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CULTIVATION OF SWEET PEPPER (*Capsicum annuum* L.) TRANSPLANTS UNDER HIGH PRESSURE SODIUM LAMPS SUPPLEMENTED BY LIGHT-EMITTING DIODES OF VARIOUS WAVELENGTHS

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Abstract. In greenhouses, artificial lighting is applied in winter and early spring as supplementary light source to increase photosynthesis and plant growth. The objective of this study was to evaluate the cultivation of sweet pepper transplants under LED lamps that were developed to supplement HPS lamps used in greenhouses. The experiments were carried out in the greenhouses at the Lithuanian Research Centre for Agriculture and Forestry Institute of Horticulture. Sweet peppers (*Capsicum annuum*) L. cultivar 'Reda' and the hybrid 'Figaro' F1 were used for investigation. Four types of solid-state lamps were used with light-emitting diodes (LEDs) with peak emissions at blue 455 nm and 470 nm, cyan 505 nm, and green 530 nm. PPFD of each type of LED lamp was 15 μmol m^{-2} s^{-1}, and the PPFD of HPS lamps was 90 μmol m^{-2} s^{-1}. The reference transplants were grown under the illumination of HPS lamps (110 μmol m^{-2} s^{-1}). The photoperiod of artificial lighting was maintained at 18 hours. Our experiments revealed different responses to supplemental LED lightings between the cultivar and the hybrid. The supplemental 470 nm illumination with HPS lamps mostly resulted in increases in the following areas: leaf area, fresh and dry weight, and the photosynthetic pigment content of the sweet pepper 'Reda' transplants. A similar positive effect was determined using supplemental 455 and 505 nm LED lights. However, the supplemental green 530 nm LED lights had no effect on growth, and they inhibited the development of the sweet pepper 'Reda' transplants. The HPS light had a positive effect on the growth parameters of the 'Figaro' F1 transplants, but all of the supplemental LED lights suppressed their growth and development.

Key word: chlorophyll, hypocotyl, growth, leaf dry weigh, root/shoot ratio

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INTRODUCTION

Light is the primary energy source for plants and one of the most important environmental factors that governs plant growth from germination to fruiting. Light also controls multiple developmental processes throughout the plant life cycle, including seed germination, phototropism, shade avoidance, circadian rhythms, and flowering time [Lau and Deng 2010, Carvalho et al. 2011, Li et al. 2012, van Ieperen 2012, Ballaré 2014]. The intensity and the quality of the light are essential for the cultivation of plants, especially in greenhouses during the autumn–winter period when the level of natural light is low [Wenke 2012, Sirtautas et al. 2014]. Supplemental light quality can be strategically used to enhance the nutritional value [Li and Kubota 2009] and strongly influence the anatomy, physiology and morphology parameters of plant leaves [Brazaitytė et al. 2009, Brazaitytė et al. 2010, Hogewoning et al. 2010, Macedo et al. 2011]. High-pressure sodium lamps are the most popular for supplemental lighting in greenhouses [Gómez et al. 2013]. These lamps have high electrical efficiencies, a long operating life and a wide spectrum of light, which are suitable for many plant species [Spaargaren 2001, Głowacka 2002, Wheeler 2008]. However, HPS lamps have high amounts of yellow light, which causes plant stem elongation and worsens the quality of transplants [Spaargaren 2001, Głowacka 2002, Wheeler 2008, Randall and Lopez 2014]. LEDs have more advantages: small size, durability, long lifetime, fast switching, simple control of the generated flux, low thermal radiation directed towards plants, assess the economic aspects, reduced production price and the option to select specific wavelengths for the targeted plant response, making them more suitable for plant-based uses than many other light sources [Massa et al. 2008, Žukauskas and Duchovskis 2009, Kubota et al. 2012, Mitchell 2012].

Sweet peppers, *Capsicum annuum* L. (Solanaceae), are high-value crops that are generally grown in a protected environment, i.e. under glass or in plastic tunnels or houses [Dewhirst et al. 2012]. Growing conditions during transplant production influence the transplant quality, performance, establishment and subsequent yield [Javanmardi and Emami 2013]. However light is a very important factor of their quality, growth, and development [Olle and Viršile 2013, Lee et al. 2014, Randall and Lopez 2014]. Therefore, this study's purpose was to evaluate the impact of high-pressure sodium lamps with supplemental blue, cyan and green LEDs on the growth of sweet pepper transplants in greenhouses. Previous research has indicated that blue light has an effect on plant growth and development [Ahmad et al. 2002, Babourina et al. 2002, Olle and Viršile 2013]. The green light influences photosynthesis and photosynthetic pigment accumulation [Kim et al. 2006, Terashima et al. 2009]. Usual lighting with supplemental green and blue light can encourage the increase of plant growth, which is important for the purpose of forcing the cultivation of vegetable transplants in greenhouses [Samuoliene et al. 2012].

The purpose of the experiment was to compare sweet pepper transplants' growth and development under illumination HPS with supplemental 455, 470, 505, and 530 nm light-emitting diodes used in greenhouses.

The object of investigation: illumination HPS with supplemental light-emitting diodes: blue 455, 470 nm, cyan 505 nm, and green 530 nm light on sweet pepper transplant cultivation in greenhouses.

MATERIALS AND METHODS

Growth conditions and plant material. Transplants of the sweet pepper (*Capsicum annuum*) L., variety 'Reda' and the hybrid 'Figaro' F1 were grown in greenhouses of a phytotron complex at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry, Plant Physiology Laboratory. The transplants were seeded in the peat substrate (pH 6.0–6.5), which was enriched with the fertilizer PG MIX (NPK 14:16:18 1.3 kg m^{-3}) within a greenhouse between March and May. Plants ware watered on a regular basis. During the transplants' cultivation, the day/night temperature was 20–23/15–18°C, and the relative air humidity was 50 to 60%.

Light devices in greenhouse. The transplants were grown under the illumination of high pressure sodium lamps ("Son-T Agro", "Philips", USA) and with the supplementation of short-wavelength monochromatic solid-state lamps. Four types of solid-state lamps were designed using high-power AlInGaN LEDs (Philips Lumileds Lighting Company, USA): blue 455, 470 nm, cyan 505 nm, and green 530 nm. The generated photosynthetic photon flux density (PPFD) of each type of solid-state modules was 15 μmol m^{-2} s^{-1} and of HPS lamps was about 90 μmol m^{-2} s^{-1}. The reference transplants were grown under illumination of HPS lamps (110 μmol m^{-2} s^{-1}). The PPFD level was measured using a photometer-radiometer RF-100 ("Sonopan", Poland). An 18-hour photoperiod was maintained.

Biomass, growth parameter. Sweet pepper transplants were harvested on the 55th day after sowing. The leaf area of the sweet pepper plants (n = 10) was measured by the "WinDias" leaf area meter (Delta-T Devices Ltd., UK). The plant height (n = 10) was measured to the top of all transplants. We measured the mostly developed inflorescence of the sweet pepper transplants. The sweet pepper transplants were oven-dried at +105°C for 24 hours to determine the dry weight (n = 10). The organogenesis stages (according to Kuperman's methodology [Kuperman and Ržanova 1985]) of the sweet pepper were determined in five replicates (n = 5) at the end of the cultivation of the transplants.

Determination of photosynthetic pigments. One gram of fresh leaf (n = 4) tissue was grounded with 0.5 g $CaCO_3$, diluted 1:250 with 100% pure acetone extract and filtered through a cellulose filter. Chlorophyll a and b and carotenoids were measured by the spectrophotometric method [Gavrilenko and Zigalova 2003]. The absorption was measured at 644, 662 and 440.5 nm, for chlorophyll *a* and *b* and carotenoids, respectively. We used the spectrophotometer "Genesys 6" (ThermoSpectronic, USA). Measurements were performed in four replica-tes during seedling transplantation (n = 5).

Statistical analysis. The experiments were arranged in a one-factorial design. Statistical analyses were conducted using STATISTICA 7.0 for Windows. Statistical differences between measurements on the different illumination were also analysed following the Student's t-test. Significant differences from the reference treatment are denoted by an asterisk (*) at $P < 0.05$ and (**) at $P < 0.01$.

RESULTS

Plant growth and development. The supplemental 470 nm light had the greatest positive impact on the sweet pepper cultivar 'Reda' transplants' quality. These transplants produced the significantly biggest above-ground sample in the following areas: fresh and dry weight, leaf area, number of leaves and height (tab. 1). The supplemental 455, 505 and 530 nm light caused a hypocotyl elongation of the sweet pepper cultivar 'Reda' transplants. Meanwhile, the supplemental 470 nm light decreased the length and increased the diameter of the hypocotyl. (tabs 1, 2). Nonetheless, the shoot/root ratio was the highest with the supplemental cyan (505 nm) light.

The supplemental LED light had a more negative impact on the morphological characteristics and physiological indices of the sweet pepper hybrid 'Figaro' F1 than it had on the sweet pepper cultivar 'Reda.' The supplemental LED light had the greatest negative impact on the sweet pepper hybrid 'Figaro' F1, producing essentially an inconsiderable above-ground sample, considering the following areas: fresh and dry weight, leaf area, number of leaves, height and smaller total number of internodes (tabs 1, 2). However, compared to the other supplemental blue and green lights, the supplemental blue 470 nm illuminations with the HPS lamps mostly increased the leaf area, and the fresh weight in the hybrid 'Figaro' F1 transplants.

Investigations showed that the light had different effects in the organogenesis stage and the inflorescence length on the sweet pepper cultivar from on the hybrid transplants. Supplemental light had no effect on the organogenesis stage of the sweet pepper cultivar 'Reda' transplants (tab. 3). However, only the supplemental 530 nm light slowed the sinflorescence length of the sweet pepper cultivar 'Reda' transplant. Our study showed that supplemental light slightly inhibited the development on the sweet pepper hybrid 'Figaro' F1 transplants. They were in the fifth and sixth organogenesis stages. The inflorescence length on the hybrid 'Figaro' F1 transplants under supplemental LED lighting was small (tab. 3).

Photosynthetic pigments. Different combinations of illumination influenced the sweet pepper cultivar 'Reda' and the hybrid 'Figaro' F1' photosynthesis systems in greenhouses (tab. 4). The chlorophyll *a* and *b* levels in the leaves of both the sweet pepper transplants were found mostly to be increased under the illumination HPS with the supplemental 470 nm light. The smallest content of chlorophyll *a* and *b* accumulated in the cultivar 'Reda' transplants, grown under the illumination HPS with the supplemental 530 nm (green) light, in the hybrid 'Figaro' F1 transplants, grown under illumination HPS with the supplemental 455 nm (blue) and 505 nm (cyan) lights. The carotenoid levels in the leaves of the sweet pepper cultivar 'Reda' transplants were found mostly to be increased under the illumination with the supplemental 470 nm light. However, in the hybrid 'Figaro' F1 transplants, we found it mostly to be increased under the illumination with the supplemental 470 and 530 nm light. The chlorophyll *a* to *b* ratio increased in the sweet pepper cultivar under all supplemental LED lighting; however, in the sweet pepper hybrid, it only increased under the supplemental 470, 505, and 530 nm lighting. The higher chlorophyll *a* and *b* ratio was found in the sweet pepper hybrid 'Figaro' F1 transplants compared with the sweet pepper cultivar 'Reda' transplants (tab. 4).

Table 1. Some morphological characteristic and physiological indices of sweet pepper transplants grown under different LEDs illumination

	Indices	HPS	HPS + 455 nm	HPS + 470 nm	HPS + 505 nm	HPS + 530 nm
Sweet pepper 'Reda'	plant height, cm	18.95 ±1.824	22.09 ±1.363*	23.03 ±1.201**	22.57 ±0.702**	18.95 ±1.363
	hypocotyls length, cm	1.80 ±0.478	1.98 ±0.282	1.72 ±0.509	2.33 ±0.829*	2.00 ±0.377*
	hypocotyls diameter, cm	0.41 ±0.039	0.42 ±0.035	0.44 ±0.036	0.43 ±0.041	0.39 ±0.031
	leaf fresh weight, g	6.74 ±0.783	8.56 ±1.314**	9.36 ±0.961**	8.44 ±1.171**	5.75 ±1.254**
	stem fresh weight, g	3.28 ±0.970	4.30 ±0.364*	4.96 ±0.397**	4.33 ±0.530*	3.16 ±0.611**
	roots fresh weight, g	6.82 ±0.911	6.00 ±1.326	4.86 ±1.822	3.88 ±1.155**	4.89 ±1.110
	total above ground fresh weight, g	16.83 ±1.786	18.87 ±2.727*	19.19 ±2.583*	16.65 ±2.602	13.81 ±3.618*
	leaf dry weight, g	1.10 ±0.227	1.20 ±0.208	1.26 ±0.181	1.25 ±0.218	0.91 ±0.359
	stem dry weight, g	0.39 ±0.248	0.56 ±0.068	0.62 ±0.075	0.58 ±0.109	0.46 ±0.099
	roots dry weight, g	0.53 ±0.073	0.56 ±0.140	0.60 ±0.145	0.50 ±0.132	0.49 ±0.112
	total above ground dry weight, g	2.03 ±0.391	2.32 ±0.388*	2.47 ±0.381*	2.34 ±0.446*	1.85 ±0.510*
	leaf area, cm^2	420.10 ±58.704	530.46 ±95.170*	606.22 ±60.540**	555.21 ±73.172*	430.97 ±78.581*
	number of leaves	9.80 ±0.422	10.90 ±0.738*	11.20 ±0.789**	10.80 ±0.789*	9.70 ±0.675
	shoot/root ratio	1.47 ±0.859	2.14 ±0.990	2.95 ±0.527*	3.29 ±1.014*	1.82 ±1.130
Sweet pepper 'Figaro' F_1	plant height, cm	23.07 ±1.708	15.15 ±1.156**	16.45 ±1.606**	14.20 ±1.670**	16.25 ±1.318**
	hypocotyls length, cm	2.33 ±0.829	2.14 ±0.337	1.78 ±0.496*	1.98 ±0.485	2.25 ±0.481
	hypocotyls diameter, cm	0.42 ±0.041	0.38 ±0.049	0.39 ±0.032	0.36 ±0.036**	0.38 ±0.027**
	leaf fresh weight, g	8.52 ±1.127	2.40 ±0.382**	7.52 ±1.790**	5.86 ±0.968*	6.65 ±0.609
	stem fresh weight, g	3.22 ±0.531	5.86 ±1.271**	2.79 ±0.697*	2.05 ±0.432**	2.98 ±1.396*
	roots fresh weight, g	4.94 ±1.172	4.11 ±1.299	5.11 ±1.321*	3.99 ±0.811	3.95 ±1.092
	total above ground fresh weight, g	16.69 ±2.617	12.37 ±2.222*	15.42 ±3.609	11.90 ±2.056**	13.58 ±2.193*
	leaf dry weight, g	1.24 ±0.220	0.36 ±0.066**	0.99 ±0.218*	0.77 ±0.124**	0.89 ±0.097*
	stem dry weight, g	0.47 ±0.094	0.83 ±0.184**	0.34 ±0.122*	0.29 ±0.074**	0.41 ±0.171*
	roots dry weight, g	0.54 ±0.131	0.42 ±0.136	0.44 ±0.127	0.36 ±0.075*	0.40 ±0.087*
	total above ground dry weight, g	2.25 ±0.407	1.60 ±0.281**	1.77 ±0.458	1.43 ±0.243**	1.69 ±0.249*
	leaf area, cm^2	521.80 ±75.369	401.90 ±81.738	436.68 ±92.390	384.33 ±107.103*	416.99 ±33.581*
	number of leaves	10.80 ±0.788	7.90 ±0.568**	8.90 ±0.876*	8.13 ±0.632**	8.20 ±0.632**
	shoot/root ratio	2.38 ±0.685	2.01 ±0.601	2.02 ±0.784	1.98 ±0.587	2.44 ±0.658

HPS – control treatment with high-pressure sodium light, other treatments consist of HPS and supplemental light emitting diode combination: HPS + 455 nm (blue), HPS + 470 nm (blue), HPS + 505 nm (cyan), HPS + 530 nm (green). Mean significantly (*$P < 0.05$, **$P < 0.01$) different from control (HPS) plants as determined by paired t-test

Table 2. Internodes length and number of sweet pepper transplants grown under different LEDs illumination

Sweet pepper	Internodes, cm	HPS	HPS + 455 nm	HPS + 470 nm	HPS + 505 nm	HPS + 530 nm
'Reda'	1 internodes	3.78 ±0.352	3.84 ±0.650	4.10 ±0.392	3.69 ±0.850	3.83 ±0.383
	2 internodes	1.88 ±1.138	2.66 ±1.086*	2.50 ±1.072	2.30 ±1.187	2.04 ±0.778
	3 internodes	1.88 ±0.590	1.97 ±0.779	1.77 ±0.291	2.37 ±0.797**	1.95 ±0.366
	4 internodes	1.63 ±0.611	2.17 ±0.780*	2.19 ±0.666*	1.74 ±0.679	1.92 ±0.244
	5 internodes	1.63 ±0.512	2.01 ±0.746*	2.10 ±1.070*	2.05 ±0.366*	1.59 ±0.475
	total number of internodes	8.00 ±0.000	8.00 ±0.000	8.00 ±0.000	8.00 ±0.000	8.00 ±0.000
'Figaro' F_1	1 internodes	3.69 ±0.850	3.74 ±0.409	3.26 ±0.857	3.12 ±0.796**	3.62 ±0.683
	2 internodes	2.30 ±1.187	2.56 ±0.700	2.57 ±0.797	2.71 ±0.888*	2.00 ±0.816
	3 internodes	2.37 ±0.797	1.57 ±0.386**	1.55 ±0.506**	1.20 ±0.200**	1.85 ±0.587**
	4 internodes	1.74 ±0.679	1.71 ±0.458	2.91 ±0.917**	1.93 ±0.287	1.83 ±0.577
	5 internodes	2.05 ±0.366	1.23 ±0.548*	1.58 ±0.681*	0.97 ±0.283**	1.62 ±0.639*
	total number of internodes	8.00 ±0.000	6.00 ±0.000**	6.00 ±0.000**	6.00 ±0.000**	6.00 ±0.000**

HPS – control treatment with high-pressure sodium light, other treatments consist of HPS and supplemental light emitting diode combination: HPS + 455 nm (blue), HPS + 470 nm (blue), HPS + 505 nm (cyan), HPS + 530 nm (green). 1, 2, 3, 4, 5 internodes – developed internodes in sweet pepper transplants. Number of internodes – all sweet pepper transplant internodes. Mean significantly (*$P < 0.05$, **$P < 0.01$) different from control (HPS) plants as determined by paired t-test

Table 3. Organogenesis stage and inflorescence length of sweet pepper transplants grown under different LEDs illumination

Cultivar		HPS	HPS + 455 nm	HPS + 470 nm	HPS + 505 nm	HPS + 530 nm
'Reda'	organogenesis stage	VII–VIII	VII–VIII	VII–VIII	VII–VIII	VII–VIII
	inflorescence length, mm	11.46 ±4.174	11.80 ±4.455	11.72 ±5.711	11.83 ±4.743	8.43 ±5.833
'Figro'F_1	organogenesis stage	VI–VII	Va–VI	Va–VI	Va–VI	Va–VI
	inflorescence length, mm	5.75 ±1.700	1.98 ±1.206*	1.95 ±0.897*	1.62 ±0.594**	1.90 ±0.514*

HPS – control treatment with high-pressure sodium light, other treatments consist of HPS and supplemental light emitting diode combination: HPS + 455 nm (blue), HPS+470 nm (blue), HPS + 505 nm (cyan), HPS + 530 nm (green). Organogenesis stage: Va – flower differentiation, VI – micro- and macrosporogenesis, VII – gametogenesis, VIII – bud formation. Mean significantly (*P < 0.05, **P < 0.01) different from control (HPS) plants as determined by paired t-test

Table 4. The content of photosynthetic pigment and chlorophyll *a* to *b* ratio in the leaves of sweet pepper transplants grown under different LEDs illumination

Cultivar	Photosynthetic pigment	HPS	HPS + 455 nm	HPS + 470 nm	HPS + 505 nm	HPS + 530 nm
'Reda'	chlorophyll *a*	0.67 ±0.091	0.83 ±0.081	0.94 ±0.167*	0.79 ±0.119	0.62 ±0.072
	chlorophyll *b*	0.29 ±0.094	0.29 ±0.022	0.32 ±0.058	0.28 ±0.044	0.21 ±0.031
	carotenoids	0.24 ±0.032	0.30 ±0.031	0.34 ±0.055**	0.28 ±0.047	0.22 ±0.023
	chlorophylls *a* and *b* ratio	2.43 ±0.465	2.89 ±0.090	2.96 ±0.134	2.85 ±0.063	2.88 ±0.113
'Figaro'F_1	chlorophyll *a*	0.93 ±0.166	0.88 ±0.131	1.10 ±0.233**	0.89 ±0.155	1.07 ±0.062*
	chlorophyll *b*	0.31 ±0.051	0.29 ±0.038	0.35 ±0.072	0.28 ±0.060	0.35 ±0.020
	carotenoids	0.31 ±0.044	0.31 ±0.044	0.36 ±0.069**	0.30 ±0.054	0.36 ±0.038*
	chlorophylls *a* and *b* ratio	3.03 ±0.091	3.00 ±0.066	3.14 ±0.047	3.19 ±0.400	3.09 ±0.072

HPS – control treatment with high-pressure sodium light, other treatments consist of HPS and supplemental light emitting diode combination: HPS + 455 nm (blue), HPS + 470 nm (blue), HPS + 505 nm (cyan), HPS + 530 nm (green). Mean significantly (*P < 0.05, **P < 0.01) different from control (HPS) plants as determined by paired t-test

DISCUSSION

The phenotypic changes associated with transplants' photomorphogenic development are among the most dramatic events mediated by light [Li et al. 2012]. Our study found that supplemental light had different effects on fresh and dry weight, number of leaves and leaf area of sweet pepper cultivar and hybrid transplants cultivated in greenhouses (tab. 1). Traditional HPS lamps are blue-deficient lighting sources; therefore, this effect may lead to unnatural stem elongation, and photoreceptors (cryptochrome) participating in the management of stem and hypocotyl elongation [Ahmad et al. 2002, Bouly et al. 2007, Wheeler 2008, Randall and Lopez 2014].

Our aim in this study was to select blue wavelengths for supplementing the HPS lamps' spectrum that would be most suitable for improving the quality of the sweet pepper cultivar and hybrid transplants. This experiment's results revealed that supplemental cyan 505 nm lights inhibited the hypocotyl elongation of hybrid transplants. The hypocotyl was shortest under 470 nm light and somewhat longer under blue (455 nm) light, but the plant height was the highest in the cultivar 'Reda' (tab. 1). Supplemental blue light caused internodes and stem elongation of the transplants (tab. 2). Our earlier investigations revealed that the effects of supplementary blue light were found to be species-dependent. Supplemental 455 and 470 nm LED illuminations with high pressure sodium lamps increased leaf area, fresh and dry weight, and photosynthetic pigment content in the leaves of tomato-, pepper-, and cucumber-vegetable transplants [Samuoliene et al. 2012]. Our study showed that supplementing HPS lamps had the greatest impact on the photosynthesis pigment content in the leaves of sweet pepper transplants (tab. 4). The best effect on the photosynthetic pigments was found under the supplemental 470 nm light.

Previous studies have indicated that blue light stimulates stomata opening and chlorophyll formation, and causes an increase in the photosynthesis rate and in the aboveground biomass per surface area [Menard et al. 2006, Hogewoning et al. 2010, Liu et al. 2011, Hernández and Kubota 2012, Olle and Viršilė 2013, Xiaoying et al. 2014]. Blue light has effects on plant growth and development, the inhibition of hypocotyls elongation, internode elongation, hypocotyl diameter, and increase in leaf mass in plants [Hogewoning et al. 2010, Samuoliene et al. 2012, Olle and Viršile 2013]. The effects of blue light depend considerably on the species of the plant, and even the cultivar [Głowacka 2004]. Scientific research has revealed that dry mass and leaf area in wheat and soybean decreased steadily with increasing blue light in the HPS lamp spectrum, but this blue light had no significant effect on chlorophyll content in wheat and soybeans. Blue light during growth is qualitatively required for normal photosynthetic functioning, and it quantitatively mediates leaf responses resembling those of irradiance intensity [Hogewoning et al. 2010]. Previous studies have indicated that blue light (455 nm) with supplemental LEDs to the HPS lamps increased the shoot dry weight of cucumbers and tomatoes, but the increase depended on the daily light integral. The photosynthesis rate of cucumbers was not significantly influenced by the different blue 455 nm light treatments, but it was low for the tomatoes under the photoperiod of 20 hours [Menard et al. 2006]. The dry mass accumulation of tomatoes cultivated under fluorescent lamps emitting blue light depends on the cultivars [Głowacka 2004].

Our earlier investigations revealed that the effect of supplementary 505 nm and 530 nm of light was found to be species dependent. Supplemental 505 nm LED illumination with HPS lamps increased the fresh and dry weight, the leaf area and photosynthetic pigment content of transplants [Samuoliene et al. 2012]. Supplemental green and cyan lights stimulated hypocotyl elongation, but 530 nm inhibited only in the sweet peppers cultivar hybrid 'Figaro' F1 height (tabs 1, 2). Green light can penetrate into the plant's canopy better than red or blue. Leaves in the lower canopy would be able to use the energy from the green light for photosynthesis more efficiently [Kim et al. 2006]. The green light influenced photosynthesis more effectively than did the red light. The green leaf should have a considerable volume of chloroplasts to contain the inefficient

carboxylation enzyme, Rubisco, and deliver the appropriate light to all the chloroplasts [Terashima et al. 2009].

In our investigations, this effect was contrary to what we determined about sweet pepper transplants under supplemental cyan 505 nm and green 530 nm light. Our study shows that green 530 nm light discourages photosynthesis pigment accumulation, and that most prevent growth and development of the sweet pepper cultivar 'Reda' transplants (tab. 4). Nonetheless, the cyan and green lights had no significant differences on the hybrid 'Figaro' F1 transplants (tab. 3). Our earlier investigations revealed that supplemental 530 nm LED illumination had positive effects on growth, development and photosynthetic pigment accumulation of cucumber transplants only. Such illumination suppressed the growth and development of tomato and sweet pepper transplants [Samuoliene et al. 2012]. Data from previous studies about the effects of green light is the same as our findings. When ordinary white light was supplemented with the green wavelengths, reductions in growth and development of various plants were obtatined, and it had a negative impact on chlorophyll accumulation in leaves [Wada et al. 2005]. However, light sources with a higher percentage of green light (> 50% of total PPF) were found to reduce plant growth [Kim et al. 2006].

CONCLUSIONS

Our results have revealed that supplemental blue and green light have different effects on cultivar and hybrid transplants' growth and development. Compared to other supplemental blue and green LED lights, supplemental blue 470 nm illuminations with HPS lamps mostly increased the leaf area, the fresh and dry weight, and the photosynthetic pigment content of sweet pepper cultivar 'Reda' transplants. A similar positive effect was determined using supplemental 455 and 505 nm LED lights. Supplemental green 530 nm LEDs caused repressed growth and slowed the development of sweet pepper cultivar 'Reda' transplants. HPS light had a positive effect on the growth parameters of hybrid 'Figaro' F1 transplants; however, all of the supplemental LED lights suppressed their growth and development. However, compared to other supplemental blue and green lights, the supplemental blue 470 nm illuminations with HPS lamps mostly increased the leaf area, the fresh and dry weight, and the photosynthetic pigment content of the sweet pepper hybrid 'Figaro' F1 transplants. Therefore, detailed studies are required regarding the correlations between light quality and growth conditions, including of sweet pepper transplants.

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UPRAWA ROZSADY PAPRYKI SŁODKIEJ POD ŚWIATŁEM LAMP HPS I LED

Streszczenie. W szklarniach sztuczne oświetlenie stosowane jest zimą i wczesną wiosną jako dodatkowe źródło światła, aby zwiększyć fotosyntezę i wzrost roślin. Celem pracy była ocena możliwości uprawy rozsady papryki słodkiej w szklarni pod lampami HPS z dodatkiem LED. Badania przeprowadzono w Instytucie Ogrodnictwa Litewskiego Centrum Nauk Rolniczych i Leśnych. Przebadano dwie odmiany papryki słodkiej (*Capsicum annuum* L.): 'Reda'i 'Figaro F1'. Jako dodatkowe światło, oprócz lamp HPS, zastosowano cztery rodzaje lamp LED o długościach fal: niebieskie 455 i 470 nm, zielono-niebieskie 505 nm oraz zielone 530 nm. PPFD LED wynosiło 15 μmol m^{-2} s^{-1}, a lamp HPS – 90 μmol m^{-2} s^{-1}. Długość dnia – 18 godzin. Na podstawie wyników stwierdzono, że dodatkowe światło LED miało różny wpływ na wzrost odmian papryki. Po dodaniu do światła lamp HPS LED-470 w rozsadzie papryki słodkiej odmiany 'Reda' stwierdzono największą powierzchnię liści, najwięcej świeżej i suchej masy roślin oraz największą zawartość barwników fotosyntetycznych. Podobny wpływ wywierało dodatkowe światło LED 455 i 505 nm. Natomiast dodatkowe zielone światło LED-530 nie miało wpływu na wzrost, a hamowało rozwój rozsady odmiany 'Reda'. Światło HPS miało korzystny wpływ na parametry wzrostu siewek 'Figaro F1', zaś dodatek światła LED hamował ich wzrost i rozwój.

Słowa kluczowe: chlorofil, hipokotyl, wzrost, masa liści, stosunek masy korzenie/część nadziemna

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