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ORIGINAL PAPER

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THE EFFECT OF SUPPLEMENTAL ASSIMILATION LIGHTING WITH HPS AND LED LAMPS ON THE CUCUMBER YIELDING AND FRUIT QUALITY IN AUTUMN CROP

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ABSTRACT

The aim of the study was to evaluate the effect of HPS and LED assimilation lighting and LED interlighting on the yielding and as cucumber fruit quality in autumn cultivation cycle. The possibilities of increasing the density of plants due to the use of LED technology were also assessed. The study was conducted in three compartments: I with HPS top light only; II with top light HPS + 2 line LED interlight, III with 100% LED, top LED + 2 line LED interlight. Light level was in every compartment kept at the level of ~320 µmol m^{-2} s^{-1}. PAR. The number and weight of cucumber fruits were investigated. The harvest was carried out every day. To assess the harvest quality for the plants grown in the two terms fruits were then examined for the chemical quality attributes of cucumber fruit, such as the content of total soluble solids (TSS), total sugars (TS), ascorbic acid and nitrate (NO_3) P, K and Ca. Another part of fruits was subjected to sensory analysis performed with the scaling method. The cucumber grown in the autumn growing cycle gave higher yield and the quality of fruits produced appeared more balanced for the plants lighted with HPS+LED or 100% LED as compared to the traditional, overhead HPS lighting. The above, together with the results from the rate of buds' abortion assessment seem to legitimate the increase in the cucumber crop density when applying LED lighting.

Key words: yielding, LED interlighting, fruit quality, sensory analysis

INTRODUCTION

The cucumber is highly ranked among key vegetable plants produced in greenhouses, and high market demand for its premium quality fruit maintains throughout the year. Harvest quantity and quality reflect the vegetable plants' growth rate and development which in turn are determined by several conditions such as cultivation time, type of substrate, fertilization, irrigation, microclimate and cultivar. Optimal levels of these factors for a particular crop vary and are closely interrelated. Light is a significant microclimate factor is, as solar energy is known to greatly affect the rate of photosynthesis and plant productivity [Blom and Ingratta 1984, Fan et al. 2008, Zoratti et al. 2014]. The plant photosynthetic efficiency increases along the increase of light intensity from the compensation point to the light satura-

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tion point. However, any further increase of light intensity no longer affects the rate of photosynthesis. For most vegetable plant species the light compensation point ranges from 2 to 10 W m^{-2}, whereas the light saturation point falls between 60 and 200 W m^{-2} PAR [Miles 1974]. According to many researchers, fluctuations in light intensity and quality as well as in time of exposure to light cause many physiological and biochemical reactions in plant chloroplasts, influencing the productivity of this process, and in consequence affecting the plant growth and development [Marcelis 1994, Chen et al. 2004, Terashima et al. 2009]. The understanding of morphological, biochemical and physiological responses of plants to different levels and quality of irradiation, enables controlling the plant growth rate in relation to the availability and possibility of environmental [Ariz et al. 2010, Smith et al. 1999].

In order to effectively grow crops throughout the year, optimum light conditions are required in periods of solar radiation shortage. Poland is located in a temperate climate zone, therefore offering to most of the cultivated plants insufficient amounts of sunlight. The lighting of plants with the use of artificial light sources is a long-known but cost consuming method of intensifying the production in greenhouses. Energy is, after manpower, a second most expensive constituent of greenhouse production [Frantz et al. 2000]. Heat and electric energy account for up to 30% of total costs in greenhouse production. Thus, plant producers are increasingly interested in such lighting technologies which are less energy-consuming but still capable to effectively enhance the crop productivity [Mitchell et al. 2012]. In terms of lighting, the horticulture industry bases mainly on high pressure sodium lamps (HPS). However, these light sources have some limitations due to their relatively short lifetime, high electrical consumption and heat emission. Moreover, the spectrum of light in those lamps is determined by their construction and is difficult to modify [Brazaitytė et al. 2010]. Recently, it is LED lighting that has gained on popularity. The application of LEDs for plant growth lighting has been studied for over two decades [Bula et al. 1991, Barta et al. 1992]. Recent technological achievements involving LEDs allow to adjust light quality to the needs of specific plants cultivated. Some researchers have indicated that the use of a single red or blue LED light source or their combination could improve the efficiency of photosynthesis to promote plant production and regulate morphogenesis [Fang and Jao 1996, Ding et al. 2005, Xiao et al. 2013]. Greenhouse industry is seeking efficient and cost-effective artificial light sources with optimal spectral characteristics for the plant grown.

While cultivating plants in a long cycle at low radiation periods, when supplemental assimilation lighting is required, it is important to guarantee a proper lighting of lower leaves and to optimize the crop density. Therefore, the aim of the study was to evaluate the density of plants and the effect of HPS and LED assimilation and intercropping lighting on the growth, development and yield as well as cucumber fruit quality in autumn cultivation cycle.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at Warsaw University of Life Sciences – SGGW (longitude 21°E, latitude 51°15'N) in autumn 2015 as a part of a scientific project conducted with Philips Lighting Holding B.V. The study was conducted in three compartments, each of about 40 m^2 of usable area: I – HPS top light only with 24 HPS lamps (Gavita GAN 600 W); II – MIX (HPS + LED) light with top light of 18 HPS lamps (Gavita GAN 600 W) + 2 lines of LEDs with 18 Philips Green Power LED interlighting units (module 2.5 m HO DR/B 100 W) per chamber; III – 100% LED light with 24 Philips Green Power LED toplighting units (DR/W – LB, 195 W) + 2 lines of LEDs with 18 Philips Green Power LED interlighting units (module 2.5 m HO DR/B 100 W) per chamber. Light conditions in terms of PAR (Photosynthetically Active Radiation) were in every compartment maintained at one level possibly closest to ~320 μmol m^{-2} s^{-1} (PPFD – photosynthetic photon flux density). Light were measured with Li-Cor Light meter LI-250A, quantum sensor LI-190. Light transmission coefficient was used 50% for the whole greenhouse structure. A dayly light exposure equaled 18 hours. The growing compartments provided computer-con- trolled microclimate conditions and fertigation. In each growing compartment there were 3 benches of plants (9 m long each) with slabs type Grotop Master 100 × 20 × 10 cm, and 7 plants per slab were used. Each combination consisted of different plants' density which was as follows: 2.62 plants per m^2 (5 slabs per one bench) for HPS combination, 3.67/m^2 (7 slabs per one bench) for HPS + LED combination and 4,19/m^2 (8 slabs per one bench) for 100% LED combination. The study involved greenhouse midi cucumber 'Svyatogor' F1 – a parthenocarpic cultivar from Rijk Zwaan – with high shade tolerance, producing fruits of a 18–22 cm lenght. It was cultivated in the autumn productive cycle. Seeds were sown on August 12. Seedlings were produced in the rockwool blocks under optimal growing conditions (temperature – 22°C day/20°C night, soil humidity – 70–80% water capacity, air humidity – approximately 70%, light intensity – daylight with supplementary HPS light at 170 μmol m^{-2} s^{-1} level). In each growing compartment cucumber plants were planted into the rockwool slabs on September 03.

The plants were trained on a single stem up a string according to the high wire system. On each plant every fruit until 6^{th} leaf was removed, and starting from 7^{th} leaf every second fruit was kept. Every second day, bottom leaves were removed (maximum 3 leaves at once). To assess the plant growth and development fitomonitoring was performed on 14 plants taken from 2 slabs in each of combination compartments. The method of removing excess buds from plants in individual light combinations was adjusted to the condition of plants in each growing compartment. Fruit pruning was done twice a week before anthesis in all growing compartments. Additionally, in each combination, on three randomly selected plants, all newly emerging buds were kept in order to assess the bud abortion rate at 100% of the fruit left on the plant. Nutrient solution for fertigation based on one-component fertilizers. pH and EC were monitored during the plant growth and maintained at the levels 5.5 and 3.0 mS cm^{-1}, respectively. Nutrient EC in the substrate ranged from 3.2 to 4.0 mS cm^{-1}. Microclimate parameters in growing rooms were controlled by Synopta Climate Computer and were as follows: temperature was 22–25°C/18–20°C during day/night respectively, CO_2 was supplied up to 800 ppm level, RH was approximately 70%.

The number and weight of cucumber fruits were assessed in terms of both marketable and unmarketable yield. The harvest was carried out every day, and harvested fruits were ca 200 g. Each combination comprised 3 replicates and a replicate constituted fruits collected from plants growing on one bench in a respective compartment. The experiment was terminated on 22 December 2015 after 17 weeks of cultivation.

The fruits' quality was assessed at harvests on the 25.11.2015 and 8.12.2015, when 40 fruits were randomly selected from each experimental combination.

One part of fruits from each harvest was then examined for the chemical quality attributes of cucumber fruit, such as the content of total soluble solids (TSS) – using the digital refractometer and expressed in per cent, total sugars (TS) – analyzed according to the Luff-Schoorl method and vitamin C according to the Tillmans method. Nitrate (NO_3) content was determined spectrophotometrically, the content of P with the colorimetric test and the content of K and Ca with the flame method. All the chemical analyses were done in three replicates.

Another part of fruits served for sensory analysis performed with the scaling method. The trained panel of 18 persons evaluated cucumber fruit samples in two replicates in relation to their skin firmness, flesh texture, juiciness of flesh, cucumber smell, strange smell, taste (sweet, sour, typical cucumber, strange) and overall quality. Each attribute of sensory analysis was expressed in a numeric 0 to 10 scale.

Statistical analysis was elaborated using analysis of variance (ANOVA). Detailed comparison of means was performed by the Tukey's test at the significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The obtained results showed that under low radiation conditions, the application of assimilation supporting lighting render the stable yield of high quality cucumber fruits. It was found that during plant vegetation, natural light was sufficient for plants' development until mid-October, when it reached 600 W m^{-2} with high daily averages of light intensity. Then the light level significantly decreased (fig. 1). To obtain comparable light conditions in each experimental growing compartment, which was PPFD at the level of ~320 µmol m^{-2} s^{-1}, lamps were turned off whenever the natural light intensity reached the level of 300 W m^{-2} and when the internal temperature exceeded 30°C. Interlighting worked independently of the conditions. It was calculated to generate the most comparable irradiance conditions in all three compartments, therefore the top lamps were turned off partially in HPS and HPS + LED combinations. Figure 2 presents lamps operating hours per growing day. During the first half of cultivation, the light flux received per day was nearly 25 mol m^{-2} PPFD. In the second half it was approximately 22 mol m^{-2} (fig. 3). The plants lighted with 100% LED showed highest yield dynamics (fig. 4). At the end of the 5th growing week, these plants gave 5.91 kg of fruit per m^2 in total, whereas at the same time in the combination with sodium lamps only, it was 4.34 kg of fruit per m^2. At that time the difference was 1.57 kg of fruit per m^2, in favor of diode lighting. Till mid-October, i.e. till 7th week, in 100% LED combination the harvest already amounted to 15.32 kg m^{-2}, in HPS + LED combination with interlighting to 12.16 kg m^{-2}, whereas in the combination only with HPS overhead lighting to 10.68 kg m^{-2}.

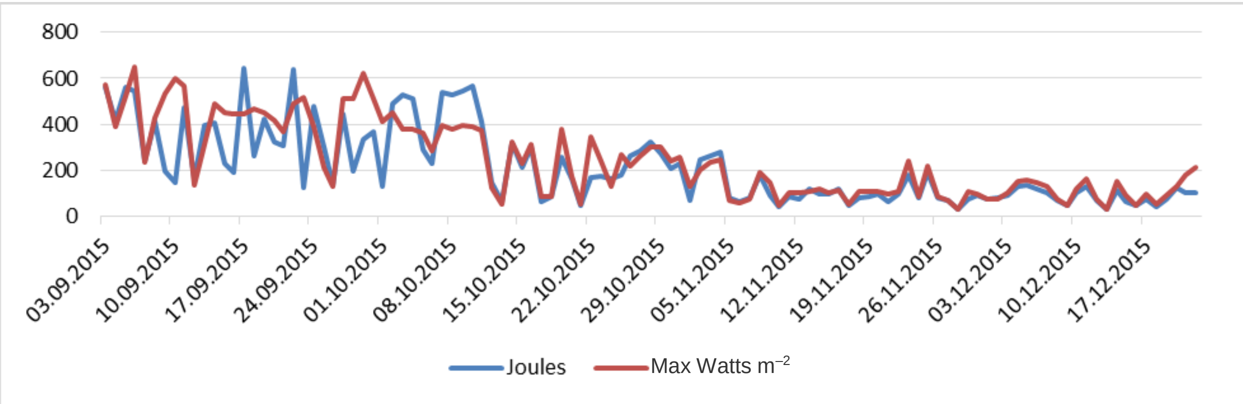

Fig. 1. Natural light conditions: Joules – J cm^{-2} day^{-1} inside and Max W m^{-2} outside

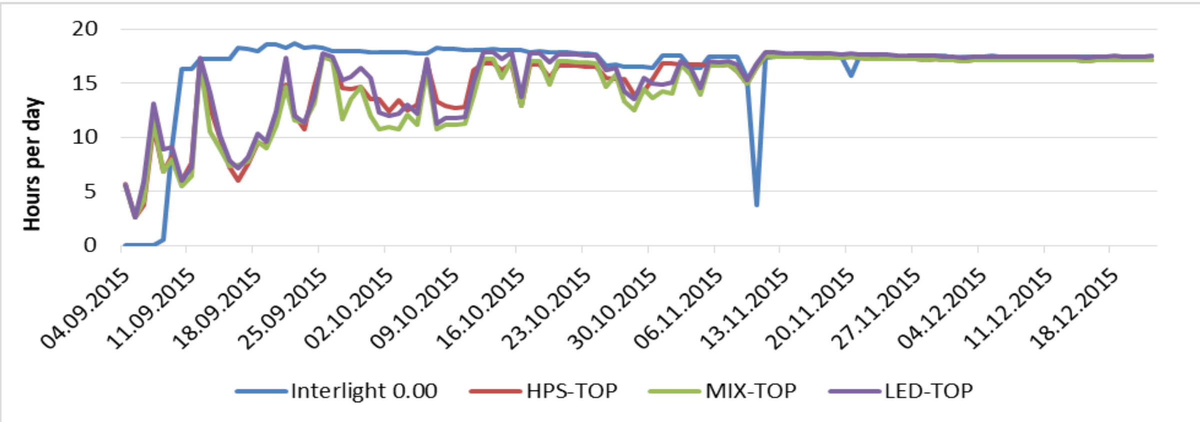

Fig. 2. Time the lamps were turned on in relation to natural light level. Interlight (2 line LED), HPS, MIX (HPS+LED) combination and LED (100% LED) respectively

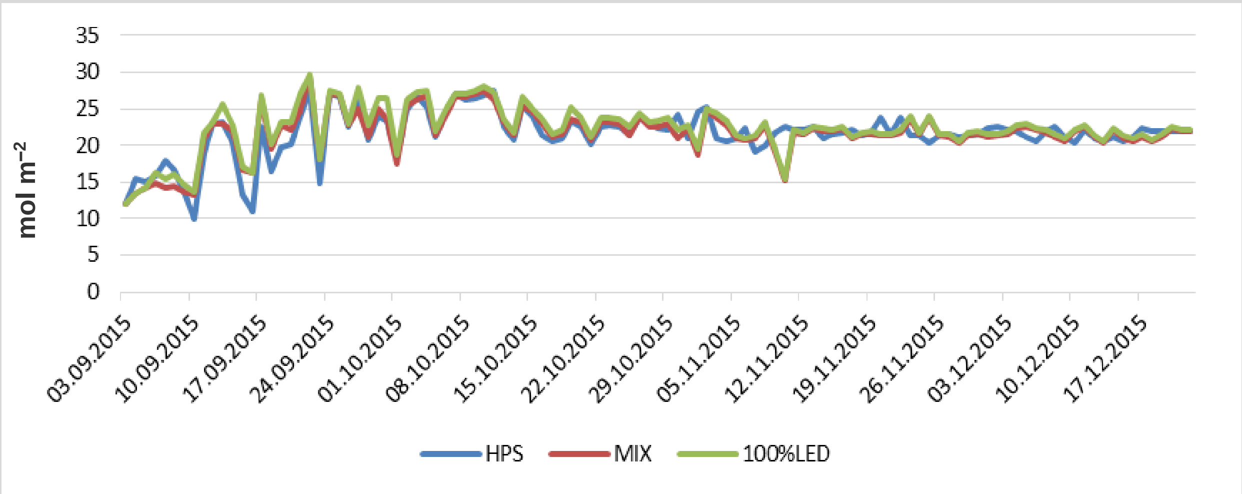

Fig. 3. Daily light sum of both natural and artificial light. HPS, MIX (HPS + LED) and LED (100% LED) combination respectively

Fig. 4. Weekly yielding of cucumber in relation to lighting

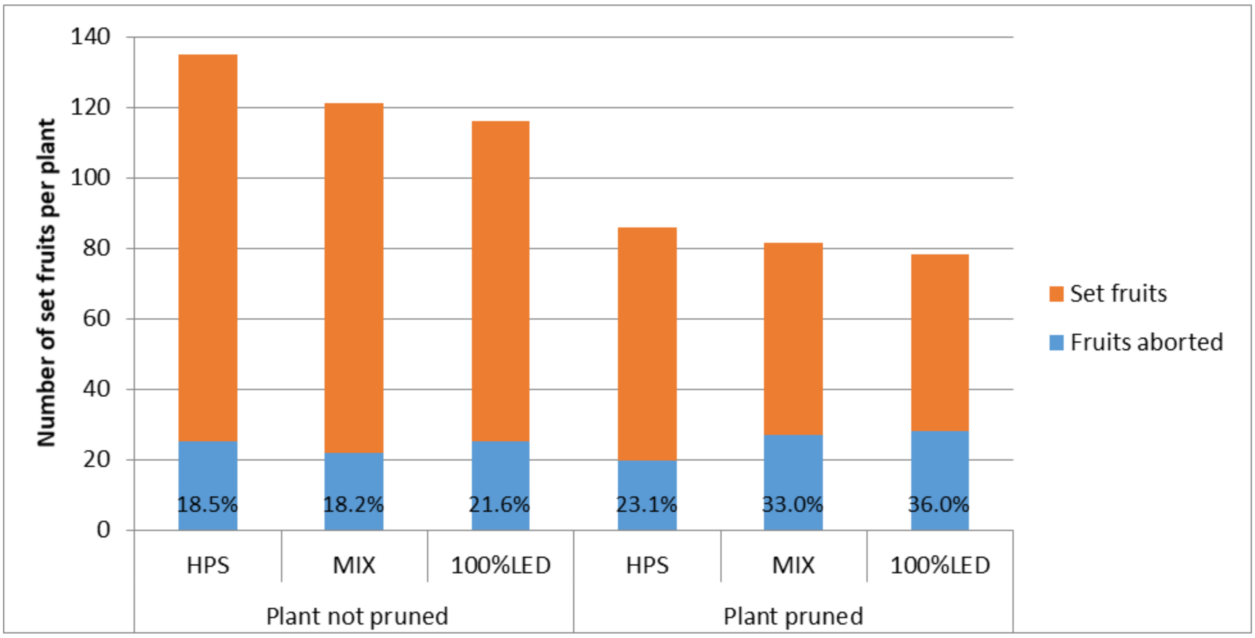

Fig. 5. The share of abortion in relation to the number of cucumber fruits in the plants purposely pruned from the excess of buds and plants not pruned in which all buds were left

Lamps for supplemental lighting are usually placed above the crop which makes the light radiation difficult to evenly reach to bottom leaves and therefore has a small effect on yield [Acock et al. 1978]. According to Kahlen [2006], cucumber plants preferentially project leaf area into light gaps and avoid poorly illuminated sites. Thus, the installation of supplemental lighting system placed in among plants and not only above the canopy seems more effective in terms of enhancing the plant efficient assimilation surface [Adams et al. 2002]. According to Trowburst et al. [2011], intercropping supplemental lighting increases crop yield throughout the reduction in light loss, as some light (6–7%) is normally reflected in upper parts of plants. Installing supplemental lighting horizontally reduces the light losses at transmission by 5–10%, and as such provides more regular intercropping lighting and promotes leaf photosynthetic efficiency. In 2010, Pettersen and et al. reported that the application of intercropping supplemental lighting improved the process of fruit ripening which was expressed by obtaining fruits from higher parts of plants. Hovi [2004] indicates that leaves located closest to intercropping lamps grow in the environment of higher temperatures what is also of importance in terms of yield. Moreover, intercropping supplemental lighting seems beneficial for yielding even at times of sufficient radiation as the lower parts of plants are naturally scarcely penetrated by sunlight [Nederhoff 1984]. As a consequence, the increased availability of light and higher temperatures make single fruits ripen faster and the total number of fruits increases [Marcelis 1993a, b]. The higher availability of light, the better fruit coloring and longevity of shelf life in greenhouse cucumber fruits, owing the increased chlorophyll content in the skin high for fruits harvested in both dates (tab. 3). Fruits harvested from HPS combination showed weaker cucumber smell and stronger strange smell, comparing either to LED or intercropping lighting combinations. The fruits had also lighter green color of skin, less numerous skin tubercles, firmer flesh, smaller core and were found sweeter than fruits from MIX and 100% LED combinations, however, no significantly important differences in fruit total sugar content had been revealed (tabs 2 and 3). Overall quality, taste desirability and overall desirability were similarly high for all fruits, irrespectively harvest date and light conditions of cultivation (tab. 3). Similarly, Dzakovich et al. [2015] did not reveal any significant differences when analyzing the quality of tomato fruits in response to supplemental lighting with LED or HPS lamps. Whereas Hao et al. [2012] observed visual improvement of cucumber fruits after involving red and blue diodes in supplemental lighting.

The assessment of bud abscission in cucumber plants with all developing buds left untreated showed that at the density of 3.66 plants per m^2, and with the applied intercropping MIX lighting, the number of buds shed was similar comparing to the one revealed for HPS supplemental lighting with 2.66 plants per m^2, and amounted to ca. 18%. Whereas at the density of 4.19 plants per m^2 and for 100% LED combination, the mean number of the buds shed was in untreated plants over 20% (fig. 5). In the case of plants with the excess buds partially removed in response to a prior plant condition assessment the highest buds' abortion rate was obtained for the density of 4.19 plants per m^2.

The cucumber grown in the autumn growing cycle gave higher yield and the quality of fruits it produced appeared more balanced for the plants lighted with HPS + LED or 100% LED as compared to the traditional, overhead HPS lighting. The above findings combined with the rate of buds' abortion assessment indicates that increasing the cucumber crop density seems reasonable, providing LED lighting is applied.

CONCLUSIONS

1. Supplemental assimilation lighting applied during autumn cultivation enabled to obtain more regular quantity and higher quality of cucumber yield.

2. At constant PPFD level, oscillating around 320 $\mu mol\ m^{-2}\ s^{-1}$, the highest cucumber harvest was obtained for 100% LED lighting with a crop density of 4.19 plants per m^2 and was accompanied by the highest rate of buds' abortion.

3. Overhead supplemental lighting with HPS, combined with intercropping LED lighting and at a 3.66 plants per m^2 crop density, resulted in higher yield as compared to HPS lighting with 2.62 plants per m^2, with similar buds' abortion rate for both combinations.

4. Intercropping supplemental LED lighting enables to increase the crop density.

5. The lighting method applied did not affect the chemical compound of cucumber fruits as opposed to the harvest date.

6. Cucumber fruits showed similar characteristics such as the sensory attributes analysed, taste desirability and overall desirability, whether it was HPS, MIX or 100% LED lighting combination.

REFERENCES

Acock, B., Charles-Edwards, D.A., Fitter, D.J., Hand, D.W., Ludwig, L.J., Wilson, W. J., Withers, A.C. (1978). The contribution of leaves from different levels within a tomato crop to canopy net photosynthesis: an experimental examination of two canopy models. J. Exp. Bot., 111, 815–827.

Adams, S.R., Woodward, G.C., Valdés, V.M. (2002). The effects of leaf removal and of modifying temperature set-points with solar radiation on tomato yields. J. Hortic. Sci. Biotechnol., 77, 733–738.

Aikman, D.P. (1989). Potential increase in photosynthetic efficiency from the redistribution of solar radiation in a crop. J. Exp. Bot., 40, 855–864.

Ariz, I., Esteban, R., García-Plazaola, J.I., Becerril, J.M., Aparicio-Tejo, P.M., Moran, J.F. (2010). High irradiance induces photoprotective mechanisms and a positive effect on NH4+ stress in *Pisum sativum* L. J. Plant Physiol., 167, 1038–1045.

Barta, D.J., Tibbitts, T.W., Bula, R.J., Morrow, R.C. (1992). Evaluation of light-emitting diode characteristics for a space-based plant irradiation source. Adv. Space Res., 12, 141–149.

Blom, T.J., Ingratta, F.J. (1984). The effect of high pressure sodium lighting on the production of tomatoes, cucumbers and roses. Acta Hort., 148, 905–914.

Brazaitytė, A., Duchovskis, P., Urbonavičiūtė, A., Samuolienė, G., Jankauskienė, J., Sakalauskaitė, J. (2010). The ffect of light-emitting diodes lighting on the growth of tomato transplants. Zemdirbyste – Agriculture, 97(2), 89–98.

Bula, R.J., Morrow, R.C., Tibbitts, T.W., Barta, D.J., Ignatius, R.W., Martin, T.S. (1991). Lightemitting diodes as a radiation source for plants. HortScience, 26, 203–205.

Chen, M., Chory, J., Fankhauser, C. (2004). Light signal transduction in higher plants. Ann. Rev Genet, 38, 87–117.

Ding, J.J., Yang, Z.C., Wang, P.B., Geng, F.Z., Gao, B. (2005). Influence of LED light intensity on growth and photosynthetic characteristics of non-heading Chinese cabbage. J. Northwest AF Univ. (Nat.), 3, 113–118.

Dzakovich, M.P., Gómez, C., Mitchell, C.A. (2015). Tomatoes grown with light-emitting diodes or high-pressure sodium supplemental light have similar fruit-quality attributes. HortScience, 50 (10), 1498–1502.

Fan, Z.Q., Yu, X., Wang, J. (2008). Effect of light intensity on leave physiological activity of *Brassica campestris* L. Anhui Agric. Sci. Bull., 20(26–27), 39.

Fang, W., Jao, R.C. (1996). Simulation of light environment with fluorescent lamps and design of a movable light mounting fixture in a growing room. Acta Hortic., 440, 181–186.

Frantz, J.M., Joly, R.J., Mitchell, C.A. (2000). Intracanopy lighting influences radiation capture, productivity, and leaf senescence in cowpea canopies. J. Am. Soc. Hortic. Sci., 125(6), 694–701.

Hao, X., Zheng, J.M., Little, C., Khosla, S. (2012). LED inter-lighting in year-round greenhouse mini-cucumber production. Acta Hortic., 956, 335–340.

Hovi, T., Näkkilä, J., Tahvonen, R. (2004). Interlighting improves production of year-round cucumber. Sci. Hortic., 102, 283–294.

Kahlen, K. (2006). 3D Architectural modeling of greenhouse cucumber (*Cucumis sativus* L.) using L-systems. Acta Hortic., 718, 51–59.

Klieber, A., Lin, W.C., Jolliffe, P.A., Hall, J.W. (1993). Training methods affect canopy light exposure and shelf life of long English cucumber. J. Amer. Soc. Hortic. Sci., 118, 786–790.

Marcelis, L.F.M. (1993a). Fruit growth and biomass allocation to the fruits in cucumber. 1. Effect of fruit load and temperature. Sci. Hortic., 54, 107–121.

Marcelis, L.F.M. (1993b). Fruit growth and biomass allocation to the fruits in cucumber. 2. Effect of irradiance. Sci. Hortic., 54, 123–130.

Marcelis, L.F.M. (1994). A simulation model for dry matter partitioning in cucumber. Ann. Bot., 74, 43–52.

Miles, C.D. (1974). Control of the light saturation point for photosynthesis in tomato. Physiol. Plant, 31, 153–158.

Mitchell, C.A., Both, A.J., Bourget, M.C, Burr, J.F., Kubota, C, Lopez, R.G., Morrow, R.C., Runkle, E.S. (2012). LEDs: The future of greenhouse lighting. Chron. Hort., 52, 6–12.

Nederhoff, E.M. (1984). Light interception of a cucumber crop at different stages of growth. Acta Hortic., 148, 525–534.

Pettersen, R.I., Torre, S., Gislerød, H.R. (2010). Effects of intracanopy lighting on photosynthetic characteristics in cucumber. Chinese Soc. Agric. Eng. (CSAE), 125, 77–81.

Shibaeva, T.G., Markovskaya, E.F., Russ, J. (2013). Growth and development of cucumber Cucumis *sativus* L. in the prereproductive period under long photoperiods. Dev Biol, 44, 78.

Smith, F.W., Cybinski, D., Rae, A.L. (1999). Regulation of expression of genes encoding phosphate transporters in barley roots. In: Plant Nutrition-Molecular Biology and Genetics. Gissel-Nielsen, G., Jensen, A.(eds). Kluwer Academic Publishers, Dordrecht, 145–150.

Terashima, I., Fujita, T., Inoue, T., Chow, W.S., Oguchi, R. (2009). Green light drives leaf photosynthesis more efficiently than red light in strong white light: revisiting the enigmatic question of why leaves are green. Plant Cell Physiol., 50, 684–697.

Trouwborst, G., Schapendonk, H.C.M., Rappoldt, K., Pot, S., Hogewoning, S.W., van Ieperen, W. (2011). The effect of intracanopy lighting on cucumber fruit yield – Model analysis. Sci Hortic., 129, 273–278.

Xiao, Y.X., Gao, X.J., Zhou, F.M. (2013). Effect of supplemental lighting on growth and development of Tobacco. Tianjin Agric. Sci.,11, 85–87.

Zoratti, L., Karppinen, K., Escobar, A.L., Häggman, H., Jaakola, L. (2014). Light-controlled flavonoid biosynthesis in fruits. Front Plant Sci., 5, 1–16.

Zuchi, S., Astolfi, S. (2012). Changes in growth irradiance are reflected on H+ATPase activity of plasma membrane enriched vesicles from maize (*Zea mays* L.) root. J. Plant Physiol., 169, 50–54.