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After-effect of light-emitting diodes lighting on tomato growth and yield in greenhouse

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The objective of our studies was to evaluate growth, development and yielding of tomato in greenhouse, which transplants were grown under various combinations of light-emitting diodes illumination. Tomato transplants were grown in phytotron chambers. System of five high-power solid-state lighting modules with the main 447, 638, 669 and 731 nm LEDs were used in the experiments. Supplemental LEDs of different wavelength were used in particular modules: L1 – without additional LEDs, L2 – 380 nm, L3 – 520 nm, L4 – 595 nm, L5 – 622 nm. The similar photon flux density (PFD) in all modules was maintained by regulating PFD of 638 nm LEDs. Tomato seedlings were transplanted to peat substratum and grown in greenhouses. It was established that significant effect of illumination using different LEDs combination on growth and development of tomato hybrid 'Raissa' F_1 transplants remained about one month after moving tomato to greenhouses. After-effect on photosynthesis pigments system of tomatoes in greenhouses lasted two weeks. Neither of light-emitting diodes combination had significant effect on early tomato yield. Yellow light, supplemental for the main LEDs combination, used for transplant illumination, decreased total tomato yield.

Key words: growth, high-power light-emitting diodes, illumination spectrum, photosynthetic pigments, tomato, yield.

Introduction. The tomato is a commercially important crop throughout the world. At northern latitudes tomato are grown in greenhouses: planted in mid-winter and harvested until late autumn. Transplants are produced under unfavourable conditions of low natural light and short daylengths, and supplementary illumination can promote plant growth and earlier yield later (Boivin et al., 1987; McCall, 1992;

McCall, 1996). Most commonly high-pressure sodium lamps (HPS) are used for such lighting. Illumination with HPS lamps is neither spectrally optimal, nor energetically effective (Spaargaren, 2001; Heuvelink et al., 2006). In 1990 light-emitting diodes (LEDs) were tested for plant growth (Bula et al., 1991) and now more and more often are used for plant lighting (Morrow, 2008). LEDs have a variety of advantages over traditional forms of horticultural lighting. Their small size, durability, long lifetime, cool emitting temperature, and the option to select specific wavelengths for targeted plant response make LEDs more suitable for plant-based uses than many other light sources (Massa et al., 2008). LED illumination has been studied for such horticultural plants as lettuce (Bula et al., 1991; Yorio et al., 2001, Brazaitytė et al., 2006; Kim et al., 2004), radish (Yorio et al., 2001; Tamulaitis et al., 2005), spinach (Yorio et al., 2001), pepper (Schuerger et al., 1997), tomato (Kaneko-Ohashi et al., 2004; Menard et al., 2006), strawberry (Yanagi et al., 2006). However, light-emitting diodes systems are most often based on such light components as blue, red and far-red LEDs (Schuerger et al., 1997; Lian et al., 2002; Jao and Fang, 2004; Matsuda et al., 2004) or hybrid illumination such fluorescent supplemented by red or blue LEDs (Schuerger et al., 1997; Yorio et al., 2001; Topchiy et al., 2005; Menard et al., 2006). Few years ago Kim et al. (2004; 2006) tested red, blue and green LEDs system for lettuce growth. Data about the use of other LED colours for plant cultivation was not found. Though in literature there are some data about tomato growth and harvest using LEDs as supplement for HPS lamps during the whole growth period (Menard et al., 2006), but there are no data about tomato transplant growth using sole illumination of light- emitting diodes and after-effects on yield.

The objective of this study was to evaluate growth, development and yielding of tomato in greenhouse, which seedlings were grown under various combinations of light-emitting diodes.

Objects, methods and conditions. Vegetative trials were performed in chambers and greenhouse of phytotron complex of LIH. Tomato hybrid 'Raissa' F_1 was sown in peat substrate (pH 6.0–6.5) enriched with fertilizers PG MIX (NPK 14-16-18; 1.3 kg/m^3). All plants were watered when necessary. Photoperiod till tomato germination was 14 h and temperature was maintained at 23 °C. After germination photoperiod was 18 h and day/night temperature was maintained at 22/18 °C.

Tomato seedlings were transplanted to the greenhouse and planted in tumblers (54 × 37 × 33 cm) with peat substratum (two plants per tumbler). Plants were watered when necessary and fertilized three times per week with 0.2 % complex fertilizes "Kemira Combi" (NPK 14:11:25 plus magnesium (1.4 %) and microelements). Tomatoes in greenhouse were grown for 4.5 months and yield was harvested from six trusses.

Tomato seedlings were grown 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 447 (LuxeonTM type LXHL-LR5C, *Lumileds Lighting*, USA), 638 (LuxeonTM type LXHL-MD1D, *Lumileds Lighting*, USA), 660 (for L1) (L660-66-60, *Epitex*, Japan), 669 (L670-66-60, *Epitex*, Japan) and 731 (L735-05-AU, *Epitex*, Japan) nm LEDs were used in the experiments. Supplemental LEDs of different wavelengths were used in particular modules: L1 – without additional LEDs, L2 – 380 nm (NCCU001E, Nichia, Japan), L3 – 520 nm (LuxeonTM type LXHL-MM1D, *Lumileds Lighting*, USA), L4 – 595 nm (LuxeonTM type LXHL-MLAC, *Lumileds Lighting*, USA), L5 – 622 nm (LuxeonTM type LXHL-MHAC, *Lumileds Lighting*, USA). The similar photon flux density (PFD) in all modules was maintained by regulating PFD of 638 nm LEDs. For comparison, a parallel growth of the same plant (reference) was performed under illumination of high-pressure sodium lamps SON-T-Agro (PHILIPS).

Table 1. Photon flux densities (PFD) in μmol m^{-2} s^{-1} in five high-power solid-state lighting modules

1 lentelė. Fotonų srauto tankis skirtinguose moduliuose automatizuotoje penkių modulių apšvietimo sistemoje (μmol m^{-2} s^{-1})

Treatment Šviestuvas	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)	total bendras
L1	-	30	-	-	-	117	24	-	7	178
L2	9	31	-	-	-	130	-	23	7	200
L3	-	30	12	-	-	122	-	23	7	194
L4	-	31	-	15	-	130	-	23	7	206
L5	-	31	-	-	29	130	-	23	7	220

Height, number of leaves and organogenesis stages (according to methodology of Kuperman (Куперман et al., 1982)) of tomato plants were determined during eight weeks, one time per week. Photosynthetic pigments content per one gram of green foliage weight was measured in 100 % acetone extract according to Wettstein method (Wettstein, 1957) using Genesys 6 spectrophotometer (ThermoSpectronic, USA). Measurements were performed in three replicates after transplantation and after two, four and eight weeks in greenhouse. The first leaf above first inflorescence was taken for measurement of photosynthetic pigments. Ripe fruits were harvested three times per week. The results were analysed using the analysis of variance (ANOVA). Standard deviations were determined by MS Excel and were denoted as error bars in all column-based figures.

Results. SON-T Agro lamps delayed the development of tomato transplants. Transplants were the shortest, formed the least number of leaves (Table 2). Some plants were only in organogenesis stages V, i. e. plants still were at flower formation stage (Полумордвинова, 1976) (Table 3). Comparing to tomato transplants, grown under different high-power solid-state lighting treatments, it was determined that the main LEDs combination with supplemental orange (662 nm) light decreased the number of leaves formed and the height of plants. Tomato transplants, grown under the main LEDs combined with supplemental 520 nm light (L3) were slightly higher and have formed one leaf more than above-mentioned plants (Table 2).

Table 2. Changes of some biometric indices in tomato after transplantation to the greenhouse
2 lentelė. Pomidorų biometrinių rodiklių pokyčiai persodinus į šiltnamį ir toliau jame auginant

Weeks after transplantation Savaitės po persodinimo	Indices Rodikliai	Treatments Apšvietimo derinys					
		"SonT-Agro"	L1	L2	L3	L4	L5
During transplantation Persodinimo metu	Height Aukštis (cm)	23.5 ± 1.1	43.4 ± 0.9	45.8 ± 3.0	38.6 ± 1.7	46.6 ± 0.7	33.0 ± 2.0
	Number of leaves Lapų skaičius	4.6 ± 0.4	7.6 ± 0.2	7.6 ± 0.2	7.4 ± 0.2	7.6 ± 0.2	6.4 ± 0.2
1	Height Aukštis (cm)	30.1 ± 2.4	41.2 ± 2.2	42.2 ± 1.2	37.4 ± 2.0	39.8 ± 1.8	32.8 ± 2.5
	Number of leaves Lapų skaičius	7.0 ± 0	7.5 ± 0.2	8.0 ± 0.2	7.2 ± 0.4	7.5 ± 0.2	6.8 ± 0.5
2	Height Aukštis (cm)	41.0 ± 1.8	56.8 ± 2.5	56.0 ± 1.8	49.7 ± 2.3	52.5 ± 2.5	45.3 ± 3.0
	Number of leaves Lapų skaičius	8.7 ± 0.2	10.2 ± 0.2	10.3 ± 0.2	9.2 ± 0.4	9.5 ± 0.2	8.8 ± 0.5
3	Height Aukštis (cm)	61.7 ± 1.7	79.3 ± 2.0	77.3 ± 2.1	68.7 ± 2.1	73.5 ± 2.7	64.8 ± 3.5
	Number of leaves Lapų skaičius	11.8 ± 0.2	13.5 ± 0.2	13.2 ± 0.2	12.8 ± 0.4	12.5 ± 0.2	11.8 ± 0.5
4	Height Aukštis (cm)	79.7 ± 1.3	94.2 ± 3.8	94.2 ± 2.4	89.2 ± 1.9	94.5 ± 4.4	85.7 ± 3.9
	Number of leaves Lapų skaičius	14.2 ± 0.4	15.7 ± 0.4	15.7 ± 0.4	14.7 ± 0.2	15.5 ± 0.2	14.8 ± 0.5
5	Height Aukštis (cm)	103.3 ± 2.1	114.8 ± 4.4	117.6 ± 3.4	113.2 ± 2.2	120.6 ± 6.1	110.4 ± 3.8
	Number of leaves Lapų skaičius	16.5 ± 0.5	17.5 ± 0.2	17.7 ± 0.2	16.7 ± 0.4	17.8 ± 0.3	16.7 ± 0.5
6	Height Aukštis (cm)	119.4 ± 2.0	130.3 ± 5.9	132.1 ± 3.4	130.3 ± 2.6	138.3 ± 6.5	126.4 ± 3.3
	Number of leaves Lapų skaičius	18.8 ± 0.4	20.2 ± 0.5	20.5 ± 0.2	19.7 ± 0.2	20.5 ± 0.4	19.0 ± 0.4
7	Height Aukštis (cm)	140.1 ± 1.9	151.1 ± 5.9	154 ± 4.3	153.8 ± 2.9	158.8 ± 6.6	147.2 ± 3.5
	Number of leaves Lapų skaičius	21.2 ± 0.5	23.2 ± 0.5	23.0 ± 0.3	23.3 ± 0.4	24.0 ± 0.4	22.2 ± 0.4
8	Height Aukštis (cm)	150.4 ± 2.8	163.5 ± 6.2	166.8 ± 4.5	169.6 ± 2.6	172.8 ± 6.8	163.6 ± 2.8
	Number of leaves Lapų skaičius	24.0 ± 0.2	25.2 ± 0.3	24.8 ± 0.4	25.0 ± 0.4	25.5 ± 0.5	24.8 ± 0.6

However, supplemental green light slightly inhibited transplant development. Most of plants were in organogenesis stages VII–VIII (gametogenesis and bud formation occurred), but there still were some plants in organogenesis stage VI, i. e. micro- and macrosporogenesis occurred (Полумордвинова, 1976). Such transplants had the smallest apex in comparison to transplants grown under other LEDs combinations (Table 3).

Table 3. Development of tomato apex after transplantation to the greenhouse (according F. Kuperman)
3 lentelė. Pomidorų kūgelio vystymąsis (pagal F. Kuperman) persodinus į šiltnamį

Weeks after transplantation Savaitės po persodinimo	Development of apex Augimo kūgelio išsivystymas	Treatments Apšvietimo derinys					
		"SonT-Agro"	L1	L2	L3	L4	L5
During transplant Persodinimo metu	Stage Etapas	V–VII	VII–VIII	VII–VIII	VI–VIII	VII–VIII	VII–VIII
	Height Aukštis (mm)	1.3 ± 0.3	8.4 ± 3.8	13.9 ± 2.8	5.7 ± 2.5	10.5 ± 2.9	7.2 ± 3.6
1	Stage Etapas	VIII	VII–IX	VIII–IX	VIII–IX	VIII–IX	VII–IX
	Height Aukštis (mm)	17.7 ± 3.9	27.5 ± 6.2	33.3 ± 3.1	25.9 ± 4.7	27.7 ± 5.2	22.8 ± 7.2
2	Stage Etapas	VIII–IX	VIII–X	IX–X	VIII–X	VIII–X	VIII–X
	Height Aukštis (mm)	35.2 ± 5.7	53.0 ± 8.4	63.2 ± 6.2	51.3 ± 4.9	54.8 ± 4.7	45.2 ± 9.8
3	Stage Etapas	IX–X	VIII–X	X	IX–X	IX–X	IX–X
	Height Aukštis (mm)	83.0 ± 9.8	106.7 ± 10.0	108.0 ± 10.5	94.8 ± 7.0	86.8 ± 7.7	85.0 ± 9.9
4	Stage Etapas	X	X	X	X	X	X
	Height Aukštis (mm)	140.0 ± 12.8	152.5 ± 6.9	130.0 ± 14.7	127.5 ± 13.5	125.0 ± 14.2	120.0 ± 8.5
5	Stage Etapas	X	X	X	X	X	X
	Height Aukštis (mm)	153.3 ± 13.3	171.6 ± 14.4	145.0 ± 14.7	147.5 ± 18.3	130.0 ± 16.6	138.3 ± 8.4
6	Stage Etapas	X	X	X	X	X	X
	Height Aukštis (mm)	164.2 ± 8.4	178.3 ± 14.0	148.3 ± 18.3	161.7 ± 16.2	142.5 ± 14.6	162.5 ± 11.2
7	Stage Etapas	XI	XI	XI	XI	XI	XI
	Height Aukštis (mm)	173.3 ± 9.1	188.3 ± 11.7	160.8 ± 19.0	174.2 ± 20.3	146.7 ± 12.6	172.5 ± 11.1
8	Stage Etapas	XI	XI–XII	XII	XI–XII	XI	XI
	Height Aukštis (mm)	181.7 ± 8.7	195.8 ± 10.5	172.5 ± 14.5	184.2 ± 20.2	156.7 ± 11.0	181.7 ± 11.5

Tomato transplants, grown under the main LEDs illumination without supplemental LEDs (L1) and under combination with supplemental 380 nm (L2) and 595 nm (L4) lights were higher than above mentioned plants, but no significant differences neither in height nor in number of leaves was determined between them (Table 2). These transplants were at organogenesis stages VII–VIII (Table 3), i. e. gametogenesis and bud formation occurred (Полумордвинова, 1976). However, the main LEDs treatment with supplemental 380 nm light stimulated the height of apexes of tomato transplants (Table 3).

In the greenhouse such tomato growth trends remained for about four weeks (Table 2). Later the height of tomato, which transplants were grown using five different high-power solid-state lighting combinations, equalised. After-effect of SON-T Agro lamps still was noticed after seven weeks growth period in greenhouse. Such plants were lower and had two leaves less than others. Tomatoes, which transplants were grown under the main LEDs combined with supplemental orange (662 nm) light (L5), formed one leaf less. Significant differences in leaf number were not observed in the eighth growth week in greenhouse (Table 2).

The effect of different illumination for tomato development was more noticeable till third growth week in greenhouse (Table 3). At that time all tomato, which transplants were grown under LEDs combined with supplemental 380 nm light (L2), were at organogenesis stages X, i. e. their fruits grew more intensively, and they had the greatest inflorescence. The first inflorescence of tomato, which transplants were grown under the main LEDs treatment, was the similar height as above mentioned, but some plants still were at organogenesis stage VIII. Later, the after-effect of different illumination was not determined. All tomatoes were at organogenesis stages X–XI, which generally last for more than forty days (Полумордвинова, 1976). Supplemental 380 nm light for transplant illumination accelerated fruit ripening. All plants were at organogenesis stage XII. Fruits also ripened on some plants, which transplants were grown under main LEDs treatment and under supplemental 520 nm light (L3). There were no matured fruits on tomatoes (organogenesis stage XI), which transplants were grown under SON-T Agro lamps and under LEDs combinations with supplemental 595 nm (L4) and 622 nm (L5) light.

Photosynthesis pigment content was significantly higher in the leaves of tomato transplants, which were grown under the main LEDs treatment and under combination with supplemental 380 nm light (L2) (Fig. 1). Such trend remained for two weeks growing period in greenhouse. Yellow LEDs, supplemental for the main combination (L4), had no negative effect on pigment contents in leaves of tomato transplants. Though total chlorophylls content in these tomatoes was significantly lower after two weeks growth in greenhouse. Differences in photosynthesis pigment contents in tomato leaves were insignificant after one and after two months of growth period in greenhouse. Ratio of chlorophyll a and b was significantly higher in leaves of tomato transplants, grown under the main LEDs treatment and under combination with supplemental 595 nm light (L4). After two weeks of growth period in greenhouse it was higher in tomatoes, which transplants were grown under LEDs combination with supplemental 595 nm and 622 nm (L5) light.

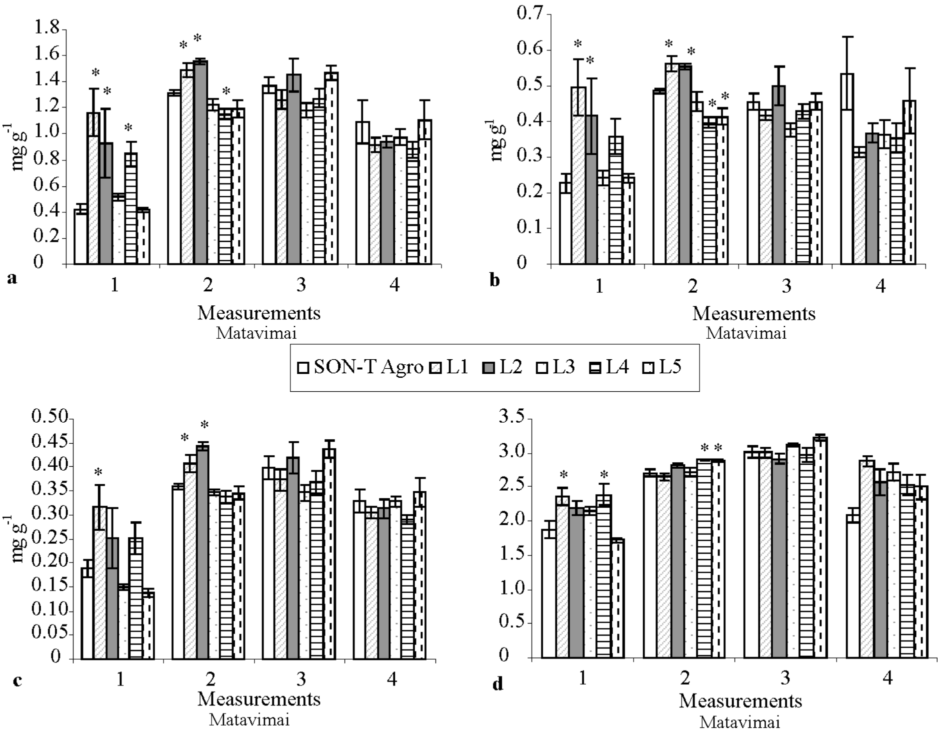

Fig. 1. Changes in photosynthesis pigment content in tomato leaves after transplantation to the greenhouse. Measurements: 1 – during transplantation, 2 – after two weeks, 3 – after four weeks, 4 – after eight weeks in the greenhouse. Significant differences from reference treatment are denoted by an asterisk (*) at $p \leq 0.05$ (mean ± SE, n = 3).

1 pav. Pomidorų fotosintezės pigmentų pokyčiai lapuose po persodinimo auginant šiltnamyje. Matavimai: 1 – persodinimo metu, 2 – po dviejų savaičių, 3 – po keturių savaičių, 4 – po aštuonių savaičių. Reikšmingi skirtumai nuo kontrolinių augalų pažymėti žvaigždute (*) $p \leq 0.05$ (vidurkis ± standartinė paklaida, n = 3).

Early yield of tomato differed insignificantly. However, the yields of tomatoes, which transplants were grown under the main LEDs treatment and under combination with supplemental 380 nm light (L2), was slightly greater and more fruits were formed. Using SON-T Agro lamps, and yellow and orange LED light, supplemental for the main in LEDs treatment for tomato transplant illumination, the lower early yield and fruit number at that moment was determined. Total yield significantly decreased using supplemental 595 nm (L4) LEDs in the main LEDs treatment for transplant illumination.

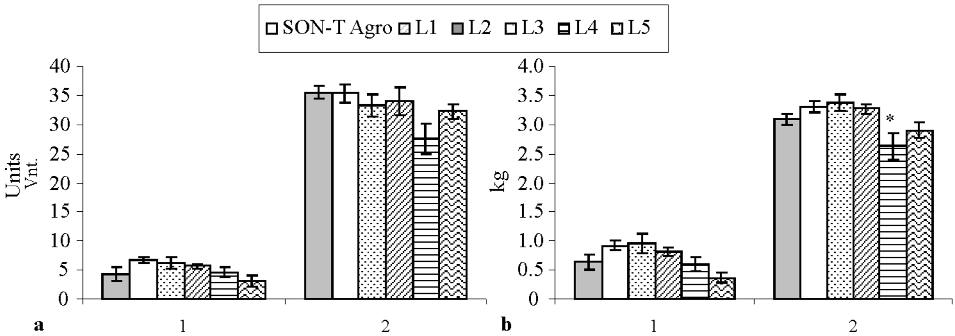

Fig. 2. Fruit number (a) and yield (b) per tomato plant. 1 – after two weeks, 2 – total. Significant differences from reference treatment are denoted by an asterisk (*) at $p \leq 0.05$ (mean ± SE, n = 6).

2 pav. Pomidorų vaisių skaičius (a) ir derlius (b) iš augalo. 1 – po dviejų savaičių, 2 – bendras. Reikšmingi skirtumai nuo kontrolinių augalų pažymėti žvaigždute (*) $p \leq 0.05$ (vidurkis ± standartinė paklaida, n = 6).

Discussion. Usually the tomato transplants are grown during autumn–winter period when natural day length is short and light intensities low. Many investigations show that supplemental illumination of various intensity and quality of light greatly enhanced plant growth and development. However, there was not much effect on subsequent plant growth after seedling transplanting or fruit production (Boivin et al., 1987; McCall, 1992; Tremblay, Gosselin, 1998). According to the literature data, the timing of the use of supplemental lighting is important. The use of supplemental lighting for tomato, the cultivation of tomato transplants in December and January showed benefits against usual lighting treatments, but, when plants were cultivated in March, lighting had no effect. As natural light conditions improves in spring, the influence of supplemental lighting was reduced (Boivin et al., 1987; Tremblay, Gosselin, 1998). For better investigation of after-effects of different lighting and for elimination of the other factor impact, experiments were carried out in phytotron chambers. It was established that different illumination conditions during tomato transplant growth had after-effect for their growth in greenhouse about four weeks. After seven weeks growth period in greenhouse, tomatoes, which transplants were grown under the main LEDs combined with supplemental orange light and under SON-T Agro lamps, still had formed less leaves and lower in height in comparison with other treatments.

Different lighting provided during transplant cultivation influenced tomato development in greenhouse. During investigation, it was established that 380 nm UV light, supplemental for the four main LED components, stimulated tomato development. This effect remained till third growth week in greenhouse. Such lighting slightly accelerated harvesting time and increased early and total yield. According to McCall (1992), greater early yield and marked value was maintained by increasing levels of supplementary light and remained throughout 16 week harvesting period. It was found no significant differences in fruit number, yield or mean fruit size in other investigations with supplemental lighting of various intensity and quality (Decoteau, Friend, 1991; Evans, McMahon, 2000). In our vegetative trials harvest period lasted for 8 weeks and yield was harvested from six clusters, because generally 4–5 inflorescences developed during tomato transplants growth under selected illumination conditions (Полумордвинова, 1976) and only they could be influenced by different lighting.

Different lighting influenced photosynthesis pigment contents in tomato transplant leaves. Leaves of tomato transplants grown under the main LEDs composition (L1) and under combination with supplemental 380 nm light (L2) had greatest pigments content in comparison to other treatments. Such trends remained for two weeks of growth in the greenhouse period. Photosynthesis pigments content was remarkably increased in the leaves of tomatoes, which transplants were grown under the main LEDs combination with supplemental 380 nm light. Higher content of photosynthesis pigments generally determines the more intensive photosynthesis process. Higher content of assimilates produced during this process could be transported to fruits at the stage of intensive growth (organogenesis stage X), thus determined a slightly greater early yield.

Tomatoes, which transplants were illuminated with the main LEDs combined with supplemental 595 nm (L4) and 622 nm (L5) light, should be mentioned individually. Though the main LEDs combination with supplemental yellow light influenced tomato transplant development and photosynthesis pigments content similarly, as the main LEDs treatment and combination with supplemental 380 nm light, but their development slowed down during the growth period in the greenhouse. These tomatoes were not ripened yet after eight weeks of growth period in greenhouse. Total chlorophyll content in leaves of these tomatoes was significantly lower after two weeks of growth period in greenhouse in comparison to other treatments. Their total yield was significantly lower. Possibly, yellow light in the main LEDs composition could disturb normal photosynthesis process, determine senescence and decreased productivity of plants. Glowacka and Piszcek (2003) also determined that the application of yellow light during transplant production considerably delayed the fruit yield. The main LEDs, combined with supplemental orange light provided for tomato transplant illumination, reduced height, number of leaves and photosynthesis pigment contents in leaves. Their growth and development in the greenhouse was slower and the yield was similar to this of tomatoes, which transplants were grown under the main LEDs combined with supplemental 595 nm light. Data about orange light effect on tomato was not found, but it was noticed in literature that the plants under orange light grew very slowly (Raab, 2003).

Conclusions. We conclude that significant effect of different LED illumination on growth and development of tomato hybrid 'Raissa' F_1 transplants remained for about one month after tomato transplantation in greenhouses. After-effect on tomato photosynthesis pigment system in greenhouses continued for two weeks. Neither of LED combinations had significant effect on early tomato yield. Yellow light, supplemental for the main LEDs treatment, used for illumination during transplant growth period decreased total tomato yield.

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Pomidorų augimas ir derėjimas šiltnamyje po kietakūnio apšvietimo poveikio daigams

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Santrauka

Tyrimų tikslas – ištirti pomidorų augimą, vystymąsi ir derėjimą šiltnamyje po to, kai daigai buvo auginami švitinant puslaidininkinėmis lempomis su skirtingų spektrinių komponenčių deriniais. Pomidorų daigai auginti fitotrono kamerose. 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 šviestukai. Atitinkamose lempose buvo naudoti tokie papildomi šviestukai: L1 – be papildomų šviestukų, L2 – 380 nm, L3 – 520 nm, L4 – 595 nm, L5 – 622 nm. Po skirtingomis lempomis išauginti pomidorų daigai buvo toliau auginti šiltnamyje. Tyrimų rezultatai parodė, kad didelis skirtingo daigų apšvietimo poveikis pomidorų augimui ir vystymuisi išliko pirmąjį auginimo šiltnamiuose mėnesį. Šis poveikis fotosintezės pigmentų sistemai truko dvi savaites. Labai didelės įtakos ankstyvam pomidorų derliui nenustatyta. Papildoma geltona šviesa, naudota daigams apšviesti, mažino bendrą pomidorų derlių.

Reikšminiai žodžiai: augimas, derlius, fotosintezės pigmentai, kietakūnis apšvietimas, spektras, pomidorai.