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Lighting source as cause of changes in cucumbers' physiology and morphology

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Abstract. The demand of fresh fruits and vegetables is growing. Therefore cultivation of them is essential all year round. The growth in the dark period of a year is not imaginable without artificial lighting sources. Therefore the experiments were carried out to investigate the effects of three different lighting sources on the growth of cucumbers at the early stages of development. Plants were grown in the polycarbonate greenhouse under three different lighting sources: Led cob Helle top LED 280, induction lamp and high pressure sodium lamp Helle magna. Cucumbers were grown in 16h photoperiod with PAR at the tips of plants 200 ± 20 µmol m^{-2} s^{-1}. Plant growth parameters, specific leaf area, pigments, phenols and flavonoids content in leaves, leaf light reflection parameters were determined. Results showed that cucumber plants grown under Led cob Helle top LED 280 in average were smaller, with less chlorophyll, carotenoids and phenols, but leaves have higher chlorophyll a and b ratio and specific leaf area in comparison with traditionally used in greenhouses High Presure Sodium Lamps (HPSL). Cucumber plants grown under Induction lamp in average were shorter, but with larger leaf area, with higher chlorophyll and carotenoids content, but decreased phenols content in comparison with HPSL. Lichtenthaler index 1 (LIC1) and NDVI are useful for assessing the physiological state of cucumber plants. Despite the fact that the plants grow well and develop normally under all lamps, the results show that sodium lamps are the most suitable for cucumbers. Further research is needed to adjust LED lighting for cucumber cultivation.

Key words: *Cucumis sativus,* LED, plant pigments, biochemical parameters, NDVI.

INTRODUCTION

The demand of fresh fruits and vegetables is growing. Therefore cultivation of them is essential all year round. Global change and development of technology provides new opportunities for influencing plant growth. The growth in the dark period of the year is not imaginable without artificial lighting sources. Development of high intensity light emitting diodes (LEDs) gives new opportunities for optimisation of light in horticulture (Dueck et al., 2016). LEDs have many benefits: they are easily integrated into digital control system, they are safer to operate, and they are cooler in comparison with High Pressure Sodium Lamps (HPSL). As light output increases while devise costs decrease, LEDs continue to become economically feasible for horticultural lighting applications (Olle & Alsina, 2019). Light production efficiency is better in LEDs than HPSL and it is increasing (Särkkä et al., 2017). However, before use of LEDs as the sole source of light can be advanced, plant responses to light quality have to be investigated for the important horticultural plants (Hernández & Kubota, 2016).

Artificial lighting has been widely used to increase product quality and yield. Many research have been done to investigate changes of bioactive compounds under additional lightning. Kataoke et al., 2003 reported about changes of anthocyanin biosynthesis in grape and lettuce, but Zhou & Singh, 2002 reported, that additional light increased phenolic and anthocyanin content in cranberry fruits. There are also evidence, that supplemental far red (FR) LED decreased carotenoid and anthocyanin accumulation in lettuce (Li & Kubota, 2009).

Cucumbers are one of the most popular greenhouse grown vegetable and are known to be more sensitive to light quality changes then other vegetables (Hernandez & Kubota, 2016). Light and temperature are important growth factors for cucumbers known to respond well to light intensity. However, cucumber forms a tall canopy where self-shading affects vertical spectral light distribution. The vertical distribution of temperature and light may affect cucumber structure and photosynthesis efficiency with consequences for yield formation (Särkkä et al., 2017).

Nevertheless, LED technology in cucumber greenhouses is being introduced very slowly. This is due to the great variability of the LED lamp combinations, controversial data obtained in different experiments and insufficient amount of research.

The aim of this investigation is to compare three commercially available lighting sources which are produced for plant cultivation.

MATERIALS AND METHODS

The experiments were carried out in a polycarbonate greenhouse of Latvia University of Life Sciences and technologies during spring (1st set of experiments) and autumn (2nd set of experiments) seasons 2019. The temperature in the greenhouse was automatically regulated so that the temperature in the greenhouse did not exceed 30 ºC during the day, but did not fall below 15 ºC during the night.Two varieties of cucumbers ‘Julian’ and ‘Victoria’ were chosen for the experiments. Plants were grown in plastic pots (volume of pots was adapted to the plant size), filled with peat substratum KKS-S from Laflora (pH_{KCl} 5.8–6.6, EC 0.25 mS cm^{-1}, PG Mix (15–10–20) 1 kg m^{-3}, Ca 1.78%, Mg 0.21%). Total number of experimental plants for each variety at the beginning of experiment was 72. After appearance of the 1st true leaf plants were fertilized once a weak with 1% solution of Kristalon Green (18–18–18) with Mg, S and microelements in proportion $v:v_{pot} = 1:50$.

Cucumbers were grown in 16 h photoperiod with PAR at the tips of plants 200 ± 20 µmol m^{-2} s^{-1}. Three different lighting sources: Led cob Helle top LED 280 (LED), induction lamp (IND) and high pressure sodium lamp Helle Magna (HPSL) were used. Lamp radiation distribution measured with portative spectrometer *Gigahertz-*Optic *MSC15* is shown at Fig. 1.

Six plants were analysed three times during the vegetative growth of cucumbers: at the stage of 1–2 true leaf; 3–5 leaves and inflorescence emergence stage). During cucumbers growth plant growth parameters (plant length, stem diameter under cotyledons, number of leaves), specific leaf area, pigments (spectrophotometrically determined in ethanol solution (Lichtenthaler & Buschmann, 2001) and with portative chlorophyll meter atLEAF$^+$, phenols and flavonoids content in leaves spectrophotometrically (Sergejeva et al., 2016), leaf light reflection parameters (with spectro-radiometer RS-3500) were determined. Indices used for evaluation of cucumbers vitality and biochemical composition as well as equations for their calculations (W- certain wavelength used for calculations) are shown in Table 1.

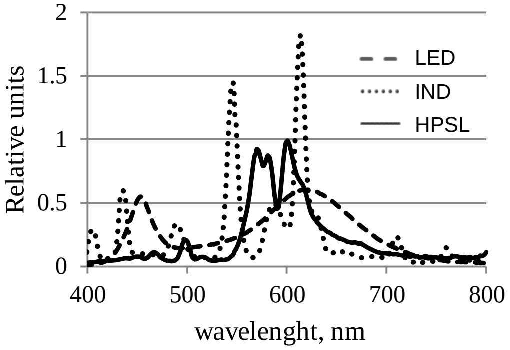

Figure 1. Lamp radiation distribution.

Table 1. Vegetation indices calculated from leaf reflectance at different wavelenghts

Vegetation index	Abbreviation	Equation	Reference
Carotenoids	CRI1	$\frac{1}{\mathrm{W510}}-\frac{1}{W550}$	Gitelson et al., 2001
Carter 1(Stress index)	CTR1	$\frac{\mathrm{W695}}{\mathrm{W420}}$	Carter, 1994
Greenness Index	GI	$\frac{\mathrm{W554}}{\mathrm{W677}}$	Zarco-Tejada et al., 2001
Lichtenthaler index 1	LIC1	$\frac{\mathrm{W800}-\mathrm{W680}}{\mathrm{W800}+\mathrm{W680}}$	Lichtenthaler, 1996
Lichtenthaler index2	LIC2	$\frac{\mathrm{W440}}{\mathrm{W690}}$	Lichtenthaler, 1996
Normalized Difference Vegetation Index	NDVI	$\frac{\mathrm{W760}-\mathrm{W670}}{\mathrm{W760}+\mathrm{W680}}$	Padilla et al., 2017b
Plant Senescence Reflectance Index	PSRI	$\frac{\mathrm{W678}-\mathrm{W500}}{\mathrm{W750}}$	Merzlyak et al., 1999
Structure Intensive Pigment Index	SIPI	$\frac{\mathrm{W800}-\mathrm{W445}}{\mathrm{W800}-\mathrm{W680}}$	Peñuelas & Filella 1998, Zarco-Tejada et al., 2001
Simple Ratio Pigment Index	SRPI	$\frac{\mathrm{W430}}{\mathrm{W680}}$	Peñuelas et al., 1994
Vegetation fluorescence	DPI	$\frac{\mathrm{W688}+\mathrm{W710}}{\mathrm{W697}^2}$	Zarco-Tejada et al., 2003
Water use efficiency	WBI3	$\frac{\mathrm{W950}}{\mathrm{W900}}$	Peñuelas et al., 1993
Water Index	WI	$\frac{\mathrm{W900}}{\mathrm{W970}}$	Peñuelas et al., 1997

Biochemical analyses were performed in three replicates, Non-destructive leaf analyses in 10 replicates. Two way analyses of variance (Anova) and correlation analyse were calculated by software included in Microsoft Office Excel 2010. For mathematical data processing the value of $P < 0.05$ was regarded as statistically significant. In cases of statistically significant differences, homogeneous groups were determined by Tukey's multiple comparison test at the level of confidence $\alpha = 0.05$.

RESULTS AND DISCUSSION

The obtained results showed that cucumber's growth significantly depends on used lighting source, growing season, plant development stage.

In average cucumber plant weight under LED lamp significantly decreased in comparison with Induction (IND) and High Pressure Sodium Lamps. (Fig. 2, A). Cucumber hypocotyl and whole plant length significantly decreased under LED and IND lamps in comparison with HPSL. It corresponds to research done by other researchers report about decrease of growth with increase blue light proportion in total light. (Hernández & Kubota, 2016, Sergejeva et al., 2018, Olle & Alsina, 2019).

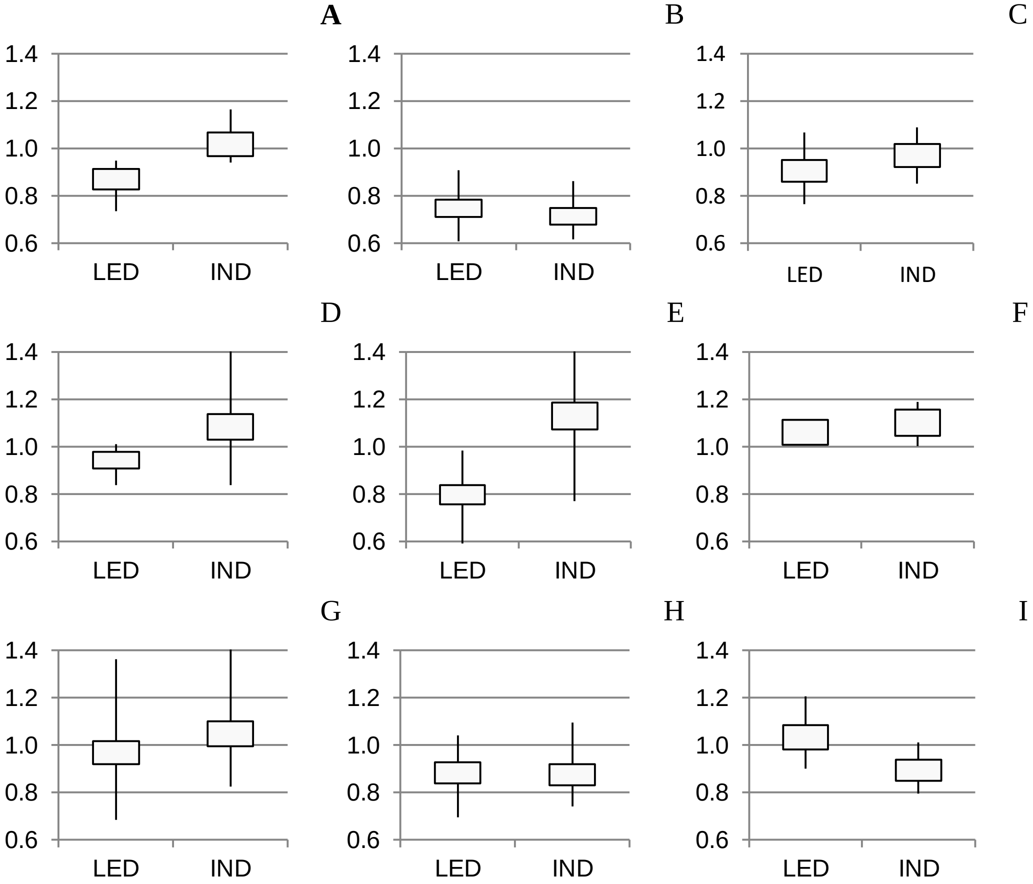

Figure 2. Ratio between plant parameters for growth under LED and IND lamps relative to the parameters obtained for growth under HPSL lamps. A – plant weight; B – plant length; C number of leaves; D – chlorophyll content; E – carotenoides content; F – ratio chlorophyll a and chlorophyll b; G – flavonoids conent; H – phenols content; I – specific leaf area.

Lighting source had significant effect of leaf properties. Cucumber leaves that had grown under the LED lamp had a smaller area, but thicker in comparison with IND and HPSL. These leaves characterized also with significantly larger specific leaf area (Fig. 2, I) in comparison with IND and HPSL. That corresponds to research done by Hernández & Kubota, (2016).

In average significant decrease of chlorophyll content in the cucumber leaves as result of LED ilumination was observed, in oposite to increase under IND ilumination in comparison with HPSL (Fig. 2, D), this difference in carotenoid content is even more noticeable ((Fig. 2, E). It is opposite to results by Sergejeva et al., 2018, Olle & Alsina, 2019. According to Padilla the average sufficiency value for all cucumber phenological phases for both maximum growth and maximum yield was 45.2 ± 0.7 SPAD units (Padilla et al., 2017a). Unfortunately leaves of our cucumbers contained chlorophyll in average 30–35 SPAD units and it leads to conclusion about unsufficiant nitrogen content in the cucumber leaves.

The most stable of the parameters studied was the ratio of chlorophyll a and b. In all vegetation seasons, for both varieties, under different lighting sources it varied between 2.0–2.76. In all sets of experiments the lowest value was observed under HPSL (Fig. 2, F).

No significant effect of used lighting source was observed on flavonoids content, but total phenols significantly decreased under LED and IND lamps. It is conversely our previous studies with leafy vegetables (Sergejeva et al., 2018).

Twelve vegetation indices were calculated from obtained cucumber leaves reflectance data (Table 2). Indices were chosen from different groups of published in the scientific literature, were previously by us and those which showed correlation with the studied morphological and biochemical parameters in our experiments.

Table 2. Vegetation indices calculated from leaf reflectance spectrums

Vegetation index	LED	IND	HPSL
CRI1	**0.086 a**	**0.126 b**	**0.122 b**
CRT1	1.332	1.228	1.347
GI	3.444	3.206	3.553
LIC1	**0.778 a**	**0.806 b**	**0.819 c**
LIC2	0.837	0.796	0.808
NDVI	**0.813 a**	**0.846 b**	**0.859 b**
PSRI	0.005	0.016	0.016
SIPI	**0.775 a**	**0.811 b**	**0.823 b**
SRPI	1.180	1.098	1.126
DPI	**0.225 a**	**0.329 b**	**0.279 a**
WBI3	**0.972 a**	**0.975 a**	**0.982 b**
WI	1.051	1.045	1.035

Significant differences in the reflected light from cucumber leaves were detected with Lichtenthaler indices 1 (LIC1). According to the literature, this index indicates the state of stress in the plant. By calculation, this index is similar to NDVI, which is the most commonly used index. The condition of plants is considered to be good if this index is larger than 0.8 (Berdugo et al., 2014). The results show that under all lamps the plants feel well. Vegetation indices connected with chlorophyll content (GI, SRPI) didn’t show significant differences between lighting sources. Our previous experiments showed high correlation between SRPI and chlorophyll content in the plant leaves (Alsiņa et al., 2016).

Significant differences were found in Structure Intensive Pigment Index (SIPI) between LED and other two lamps used in experiments.

One of used water regime characterising index showed significantly higher value (WBI3 under HPSL), but in average seems that no water stress detected in cucumber leaves.

The results show that vegetative growth of cucumbers under the used LED and induction lamps is slightly inhibited compared to HPSL. Further research is required to optimize cucumber growing conditions

CONCLUSIONS

1. Cucumber plants grown under Led cob Helle top LED 280 in average were smaller, with less chlorophyll, carotenoids and phenols, but leaves have higher chlorophyll a and b ratio and specific leaf area in comparison with traditionally used in greenhouses High Pressure Sodium Lamps (HPSL).
2. Cucumber plants grown under Induction lamp in average were shorter, but with larger leaf area, with higher chlorophyll and carotenoids content, but decreased phenols content.
3. Lichtenthaler indices 1 (LIC1) and NDVI are useful for assessing the physiological state of cucumber plants.
4. Despite the fact that the plants grow well and develop normally under all lamps, the results show that sodium lamps are the most suitable for cucumbers. Further research is needed to adjust LED lighting for cucumber cultivation.

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