenols is higher in lettuce leaves grown in at high ratios of blue light.

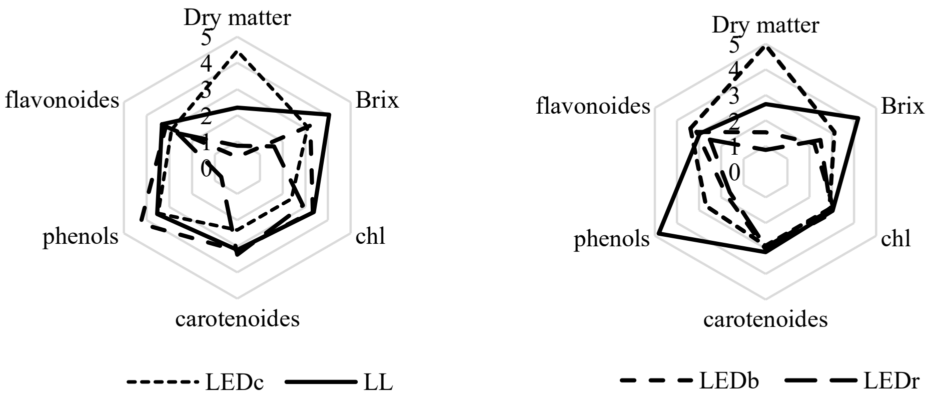

Figure 5. Relative dry matter, soluble solids, chlorophylls, carotenoids, total phenols and flavonoids content in the cv. 'Dubacek' (left) and cv. 'Michalina' (right) leaves at the 4^{th} week of vegetation.

Lithuanian researchers reported that the significant increase of total phenols was found under both blue (455 nm, 470 nm) and 535 nm green LEDs lighting (Samuoliene et al., 2012).

Flavonoid content is one of the important factors influenced lettuce nutrition quality. Flavonoids content affect colour, flavour and fragrance of plants (Son & Oh, 2013). Our results showed the significant effect of cultivar, sampling time and light spectrum. In average cv. 'Dubacek' had 24% higher flavonoids content. Increase of flavonoid content during vegetation was observed (Table 1). Illumination spectrum effect depended on cultivar. In average increase of flavonoid content as result of LEDb treatment was observed for cv. 'Dubacek', but the same light for cv. 'Michalina 'at the end of vegetation was the worst one. Contradictory results are reported also in other studies (Son & Oh, 2013, Viršilė et al., 2017, Taulavuori et al., 2017).

The obtained results show that the influence of light is complex and depends on lighting spectral conditions, plant variety and sampling time. The highest fresh and dry matter derived from plants grown under the comercial LEDs, the highest soluble dry matter content for both varieties was detected in plants grown under LL. Under the same illumination source also more physiologically active compounds were detected.

CONCLUSIONS

Higher lettuce yield was obtained under commercial LED (V-TAC premium series), but these plants contain less soluble sugars, pigments and phenols.

Better plant quality was obtained with luminescence lamps. These lettuces have higher sugar, phenols and flavonoids content.

Lettuce growth under LEDb was delayed, but these plants contain higher chlorophylls content.

The differences in plant growth, response to light and biochemical content between cultivars were detected.

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REFERENCES

Bian, Z.H., Cheng, R.F., Yang, Q.C. & Wang, J. 2016. Continuous light from red, blue, and green light-emitting diodes reduces nitrate content and enhances phytochemical concentrations and antioxidant capacity in lettuce. *J Amer Soc Hort Sci.* **141**, 186–195.

Bourget, C.M. 2008. An introduction to light-emitting diodes. *HortScience* **43**(7), 1944–1946.

Chen, X.L., Guo, W.Z., Xue, X.Z., Wang, L.C. & Qiao, X.J. 2014. Growth and quality responses of 'Green Oak Leaf' lettuce as affected by monochromic or mixed radiation provided by fluorescent lamp (FL) and light-emitting diode (LED). *Sci. Hortic.* **172**,168–175.

Dougher, T.A.O. & Bugbee, B. 2001. Differences in the Response of Wheat, Soybean and Lettuce to Reduced Blue Radiation. *Photochemistry and Photobiology* **73**(2), 199–207.

Duma, M., Alsina, I., Zeipina, S., Lepse, L. & Dubova, L. 2014. Leaf Vegetables As Source of Phytochemicals. *9th Baltic Conference on Food Science and Technology – Food for Consumer Well-Being: Foodbalt 2014*, 262–265.

Duma, M., Alsina, I. & Dubova, L. 2016. Changes of chemical composition of rhubarb during vegetation. *Acta Horticulturae* **1142**, 253–259.
Duma, M., Alsina, I., Dubova, L. & Erdberga, I. 2017. Quality of tomatoes during storage. *11th Baltic conference on food science and technology "Food science and technology in a changing world" : conference proceedings, Jelgava, April 27-28, 2017 / Latvia University of Agriculture. Faculty of Food Technology. - Jelgava:* LLU, 130–133.
Hogewoning, S.W., Trouwborst, G., Maljaars, H., Poorter, H., van Ieperen, W. & Harbinson, J. 2010. Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of Cucumis sativus grown under different combinations of red and blue light. *Journal of Experimental Botany* **61**(11), 3107–3117.
Johkan, M., Shoji, K., Goto, F., Hahida, S. & Yoshihara, T. 2010. Blue light-emitting diode light irradiation of seedlings improves seedling quality and growth after transplanting in red leaf lettuce. *HortScience* **45**, 1809–1814.
Li, Q. & Kubota, C. 2009. Effects of supplemental light quality on growth and phytochemicals of baby leaf lettuce. *Environmental and Experimental Botany* **67**(1), 59–64.
Lin, K.H., Huang, M.Y., Huang, W.D., Hsu, M.H., Yang, Z.W. & Yang, C.M. 2013. The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. var. capitata). *Scientia Horticulturae* **150**, 86–91. https://doi.org/10.1016/j.scienta.2012.10.002
Massa, G., Graham, T., Haire, T., Flemming, C., Newsham, G. & Wheeler, R. 2015. Light-emitting diode light transmission through leaf tissue of seven different crops. *HortScience* **50**(3), 501–506.
Morrow, R.C. 2008. LED Lighting in Horticulture. *HortScience* **43**(7), 1947–1950.
Olle, M. & Viršilė, A. 2013. The effects of light-emitting diode lighting on greenhouse plant growth and quality. *Agricultural food and science* **22**, 223–234.
Samuolienė, G, Sirtautas, R, Brazaitytė, A, Duchovskis, P. 2012. LED lighting and seasonality effects antioxidant properties of baby leaf lettuce. *Food Chem* **134**(3),1494–1499.
Son, K.H. & Oh, M.M. 2013. Leaf Shape, Growth, and Antioxidant Phenolic Compounds of Two Lettuce Cultivars Grown under Various Combinations of Blue and Red Light-emitting Diodes *HortScience* **48**(8), 988–995.
Stutte, G.W., Edney, S. & Skerritt, T. 2009. Photoregulation of bioprotectant content of red leaf lettuce with light-emitting diodes. *HortScience* **44**(1), 79–82.
Taulavuori, E., Taulavuori, K., Holopainen, J.K., Julkunen-Tiitto, R., Acar, C. & Dincer, I. 2017. Targeted use of LEDs in improvement of production efficiency through phytochemical enrichment. *J Sci Food Agric*. **97**(15), 5059–5064.
Viršilė, A., Olle, M. & Duchovskis, P. 2017. LED Lighting in Horticulture. In: Dutta Gupta S. (eds) *Light Emitting Diodes for Agriculture*. Springer, Singapore, 113–147.
Zukauskas, A., Bliznikas, Z., Breivė, K., Novičkovas, A., Samuolienė, G., Urbonavičiūtė, A., Brazaitytė, A., Jankauskienė, J. & Duchovskis, P. 2011. Effect of supplementary pre-harvest LED lighting on the antioxidantproperties of lettuce cultivar. *Acta Horticulturae* **907**, 87–90.
Wheeler, R.M. 2008. A historical background of plant lighting: An introduction to the workshop. *HortScience* **43**(7), 1942–1943
Yano, A. & Fujiwara, K. 2012. Plant lighting system with five wavelength-band light-emitting diodes providing photon flux density and mixing ratio control. Plant Methods **8**(46), 1–12.