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The effect of light-emitting diodes lighting on the growth of tomato transplants

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Abstract

The objective of our studies was to evaluate the growth of tomato transplants, cultivated under various combinations of light-emitting diodes and high-pressure sodium (HPS) lamps. The transplants of tomato hybrid ‘Raissa F_1’ were grown in phytotron chambers. Day/night temperature till germination was 23°C, and a 14-h photoperiod was maintained. After the germination, photoperiod was 18 h and the day/night temperature was 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 – 380 nm, L3 – 520 nm, L4 – 595 nm, L5 – 622 nm. For comparison, tomato transplants were grown under the illumination of high-pressure sodium lamps “SON-T Agro” (“Philips”, USA). Our investigations revealed that the growth of tomato hybrid ‘Raissa F_1’ transplant was enhanced under supplemental UV (380 nm) light in the high-power solid-state lighting modules with the main blue, red and far red LEDs. Therefore such LEDs can be used in modules for the cultivation of tomato transplants and it is important for their quality. Supplemental orange (622 nm), yellow (595 nm) and green (520 nm) light was not suitable for the growth of tomato transplants. The positive effect of supplemental UV and the negative effect of orange, yellow and green light were revealed in the later growing stages of tomato transplants.

Key words: growth, illumination spectrum, solid-state lighting, tomato, transplants.

Introduction

Electric lamps have been used to grow plants for nearly 150 years (Wheeler, 2008). The path of their development followed from incandescent lighting, open arc lighting and enclosed gaseous discharge lamps till high-pressure sodium (HPS) lamps, which still are the most popular for supplemental lighting in greenhouses. HPS lamps have high electrical efficiencies, a long operating life and a wide spectrum of light, which is suitable for many plant species (Wheeler et al., 1991; Spaargaren, 2001; Wheeler, 2008). These lamps emit light in the visible (400–700 nm) and the invisible (700–850 nm) ranges, but the peak emission is in the yellow light (~589 nm) region. High amount of yellow light causes the stem elongation of plants and worsens the quality of transplants (Wheeler et al., 1991; Glowacka, 2002). The solid-state lighting using light-emitting diodes (LEDs) represents a fundamentally different technology from the gaseous discharge-type lamps currently used in horticulture and has more advantages than the traditional forms of lighting. 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 (Massa et al., 2008; Morrow, 2008). One of the main advantages of LEDs is the ability to control spectral output of the lighting system. LEDs are already available in the entire relevant spectral range from near infrared (IR) to near ultraviolet (UV) and can be customized for the specific crops, optimized for maximum production without wasting energy and nonproductive wavelengths (Tamulaitis et al., 2005; Morrow, 2008). Due to the high cost of LED lighting systems, early investigations were aimed at developing better light sources for space-based plant-growth systems (Goins et al., 1997; Yorio et al., 2001; Morrow, 2008). LEDs are well suited for the tissue culture applications because of their low profile and low radiant heat output (Morrow, 2008). They were tested *in vitro* for such plants as potato (Seabrook, 2005), chrysanthemum (Kurilčik et al., 2008), and strawberry (Nhut et al., 2003). LEDs were also used for lighting of various plants in controlled environments and supplemental lighting in greenhouses (Tennessen et al., 1995; Schuerger et al., 1997; Yorio et al., 2001; Tamulaitis et al., 2005; Morrow, 2008; Brazaitytė et al., 2009 b; Urbonavičiūtė et al., 2009), but these applications are still in the early stages of development (Morrow, 2008). Although in literature there is some data about tomato growth and harvest using LEDs as supplement for HPS lamps during the whole growth period (Menard et al., 2006), there is no data about tomato transplant growth using light-emitting diodes. The tomato is a commercially important crop throughout the world. At the northern latitudes tomatoes are grown in the greenhouses: planted in mid-winter and harvested until late autumn. Transplants are produced under unfavourable conditions of low natural light and short daylengths, therefore supplementary illumination can promote plant growth and early yield (Boivin et al., 1987; McCall, 1992). Supplementary illumination also requires high electrical power input, whereas solid-state lighting using light-emitting diodes is energy-saving.

The objective of our studies was to evaluate the growth dynamics of tomato transplants, cultivated under various combinations of light-emitting diodes and high-pressure sodium (HPS) lamps.

Materials and methods

Pot experiments were performed in 2007 in chambers and greenhouse of phytotron complex at the Lithuanian Institute of Horticulture. Tomato hybrid 'Raissa F_1' was seeded in the peat substrate (pH 6.0–6.5) enriched with fertilizers PG MIX (NPK 14:16:18; 1.3 kg m^{-3}). Plants were watered when necessary. A 14-h photoperiod and 23°C temperature were maintained till tomato germination. After the germination, the photoperiod was 18 h and the day/night temperature 22/18°C. The relative air humidity was 75%.

After sowing, tomato transplants were cultivated for 30 days under illumination, in which photon flux density (PPFDs) and spectral distributions were maintained as specified in Table 1. A 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. The 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). Reference plants were grown under the illumination of high-pressure sodium lamps "SON-T Agro" ("Philips", USA) with similar photon flux density (PPFDs) as in the LED modules.

Five plants (n = 5) were harvested at weekly intervals starting from the day 7 after expanding of the first leaf to determine height, hypocotyl diameter, number of fully expanded leaves, leaf area, shoot and root fresh and dry weight. Tomato seedlings were harvested three times, until plants were transplanted in greenhouses. Shoots and roots were dried in a drying oven at 105°C for 24 h to determine dry weight. The leaf area of tomato plants was measured by "WinDias" leaf area meter (Delta-T Devices Ltd, UK). Plant height was measured to the tip of the youngest leaf. Dry weight and leaf area data were used to determine the relative growth rate (it was obtained by the following formula $RGR = (\ln W_2 - \ln W_1)/(t_2 - t_1)$), where W_2 and W_1 are total plant dry weights at times t_2 and t_1, respectively), the net assimilation rate ($NAR = (1/A)\,(dW/dt)$, where A is leaf area and dW/dt is the change in plant dry matter per unit time), leaf area ratio (LAR, leaf area divided by total dry weight), specific leaf area (SLA, leaf area divided by the dry weight of leaves), leaf weight ratio (LWR, the dry weight of leaves divided by the total dry weight) and shoot:root ratio (SRR).

The levels of significance for the 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 $P \leq 0.05$.

Table 1. Photon flux densities (PPFDs) in five high-power solid-state lighting modules

Treatment	Photon flux densities 10 cm from light source (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

Results and discussion

Light is the main environmental factor affecting plant growth and biomass production. Insufficient light intensity or quality limits the growth and the development of tomato transplants, especially during the first inflorescence development and therefore their quality worsens (Atherton, Rudich, 1986). Properly grown tomato seedlings should be compact, with short internodes and firm stems, large and intensive green leaves. Such seedlings guarantee optimal development of root system after transplanting and have effect on earliness, quality and quantity of the yield (Glowacka, 2002). Our investigations revealed that the growth of plants under "SON-T Agro" lamps was worse during the whole period of transplant cultivation compared with the solid-state lighting module with various spectrum LEDs. The outcome of the experiment showed that plants grown under these lamps were the shortest, they had the longest and thinnest hypocotyls, the smallest number of fully formed leaves, as well as the smallest leaf area, fresh and dry weight (Table 2, Fig. 1).

The morphological characteristics of tomato transplants cultivated under solid-state lighting module with LEDs of various parts of spectrum at different growth stages varied greatly (Table 2). On 7th day after expanding of the first leaf (1st measurement) tomato transplants under the module with supplemental green 520 nm (L3) LEDs had the largest leaf area (Fig. 1) and under the module with supplemental orange 622 nm (L5) LEDs had produced more leaves (Table 2). After a week (2nd measurement) transplants under modules with supplemental UV 380 nm (L2) LEDs had significantly larger leaf area. Meanwhile, plants under the solid-state lighting module supplemented with green 520 nm (L3), yellow 595 nm (L4) and orange 622 nm (L5) LEDs formed less leaf area compared with plants under the lighting modules with the main LEDs and additional UV 380 nm (L2) LEDs (Fig. 1) only. Plants supplemental illuminated by orange 622 nm (L5) LEDs were lower, their stems thinner and they had fewer leaves (Table 1).

The greater differences between plants grown under various solid-state lighting modules were revealed by the 21st day after expanding of the first leaf (3rd measurement). Tomato transplants under the module with the supplemental UV 380 nm (L2) LEDs had the largest leaf area and had greater hypocotyl diameter (Table 2). Hypocotyls and the first internodes of such plants were quite short (Table 3). The growth of tomato transplants under the solid-state lighting module without the additional LEDs was also quite good. Plants under module with the supplemental orange 622 nm (L5) LEDs were the shortest (Table 2), but such lighting determined hypocotyl elongation (Table 3). It shows that such illuminating conditions were unfavorable for the cultivation of tomato transplants. The lighting with the supplemental yellow 595nm (L4) LEDs also resulted in the elongation of both hypocotyls and the first internodes of tomato transplants. All tomato transplants formed a similar number of leaves below the first inflorescence (Table 3). However, plants under the solid-state lighting modules had more flowers in the first inflorescence than under the "SON-T Agro", except for the module with supplemental green 520 nm (L3) LEDs. According to our data published earlier, supplemental green light slightly inhibited transplant development. Most plants were in the 7th–8th organogenesis stages, but some plants were still in the organogenesis stage 6th. Such transplants had the smallest apex in comparison with transplants grown under other LEDs combinations (Brazaitytė et al., 2009 a).

The fresh weight of tomato seedlings grown under the solid-state lighting modules (L1–L5) during the first measurement were quite similar (Table 2). But it was determined that the total fresh weight of transplants was slightly greater under the modules with supplemental green (520 nm), yellow

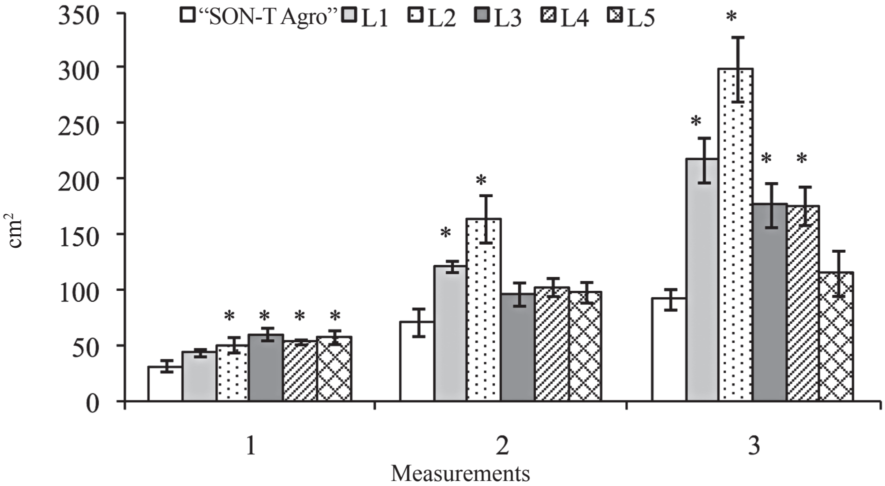
595 nm (L4) and orange 622 nm (L5) LEDs. In the later growing stages significantly higher total (Table 2) fresh weight was achieved under the module with supplemental UV 380 nm (L2) LEDs. The dry total (Table 2) and shoot weight (Fig. 3 a) of such plants was also greater. Tomato transplants cultivated under the module with supplemental orange LEDs had the least total (Table 2) and shoot dry weight (Fig. 2 a). The dry weight (Fig. 2 b) of tomato transplants' roots was the least under the module with supplemental green 520 nm (L3) LEDs.

Table 2. Morphological characteristic of tomato transplants grown under different LEDs illumination

Treatments	Plant height cm	Total fresh weight g	Total dry weight g	Hypocotyls diameter mm	Number of leaves
			1st measurement		
"SON-T Agro"	18.5 ± 0.70	1.4 ± 0.22	0.13 ± 0.024	2.7 ± 0.09	2.5 ± 0.04
L1	19.8 ± 0.53*	2.5 ± 0.26*	0.25 ± 0.015	3.1 ± 0.09*	2.4 ± 0.03*
L2	20.9 ± 0.59*	2.5 ± 0.46*	0.23 ± 0.045	3.6 ± 0.17*	2.5 ± 0.05
L3	21.1 ± 0.63*	3.3 ± 0.37*	0.35 ± 0.060*	3.3 ± 0.09*	2.5 ± 0.06
L4	21.9 ± 0.61*	2.9 ± 0.16*	0.35 ± 0.056*	3.4 ± 0.13*	2.6 ± 0.06
L5	20.3 ± 0.51*	3.1 ± 0.32*	0.36 ± 0.039*	3.6 ± 0.08*	2.7 ± 0.05*
			2nd measurement		
"SON-T Agro"	22.1 ± 0.83	3.1 ± 0.42	0.35 ± 0.036	3.9 ± 0.38	2.6 ± 0.12
L1	34.9 ± 0.67*	9.8 ± 0.55*	1.13 ± 0.225*	4.4 ± 0.12	3.8 ± 0.08*
L2	34.5 ± 1.17*	12.6 ± 1.83*	1.21 ± 0.239*	4.3 ± 0.17	3.9 ± 0.15*
L3	30.6 ± 0.66*	7.1 ± 1.02*	0.92 ± 0.134*	4.0 ± 0.18	3.7 ± 0.15*
L4	33.0 ± 0.51*	7.8 ± 0.55*	1.09 ± 0.098*	4.3 ± 0.08	4.0 ± 0.14*
L5	26.0 ± 0.98*	6.9 ± 0.63*	0.99 ± 0.085*	3.7 ± 0.17	3.5 ± 0.14*
			3rd measurement		
"SON-T Agro"	23.5 ± 1.09	5.4 ± 0.94	0.86 ± 0.161	3.8 ± 0.30	4.6 ± 0.40
L1	43.4 ± 0.93*	18.3 ± 2.01*	2.09 ± 0.339*	5.0 ± 0.16*	7.6 ± 0.24*
L2	45.8 ± 3.02*	25.1 ± 2.06*	2.73 ± 0.331*	5.6 ± 0.36*	7.6 ± 0.24*
L3	38.6 ± 1.69*	13.4 ± 1.41*	1.88 ± 0.235*	4.6 ± 0.21*	7.4 ± 0.24*
L4	46.6 ± 0.68*	16.4 ± 1.15*	2.15 ± 0.194*	4.4 ± 0.17	7.6 ± 0.24*
L5	33.0 ± 2.04*	10.2 ± 1.41*	1.55 ± 0.243	4.3 ± 0.19	6.4 ± 0.24*

Note: see LEDs modules in Table 1.

At the beginning of tomato seedlings growth (the 1st measurement) the relative growth rate (RGR) was greater in the plants under the solid-state lighting module with various LEDs spectra than under the "SON-T Agro" (Table 4). The plants under the modules with supplemental yellow 595 nm (L4) and orange 622 nm (L5) LEDs had the highest net assimilation rate (NAR), but the leaf area ratio (LAR) and specific leaf area (SLA) of such transplants were the lowest. Conversely, NAR was the lowest and LAR, SLA were the highest in tomato transplants under the "SON-T Agro" lamps and under the modules with supplemental UV 380 nm (L2) LEDs. The similar consistent pattern of LAR and SLA remained at other growing stages of tomato transplants. RGR at other growing stages (the 3rd measurement) was slightly higher in plants under the modules with additional UV LEDs and under "SON-T Agro" lamps. The differences in leaf weight ratio (LWR) of plants grown under the various solid-state lighting modules appeared only at the final stages of tomato transplants' growth. It was the least in plants under the modules with supplemental orange 622 nm (L5) LEDs and the "SON-T Agro" lamps. The shoot-root ratio (SRR) depends on a growth stage. On the 7th day after expanding of the first leaf of tomato transplants SRR was the highest in plants under the "SON-T Agro" lamps and under the modules with supplemental yellow 595 nm (L4) LEDs. This index during the second measurement was similar in plants under the various solid-state lighting modules and during the third measurement it was the least in tomato transplants under the module with supplemental 622 nm (L5) LEDs.



Note: see LEDs modules in Table 1.

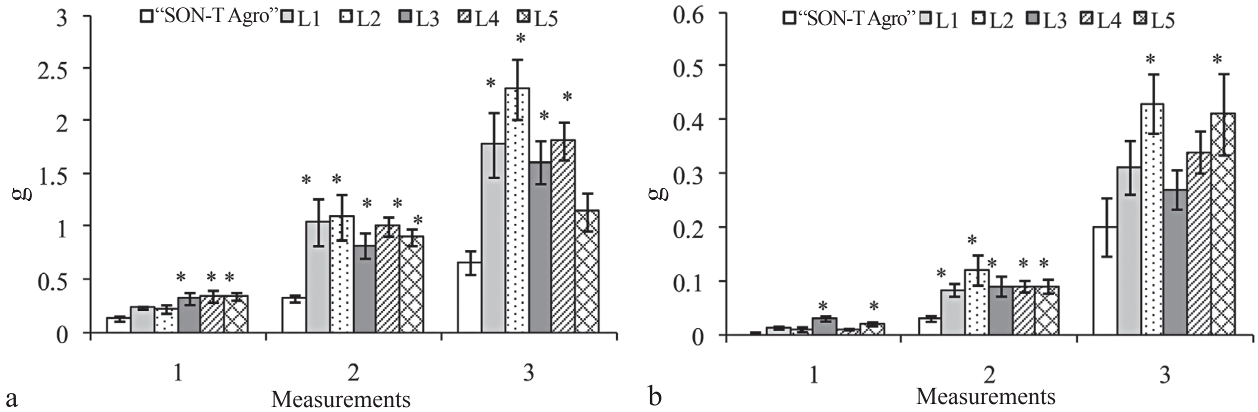
Figure 1. The leaf area of tomato transplants grown under different LEDs illumination

Table 3. Some morphological characteristics of tomato transplants grown under different LEDs illumination (3rd measurement)

Treatments	Hypocotyl length cm	First internode length cm	No. of leaves below the first inflorescence	No. of flowers in the first inflorescence
"SON-T Agro"	5.3 ± 0.21	3.3 ± 0.09	7.7 ± 0.25	5.2 ± 0.20
L1	2.8 ± 0.15*	5.0 ± 0.31*	8.0 ± 0.49	6.0 ± 0.00*
L2	3.4 ± 0.14*	4.1 ± 0.09*	8.2 ± 0.20	6.4 ± 0.25*
L3	4.5 ± 0.13*	4.0 ± 0.27	7.5 ± 0.25	5.2 ± 0.20
L4	5.0 ± 0.02	5.0 ± 0.38*	7.5 ± 0.25	6.0 ± 0.00*
L5	4.6 ± 0.18*	3.2 ± 0.11	7.5 ± 0.25	5.8 ± 0.25*

Note: see LEDs modules in Table 1.

Our investigations revealed that supplemental various spectra LEDs in the high-power solid-state lighting modules with the main 447, 638, 669 and 731 nm LEDs had different effect on the growth of tomato hybrid 'Raissa F_1' transplants. By comparing plants under various high-power solid-state lighting modules, it was established that supplemental LEDs of 622 nm wavelengths (L5) influenced the decrease in growth. These transplants were not high, but their hypocotyls were elongated and quite thin (Table 2). Their leaf number, area and fresh and dry weight were lower compared with plants under other modules (Table 2, Fig. 1, 2). The shoot-root ratio (SRR), which shows partitioning direction of dry matter, was lower in these plants compared with plants under other modules (Table 4). Therefore, it is possible to maintain that the roots had preferential utilization of photosynthates under the modules with additional orange 662 nm (L5) LEDs. Such parameters as LAR, SLA and LWR, which depend on the growth environment, can describe morphological adaptation to this environment and NAR –



Note: see LEDs modules in Table 1.

Figure 2. The dry weight of tomato transplants grown under different LEDs illumination: a – shoots, b – roots

physiological adaptation (De Pinheiro Henriques, Marcelis, 2000; De Groot et al., 2001). NAR of tomato seedlings under the module with supplemental orange 622 nm (L5) LEDs was quite high, although significant differences between various modules were not determined. LAR and LWR of these plants were the lowest at the end of transplant growth (Table 4). It is possible to maintain that tomato seedlings physiologically adapted to grow under additional orange light, but morphological adaptation was not established. There is no much data about orange light effect on plants in literature and they are contradictory. According to some data, plants under orange light grew very slowly (Raab, 2003). Other authors state that orange lighting results in internodes' elongation, higher shoot dry weight and a little higher chlorophyll content (Maas, van Hattum, 1998). Our findings suggest that supplemental orange light decreased chlorophyll content in leaves of tomato transplants (Brazaitytė et al., 2009 a). The supplemental yellow light in the modules had similar effect on tomato transplant growth. It especially enhanced their elongation. The hypocotyls of these plants as well as the first internodes were long. Other authors also indicate that yellow light enhanced internode elongation of various plants (Mortensen, Strømme, 1987). Some authors noticed that such plants had delicate stems, small leaves, reduced fresh and dry weight (Glowacka, 2002), others state that yellow light increased leaf area (Mortensen, Strømme, 1987; Spaargaren, 2001). Our investigations revealed that supplemental yellow light (595 nm) in the modules caused the decrease in leaf area and shoot and total dry weight, but it slightly increased root dry weight compared with plants under the modules with main LEDs set. The ratio of blue (400–500 nm), red (600–700 nm) and far red (700–800 nm) is important for the normal photomorphogenesis of various plants (Kim et al., 2004; Kim et al., 2006). Adding 622 nm and 595 nm LEDs to the main set of LED increased the amount of red part in spectrum and could distort that ratio. Stem elongation depends on the red to far red ratio (R:FR) (Maliakal et al., 1999; Alokam et al., 2002). Supplemental orange and yellow LEDs could also affect this ratio and determine the worse quality of tomato transplants under these modules. Meanwhile, the supplementation to the main high-power solid-state lighting module with the UV 380 (L2) LEDs had positive effect on the growth of tomato transplants. These plants formed the greatest leaf area and fresh and dry mass (Table 2, Fig. 2). Supplemental UV LEDs increased blue range in total lighting of modu-les. Some authors reported that blue light determine shorter internodes of plant, increased leaf area, fresh and dry weight (Glowacka, 2002; Kim et al., 2004). In our modules 380 nm (L2) LEDs were applied. UV-A (320–390 nm) represents the least hazardous part of the UV radiation (Murthy, Rajagopal, 2005). Over 90% of the UV radiation reaching the Earth surface is UV-A, while the rest (10%) includes UV-B (Hamada, 2002). Tomatoes come from the mountainous terrain of South America (Atherton, Rudich, 1986), as a result, demand for or resistance to the UV radiation can be genetically determined by their parentage. Therefore this illumination had no negative effect on tomato growth (Table 2, Fig. 1, 2), although in various studies of UV-A, inhibition effect on the plant growth in different species was determined, such as cucumber (Krizek et al., 1997;

Table 4. Some physiological indices of tomato transplants grown under different LEDs illumination

Treatments	RGR g d^{-1}	NAR g m^{-2} d^{-1}	LAR m^2 kg^{-1}	SLA m^2 kg^{-1}	LWR kg kg^{-1}	SRR
			1st measurement			
"SON-T Agro"	0.46 ± 0.027	5.6 ± 0.31	24.7 ± 1.28	25.7 ± 1.43	0.96 ±0.007	25.1±3.74
L1	0.55 ± 0.009*	8.0 ± 0.34	17.6 ± 0.74*	18.6 ± 0.81*	0.95 ±0.008	21.3 ±3.78
L2	0.54 ± 0.027*	6.2 ± 0.44	23.1 ± 1.57	24.4 ± 1.51	0.94 ±0.007	17.6 ±2.33
L3	0.61 ± 0.034*	8.1 ± 1.18	19.0 ± 2.71*	20.5 ± 2.86	0.93 ±0.007*	13.0 ±1.35*
L4	0.60 ± 0.021*	9.4 ± 1.53*	16.2 ± 1.91*	16.9 ± 2.03*	0.96 ±0.006	27.3 ±1.50
L5	0.61 ± 0.039*	9.0 ± 0.53*	16.0 ± 1.10*	17.0 ± 1.12*	0.94 ±0.004*	15.7 ±1.12*
			2nd measurement			
"SON-T Agro"	0.15 ± 0.025	4.6 ± 0.25	20.0 ± 2.54	21.6 ± 2.78	0.93 ±0.010	13.6 ±2.29
L1	0.21 ± 0.049	10.4 ±2.49*	12.0 ± 1.68*	13.1 ± 1.86*	0.92 ±0.012	12.9 ±2.52
L2	0.24 ± 0.049	8.0 ± 1.17	14.1 ± 0.96*	15.6 ± 1.14*	0.90 ±0.016	11.0 ±2.54
L3	0.14 ± 0.046	7.8 ± 1.39	10.7 ± 0.71*	11.9 ± 0.87*	0.90 ±0.014	9.5 ±1.07
L4	0.16 ± 0.010	10.3 ±0.35*	9.5 ± 0.12*	10.3 ± 0.13*	0.92 ±0.007	11.9 ±1.54
L5	0.14 ± 0.016	9.1 ±0.61*	9.9 ± 0.42*	10.9 ± 0.35*	0.91 ±0.011	10.4 ±1.33
			3rd measurement			
"SON-T Agro"	0.12 ± 0.038	7.3 ± 2.12	11.6 ± 1.60	15.1 ± 2.31	0.77 ±0.029	3.8 ±0.74
L1	0.09 ± 0.011	6.2 ± 0.52	10.9 ± 0.89	12.9 ± 1.13	0.84 ±0.021*	6.0 ±1.17*
L2	0.12 ± 0.036	7.6 ± 2.53	11.6 ± 1.62	13.8 ± 1.93	0.84 ±0.011*	5.5 ±0.48
L3	0.10 ± 0.023	7.6 ± 1.57	9.5 ± 0.47	11.1 ± 0.56	0.86 ±0.009*	6.1 ±0.46*
L4	0.10 ± 0.023	8.3 ± 1.46	8.2 ± 0.38*	9.7 ± 0.33*	0.84 ±0.019*	5.4 ±0.56
L5	0.08 ± 0.016	8.9 ± 1.75	7.6 ± 0.72*	10.3 ± 0.85*	0.73 ±0.019	2.8 ±0.28

Notes: see LEDs modules in Table 1. RGR – relative growth rate, NAR – net assimilation rate, LAR – leaf area ratio, SLA – specific leaf area, LWR – leaf weight ratio, SRR – shoot-root ratio.

Yao et al., 2006, Brazaitytė et al., 2009 b), lettuce (Krizek et al., 1998), and soybean (Yao et al., 2006). Generally, LEDs of ultraviolet wavebands still have low output (Morrow, 2008) and we found no data about the transplant cultivation using them.

According to the data of various authors, the addition of green light in combination with blue and red light affects growth processes as well as the development of plant, because green light penetrates the foliage better and its deeper layers use green light for photophysiological processes more effectively (Kim et al., 2006; Folta, Maruhnich, 2007). Our investigations revealed that tomato seedlings under the modules with the supplemental green 520 nm (L3) LEDs were not elongated, but leaf area, and fresh and dry weight, especially roots, were small (Table 2, Fig. 1, 2). Our earlier investigations showed the positive effect of the supplemental green light in the main LEDs module on the growth and development of cucumber transplants (Brazaitytė et al., 2009 b).

Our investigations revealed that tomato transplants under high-power solid-state lighting modules with the main 447, 638, 669 and 731 nm LEDs showed only slightly slower growth and development than under the module with supplemental UV. According to literature data, light-emitting diodes systems are most often based on such light components as blue, red and far-red LEDs. Such plants as peppers, spinach, radish, lettuce were successfully cultivated using the LEDs of those wavebands (Schuerger et al., 1997; Yorio et al., 2001; Matsuda et al., 2004).

This investigation demonstrated that high-power solid-state lighting with properly selected LEDs wavebands could be used for vegetable transplants cultivation instead of less efficient high-pressure sodium lamps. This and our earlier experiments with cucumbers (Brazaitytė et al., 2009 b) and tomatoes (Brazaitytė et al., 2009 b) revealed that for different plant species LEDs spectrum should be selected individually.

Conclusion

Our investigations revealed that growth of the tomato hybrid 'Raissa F_1' transplants was enhanced under supplemental UV (380 nm) light in the high-power solid-state lighting modules with the mains blue, red and far red LEDs. Therefore such LEDs can be used in the modules for the cultivation of tomato transplants and it is important for their quality. Supplemental orange (622 nm), yellow (595 nm) and green (520 nm) light was not suitable for the growth of tomato transplants. The positive effect of supplemental UV and the negative effect of orange and yellow light were revealed in the later growing stages of tomato transplants.

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Kietakūnio apšvietimo poveikis pomidorų daigų augimo dinamikai

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Santrauka

Tyrimų tikslas – nustatyti pomidorų daigų augimo dinamiką esant įvairaus spektro kietakūniam apšvietimui aukšto slėgio natrio lempomis. Pomidorų hibrido 'Raissa F1' daigai 2007 m. auginti Lietuvos sodininkystės ir daržininkystės instituto Fiziologijos laboratorijos fitotrono kamerose. Iki sudygimo dienos ir nakties temperatūra buvo +23 °C, fotoperiodas – 14 h. Po sudygimo dienos ir nakties temperatūra buvo atitinkamai +22 °C ir +18 °C, fotoperiodas – 18 h. Tyrimams naudotas kietakūnio apšvietimo modulis, sudarytas iš penkių puslaidininkinių lempų su skirtingais šviestukų deriniais. Kaip pagrindiniai visose lempose 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. Nustatyta, kad kietakūnio apšvietimo, sudaryto iš mėlynos, raudonos ir tolimosios raudonos bangų ilgio šviestukų, papildymas UV (380 nm) šviestukais skatino pomidorų hibrido 'Raissa F1' daigų augimą, todėl tokie šviestukai gali būti naudojami kuriant kietakūnio apšvietimo modulius pomidorų daigams ir yra svarbūs jų kokybei. Gauti duomenys parodė, kad tokiuose moduliuose papildomos oranžinė (622 nm) ir geltona (595 nm) šviesos buvo netinkamos pomidorų daigų augimui. Teigiamas papildomos UV ir neigiamas oranžinės bei geltonos šviesų poveikis išryškėjo vėlesniais pomidorų daigų augimo tarpsniais.

Reikšminiai žodžiai: augimas, daigai, kietakūnis apšvietimas, šviesos spektras, pomidorai.