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The effect of light-emitting diodes lighting on cucumber transplants and after-effect on yield

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Abstract

The objective of our studies was to optimize lighting spectrum for the cultivation of cucumber transplants under various combinations of light-emitting diodes (LEDs) and to determine the after-effect on yield. Transplants of cucumber hybrid ʽMandy F1' were grown in 2007 at the Lithuanian Institute of Horticulture in phytotron chambers. After the germination, photoperiod was 18 h and day/night temperature +22/18°C. A system of five high-power solid-state lighting modules with the main 447, 638, 669 and 731 nm LEDs was used in the experiments. Supplemental LEDs of different wavelength were used in particular modules: L1 – without supplemental LEDs, L2 – supplemented by 380 nm, L3 – supplemented by 520 nm, L4 – supplemented by 595 nm, L5 – supplemented by 622 nm. For comparison, growth of cucumber transplants (reference) was performed under the illumination of high-pressure sodium lamps "SON-T Agro" ("Philips", USA). Cucumber seedlings were transplanted to the greenhouse and planted in tumblers with peat substratum. Our investigations revealed that optimizing LEDs illumination for cucumber transplant with green or orange light could accelerate their growth till technical maturity and to decrease an input of energy. The obtained data shows that it is necessary to avoid UV light in such modules. After-effect of different illumination of various high-power solid-state lighting on cucumber yield was not revealed, but it had effect on the beginning of flowering and harvest.

Key words: development, growth, photosynthesis pigments, saccharides, LEDs, illumination spectrum, yield.

Introduction

The cucumber is the most important crop in the commercial greenhouses. Their seedlings are grown during autumn–winter period, when natural light level is low and, consequently, supplemental lighting is needed. Their illumination is based on conventional light sources such as incandescent, fluorescent, metal halide, and high-pressure sodium lamps. Fixed-spectrum lighting is neither spectrally optimal nor energetically effective and remains probably the most conservative technological factor of plant cultivation /Spaargaren, 2001; Heuvelink et al., 2006/.

Light is the main environmental factor affecting the growth of plant and the production of biomass. Many metabolic processes are stimulated by light, which regulates photosynthetic activity at different levels in higher plants /Astolfi et al., 2001/. Light is the most important factor which determines quality of vegetable seedlings. Properly cultivated seedlings should be compact, with short internodes and firm stems, large and intensively green leaves. It guarantees the optimal development of root system after transplanting, and have an effect on the earliness, quality and quantity of the yield /Glowacka, 2002; Piszczek, Glowacka, 2008/. Seedlings cultivated in insufficient light become etiolated, more susceptible to damage and disease, and come into bearing later /Piszczek, Glowacka, 2008/.

Recently developed high-brightness light-emitting diodes (LEDs) base the future lighting technology (solid-state lighting). The option to select specific wavelengths for targeted plant response makes LEDs more suitable for plant-based uses than many other light sources /Massa et al., 2008/. These optoelectronic devices feature high radiant efficiency, long lifetime, cool emitting temperature, relatively narrow emission spectra, short switching time, and contain no mercury as most conventional light sources do. Using the new-generation light sources offers tremendous untapped reserves to increase efficiency of photophysiological processes in plants, accelerate the selection cycles, improve quality of vegetable food, save energy resources and eliminate the impact of mercury on the environment due to plant cultivation systems with conventional artificial lighting /Žukauskas et al., 2004; Massa et al., 2008/. In 1990 light-emitting diodes (LEDs) were tested for the plant growth /Bula et al., 1991/. The first attempts to design LED-based lighting systems for plant illumination were targeted to space applications /Barta et al., 1992/. Later investigations were mostly related to vegetable morphogenesis control, especially plants *in vitro* /Miyashita et al., 1997; Okamoto et al., 1999; Kim et al., 2004 b; Kurilčik et al., 2008/. Such vegetable species as lettuce, radish, pepper, spinach, tomato, have been reported to grow successfully under LEDs /Tennessen et al., 1995; Schuerger et al., 1997; Yorio et al., 2001; Tamulaitis et al., 2005; Urbonavičiūtė et al., 2007/. We did not find any data about cucumber seedlings growth using LED-based lighting systems in literature. Some researchers used blue LEDs with HPS lamps as additional light sources for cucumber plant growth /Menard et al., 2006/.

The objective of our studies was to optimize lighting spectrum for cultivation of cucumber transplants under various combinations of light-emitting diodes and determine after-effect on yield.

Materials and methods

Vegetative experiments were performed in 2007 in chambers and greenhouse of phytotron complex of Lithuanian Institute of Horticulture. Cucumber hybrid 'Mandy F1' was seeded in peat substrate (pH 6.0–6.5) enriched with fertilizes PG MIX (NPK 14:16:18, 1.3 kg m^{-3}). Plants were watered when necessary. Photoperiod till cucumber plant germination was 14 h and day/night temperature was maintained at +25°C. After the germination, photoperiod was 18 h and day/night temperature +22/18°C. Relative air humidity was 75%.

Cucumber transplants from sowing were cultivated for 30 days under illumination, which PFDs and spectral distributions were maintained as specified in Table 1. System of five high-power solid-state lighting modules with the main blue 447 nm (LuxeonTM type LXHL-LR5C, "Lumileds Lighting", USA), red 638 nm (LuxeonTM type LXHL-MD1D, "Lumileds Lighting", USA), red 660 nm (for L1) (L660-66-60, "Epitex", Japan), red 669 nm (L670-66-60, "Epitex", Japan) and far red 731 nm (L735-05-AU, "Epitex", Japan) LEDs were used in the experiments. Supplemental LEDs of different wavelengths were used in particular modules: UV 380 nm (NCCU001E, "Nichia", Japan), green 520 nm (LuxeonTM type LXHL-MM1D, "Lumileds Lighting", USA), yellow 595 nm (LuxeonTM type LXHL-MLAC, "Lumileds Lighting", USA) and orange 622 nm (LuxeonTM type LXHL-MHAC, "Lumileds Lighting", USA). For comparison, growth of cucumber transplants (reference) was performed under the illumination of high-pressure sodium lamps "SON-T Agro" ("Philips", USA) with similar photon flux density (PFD) as in modules.

Cucumber seedlings were transplanted to the greenhouse and planted in tumblers (54 x 37 x 33 cm) with peat substratum (two plants per tumbler). Plants were watered when necessary and fertilized three times per week with 0.2% complex fertilizers "Kemira Combi" (NPK 14:11:25 plus magnesium (1.4%) and microelements). Temperature in sunny days was +24–28°C, temperature in heavy days – +20–22°C, night temperature – +17–18°C and relative air humidity – 60–70%. Cucumbers in the greenhouse were grown for 11 weeks and yield was harvested in four weeks.

Table 1. Photon flux densities (PFD) in five high-power solid-state lighting modules
1 lentelė. *Fotonų srauto tankis skirtinguose moduliuose automatizuotoje penkių modulių apšvietimo sistemoje*

Treatments *Variantai*	Photon flux densities 10 cm from light source µmol m^{-2} s^{-1} *Fotonų srauto tankis 10 cm atstumu nuo šviesos šaltinio µmol m^{-2} s^{-1}*								
	380 nm	447 nm	520 nm	595 nm	622 nm	638 nm	660 nm	669 nm	731 nm
L1	–	30	–	–	–	117	24	–	7
L2	9	31	–	–	–	130	–	23	7
L3	–	30	12	–	–	122	–	23	7
L4	–	31	–	15	–	130	–	23	7
L5	–	31	–	–	29	130	–	23	7

Photosynthetic pigments content per one gram of fresh foliage weight was measured in 100% acetone extract according to D. Wettstein method /Wettstein, 1957/ using "Genesys 6" spectrophotometer ("ThermoSpectronic", USA). Measurements were performed in three replicates (n = 3) during seedling transplantation and after four weeks in the greenhouse.

1–2 g of fresh cucumber transplants leaf per sample for soluble sugar analysis was ground, diluted with 4 mL double distilled water, extracted for 24 h and filtered, and before analysis purified using 0.2 µm syringe filters. Fructose (Fru), glucose (Glu), sucrose (Suc) and maltose (Mal) were determined using HPLC system (model 10A, "Shimadzu", Japan) equipped with refractive index detector (RID 10A, "Shimadzu"), column oven (CTO-10AS VP, "Shimadzu", Japan), degasser (DGU-14A, "Shimadzu") and pump (LC-10AT VP, "Shimadzu"). Separations were performed on an "Adsorbosil" column with NH_2 grups (150 mm × 4.6 mm). The mobile phase of 75% acetonitrile in double distilled water was used. Three analytical samples of sugars (*n* = 3) were measured for each treatment.

Plants were harvested on 22nd and 30th day after sowing and oven-dried at +105°C for 24 h to determine the dry weight. Leaf area of cucumber plants was measured by "WinDias" leaf area meter ("Delta-T Devices Ltd", UK). Plant height was measured up to the top of cucumber transplants.

Organogenesis stages of cucumber plants were identified according to methodology of F. M. Kuperman /Куперман и др., 1982/ and biometric and physiological indices were determined in five replicates (*n* = 5) at the end of cultivation of transplants (30 days after sowing). Ripe fruits were harvested from eight (*n* = 8) plants three times per week.

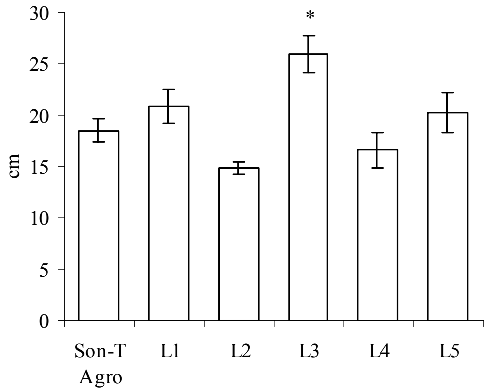
The levels of significance for differences between various indices were analysed using one-way *Anova* (*Anova* for *MS Excel*, version 3.43). The results were expressed as mean values and their standard errors (SE) using *MS Excel* software. Significant differences from reference treatment are denoted by an asterisk (*) at $P \leq 0.05$.

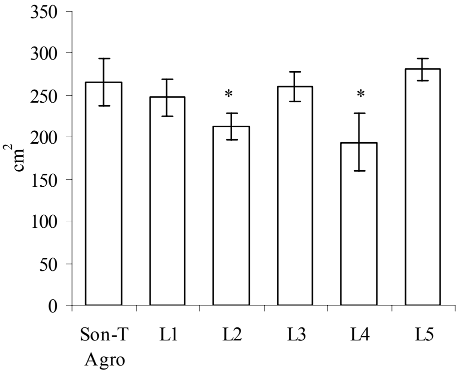
Results and discussion

The highest plants were under module where the main LEDs were combined with supplemental 520 nm light and the shorter ones were cultivated under module with supplemental UV 380 nm LEDs (Fig. 1). Significantly lower hypocotyls were in cucumber transplants under module with the main set of LEDs, under modules with supplemental green and orange light (Fig. 3). Internodes length of plants under high-power solid-state lighting modules with supplemental illumination by UV (380 nm) LEDs were the shortest. The longest internodes were in plants under module with supplemental 520 nm light (L3) (Fig. 3). But these plants had the most (~5) fully expanded leaves (Fig. 4), so their fourth internodes could be grown up completely. Similar trends were noticed in cucumber transplants under module with the main set of LEDs, and under modules with supplemental 622 nm LEDs. Meanwhile, plants under "SON-T Agro", under modules with supplemental UV 380 nm and 595 nm LEDs had almost one fully expanded leaf less than the plants mentioned above (Fig. 4), and their fourth internodes were shorter (Fig. 3).

Cucumber transplants formed significantly smaller leaf area under the effect of supplemental UV 380 nm and 595 nm LEDs in modules (Fig. 2). Leaf area of transplants under other high-power solid-state lighting modules was similar.

Hypocotyls of cucumber transplants were thicker under modules of the main set of LEDs and under module in which green 520 nm LEDs was installed (Fig. 6). But these plants had greater fresh weight (Fig. 7).

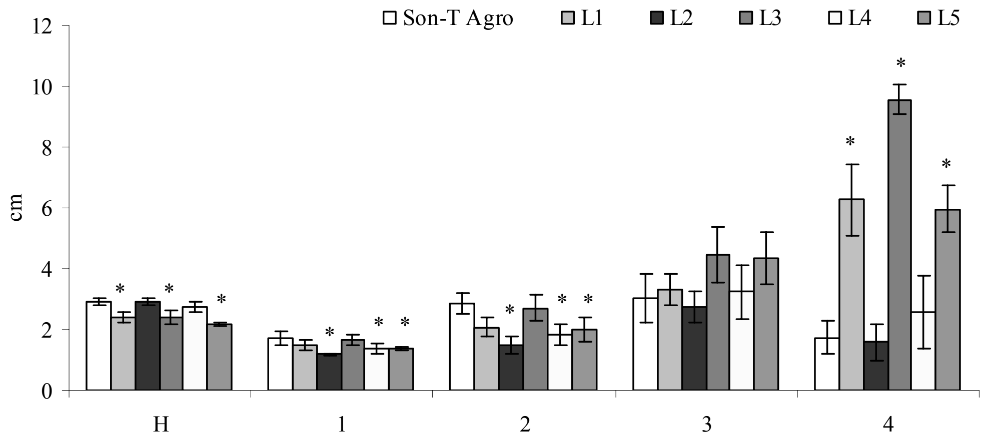




Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

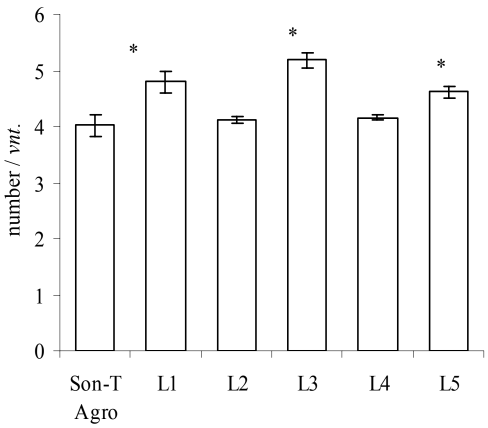
Figure 1. Height of cucumber transplants grown under different LEDs illumination
1 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, aukštis*

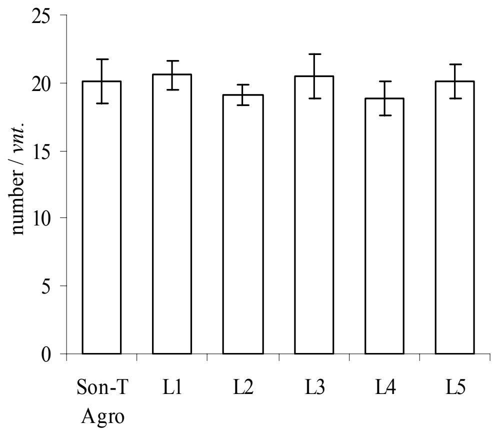
Figure 2. Leaf area of cucumber transplants grown under different LEDs illumination
2 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, lapų plotas*



Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

Figure 3. Hypocotyl and internodes length of cucumber transplants grown under different LEDs illumination
3 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, hipokotilio ir tarpubamblių ilgis*

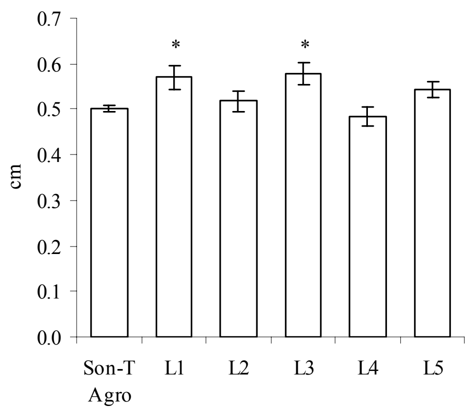


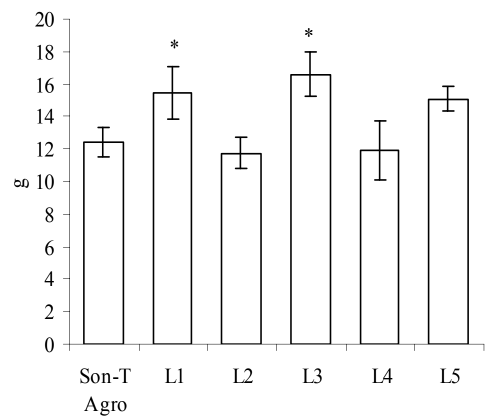


Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

Figure 4. Leaf number of cucumber transplants grown under different LEDs illumination
4 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, lapų skaičius*

Figure 5. Leaf number of cucumber after four weeks in greenhouse
5 paveikslas. *Agurkų lapų skaičius po keturių savaičių auginimo šiltnamyje*



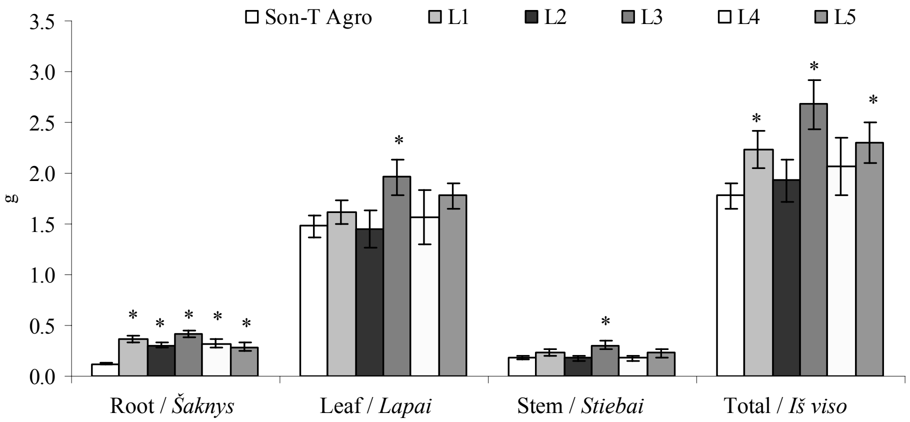


Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

Figure 6. Hypocotyl diameter of cucumber transplants grown under different LEDs illumination
6 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, hipokotilio skersmuo*

Figure 7. Fresh weight of cucumber transplants grown under different LEDs illumination
7 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, žalia masė*

During investigation it was determined that the dry weight of cucumber transplants roots under high-power solid-state lighting modules were significantly greater than under "SON-T Agro" lamps (Fig. 8). It was established that leaves and stems of cucumber transplants under module with supplemental green 520 nm LEDs had significantly greater dry weight. Total dry weight was also higher in these plants. A little less of total dry weight had cucumber transplants under modules with the main set of LEDs and under module with supplemental orange 622 nm LEDs. The total dry weight in plants under "SON-T Agro" lamps and under modules with supplemental UV and orange LEDs was less than in above mentioned cucumber transplants (Fig. 8).

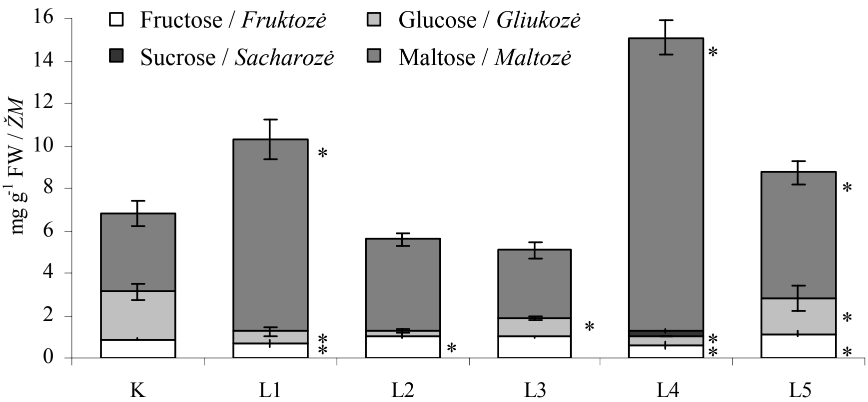


Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

Figure 8. Dry weight of cucumber transplants grown under different LEDs illumination
8 paveikslas. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, sausa masė*

Development stage, height of apex and number of flower were determined above each fully expanded leaf in tomato seedlings before transplanting them to greenhouse (Table 3). Cucumber seedlings under module with supplemental 520 nm LEDs were mostly developed. Apex above third leaves of some plants was at 7th organogenesis stage. Apex height of these plants above all leaves was greater and they had the large amount of structured germ flowers. Cucumber transplants under module with supplemental 622 nm LEDs were developed similarly as plants mentioned above. The development of plants, which grew under "SON-T Agro" lamps, was the slowest (Table 3).

Total content of monosaccharides in leaves of cucumber transplants under high-power solid-state lighting modules were less than under "SON-T Agro" lamps (Fig. 9). But content of maltose was significantly higher in plants under modules with the main set of LEDs and under module nm s with supplemental yellow 595 nm and orange 622 nm LEDs. Supplemental yellow light particularly stimulated synthesis of disaccharides. Plants in this module accumulated three times more maltose than plants in control. There was also detected some sucrose. Cucumber transplants in modules supplementary illuminated by 380 nm and 595 nm LEDs accumulated the smallest content of monosacharides (Fig. 9).



Note / *Pastaba*. FW / *ŽM* – fresh weight / *žalia masė*.

Figure 9. Mono and disaccharides content in the leaves of cucumber transplants grown under different LEDs illumination
9 paveikslas. *Mono- ir disacharidų kiekis agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, lapuose*

Table 2. Apex development of cucumber transplants grown under different LEDs illumination
2 lentelė. *Agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, augimo kūgelių išsivystymas*

Leaves *Lapai*	Development of apex *Augimo kūgelio išsivystymas*	Treatments / *Variantai*					
		"SON-T Agro"	L1	L2	L3	L4	L5
1	2	3	4	5	6	7	8
1	Stage *Etapas*	Va	Va–Vb	Va–Vb	Vb–Vc	Va–Vb	Va–Vb
	Height *Aukštis mm*	0.21±0.032	0.37±0.103	0.29±0.068	0.53±0.086*	0.31±0.065	0.44±0.113*
	Number of flowers *Žiedų skaičius*	5.4±1.04	4.0±0.44	4.4±1.04	3.2±0.28 *	2.4±0.34 *	3.6±0.55 *
2	Stage *Etapas*	Va–Vd	Vc–VI	Vb–VI	Vd–VI	Vb–VI	Vc–VI
	Height *Aukštis mm*	0.59±0.154	1.00±0.192*	0.74±0.139	0.97±0.042*	0.65±0.205	0.91±0.153
	Number of flowers *Žiedų skaičius*	6.8±1.72	7.6±0.83	6.6±1.56	7.2±1.19	7.6±1.28	7.2±1.83

Table 2 continued
2 lentelės tęsinys

1	2	3	4	5	6	7	8
3	Stage *Etapas*	Vd	Vd–VI	Vd–VI	VI–VII	Vd–VI	Vd–VI
	Height *Aukštis mm*	0.64±0.041	1.12±0.100*	0.89±0.058*	1.36±0.230*	1.05±0.112*	1.12±0.096*
	Number of flowers *Žiedų skaičius*	3.6±0.34	4.2±0.81	4.4±0.94	6.0±0.62 *	4.0±0.44	5.0±0.88 *
4	Stage *Etapas*	Vd	Vd–VI	Vd–VI	Vd–VI	Vd	Vd–VI
	Height *Aukštis mm*	0.53±0.056	0.98±0.122*	0.84±0.079*	1.16±0.164*	0.87±0.066*	0.98±0.052*
	Number of flowers *Žiedų skaičius*	4.2±0.28	5.0±0.76	5.4±1.04	5.6±0.83*	4.4±0.34	3.8±0.28
5	Stage *Etapas*	Va–Vd	Vb–Vd	Vc–Vd	Vd–VI	Vc–Vd	Vd
	Height *Aukštis mm*	0.44±0.106	0.71±0.171*	0.62±0.085	0.98±0.141*	0.68±0.081*	0.80±0.339*
	Number of flowers *Žiedų skaičius*	4.0±0.44	4.6±1.28	4.2±0.52	5.6±1.13 *	3.8±0.52	3.4±0.34
6	Stage *Etapas*	–	Vd	–	Vd	–	Vd
	Height *Aukštis mm*	–	0.72±0.121	–	0.63±0.117	–	0.59±0.046
	Number of flowers *Žiedų skaičius*	–	4.3±0.78	–	5.0±0.51	–	4.0±0.62
Total number of flowers *Iš viso žiedų*		24,0±2.36	28.8±2.57 *	25.0±0.76	31.6±3.78 *	22.2±1.72	27.0±0.98

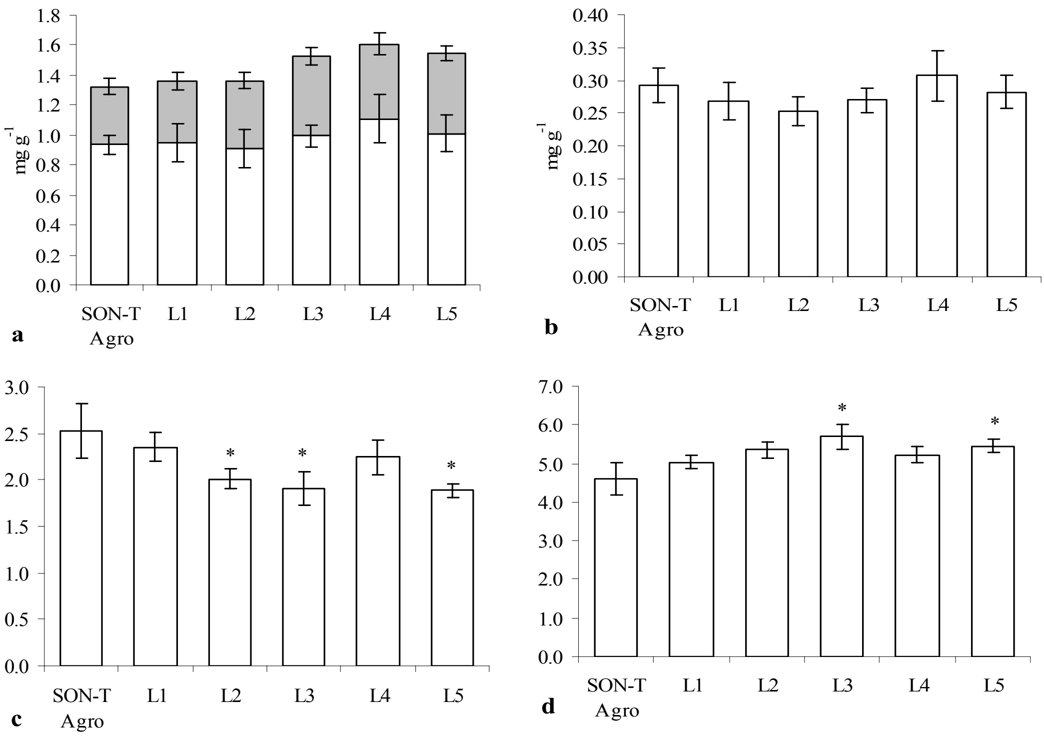
Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

Table 3. Number of days from cucumber sowing to flowering and harvest
3 lentelė. *Dienų skaičius nuo agurkų sėjos iki žydėjimo ir derėjimo*

	Treatments / *Variantai*					
	"SON-T Agro"	L1	L2	L3	L4	L5
Beginning of flowering *Žydėjimo pradžia*	38	35	37	34	37	35
Beginning of harvest *Derėjimo pradžia*	56	51	51	48	51	48

Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

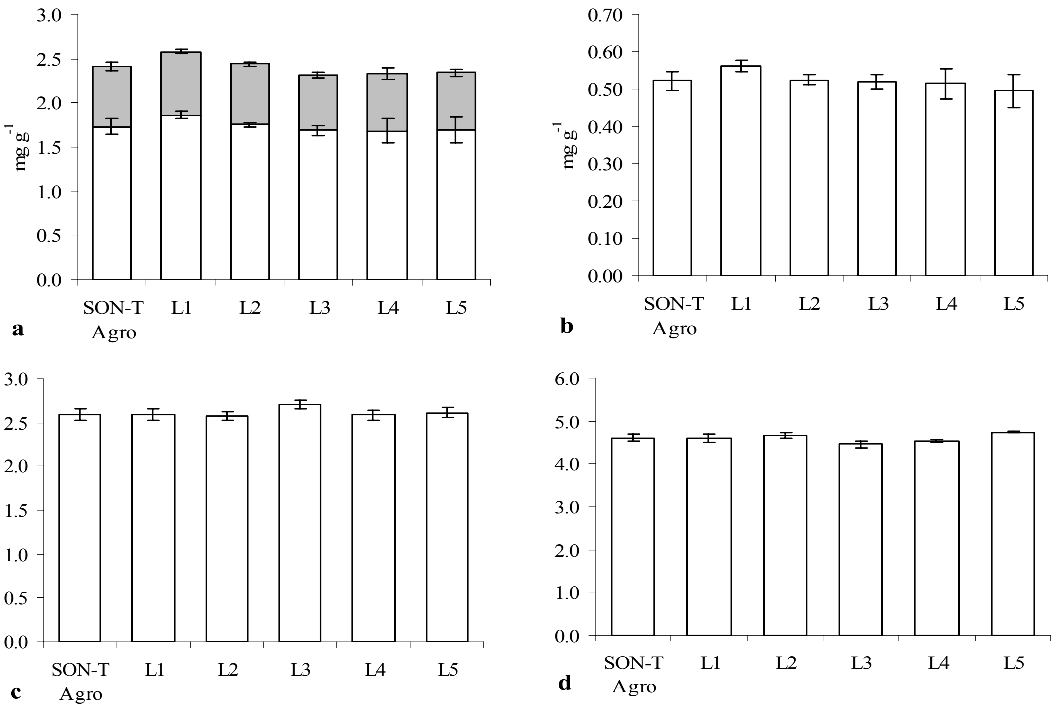
Different illumination had no effect on photosynthesis pigments content in cucumber leaves (Fig. 10). It was established that a slightly smaller content of chlorophyll *b* (Fig. 10 a) and carotenoids (Fig. 10 b) were in plants under modules with supplemental UV LEDs and chlorophyll *b* – under "SON-T Agro" lamps. The content of the latter pigment insignificantly increased under supplemental illumination by green 520 nm and orange 622 nm LEDs installed in modules. The content of chlorophyll a and carotenoids increased under module with supplemental yellow 595 nm LEDs. Meanwhile different illumination had effect on ratio of chlorophyll *a* to *b* and ratio of chlorophylls to carotenoids. The least chlorophyll *a* to and *b* ratio was in leaves of cucumber transplants under modules with supplemental UV (380 nm), green (520 nm) and orange (622 nm) LEDs (Fig. 10 c), but supplemental green and orange light increased chlorophyll and carotenoids ratio (Fig. 10 d).



Note. Treatments explanation in Table 1.
a – chlorophyll *a* and *b*, b – carotenoids, c – chlorophyll *a* to *b* ratio, d – chlorophylls to carotenoids ratio.
Pastaba. Variantai paaiškinti 1 lentelėje.
a – chlorofilas a ir b, b – karotenoidai, c – chlorofilo a ir b santykis, d – chlorofilų ir karotenoidų santykis.

Figure 10. Photosynthesis pigment content and ratio in green leaves of cucumber transplants grown under different LEDs illumination
10 paveikslas. *Fotosintezės pigmentų kiekis bei santykis agurkų daigų, augusių esant skirtingam diodiniam apšvietimui, žaliuose lapuose*

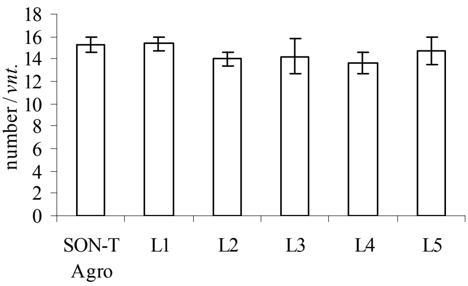
After four weeks of cultivation in the greenhouse, after-effect of different illumination on cucumber was observed. Growth and development of cucumber in greenhouse was estimated according to the developed leaf number. Significant differences were not established, but cucumbers whose transplants grew under module with the main set of LEDs and modules with supplemental green (520 nm) and orange (622 nm) light (Fig. 5) had slightly more leaves. Significant after-effect of illumination on the photosynthesis pigments content of cucumber in greenhouses was not determined. Slightly more photosynthetic pigments were in leaves of plants, whose transplants grew under module with the main set of LEDs (Fig. 11 a, b). Chlorophyll *a* to *b* ratio was insignificantly higher in cucumbers whose transplants grew under module with supplemental green light and chlorophyll to carotenoids ratio – under module with supplemental orange light (Fig. 11 c, d).

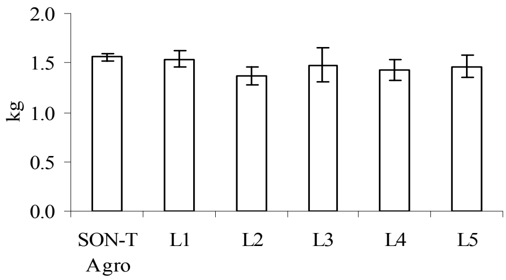


Note. Treatments explanation in Table 1.
a – chlorophyll *a* and *b*, b – carotenoids, c – chlorophyll *a* to *b* ratio, d – chlorophylls to carotenoids ratio.
Pastaba. Variantai paaiškinti 1 lentelėje.
a – chlorofilas a ir b, b – karotenoidai, c – chlorofilo a ir b santykis, d – chlorofilų ir karotenoidų santykis.

Figure 11. Photosynthetic pigment content and ratio in green leaves of cucumber after four weeks' cultivation in greenhouse
11 paveikslas. *Fotosintezės pigmentų kiekis bei santykis agurkų žaliuose lapuose po keturių savaičių auginimo šiltnamyje*

Supplemental illumination of cucumber transplants in various parts of spectrum had no effect either on fruit number (Fig. 12) of cucumber or on the yield (Fig. 13). Insignificantly lower yield was in those cucumbers whose transplants grew under module with supplemental UV 380 nm LEDs. Meanwhile the effect of different illumination was noticed on the beginning of flowering and harvest. Cucumbers whose transplants were grown under modules with supplemental green (520 nm) and orange (622 nm) LEDs began to flower and bear fruit earlier while those under "SON-T Agro" lamps (Table 4). By comparing illumination of various high-power solid-state lighting modules it was determined that cucumbers whose transplants were grown under module with supplemental UV 380 nm LEDs began to flower later.





Note. Treatments explanation in Table 1.
Pastaba. Variantai paaiškinti 1 lentelėje.

Figure 12. Number of fruit per plant
12 paveikslas. *Agurkų vaisių skaičius augale*

Figure 13. Cucumber yield per plant
13 paveikslas. *Agurkų derlius iš augalo*

The supplementation of the main high-power solid-state lighting module with 520 nm (green) LEDs had positive effect on cucumber seedling growth and development. These plants were most developed, i. e. were in 7th organogenesis stage, had more flowers (Table 2) and leaves (Fig. 4). Due to more rapid development, they grew up taller (Fig. 1). Cucumber transplants under modules with supplemental green 520 nm LEDs were thicker (Fig. 6), had greater fresh (Fig. 7) and dry weight (Fig. 8). These plants after transplant to the greenhouse began to flower and bear fruit earlier (Table 3). These results confirm literature data that the green light has a positive effect on plant growth. The supplemental green light in combination with red and blue LEDs may increase plant growth, since green light can penetrate into the plant canopy better than red or blue light /Kim et al., 2004 a; Kim et al., 2006/. However, it is claimed that the effect of green light for plants depends on its amount in illumination spectrum. Small flux of green light (5%) added to red and blue LEDs maintained the same growth rate compared to plants grown under red and blue LEDs. But among the other tested treatments the levels of green light (the addition of 24% green light to red and blue LEDs) enhanced plant growth. However, light sources with a higher fraction of green light (>50% of total PPF) were found to reduce plant growth /Kim et al., 2006/. Consequently, it is possible to consider that green LEDs quantum in the main high-power solid-state lighting module was optimal for cucumber seedlings' growth. Generally, literature data about the effect of green light is controversial. Some authors obtained reductions in growth, leaf number, internodes length, and a delay in flower induction of marigold, carnation and lettuce when white light was supplemented with green wavelengths /Klein et al., 1965/. Our investigations with tomato revealed that supplemental green light slightly inhibited transplant development /Brazaitytė et al., 2009/. This fact demonstrates that LEDs illumination requires selecting individual spectrum for each species.

The supplementation of the main high-power solid-state lighting module by UV LEDs decreased the growth and development of cucumber seedlings. In other studies the UV-A inhibition effect on cucumber growth /Krizek et al., 1998/ and growth of other different species /Flint, Caldwell, 2003; Yao et al., 2006/ also was determined. Many authors noted harmful effect of ultraviolet-A on photosynthetic apparatus /Turcsinyi, Vass, 2002; Yao et al., 2006/. In our investigations photosynthetic pigments contents in cucumber seedlings were only insignificantly lower compared with plants under the main high-power solid-state lighting module (Fig. 10).

Our experiments showed that the impact of supplemental yellow and orange light on cucumber transplants was contrary. Supplemental yellow light similar to UV decreased transplant growth and development. Literature data also shows that plant affected by yellow light had delicate stem, small leaves, reduced fresh and dry weight /Glowacka, 2002/. Other authors suggest that yellow light increased leaf area /Mortensen, Strømme, 1987; Spaargaren, 2001/, but enhanced internode elongation of various plants /Mortensen, Strømme, 1987/. Meanwhile, under effect of supplemental orange light growth and development of cucumber transplant were as rapid as under effect of green light. There is not much data about orange light effect on plants in literature and data are contradictory. Some authors state that orange lighting results in the elongation of internodes, higher shoot dry weight and a little higher chlorophylls content /Maas et al., 1995/. Another data of literature showed that the plants under orange light grow very slowly /Raab, 2003/.

Photosynthesis system responds to light most sensitively. Photosynthetic pigment content in higher plants is an important indicator for determining plants' physiological state. Chlorophyll loss is associated to environmental stress and the ratio of chlorophyll a to b is widely used as an indicator of plants response to stress /Netto et al., 2005/. Several studies have shown that carotenoids play an important role in the light harvesting complex and in the photoprotection of the photosystems /Demmig-Adams, Adams, 1996; Ort, 2001, Netto et al., 2005/. Changes in chlorophyll/carotenoids ratios are sensitive indicators of stress /Buckland et al., 1991/. Our investigations revealed that different illumination had no effect on photosynthetic pigments content in cucumber leaves (Fig. 10 a, b) Meanwhile, the smallest chlorophyll *a* to *b* ratio was in the leaves of cucumber transplants under modules with supplemental green (520 nm) and orange (622 nm) LEDs (Fig. 10 c) Higher chlorophyll to carotenoids ratio in these transplants shows that illumination conditions were suitable. Carotenoid content as a tool of photoprotection did not increase and plants were not in stress because of unsuitable illumination (Fig. 10 d). Chlorophyll *a* to *b* ratio could be less due to increased chlorophyll *b* synthesis. Suitable illumination conditions in modules with supplemental green (520 nm) and orange (622 nm) LEDs show more rapid growth and development of these transplants.

In plants sugar status modulates and coordinates internal regulators and environmental cues that govern growth and development /Rolland et al., 2002/. Low sugar status enhances photosynthesis, reserve mobilization, and export, whereas the abundant presence of sugars promotes growth and carbohydrate storage /Koch, 1996; Rolland et al., 2002/. High sugar accumulation during early seedling development may reflect undesirable growth conditions at a crucial developmental period /Rolland et al., 2002/. Metabolism reactions of hexoses are one of examples of reaction of plants metabolic flexibility during adaptation to unfavorable conditions /Plaxton, 1996/. Our investigations showed that the least content of monosaccharides was in the leaves of cucumber transplants under module with supplemental yellow 595 nm LEDs (Fig. 9). Total soluble sugar content was higher in these plants. It demonstrated that yellow light caused stress to cucumber transplants. Plants under module with supplemental yellow 595 nm LEDs also developed slowly (Table 2), had the smallest leaf area (Fig. 2).

Many investigations show that supplemental illumination of various intensity and quality of light greatly enhances plant growth and development. However, there was not much effect on subsequent plant growth after seedling transplantation or fruit production /McCall, 1992; Tremblay, Gosselin, 1998/. Our investigations also revealed that greenhouse conditions uniformed cucumber growth, i. e. after four weeks in the greenhouse they had similar leaf number. Photosynthetic pigments content also was similar. It was revealed that cucumber whose transplants developed the most (modules with supplemental green and orange light), began to flower and bear fruit earlier. Meanwhile, that had no effect on yield. Insignificantly lower yield was in cucumber whose transplants were grown under module with supplemental UV LEDs.

Summarizing our data it was revealed that optimizing lighting spectrum for growing of cucumber transplants it is worth supplementing the main set of blue, red and far red LEDs by green and orange LEDs.

Conclusions

1. Our experimental evidence suggests that optimizing LEDs illumination for cucumber hybrid ‘Mandy F1’ transplant with green or orange light could accelerate growth till maturity and decrease input of energy.

2. Obtained data shows that in such modules it is necessary to avoid UV light. After-effect of different illumination of various high-power solid-state lighting on cucumber yield was not revealed, but it had effect on the beginning of flowering and harvest.

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REFERENCES

1. Astolfi S., de Biasi M. G., Passera C. Effects of irradiance-sulphur interactions on enzymes of carbon, nitrogen, and sulphur metabolism in maize plants // Photosynthetica. – 2001, vol. 39, p. 177–181

2. Barta D. J., Tibbitts T. W., Bulla R. J. et al. Evaluation of light emitting diode characteristics for a space-based plant irradiation source // Advances in Space Research. – 1992, vol. 12, p. 141–150

3. Brazaitytė A., Duchovskis P., Urbonavičiūtė A. et al. After-effect of light-emitting diodes lighting on tomato growth and yield in greenhouse // Sodininkystė ir daržininkystė. – 2009, vol. 28, No. 1, p. 115–126

4. Buckland S. M., Price A. H., Hendry G. A. F. The role of ascorbate in drought-treated *Cochlear atlantic* Poked. and *Armeria maritima* (Mill) Wilid. // New Phytologist. – 1991, vol. 119, p. 155–160

5. Bula R. J., Morrow R. C., Tibbitts T. W. et al. Light-emitting diodes as a radiation source for plants // Horticultural Science. – 1991, vol. 26, No. 2, p. 203–205

6. Demmig-Adams B., Adams W. W. The role of xanthophyll cycle carotenoids in the protection of photosynthesis // Trends in Plant Science. – 1996, vol. l, p. 2l–26

7. Flint S. D., Caldwell M. M. Field testing of UV biological spectral weighting functions for higher plants // Physiologia Plantarum. – 2003, vol. 117, p. 145–153

8. Głowacka B. Wpływ barwy swiatła na wzrost rozsady pomidora (*Lycopersicon esculentum* Mill.) // Acta Scientiarum Polonorum. Hortorum Cutlus. – 2002, vol. 1, No. 2, p. 93–103

9. Heuvelink E., Bakker M. J., Hogendonk L. et al. Horticultural lighting in the Netherlands: new developments // Acta Horticulturae. – 2006, vol. 711, p. 25–33

10. Kim H. H., Goins G. D., Wheeler R. M. et al. Stomatal conductance of lettuce grown under or exposed to different light qualities // Annals of Botany. – 2004 (a), vol. 94, p. 91–97

11. Kim H. H., Wheeler R. M., Sager J. C. et al. Evaluation of lettuce growth using supplemental green light with red and blue light-emitting diodes in a controlled environment: a review of research at Kennedy Space Center // Acta Horticulturae. – 2006, vol. 711, p. 111–119

12. Kim S. J., Hahn E. J., Heo J. W., Paek K. Y. Effects of LEDs on net phothosynthetic rate, growth and leaf stomata of chrysanthemum plantlets *in vitro* // Scientia Horticulturae. – 2004 (b), vol. 101, p. 143–151

13. Klein R. M., Edsall P. C., Gentile A. C. Effects of near ultraviolet and green radiations on plant growth // Plant Physiology. – 1965, vol. 40, p. 903–906

14. Koch K. E. Carbohydrate modulated gene expression in plants // Annual Review of Plant Physiology and Plant Molecular Biology. – 1996, vol. 47, p. 509–540

15. Krizek D. T., Britz S. J., Mirecki R. M. Inhibitory effects of ambient levels of solar UV-A and UV-B radiation on growth of cv. 'New Red Fire' lettuce // Physiologia Plantarum. – 1998, vol. 103, p. 1–7

16. Kurilčik A., Miklušytė-Čanova R., Dapkūnienė S. et al. In vitro culture of Chrysanthemum plantlets using light-emitting diodes // Central European Journal of Biology. – 2008, vol. 3, No. 2, p. 161–167

17. Maas F. M., Bakx E. J., Morris D. A. Photocontrol of stem elongation and dry weight partitioning in *Phaseolus vulgaris* L. by the blue-light content of photosynthetic photon flux // Journal of Plant Physiology. – 1995, vol. 146, p. 665–671

18. Massa G. D., Kim H. H., Wheeler R. M. et al. Plant productivity in response to LED lighting // Horticultural Science. – 2008, vol. 43, No. 7, p. 1951–1956

19. McCall D. Effect of supplementary light on tomato transplant growth, and the after-effects on yield // Scientia Horticulturae. – 1992, vol. 51, No. 1–2, p. 65–70

20. Menard C., Dorais M., Hovi T. et al. Developmental and physiological responses of tomato and cucumber to additional blue light // Acta Horticulturae. – 2006, vol. 711, p. 291–296

21. Miyashita Y., Kimura T., Kitaya Y. et al. Effects of red and far-red light on the growth and morphology of potato plantlets in vitro: using light emitting diode (LEDs) as a light source for micropropagation // Acta Horticulturae. – 1997, vol. 418, p. 169–176

22. Mortensen L. M., Strømme E. Effect of light quality on some greenhouse crops // Scientia Horticulturae. – 1987, vol. 33, p. 27–36

23. Netto A. T., Campostrini E., de Oliveira J. G. et al. Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves // Scientia Horticulturae. – 2005, vol. 104, p. 199–209

24. Okamoto K., Yanagi T., Kondo S. Growth and morphogenesis of lettuce seedlings raised under different combinations of red and blue light // Acta Horticulturae. – 1999, vol. 435, p. 149–158

25. Ort D. When there is too much light // Plant Physiology. – 2001, vol. 125, p. 29–32

26. Piszczek P., Głowacka B. Effect of the colour of light on cucumber (*Cucumis sativus* L.) seedlings // Vegetable Crops Research Bulletin. – 2008, vol. 68, p. 71–80

27. Plaxton W. C. The organization and regulation of plant glycolysis // Annual Review of Plant Physiology and Plant Molecular Biology. – 1996, vol. 47, p. 185–214

28. Raab A. S. Plants under the rainbow. <www.edu./CSSF/History/2003/Projects/J1621.pdf> [accessed 23 11 2007]

29. Rolland F., Moore B., Sheen J. Sugar sensing and signaling in plants // The Plant Cell. – 2002, supplement, p. 185–205

30. Schuerger A. C., Brown C. S., Stryjewski E. C. Anatomical features of pepper plants (*Capsicuum annuum* L.) grown under red light-emitting diodes supplemented with blue or far-red light // Annals of Botany. – 1997, vol. 79, p. 273–282

31. Spaargaren J. J. Supplemental lighting for greenhouse crop. Hortilux Schreder B. V. and P. L. Light System, Inc. – Ontario, Canada, 2001, p. 26–29

32. Tamulaitis G., Duchovskis P., Bliznikas Z. et al. High-power light-emitting diode based facility for plant cultivation // Journal of Physics. D: Applied Physics. – 2005, vol. 38, p. 3182–3187

33. Tennessen D. J., Bula R. J., Sharkey T. D. Efficiency of photosynthesis in continuous and pulsed light emitting diode irradiation // Photosynthesis Research. – 1995, vol. 44, p. 261–269

34. Tremblay N., Gosselin A. Effect of carbon dioxide enrichment and light // Horticulture Technology. – 1998, vol. 8, No. 4, p. 524–528

35. Turcsinyi E., Vass I. Effect of UV-A radiation on photosynthetic electron transport // Acta Biologica Szegediensis. – 2002, vol. 46, No. 3–4, p. 171–173

36. Urbonavičiūtė A., Pinho P., Samuolienė G. et al. Effect of short-wavelength light on lettuce growth and nutritional quality // Sodininkystė ir daržininkystė. – 2007, vol. 26, No. 1, p. 157–165

37. Wettstein D. Chlorophyll Letale und der submikroskopishe Formweschsel der Plastiden // Experimental Cell Research. – 1957, vol. 12, p. 427

38. Yao Y., Yang Y. J., Ren J. et al. UV-spectra dependence of seedling injury and photosynthetic pigment change in *Cucumis sativus* and *Glycine max.* // Environmental and Experimental Botany. – 2006, vol. 57, p. 160–167

39. Yorio N. C., Goins G. D., Kagie H. R. et al. Improving spinach, radish, and lettuce growth under red light-emitting diodes (LEDs) with blue light supplementation // Horticultural Science. – 2001. vol. 36, p. 380–383

40. Žukauskas A., Shur M. S., Gaska R. Intruduction to Solid-State Lighting. – New York, 2002. – 220 p.

41. Куперман Ф. М., Ржанова Е. И., Мурашев В. В. и др. Биология развития культурных растений. – Москва, 1982. – 342 с.

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Kietakūnio apšvietimo poveikis agurkų daigams ir derliui

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Santrauka

Tyrimų tikslas – optimizuoti kietakūnio apšvietimo spektrą auginant agurkų daigus ir nustatyti jo poveikį derliui. Agurkų daigai auginti 2007 m. LSDI Fiziologijos laboratorijos fitotrono kamerose. Fotoperiodas – 18 h, dienos ir nakties temperatūra – atitinkamai +22 ir +18 °C. Tyrimams naudotas kietakūnio apšvietimo modulis, sudarytas iš penkių puslaidininkinių lempų su skirtingais šviestukų deriniais. Kaip pagrindiniai visose lempose buvo naudoti 447, 638, 669 ir 731 nm bangos ilgio šviestukai. Atitinkamose lempose naudoti tokie papildomi šviestukai: L2 – 380 nm, L3 – 520 nm, L4 – 595 nm, L5 – 622 nm, o L1 – be papildomų šviestukų. Kontroliniai augalai auginti po „SON-T Agro“ („Philips“, JAV) lempomis. Agurkų daigai persodinti į šiltnamį ir auginti durpių substrate. Nustatyta, kad, kietakūnio apšvietimo spektrą papildžius mėlynos, raudonos bei tolimosios raudonos bangų ir žalios arba oranžinės šviesos šviestukais, galima pagreitinti agurkų daigų auginimą iki techninės brandos ir taip sumažinti energijos sąnaudas. Gauti duomenys parodė, kad tokiuose moduliuose reikėtų vengti UV ir geltonos spektro dalies šviestukų. Agurkų derliui dėsningo skirtingo apšvietimo poveikio nebuvo aptikta, bet toks apšvietimas turėjo įtakos žydėjimo ir derėjimo pradžiai.

Reikšminiai žodžiai: vystymasis, augimas, fotosintezės pigmentai, sacharidai, šviesos spektras, derlius.