IOP Conf. Series: Materials Science and Engineering **510** (2019) 012018 doi:10.1088/1757-899X/510/1/012018

The influence of the LED lighting on structural-functional parameters of lettuce plants

M S Yamburov[1], V V Volkomorov, K S Rogaev[1], E R Gorpinich[1], S B Romanova[1], M V Nevidomaya[1], E Yu Zharnakova[1], A A Burenina[1], T P Astafurova[1] and S B Turanov[2]

[1]National Research Tomsk State University, Lenin avenue 36, Tomsk, 634050, Russia
[2] National Research Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk 634050, Russia

E-mail: tyrsb@yandex.ru

Abstract. Comparative studies were conducted on morphofunctional parameters of lettuce (*Lactuca sativa*) plants cultivated with the use of supplementary lighting from different light sources – LED lamps, high-pressure mercury arc lamp (HPM) and high-pressure sodium arc lamp (HPS). The work showed that morphofunctional parameters of lettuce were significantly higher with LED lighting, in comparison to plants cultivated with HPM illumination, and main parameters of leaves grown under LED were barely discernible from the samples grown under HPS lighting. We observed accelerated transfer into reproductive period during HPM lighting, what can lead to quality degradation of the product. Considering the approximate values of leaf character range in experiments with HPS and LED lighting and greater energy efficiency of LED, light emitting diodes are obviously more promising for supplementary illumination in protected ground conditions.

1. Introduction

Sun light is the ideal lighting source for plants development, though natural illumination is insufficient for heliophilous horticultural crops during winter time. It is necessary for greenhouse facilities to provide supplementary illumination to increase light flux and extend photoperiod (length of lighting). Nowadays, sodium-vapor, metal-halide lamps and luminous tubes are used for industrial lighting. Although these lighting sources are efficient for electric power- photon flux transformation, they have some disadvantages [1]. HPS lamps are widely used as supplementary lighting sources under protected ground conditions; they have long-term service and satisfactory spectrum quality. However, only 30% of electrical power, consumed by these lamps, is transformed to light emission, while 70% of it is lost for heat emanating from the power supply. The spectrum of metal-halide lamps is more suitable for plants cultivation, unlike HPS lamps. Nevertheless, just 24% of power is converted into visible radiation, what is considerably lower than HPS lamps can provide. Luminous tubes appliance in protected ground conditions is limited due to their illumination intensity, which is far behind the intensity of sodium-vapor and metal-halide lamps [2].

Modern light emitting diodes cover the whole visible range of optical spectrum, from violet to red. Light energy output of LED depends on current intensity through the crystal, what is used to adjust radiant power of the lighting source. By changing current value of different light emitting diodes, spectra with various structures and intensities can be achieved. Therefore, we can select spectrum of the illuminant, according to the exact nascent stage of the plant [3-8].

The aim of this investigation is to obtain the insight into how LED lighting affects morphofunctional and physiological parameters of lettuce leaves and compare to HPS and HPM lighting sources impacts.

2. Materials and methods

Lettuce (*Lactuca sativa* subsp. *secalina* Alef.) of Moskovsky Parnikivy variety was chosen as model site. Plants were cultivated in 7 L containers, filled with soil mix of acid-free turf, vermicompost and sand at the ratio of 3:1:1, maintained at the temperature range +22–25°C and water vapor saturation 70–80%. Cultivation proceeded within 12 h photoperiod, supplementary lighting was provided by different light sources. Group 1 was illuminated with LED lamp, group 2 – high-pressure mercury arc lamp (HPM; Philips 250 W), group 3 – high-pressure sodium arc lamp (HPS; Reflax 150 W).

LED system was configured to equal-energy light output for red, blue and green spectral band. LED array consisted of 1 blue, 1 green and 2 red diode contours. Blue contour included powerful high-brightness light-emitting diodes 3GR-B-5630, wavelength 445-452 nm and half-breadth of a spectral line 25 nm. Lightness – 295-340 mW during 350 mA current. Green contour contained powerful high-brightness light-emitting diodes Cree XPEGRN-L1-0000-00C01 (green), wavelength 520-535 nm. The first red contour comprised powerful high-brightness light-emitting diodes Cree XPERED-L1-0000-00501 (red), wavelength 620 nm; the second – powerful high-brightness light-emitting diodes 3GR-R, chip AlGaInP 38x38 mil (Epistar), wavelength 650-660 nm and half-breadth of a spectral line 20 nm. Lighting sources were arranged at height which ensured equal irradiance of plants throughout all 3 experiments.

The measurements of physiological and morphological parameters of plants were carried out after 30 days from the sprouts appearance. Physiological parameters determination included investigation of chlorophyll-a and chlorophyll-b sum and amount of polyphenols and valuation of nitrogen balance index. The examinations were conducted on leaves of living plants by field non-destructive testing device – flavonoid- and chlorophyllmeter Dualex (Forse-A, France). Morphological and physiological parameters of 25 differentiated leaves (1 leaf per 1 plant) were determined in each alternative experiment. We measured such morphological parameters as length, width, area, dry weight. To evaluate the area, we scanned leaves, measured each leaf area in pixels, using the program AxioVision (Carl Zeiss), and converted obtained data into cm^2. Leaf density per unit surface (LMA) illustrates the amount of dry matter per area unit; LMA was estimated according to the data.

Statistical processing of the data was conducted on program Statistica (StatSoft). The average values of parameter and standard deviation were calculated. Statistical significance of differences was determined by Student's t-test ($p \leq 0.05$ and $p \leq 0.01$). For leaves of plants grown under LED lighting significance of differences was evaluated with use of t-test and then contrasted with other experimental samples.

3. Results and discussion

Lettuce plants cultivated with LED supplementary lighting had higher values of major leaf parameters, compared to those, which were illuminated by HPM lamp (table 1). The length and width of leaves grown under LED were 1.8 times greater, area – 3 times, dry weight – 2.7 times, flavonoids sum – 1.6 times. However, plants cultivated with the use of HPM lamp had 20% higher density per unit surface (LMA) factor, 1.5 times larger chlorophylls sum and 2.3 times greater nitrogen balance index.

It is recognized, that plants with low level of LMA (thinner leaf) photosynthesize more efficiently due to less ground tissue development outgoings and light energy loss. The LMA decrease can illustrate the rise of photosynthetic active tissue ratio to the volume of cell walls in dry weight [9].

It should be noted, that 30% of lettuce plants cultivated under HPM supplementary illumination had formed flower-bearing stem and transferred into reproductive period. Possible reason for this oddity is high rate of nitrogen balance index within exact experiment. Most crops extensively consume nitrogen from the soil when approach reproductive form. At this period lettuce plants become inapplicable over their dull eating qualities.

Table 1. Morphological and physiological parameters of lettuce leaves cultivated under different experimental conditions.

Factor	Lighting source		
	LED lamp	High-pressure mercury arc lamp (HPM)	High-pressure sodium arc lamp (HPS)
Length, mm	149.1±13.5	78.0±17.9[b]	137.9±19.1[a]
Width, mm	58.5±4.8	31.6±8.5[b]	58.1±7.4
Area, cm^2	45.6±5.3	15.6±7.2[b]	46.2±11.1
Dry weight, mg	52.6±7.7	21.8±12.0[b]	58.6±23.6
LMA, mg/cm^2	1.16±0.11	1.38±0.25[b]	1.26±0.29
Chlorophylls sum, mg/cm^2	8.61±1.20	13.77±1.30[b]	9.48±1.16[b]
Flavonoids sum, mg/cm^2	0.79±0.15	0.65±0.18[b]	1.02±0.28[b]
Nitrogen balance index	11.24±2.52	22.42±6.31[b]	9.94±2.77

[a] Statistically significant difference to LED lighting under $p \leq 0.05$.
[b] Statistically significant difference to LED lighting under $p \leq 0.01$.

Plants grown with the use of HPS supplementary lighting had 8% less leaf length and 13% lower nitrogen balance index, but 10% greater chlorophylls sum and 29% higher flavonoids sum in contrast to LED illumination. Statistically significant differences among major parameters (width, area, dry weight, density per unit surface) were not observed.

4. Conclusion

Comparative investigation was carried out in lettuce (*Lactuca sativa*) plants which were cultivated under LED supplementary lighting. Morpho-physiological parameters of leaves were notably higher than one’s of samples, grown under HPM lamp. Slight difference within main indexes was detected between samples with LED and HPS illumination. Considering the close values of leaf character variety of lettuce plants in experiments with HPS and LED lamps and way more energy efficient LED sources, it is obvious, light emitting diodes are more promising for supplementary illumination for protected ground conditions.

Acknowledgement

This research was supported by “Tomsk State University competitiveness improvement program” grant (№ 8.1.29.2018).
The work was supported by the Ministry of Education and Science of the Russian Federation under the State Program in the field of scientific investigations №13.3647.2017/PP.

References

[1] Wheeler R M 2008 A historical background of plant lighting: an introduction to the workshop *Hortscience* **43** 1942–43

[2] Wallace C and Both A J 2016 Evaluating operating characteristics of light sources for horticultural applications *Acta Horticulturae* **1134** 435–43

[3] Astafurova T, Lukash V, Goncharov A and Yurchenko V 2010 Phytotron for supplementary LED lighting of plants in greenhouses and at home *Solid-state lighting* **3** 36–38

[4] Avercheva O V, Bassarskaya E M, Zhigalova T V, Leonteva M R, Berkovich Y A, Smolyanina S O and Erokhin A N 2010 Photochemical and photophosphorylation activities of chloroplasts and leaf mesostructure in chinese cabbage plants grown under illumination with light-emitting diodes *Russian Journal of Plant Physiology* vol 57 **3** 382–91

[5] Prokofev A, Turkin A and Yakovlev A 2010 The perspectives of LED appliance i for crop farming *Solid-state lighting* **5** 60–63

[6] Singh D, Basu C, Meinhardt-Wollweber M and Roth B 2015 LEDs for energy efficient greenhouse lighting *Renewable and Sustainable Energy Reviews* **49** 139–47

[7] Berkovich Y A, Konovalova I O, Smolyanina S O, Erokhin A N, Avercheva O V, Bassarskaya E M, Kochetova G V, Zhigalova T V, Yakovleva O S and Tarakanov I G 2017 LED crop illumination inside space greenhouses *REACH - Reviews in Human Space Exploration* **6** 11–24

[8] Viršilė A, Olle M and Duchovskis P 2017 LED Lighting in Horticulture *Light Emitting Diodes for Agriculture* ed Dutta Gupta S (Singapore: Springer)

[9] Vasfilov S P 2011 The analysis of the cause of variability of the relationship between leaf dry mass and area in plants *General biology journal* **72** 436–54