Effect of supplementary lighting on selected physiological parameters and yielding of tomato plants (*Solanum lycopersicum* L.) in autumn-winter cultivation

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INTRODUCTION

Light is one of the most important factors affecting many physiological processes including the intensity of photosynthesis resulting in proper growth and development of plants, as well as their yield and crop quality [Blom and Ingratta 1984, Blain et al. 1987, Hendriks 1992, Perez-Balibrea et al. 2008].

Supplemental lighting with HPS lamps is applied mainly in the production of seedlings of vegetable and ornamental plants as well as pot and cut flowers [Massson et al. 1991, Hendriks 1992, McCall 1992]. Adverse economical conditions (extreme costs of energy carriers) do not allow the common usage of those lamps in plant cultivation, despite positive research results [Blom and Ingratta 1984]. Supplemental lighting increased leaf photosynthesis rates, plant growth and development, and fruit yield and quality of greenhouse crops [Hovi et al. 2004, Gunnlaugsson and Adalsteinsson 2006]. Despite a number of investigations on supplemental lighting of plants with lamps that have various light effectiveness, there is still little information showing how the quality of light affects the growth and development of plants and how particular light spectra may cause various changes in a plant. Joining red and blue light together in a proper ratio may significantly modify the content of such parameters as chlorophyll, net photosynthesis or the total nitrogen content [Matsuda et al. 2004]. Thus intensive research are performed on the LED (Light-Emitting Diodes) lamps whose spectrum may be composed of the point spectra of particular diodes and readjusted to particular plant species and cultivars needing different light spectra at particular times of their development [Wang et al. 2009].

The present research aimed at revealing the effect of supplementary lighting of tomato plants with the HPS and LED lamps on the chosen physiological parameters (photosynthesis, transpiration, stomatal conductance) and yielding of the autumn-winter cultivation crops.

MATERIAL AND METHODS

The investigations were performed in the greenhouse of Department of Vegetable and Medicinal Plants, Warsaw University of Life Sciences – SGGW (longitude 21ºE, latitude 51º15'N) in 2010 and 2011. They were performed on two greenhouse tomato cultivars (Komeett F1 and Starbuck F1 by De Ruiter Seeds Company) cultivated in the autumn-winter productive cycle. Seeds were sown at August 12 2009 and 10, 2010. Seedlings were produced in the mineral wool blocks under optimal conditions. Tomato plants were planted on the mineral wool slabs in three chambers of 60 m^2 each, in each chamber plant grown in three 9 meters long rows, at September 23, 2009 and 17, 2010. Immediately after planting, LED lamps of 100 µmol m^{-2} s^{-1} light intensity were installed in one chamber and high-pressure sodium (HPS) discharge lamps of the light intensity 100 µmol m^{-2} s^{-1} in the other. Expected light intensity was obtained at 1m distance from LED lamps and was uniform at whole length of row at width of 60 cm, HPS lamp light intensity was variable all across the row but average level was maintained at the same level at the same area (60 cm per 9 m). Experiment was finished at March 31, 2011.

LED lamps were made in custom design by Electrotechnical Institute, one lamp consists of 2 units each contains 16 pieces of 640 nm diodes, 8 pieces of 660 nm diodes and 8 pieces of 450 nm diodes. Diodes were supplied with 350 mA current resulting 1W power. There were used LUXEON REBEL Diodes. HPS lamps were provided by Gavita, light sources were GE Lucalox lamps 400W with 220V power supply. Such configuration resulted in double power consumption of HPS lamps comparing to LED.

In the third chamber plants were cultivated under natural light source (control combination). Lamps were installed 1 m over the plants and as the plants grew they were lifted. The lamps were automatically switched on when the natural light intensity was below 175 µmol m^{-2} s^{-1} and switched off when the natural light intensity was above 225 µmol m^{-2} s^{-1}. The lighting period for lamps was 16 h. The plants were trained on a single stem up a string according to the high wire system for the entire growing cycle with the mean density of 2.7 plants m^{-2}. Tomatoes were fertigated by a computer controlled drip-irrigation system and fertilized with similar rates of macro- and micro-nutrients, according to the levels recommended for tomato. The amount of the nutrient supply ranged from 70 to 200 cm^3 per plant and was adjusted in accordance to the standard recommendations for a tomato development stage. Nutrients concentration in the solution, EC and pH were continuously controlled and kept at same levels for all experimental objects. The concentration of nutrients (mg dm^{-3}) was as follows: N-NO3 – 210, P – 60, K – 340, Mg – 50, Ca – 200, Fe – 2, Mn – 0.6, B – 0.3, Cu – 0.15, Zn – 0.3, Mo – 0.05. The experiment was established in randomized block design, in six replicates, with 12 plants in each. Temperature, RH, CO_2 level was kept equal in all the chambers by Synopta climate computer. Temperature was at 22-23ºC/18-19ºC at day/night respectively. CO_2 was supplied up to 800 ppm level and supply was disabled during physiological measurements. RH was approximately 70 %.

The following physiological parameters were determined with the CIRAS-2 (PP Systems) apparatus:

- Photosynthesis (µmol CO_2 m^{-2} s^{-1})
- Transpiration (mmol H_2O m^{-2} s^{-1})
- Stomatal conductance (mmol CO_2 m^{-2} s^{-1})
- Light intensity at measurement point (µmol)
- The chlorophyll content was determined in SPAD units.

Both chlorophyll content and physiological parameters were measured twice a month starting at October 21, 2009 until February 24 2010 and October 18, 2010 until February 20, 2011. There were 6 measurements per chamber, it means 3 per combination, taken from various plants on the 6 leaf from top of the plant. There was always maintained over 1 m distance from light source, measurement apparatus light source was removed. Light intensity was used to calculate quantum yield.

Plant yielding was assessed. Marketable yield (kg m^{-2}) was calculated as well as the number of fruits per 1m^{-2} and fruit weight (g).

RESULTS

The obtained results of the investigations show that the intensity of photosynthesis in tomato plants in autumn-winter cultivation, even with the supplemental lighting in the form of high-pressure sodium discharge lamps and LED lamps was at a low level. However, there were some significant differences in the intensity of photosynthesis in plants supplementary lighted with an additional light source. The highest photosynthesis intensity was obtained in plants lighted with HPS lamps and the lowest in the control combination without supplementary lighting. Plants supplementary lighted with LED lamps were characterized by the higher photosynthesis as compared to the control combination but significantly lower as compared to the combination with HPS lamps (tab. 1). Significant differences that occurred between photosynthesis rates of both types of lighting were results of difference of light flux at the measurement point (nearly 150 µmol for HPS and nearly 85 µmol for LED). Such situation was effect of incomparable way of distribution of light in the canopy in each lamp configuration and therefore lack of ability to find matching points. As the major observable effect we can consider quantum yield which appeared to be the similar in each combination.

The highest stomatal conductance was obtained in plants supplementary lighted with HPS lamps and it was 62.1 % higher than stomatal conductance obtained for plants supplementary lighted with LED lamps and 16.6 % higher than in plants from the control combination (tab. 1). The obtained results of the investigations show that higher transpiration was characteristic for plants supplementary lighted with high-pressure sodium discharge lamps and LED lamps as compared to plants from the control combination (tab. 1). Similar results were obtained in the investigations by Kim et al. [2004], Blom and Zheng [2009]

Additional light source significantly increased the content of chlorophyll in tomato leaves. This content in the combination with sodium discharging lamps and LED lamps was higher by 24.4 %, on the average, than in the control combination (tab. 1).

Among tested physiological parameters, there was only significant difference between transpiration and chlorophyll content. Starbuck F1 cultivar plants had both higher transpiration rate and chlorophyll content than Comeet F1 cultivar (tab. 2).

Introducing a supplementary light source into tomato cultivation increased the tomato fruit yield by 150.9 % on the average as compared to the control combination. The yield of tomato fruit obtained with supplementary lighting with LED lamps was higher by 76.3 % from the yield obtained in the control combination but 54.1 % lower than that obtained in the combination with HPS lamps. In high light intensity, more uniform light level is generally beneficial because of easier plant maintenance, equal yielding and lack of harmful effect of overheating [Hao and Papadopoulos 1999]. In low light level conditions situation is different. Yield response is generally non-linear in long period [Papadopoulos, and Pararajasingham 1997]. In described experiment there were areas of high light intensity under HPS lamps which caused increase of fruit growth, while in other areas growth was reduced. Under LED lamps we had generally similar rate of fruit growth on the whole lighted area. Nonlinearity of yield response resulted in increase of total yield under HPS lamps while light level on average was similar (tab. 3).

Number and mean weight of fruit were significantly distinct between combinations. The highest number and mean weight of fruit was characteristic for tomato plants supplementary lighted with HPS lamps and the lowest for plants from the control combination (tab. 3).

Investigation over influence of tomato cultivar on yield and its properties it was stated that higher yield and fruit number characterized Comeet F1 cultivar but the Starbuck F1 cultivar had higher average fruit weight (tab. 4).

Table 1. Effect of supplementary lighting of plants on photosynthesis, transpiration, stomatal conductivity, chlorophyll, Pn/Q (mean 2010-2011).

	Control	HPS Lamps	LED Lamps
Photosynthesis (µmol CO_2 m^{-2} s^{-1})	2.0 b*	4.1 a	2.2 b
Transpiration (mmol H_2O m^{-2} s^{-1})	3.48 c	4.80 a	4.05 b
Stomatal conductivity (mmol H_2O m^{-2} s^{-1})	400.50 b	647.83 a	466.33 b
Chlorophyll (SPAD)	36.00 c	46.00 a	44.00 b
Pn/Q	0.0281 a	0.0274 a	0.026a

Table 2. Effect of supplementary lighting and cultivar on photosynthesis, transpiration, stomatal conductivity, chlorophyll, Pn/Q (mean 2010-2011).

	Starbuck	Komeett
Photosynthesis (µmol CO_2 m^{-2} s^{-1})	2.8 a	2.7 a
Transpiration (mmol H_2O m^{-2} s^{-1})	4.46 a	3.77 b
Stomatal conductivity (mmol H_2O m^{-2} s^{-1})	543.78 a	466.00 a
Chlorophyll (SPAD)	42.89 a	41.11 b
Pn/Q	0.0268 a	0.0274 a

Table 3. Effect of supplementary lighting of plants on marketable yield, numbers of fruits and average weight of fruit (mean 2010-2011).

	Control	HPS Lamps	LED Lamps
Marketable yield (kg m^{-2})	4.49 c	14.63 a	7.92 b
Numbers of fruits (m^{-2})	49.14 c	136.34 a	82.26 b
Average weight of fruits (g)	99.96 b	120.71 a	108.69 ab

Table 4. Effect of supplementary lighting and cultivar on marketable yield, numbers of fruits and average weight of fruit (mean 2010-2011).

	Starbuck	Komeett
Marketable yield (kg m^{-2})	8.50 b	9.53 a
Numbers of fruits (m^{-2})	57.83 b	120.66 a
Average weight of fruits (g)	141.99 a	77.58 b

Statistical analysis was elaborated using a two-way analysis of variance (ANOVA 2).
Detailed comparison of means was performed by the Tukey's test, means followed by the same letters are not significantly different at $\alpha = 0.05$.

CONCLUSIONS

1. Introduction of a supplementary light source to tomato cultivation caused an increase of the intensity of photosynthesis, transpiration, stomatal conductance and chlorophyll by 57.7 %, 17.1 %, 39.3 % and 24.4 %, respectively. Higher values of those parameters were obtained while supplementary lighted cultivated plants with HPS lamps than with LED lamps.
2. Commercial crop, number of fruits and mean fruit weight were higher in the combinations in which the supplementary lighting was applied. However, the values of those traits were higher when the cultivation was supplementary lighted with HPS lamps than with LED lamps.
3. Better physiological parameters readouts, as well as higher yield in HPS lighted plants were result of better light concentration, higher non-vertical and reflected light penetration - which was eliminated in LED by lamp optics to maximize flux in top of the plant area.

LITERATURE

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