https://doi.org/10.17221/4/2020-HORTSCI

Effects of LED and HPS lighting on the growth, seedling morphology and yield of greenhouse tomatoes and cucumbers

Jacek Dyśko, Stanisław Kaniszewski*

Research Institute of Horticulture in Skierniewice, Skierniewice, Poland

**Corresponding author: jacek.dysko@inhort.pl*

Citation: Dyśko J., Kaniszewski S. (2021): Effects of LED and HPS lighting on the growth, seedling morphology and yield of greenhouse tomatoes and cucumbers. Hort. Sci. (Prague), 48: 22–29.

Abstract: In an experiment with tomato and cucumber transplants, light units equipped with purpose-built LED arrays were compared with HPS sodium lamps with a power of 600 W and a voltage of 230 V. For both the LED and HPS lamps, the same PAR radiation level was used at the plant height, which was about 70–80 μmol/m^2/s in conditions without daylight. The supplementary lighting was carried out for 8 to 24 hours and was switched on during the day when the solar radiation outside the greenhouse was lower than 200 W/m^2. The supplementary lighting with the LED and HPS lamps did not have a significant impact on the growth of the tomato and cucumber seedlings and the fresh and dry mass of the tomato and cucumber plants. The plants grown without the additional artificial lighting were significantly smaller in height, had fewer leaves, a smaller spread and produced lower fresh and dry weights. The tomato and cucumber plants grown under the LED lamps had a higher chlorophyll index than those grown under the HPS lamps and without any lighting. The supplementary lighting with the LED lamps increased the early yield of the tomatoes compared to the HPS and control plants but has no effect on the early yield of the cucumbers. Both the LED and HPS lighting significantly increased the total and marketable yield of the tomatoes and cucumbers.

Keywords: artificial lighting; transplants; plant growth; chlorophyll

Greenhouse lighting is the most important parameter in the production of tomato and cucumber transplants during light-limited winter months. Supplementary lighting increases the leaf photosynthesis rates, plant growth and development, and yield quality (Gajc-Wolska et al. 2013; Hernández et al. 2016; Bantis et al. 2018). High-pressure sodium lamps (HPS) are the conventional lighting technology used in the production of tomato and cucumber seedlings (Kumar et al. 2016). Recently, lighting systems with light-emitting diodes (LED) have been increasingly used in greenhouse seedling production (Massa et al. 2008; Morrow 2008). Numerous experiments have been undertaken on the effect of supplementary LED lighting on the photosynthesis and the growth and development of vegetable crops grown in greenhouses (Gajc-Wolska et al. 2013; Li et al. 2016; Bian et al. 2018; Hao et al. 2018). A major advantage of LEDs over all other types of lamps is the electrical efficiency and photosynthetic efficacy (Olle, Viršile 2013). Furthermore, the combination of red (R) LEDs with blue (B) LEDs can form a spectral absorption peak suitable for photosynthesis and morphogenesis, with an 80–90% light energy utilization and a remarkable energy saving effect (Yang 2008). The photosynthesis ability of plant leaves is directly proportional to the R/B ratio of LEDs (Hogewoning et al. 2010). A higher B/R ratio resulted in a shorter stem length (Nanya et al. 2012). Głowacka (2002) stated that a blue light had a positive effect on the length, number and weight of the roots of tomato seedlings, while a red light

https://doi.org/10.17221/4/2020-HORTSCI

(600–700 nm) was very efficient in the photosynthesis and influenced the formation and development of leaves as well as the production of chlorophyll. Green light (500–600 nm) gives an effect opposite to blue light, causes the elongation of the stems and looser plant habit. Far red light (700–800 nm) stimulates the elongation growth, limits the branching, the leaves become thin and large, stimulates flowering and rooting, and also positively affects the weight of the harvested fruit. Li et al. 2016 showed that LED supplementary lighting with a high blue-to-red ratio is more favourable for enhancing a pepper plant's natural ability to capture the light energy and improve the photosynthetic ability of the plants.

The small size and low heat energy emission mean that LED lighting can be installed near plants. An important advantage of LEDs is also their long durability of more than 100 000 available hours in the currently offered lamps.

The aim of the study was to assess the impact of supplementary lighting with the new type of Sunray 300 LED lamps on the growth and development of tomato and cucumber seedlings, and the subsequent yield of the mature plants, compared to the effects of lighting with commonly used HPS lamps.

MATERIALS AND METHODS

Transplant production. The study was carried out in an experimental greenhouse of the Research Institute of Horticulture in Skierniewice. In the experiment, light units equipped with purpose-built LED arrays containing OSRAM diodes (Germany) were compared with HPS sodium lamps made by Finnish Hellight with Osram Plantstar bulbs with a power of 600 W and a voltage of 230 V, commonly used in greenhouse production (the spectral characteristics are given in Figure 1). Control plants were grown without lighting. The LED lamps were installed in such a way (at an appropriate height and distance) as to make the intensity of the irradiation the same as that of the HPS lamps. For both the LED and HPS lamps, the same photosynthetically active radiation (PAR) radiation level was used at the plant's height, which was about 70–80 $\mu mol/m^2/s$ in conditions without daylight. In the daytime conditions, the PAR radiation intensity was higher because it was the sum of the radiation of the lamps and the daylight reaching the greenhouse. The supplementary lighting was carried out for 8 to 24 h and was switched on during the day (controlled with an LCC900 climate computer) when the solar radiation outside the greenhouse was lower than 200 W/m^2. The experiment was carried out with the tomato cv. 'Altadena F_1' and cucumber cv. 'Pacto F1'. The tomato seeds were sown into plugs of mineral wool on 15 January 2018. After sowing, the sticks were placed in a phytotron at 23–25 °C. After emergence and the cotyledons unfolded, the temperature was lowered to 22 °C during the day and 20 °C at night. Then, on the 10^{th} day after sowing, the seedlings were transplanted into cubes of Grodan Delta mineral wool (100 × 100 × 60 mm). The cucumber seeds were sown into identical sticks of mineral wool on 29 January 2018, and after 5 days (February 2), the seedlings were transplanted into cubes of Grodan Delta rockwool. After transplanting, the tomato and cucumber seedlings were transferred to the greenhouse chambers equipped with a floodplain and a floor heating system. The cubes were fertigated with a nutrient solution of electrical conductivity (EC) of 2.3 mS/cm and a pH of 5.5 in accordance with the recommendations for toma-

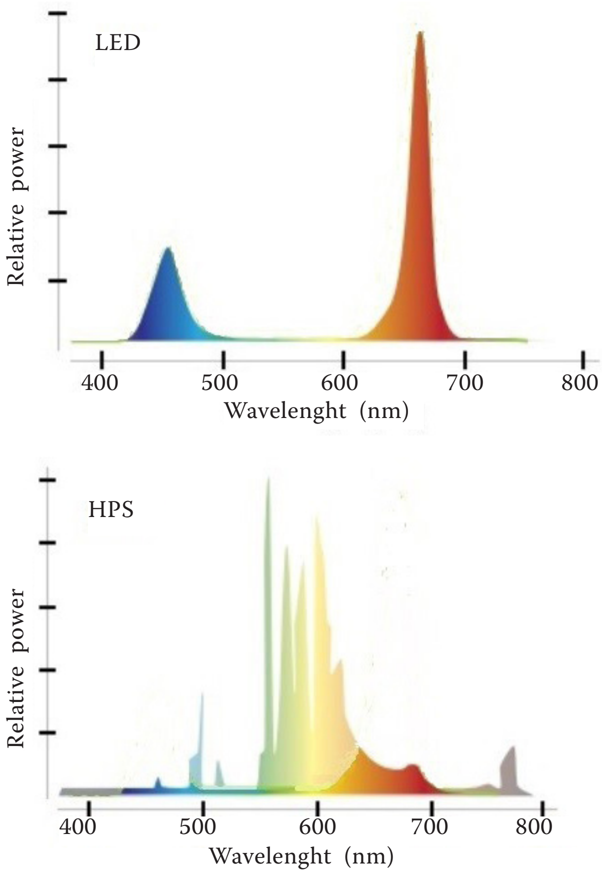

Figure 1. Spectral characteristics of the Sunray 300 LED and HPS Osram Plantastar 600

https://doi.org/10.17221/4/2020-HORTSCI

to and cucumber seedling production on rockwool. During the seedling production, the day and night air temperature was maintained at 20 °C and 19 °C, respectively. The greenhouse was controlled by a computerised Superlink 3 system made by Clauhan (Steinose, Denmark). The experiment was prepared in three replications, and there were thirty plants in each replicate. The production of the tomato seedlings under both types of LED and HPS lamps lasted 39 days (January 15–February 22), while the cucumber seedlings were grown for 36 days (January 29–March 6). During the experiment, a Force-A Dualex Scientific+ optical sensor (Force-A, Paris, France) was used to assess the chlorophyll index (Agati et al. 2016). The chlorophyll index of the tomato leaves was measured at the 5th and 8th stage of true leaves while the chlorophyll index of the cucumbers leaves was measured at the 3rd and 5th stage of true leaves. The following plant growth parameters were measured: height, stem diameter, fresh and dry mass of the plants, and a visual assessment of the roots were conducted after the seedling production and plant transfer to a permanent place in the greenhouse. The root system assessment was carried out on a 5-point scale: 1 – very numerous roots, evenly distributed throughout the cubes and on the side walls, a lot of roots in the lower part of the cubes, thin and thick white roots, 2 – numerous roots, also evenly distributed throughout the cubes, on the side walls and from the bottom of the cubes, white roots, 3 – less numerous roots, less evenly distributed in the cubes, more roots on the side walls and from the bottom of the cubes, white roots, 2 – cubes slightly overgrown, few roots on the side walls and in the bottom, white or brown discoloured roots, 1 – cubes not overgrown, single brownish roots at the bottom of the cubes.

Plant cultivation. The tomato transplants were planted into lignite mats on 22 February and were grown until July 5. The cucumber transplants were planted into rockwool mats on March 6 and were grown until July 25 without supplementary lighting. A nutrient solution with a standard concentration of nutrients (in mg/dm^3): N – 200–240, P – 40–60, K – 250–400, Mg – 60–80, Ca – 190–220, Fe – 2.0–2.5, Mn – 0.6–0.8, Cu – 0.15, Zn – 0.10, B – 0.20, Mo – 0.05, was applied to fertigate all the plants. The early, those of the plants under additional illumination, marketable and total yields of the tomato and cucumber fruits were determined.

Statistical analysis. The results of the experiment were subjected to a single factor analysis of variance (ANOVA) with the significance of the means tested with the Newman-Keuls test at P = 0.05.

RESULTS

Plant growth and morphology. There were no significant differences in the growth between the plants under the supplementary lighting with the LED and HPS lamps. The tomato and cucumber transplants should have a compact habit, a rigid stem, short internodes, and well-developed, intensely green leaves. Such plants were obtained by the additional illumination with both types of lamps (Table 1). This guarantees the optimal development of the root system and a high early yield. In our study, the strongest growth inhibition was found in the (tomato and cucumber) plants that were not subjected to any supplementary lighting. All the values of the measured parameters of the plants in this treatment were significantly lower than those of the plants under the additional illumination. The con-

Table 1. Effect of the type of lamps on the selected parameters of the morphological structure of the tomato and cucumber plants

Type of lamp	Tomato						Cucumber					
	Plant height (cm)	Number of leaves	Stem diameter (mm)	Root system assessment	Fresh weight (g)	Dry weight (g)	Plant height (cm)	Number of leaves	Stem diameter (mm)	Root system assessment	Fresh weight (g)	Dry weight (g)
LED	32.7^a	8.2^a	7.7^a	4.7^a	40.8^a	1.20^a	67.3^a	6.9^a	7.4^a	3.8^a	69.3^a	5.0^a
HPS	33.8^a	8.1^a	7.5^a	4.3^a	39.5^a	1.10^a	72.4^a	7.1^a	7.3^a	3.3^b	71.4^a	4.9^a
None (control)	8.2^b	4.5^b	2.9^b	1.2^b	3.04^b	0.16^b	41.3^b	5.4^b	4.0^b	2.3^c	18.7^b	1.4^b

Means marked with the same letter do not differ significantly according to the Newman-Keuls test at P = 0.05

https://doi.org/10.17221/4/2020-HORTSCI

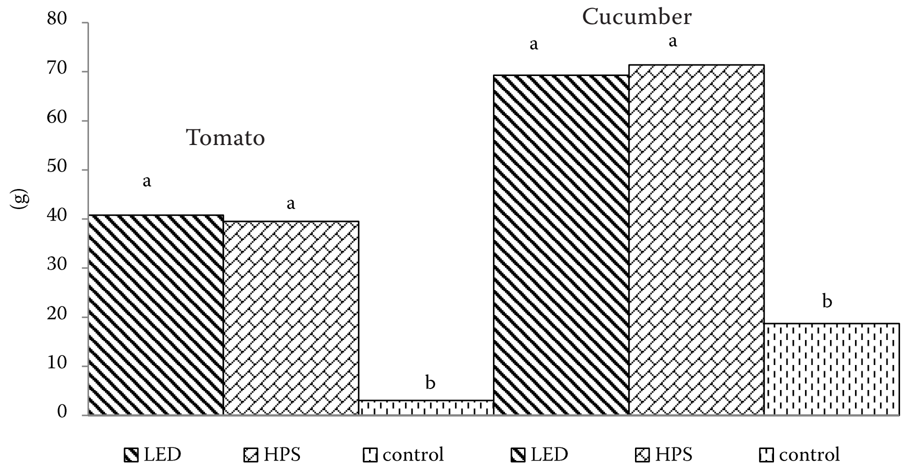

Figure 2. Effect of supplementary lighting on fresh weight of tomato and cucumber transplants

trol plants produced without any supplementary lighting were 5 times shorter in comparison with the plants grown under the lamps, and the other values of their morphological structure parameters were considerably lower (size and number of leaves, stem diameter). The cucumber control plants were significantly smaller in terms of height, size and number of leaves, and stem diameter.

There were no significant differences in the fresh and dry weights of the tomato and cucumber plants under the additional illumination with the LED and HPS lamps. The control (cucumber and tomato) plants without any supplementary lighting had significantly lower fresh and dry weights (5 and 3.5 times in the cucumbers, and 13 and 7.5 times in the tomatoes, respectively) in comparison with the plants under the additional illumination (Figures 2 and 3).

The supplementary lighting of the plants significantly modified the size of their root system; by far, the most developed cucumber root system was found when the seedlings were additionally illuminated with the LED lamps (Table 1). A slightly less developed root system was observed when the HPS lamps were used to illuminate the tomato plants. The cucumber plants grown under the additional illumination with sodium lamps were characterised by a significantly smaller root system. The control (both the tomato and cucumber) plants exhibited a significantly smaller root system in comparison with the plants subjected to the supplementary illumination.

Chlorophyll index. The chlorophyll index in the tomato and cucumber leaves, regardless of the species, are closely related to the nitrogen nutritional status of the plants (which directly affects the plant growth). The highest chlorophyll index was found in the leaves of the plants (tomato and cucumber on both measurement dates) additionally illuminated with the LED lamps (Figure 4). The lowest chlorophyll index was found in the plants produced without access to the artificial light. The chlorophyll index in the plants produced under the supplementary lighting with the HPS lamps varied and depended on the plant species and the measurement date. In the production of the tomato transplants, the chlorophyll index on the first measurement date

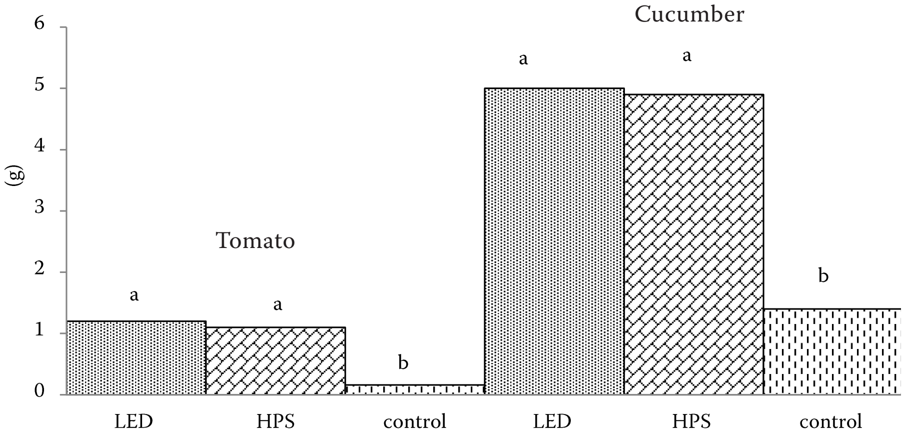

Figure 3. Effect of supplementary lighting on dry weight of tomato and cucumber transplants

https://doi.org/10.17221/4/2020-HORTSCI

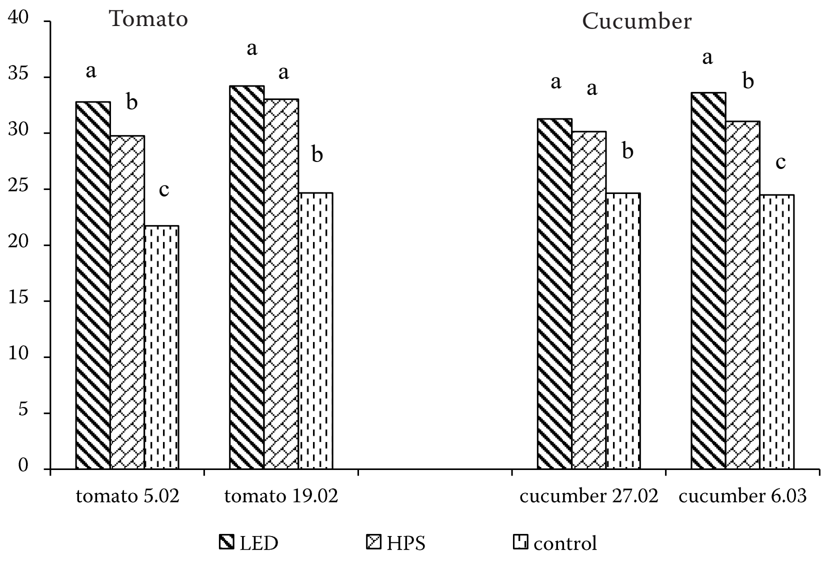

Figure 4. Effect of supplementary lighting on the chlorophyll index in tomato and cucumber transplants

was significantly lower under the HPS lamps than under the LED lamps, whereas at the time when the experiment was liquidated, the chlorophyll index was at the same level for the two types of supplementary lighting (LED and HPS). When the cucumber seedlings were additionally subjected to artificial lighting, the chlorophyll index on the first measurement date did not differ significantly for the illumination with the LED and HPS lamps.

Yield. The supplementary lighting of the tomato and cucumber seedlings had an influence on further growth and yielding of both plant species (Table 2). The tomato plants that had been additionally illuminated with the LED lamps fruited earlier. A significantly higher yield of tomato fruits from the first 3 harvests was obtained when the seedlings had been grown under the supplementary lighting with the LED lamps; this yield was significantly higher than the yield obtained when the additional illumination was with the HPS lamps (by almost 30%) and in the control without the additional lighting (by 65%). Subsequently, the differences in the yields between the treatments with the LED and HPS lamps decreased markedly; however, higher yields were still obtained with the LED lamps. By far, the lowest marketable and total yields of tomato fruits were obtained from the control plots without any additional lighting. There were no significant differences in the yields of the Pacto F_1 cucumber plants additionally illuminated with the LED and HPS lamps. The early yield of the cucumber was at the same level from both the additionally illuminated plants and the control plants, whose seedlings had been produced without any supplementary lighting. Subjecting the cucumber seedlings to the additional illumination with the LED and HPS lamps did not have a significant impact on the marketable and total yields.

DISCUSSION

The tested LED lamps contained diodes emitting a red light (maximum at a wavelength of 650 nm) and a blue light (maximum at 440 nm). According to the literature, a red LED stimulates the production and accumulation of the fresh plant mass, stem growth, and leaf surface area (Johkan et al. 2010; Li et al. 2012; Son et al. 2012). A blue LED is responsible for the chlorophyll production, opening of the stomata, and

Table 2. Effects of growing seedlings under supplementary lighting with LED lamps on the yield of the 'Altadena F_1' tomato (marketable and total yields, harvested 8 May–5 July 2018) and the 'Pacto F_1' cucumber

Treatment	Tomato			Cucumber		
	early yield	marketable yield	total yield	early yield	marketable yield	total yield
	(kg/m^2)					
LED	7.45^a	25.01^a	25.13^a	10.5^a	25.51^a	27.4^a
Control	2.60^c	19.32^b	19.72^b	10.0^a	23.80^b	24.9^b

Means marked with the same letter do not differ significantly according to the Newman-Keuls test at P = 0.05

https://doi.org/10.17221/4/2020-HORTSCI

photosynthesis (Wang et al. 2015; 2016; Miao et al. 2016). Our study showed that exposing plants to additional lighting with sodium and LED lamps did not differently affect the growth of the tomato and cucumber seedlings. The transplants produced under the supplementary illumination with both types of lamps had a similar height, number of leaves and diameter of the base of the stem. Similar results were obtained by Gómez and Mitchell (2015) after the additional illumination of tomato seedlings with sodium and LED lights. The study by Barazaityte et al. (2009) found a significant impact caused by various types of LED lamps on the growth and development of 'Raissa F_1' tomato seedlings. The tallest tomato seedlings were obtained by providing supplementary lighting with LED lamps combined with an additional contribution of light with a wavelength of 520 nm. Klamkowski et al. (2012) found that tomato plants subjected to supplementary lighting with LED lamps were characterised by a high rate of photosynthesis and rapid growth. However, those plants had a less compact habit (they were taller and had longer internodes) than the plants illuminated with sodium lamps. In our study, the lack of supplementary lighting adversely affected the tomato and cucumber seedlings by causing the inhibition of their growth. The tomato control plants were 5 times shorter in comparison with the plants produced with the help of the HPS and LED lamps. Confirmation of these results can be found in the literature; Gómez and Mitchell (2015), growing tomato seedlings in a greenhouse (lat. 40°N, long. 86°W), where they obtained significantly shorter transplants in the absence of additional illumination. Providing supplementary lighting with LED and HPS lamps did not have a significant impact on the fresh and dry mass of the tomato and cucumber plants; only the plants grown without the additional artificial lighting had significantly lower fresh and dry weights. Our results confirm the results reported by other authors (Hernandez et al. 2016; Gómez, Mitchell 2015; Urrestarazu et al. 2016). We found that both the cucumber and tomato plants grown under supplementary lighting with the LED lamps had the most developed root systems. According to Urrestarazu et al. (2016), increasing the amount of light reaching the plants significantly contributes to the development of the root system in tomatoes and peppers. However, in the study by Klamkowski et al. (2015) the use of LED and HPS lamps had no effect on the development of the root system of strawberry plants. Gajc-Wolska et. al. (2013) found that the additional illumination of tomato plants with sodium and LED lamps resulted in a chlorophyll content that was, on average, 24.4% higher than that in the control treatment, regardless of the type of lamps. Klamkowski et. al. (2015), too, did not show any significant differences in the value of the green colour index between plants under different supplementary lighting, which could indicate a similar chlorophyll content in their leaves. The introduction of supplementary lighting in the cultivation of tomato and cucumber seedlings positively influenced the further growth of both the tomato and cucumber plants. The available literature contains very little data on the impact of using sodium and LED lamps to provide seedlings with additional illumination during periods of adverse lighting conditions on the subsequent growth and yield of tomato and cucumber plants. In our study, the tomato plants exposed to supplementary lighting with the LED lamps came into fruiting earlier, thus increasing the early yield, in comparison with the HPS lamps and the control (no additional lighting). In the study by Brazaityte et al. (2009), tomato plants of the cultivar Raissa F_1 subjected to additional illumination with LED lamps were better at setting the fruit, thus increasing the size of the early crop. With respect to the yield of the two plant species under assessment here, more of the available reports concern the use of supplementary lighting in the later stages of growth of tomato and cucumber plants that were already growing in a permanent place during a period of light deficiency (Gajc-Wolska et al. 2015; Wenkai et al. 2018).

CONCLUSION

The supplementary lighting of tomato and cucumber plants with M-Tech Sunray 300 LED lamps allows good seedling growth and development, and can replace the high-energy, high-pressure sodium (HPS) lamps commonly used for this purpose. The plants grown under LED lamps were characterised by a compact habit, had proper fresh and dry weights, and had a better developed root system than under the HPS lamps. A lack of light was found to cause a significant growth inhibition in the plants that were not provided with supplementary lighting. Those plants were much smaller in height, had fewer leaves, a smaller spread, lower fresh and dry weights, and their shoots were thinner in comparison with the plants grown under the supplementary lighting.

https://doi.org/10.17221/4/2020-HORTSCI

The additional illumination of the tomato and cucumber seedlings with artificial light had an impact on the subsequent growth and yield of these plant species. The early yield of the tomato fruits was significantly higher after the seedlings had been illuminated with the LED lamps when compared to the HPS lamps. The supplementary lighting of the cucumber seedlings with the LED and HPS lamps did not have a significant effect on the size of the marketable and total yields.

REFERNCES

Agati G., Tuccio L., Kusznierewicz B., Chmiel T., Bartoszek A., Kowalski A., Grzegorzewska M., Kosson R., Kaniszewski S. (2016): Nondestructive optical sensing of flavonols and chlorophyll in white head cabbage (*Brassica oleracea* L. var. capitata subvar. alba) grown under different nitrogen regimens. Journal of Agricultural and Food Chemistry, 64: 85–94.

Bantis F., Smirnakou S., Ouzounis T., Koukounaras A., Ntagkas N., Radoglou K. (2018): Current status and achievements in the field of horticulture with the use of light – emitting diodes (LEDs). Scientia Horticulturae, 235: 437–451.

Bian Z., Jiang N., Grundy S., Lu C. (2018): Uncovering LED light effects on plant growth: new angles and perspectives - LED light for improving plant growth, nutrition and energy-use efficiency. Acta Horticulturae (ISHS), 1227: 491–498.

Brazaityte A., Duchovskis P., Urbonaviciute A., Samouliene G., Jankauskiene J., Kazenas V., Kasiuleviciute-Bonakere A., Bliznikas Z., Novickovas A., Breive K., Zukauskas A. (2009): After-effect of light-emitting diodes lighting on tomato growth and yield in greenhouse. Scientific works of the Lithuanian Institute of Horticulture and Lithuanian University of Agriculture. Sodininkystė ir daržininkystė.

Gajc-Wolska J., Kowalczyk K., Metera A., Mazur M., Bujalski D., Hemka L. (2013): Effect of supplementary lighting on selected physiological parameters and yielding of tomato plants. Folia Horticulturae, 25/2: 153–159

Głowacka B. (2002): Effect of light colour on the growth of tomato (Lycopersicon esculentum Mill) transplant. Hortorum Cultus 1: 93–103

Gómez C., Mitchell C. (2015): Growth responses of tomato seedlings to different spectra of supplemental lighting. HortScience, 50: 112–118.

Hao X., Guo X., Lanoue J., Zhang Y., Cao R., Zheng J., Little C., Leonardos D., Kholsa S., Grodzinski B., Yelton M. (2018): A review on smart application of supplemental lighting in greenhouse fruiting vegetable production. Acta Horticulturae (ISHS), 1227: 499–506.

Hernández R., Eguchi T., Kubota C. (2016): Growth and morphology of vegetable seedlings under different blue and red photon flux ratios using light-emitting diodes as sole-source lighting. Acta Horticulturae (ISHS), 1134: 195–200.

Hogewoning S., Trouwborst G., Maljaars H., Poorter H., Ieperen W., Harbinson J. (2010): Blue light dose-responses of leaf photosynthesis, morphology and chemical cpmposition of cucumis sativus grown under different combinations of red and blue light. Journal of Experimental Botany. 61:3107–3117.

Johkan M., Shoji K., Goto F., Hashida 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.

Klamkowski K., Treder W., Masny A. (2015): Influence of supplementary lighting with high pressure sodium and LED lamps on growth, yield and photosynthetic activity of strawberry plants. Prace Instytutu Elektrotechniki, 268: 73–82.

Klamkowski K., Treder W., Wójcik K., Puternicki A., Lisak E. (2012): Influence of supplementary lighting on growth and photosynthetc activity of tomato transplants. Infrastructure and Eclogy of Rural Areas, IV: 1377–1385

Kumar K.G.S., Hao X., Khosla S., Guo X., Bennett N. (2016): Comparison of HPS lighting and hybrid lighting with top HPS and intra-canopy LED lighting for high-wire mini-cucumber production. Acta Horticulturae (ISHS), 1134: 111–118.

Li H., Tang C., Xu Z., Liu X., Han X. (2012): Effects of different light sources on the growth of non-heading Chinese cabbage (*Brassica campestris* L.). The Journal of Agricultural Science, 4: 262.

Li X., Lu W., Hu G., Wang X. Ch., Zhang Y., Sun G.X., Fang Z. (2016): Effects of light-emitting diode supplementary lighting on the winter growth of greenhouse plants in the Yangtze River Delta China Botany Study, 57: 2.

Massa G.D., Kim H.-H., Wheeler R.M., Mitchell C.A. (2008): Plant productivity in response to LED lighting. HortScience, 43: 1951–1956.

Miao Y.X., Wang X.Z., Gao L.H., Chen Q.Y., Qu M. (2016): Blue light is more essential than red light for maintaining the activities of photosystem II and I and photosynthetic electron transport capacity in cucumber leaves. Journal of Integrative Agriculture, 15: 87–100.

Morrow R. C. (2008): LED lighting in horticulture. HortScience, 43: 1947–1950.

Nanya K., Ishigami Y., Hikosaka S., Goto E. (2012): Effects of blue and red light on stem elongation and flowering of tomato seedlings. Acta Horticulturae (ISHS), 956: 261–266

Olle M., Viršile A. (2013): The effects of light-emitting diodes on greenhouse plant growth and quality. Agricultural and Food Science, 22: 223–234.

Son K.-H., Park J.-H., Kim D., Oh M.-M. (2012): Leaf shape index, growth, and phytochemicals in two leaf lettuce cultivars grown under monochromatic light-emitting diodes.

https://doi.org/10.17221/4/2020-HORTSCI

Korean Journal of Horticultural Science and Technology, 30: 664–672.

Urrestarazu M., Najera C., Del Mar Gea M. (2016): Effect of the spectra quality and intensity of light- emitting diodes on several horticultural crops. HortScience, 51; 268–271.

Wang J., Lu W., Tong Y., Yang Q. (2016): Leaf morphology, photosynthetic performance, chlorophyll fluorescence, stomatal development of lettuce (*Lactuca sativa* L.) exposed to different ratios of red light to blue light. Frontiers in Plant Science, 7: 250.

Wang X.Y., Xu X.M., Cui J. (2015): The importance of blue light for leaf area expansion, development of photosynthetic apparatus, and chloroplast ultrastructure of *Cucumis sativus* grown under weak light. Photosynthetica, 53: 213–222.

Wenkai Y., Yugi Z., Yating Z.,Ruifeng Ch., Yi Z., Qichang Y., Tao L. (2018): Effects of supplemantary artifical light on the growth of the tomato (*Solanum lycopersicum*) in a Chinese Solar Greenhouse. The Horticulture Journal, 87: 1–4

Yang Q.C. (2008): Application and prospect of light emitting diode (LED) in agriculture and bio-industry. Journal of Agricultural Science and Technology, 6: 42–47.

Received: January 10, 2020
Acccepted: October 22, 2020