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EFFECT OF SUPPLEMENTARY LIGHTING ON YIELD AND QUALITY OF TOMATO FRUITS (*SOLANUM LYCOPERSICUM* L.)

INTRODUCTION

Tomato is almost the best-known, primary consumed and popular vegetable – about 122 million tons are produced worldwide in 2005 (Moco et al., 2007; Causse et al., 2010). Tomato fruits contain simple sugars, organic acids and aromatic compounds. It is rich in vitamins (A, C, E), carotenoids and phenolic compounds, which cause high antioxidant activity (Raffo et al., 2006). It is appreciated because of high nutritional value causing beneficial effects on the human body, especially for chronic diseases and many kind of cancer (Yahia et al., 2001; Guil-Guerrero and Rebolloso-Fuentes, 2009).

The light is an essential energy source and one of the most important factors influencing chemical compounds concentration in higher plants (Wu et al., 2007; Li and Kubota, 2008). Fruits lighted by direct light have higher levels of nutritious substances and secondary metabolites, so it may be useful to supplement or replace the HPS lamps – traditional method of lighting in greenhouses by LED lamps, which are the source of blue and red light and can be used as an alternative (Dumas et al., 2003; Shin et al., 2008). They emit light radiation spectrum consisting of a selected wavelength adjusted to the absorption spectrum of chlorophyll a and b (Hao and Papadopoulos, 1999; Kim et al., 2004; Samuolienė et al., 2009). Such adjustment leads to increase of the photosynthetic system efficiency and synthesis of primary and secondary metabolites. The effect is dependent not only on the duration of this method of supplementation, but also other environmental conditions. Certain wavelength and light quality promotes various benefits for plants. The blue and red light promotes the plants growth, also increases the content of fresh and dry weight and leaf area. LED lamps allow either promoting or inhibiting the growth of roots and stems, and allow flowering control (Wu et al., 2007). Usage of LED lamps in cultivation as an supplementary light source may be beneficial for growers including advantages such as high light efficiency, low shading as effect of small size, extended durability, adjustable spectra, and low power consumption compared to another lamps.

The objective of this study was to determine the effect of supplementary lighting with HPS and LED lamps on growth, yield and quality of tomato cultivars 'Komeett F1' and 'Starbuck F1' grown in the autumn-winter growing cycle.

MATERIALS AND METHODS

The research was carried out in 2010-2011 year in the experimental greenhouse of Warsaw University of Life Sciences – SGGW in Warsaw. Seeds were sown on August 10th to rockwool blocks and after five weeks transplanted to Grodan rockwool slabs (100 × 15 × 10 cm) at the density of 2.7 plants per square meter. Tomato plants were planted on September 17, 2010 in three climate controlled greenhouse chambers of 60 m^2 each. After planting, light emitting diodes (LED) lamps were installed in one chamber and high pressure sodium lamps (HPS) in the other. Both lamp types had the average light intensity of 100 $\mu mol\ m^{-2} s^{-1}$ at the 1m distance from lamp in 60 cm wide strip over the table. In the third chamber, plants were cultivated under natural light conditions, which was used as a control variant.

Electrotechnical Institute custom made LED lamps were designed as follows: lamp consisted of 2 units each contained 16 pieces of 640 nm diodes, 8 pieces of 660 nm diodes and 8 pieces of 450 nm diodes. Diodes supplier was LUXEON. Diodes were supplied with 350 mA current that resulted with 1 W power. HPS lamps were provided by Gavita, while light sources were 400 W GE Lucalox lamps with 220 V power supply.

Lamps were installed 1 m over the plants they were lifted as the plants grew. Light level was measured at the top of the plants. The lamps were automatically switched on when the natural light intensity was below 175 W m^{-2} and switched off when the natural light intensity was above 225 W m^{-2}. Natural light was single point measured by Hortimax CLIMA 500 computer with standard sensor.

Temperature was maintained at equal level in all the rooms and average day/night temperature was kept within range 17.5-25.3 ° C, average of 24 hour averages was stated as follows: 20.7, 20.8 and 20.8 ° C for control, HPS and LED respectively. Relative humidity was within range 30-80% and on average it was 55.9, 58.8 and 60.5 % for control, HPS and LED respectively. The EC at all chambers was kept as the same average 4.2 mS, and pH was stated within range 6.3-6.4 in all chambers.

The experiment was set in 3 replications in split-split plot design where major factor was light source, and secondary was cultivar of 12 plants per cultivar at every combination. Tomatoes were fertigated with same rates of macro- and micro-nutrients, according to the levels recommended for tomato. The concentration of nutrients (mg dm^{-3}) was as follows: N-NO_3 – 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.

Fruits were harvested 13 times starting from Dec., 3th 2010 up to Mar., 21st 2011, marketable fruits weight and yield was obtained and fruits were taken for analyses at full maturity stage three times during harvest. Leaves and side stems were pruned 17 times starting from 22nd October 2010 to 16th February 2011, leaves were weighted every time. LAI was measured five days after pruning. Samples for chemical analysis were obtained at: December 13th, 2010, January 4th, 2011 and February 8th, 2011, close to the end of cultivation. Dry matter, total sugars, potassium, phosphorus and nitrate content were determined. The dry matter content of tomato fruits was determined by drying method at 104 °C, total sugars by Luff-Schoorl method (g 100 g^{-1}), content of potassium and phosphorus by spectrophotometric method, nitrate nitrogen with FIAstar 5000 device (mg 100 g). Statistical analysis was done with the ANOVA using the multiple Tukey's test at the significance level a = 0.05.

RESULTS AND DISCUSSION

The application of supplementary lighting resulted in increase of average leaf weight. Leaf area index appeared different, it was significantly higher at the HPS treated plants (2.25) and in the remaining plants it was at lower level (2.07). Leaves under LED treatment were more sturdy, thicker and appeared healthier than in other two cases. Leaf weight was the highest at HPS lighted plants (43.17 g per leaf), while it was 38.19 g and 28.04 g for LED and control plants respectively. The same situation, that HPS treated plants gave the highest values, applies for number and weight of leaves per m^{-2} (Tab. 1). Enlarged leaf under the supplemental lighting treatments allows increase of light interception which led to increase biomass. Red light increased levels of cytokines, which plays important role in plants development (Li and Kubota 2008).

The highest marketable yield was achieved by cultivar 'Komeett F1', with HPS lamps lighting. Fruits of this cultivar achieved the highest average weight (Tab. 2). The greatest average weight had fruits from HPS lamps (120.71 g). Marketable yield obtained from plants under HPS lamps was higher by 45.84 % compared to plants under LED lamps. At the experiment by Demers et al. (1998) tomato plants lighted by HPS lamps (400 W, for 16 hours) gave 13.2 kg m^{-2} of marketable yield. Fruits both cultivars treated by HPS lamps gave the highest marketable yield (13.80 kg m^{-2}) and (12.86 kg m^{-2}).

Optimizing of supplemental lighting spectra might be strategically used to enhance nutritional value, i.e. can positively affect content of various phytonutriens. Supplemental lighting treatments can significantly increase biomass of plants. Dry weight, stem length, leaf length and leaf width can be significantly affected by different light quality and increased by 15 %, 14 %, 44 % and 28 %, respectively (Li and Kubota 2008).

Tomato fruits lighted with both HPS and LED lamps had comparable dry matter content (3.90 %; 3.74 %) with the control (3.60 %) so there were no significant differences (Tab. 3). Term of harvest has been a factor in three way ANOVA analysis relevant to chemical compounds. The influence of the harvest term and cultivar separately was significant. Compared to the other two harvest terms, significantly higher dry weight (4.04 %) was determined in fruits harvested in early January. The fruits of cultivar 'Komeett F1' had a significantly higher dry weight (3.88 %) than 'Starbuck F1'. At Masson et al. (1991) experiment supplementary lighting significantly increased dry weight of broccoli, celery, tomato, and lettuce ranged among 19 %, 22 %, 24 % and 40 %, respectively. There were no interactions between tested factors in this case.

There was a significant difference in total sugars content in fruit between types of light, the terms of harvest and cultivars separately. The highest total sugars content was determined in fruit from the second sampling date (1.67 mg 100 g^{-1} FW). The fruits of cultivar 'Starbuck F1' had higher total sugars content than 'Komeett F1' (1.48 and 1.40 mg 100 g^{-1} FW respectively). HPS lamps gave the greatest content of total sugars in fruit (Tab. 4). The significantly highest total sugar content was observed in fruit 'Komeett' treated HPS lamps on January 4th 2011 (1.84). In both types of supplementary lighting was observed higher concentration of total sugars in fruit.

The lowest content of total sugars was observed in fruits without artificial lighting application (1.31 g 100 g^{-1}).

There was a significant difference in fruit potassium content between supplemental lighting treatments and the term of harvest separately. The highest potassium content in fruit was obtained at the third sampling date (269.83 mg 100 g^{-1}). There were no significant differences on potassium concentration in fruit between cultivars. The fruits picked from plants grown without supplemental lighting had the lowest potassium content (166.16 mg 100 g^{-1}). The fruit from lamp treatments gave the similar concentration of potassium (Tab. 5). The highest content of potassium was observed in 'Starbuck F1' fruits, collected in early February from plants lighted with LED lamps (305.45 mg 100 g^{-1}).

Tested factors did not affect phosphorus content in fruit (Tab. 6). The application of different types of supplemental lighting lamps did not affect phosphorus content (16.96 mg 100 g^{-1}; 17.21 mg 100 g^{-1}). There were no interactions between tested factors in this case.

Usage of both types of supplementary lighting causes decrease of nitrate nitrogen accumulation in fruit. The accumulation of nitrate nitrogen in tomato fruits was significantly lower when HPS lamps were used (11.73 mg 100 g^{-1}), accumulation in fruits grown with LED light was higher (12.20 mg 100 g^{-1}) but still lower compared to fruits grown without supplemental lighting (14.37 mg 100 g^{-1}). The lowest concentration of nitrate nitrogen in fruit had 'Comeett F1' cultivar. At the third term, the accumulation of nitrate nitrogen in fruits was higher than at first and second which were statistically the same (Tab. 7).

Papadopoulos and Pararajasingham (1997) shown that lighting of plants can significantly increase tomato marketable yield. The application of HPS lamps resulted with variable conditions which may be due to a less uniform distribution of light. In high light amount conditions such effect would be harmful, but in this experiment they had low, or even extremely low light conditions. It resulted in maintaining plant near photosynthesis compensation point, therefore plants under HPS lamps obtained in some areas much higher light level, and in some they get almost no light at all. This case reminds comparison between too dense planted canopies where they get lower crop comparing to sparser placement. Therefore we compared influence of lower or higher long term average light level. In this study was similar situation with HPS lamps, where were less plants lighted at the same time but they gave higher yield, due to non-linear yield response to light level (Papadopoulos and Pararajasingham, 1997 after Cockshull et al., 1992) Under the LED lamps we had more equal conditions, which normally would be beneficial both for yield directly and plant treatment (harvesting, pruning), but under low light levels it result in lower yield. The more research is needed for confirmation.

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Tab. 1. Effect of supplemental lighting and cultivar on average weight of leaf (g), number of leaves (per m^2) and weight of leaves (g m^{-2}) and effect of supplemental lighting on LAI

		Light source			
	Cultivar	Control	HPS lamps	LED lamps	Mean for cultivar
Average leaf weight	Komeett	26.85 a	41.05 a	37.09 a	35.00 b
	Starbuck	29.23 a	45.28 a	39.29 a	37.93 a
	Mean for light source	28.04c	43.17 a	38.19 b	
Number of leaves	Komeett	5.49 a	6.88 a	5.90 a	6.09 a
	Starbuck	5.33 a	6.63 a	6.03 a	6.00 a
	Mean for light source	5.41 c	6.76 a	5.96 b	
Weight of leaves	Komeett	147.56 a	281.97 a	219.10 a	216.21 b
	Starbuck	155.89 a	300.60 a	236.79 a	231.09 a
	Mean for light source	151.72 c	291.29 a	227.95 b	
LAI		2.07 b	2.25 a	2.07 b	

* Means separation at 5 % level, small letter between combination and cultivar values.

Tab. 2. Effect of supplemental lighting and cultivar on marketable yield (kg m^{-2}) and average weight of fruit (g)

		Light source			
	Cultivar	Control	HPS lamps	LED lamps	Mean for cultivar
Marketable yield	Komeett	4.50 c	13.80a	7.75 b	8.68 a
	Starbuck	3.69 c	12.86 a	6.69 bc	7.75 a
	Mean for light source	4.10 c	13.33 a	7.22 b	
Average fruit weight	Komeett	74.75 a	82.32 a	75.67 a	77.58 b
	Starbuck	125.16 a	159.11 a	141.71 a	141.99 a
	Mean for light source	99.96 b	120.71 a	108.69 ab	

* Suitable like in the first table.

Tab. 3. Effect of harvest term, supplemental lighting and cultivar on fruit dry weight (%)

		Term of harvest				
Light source	Cultivar	Dec 13, 2010	Jan 4, 2011	Feb 8, 2011	Mean for light source	Mean for cultivar
Control	Komeett	3.54 a	4.22 a	3.48 a	3.60 a	
	Starbuck	3.06 a	3.48 a	3.85 a		
HPS lamps	Komeett	3.82 a	4.38 a	3.87 a	3.90 a	
	Starbuck	3.69 a	4.19 a	3.47 a		
LED lamps	Komeett	3.67 a	4.06 a	3.87 a	3.74 a	3.88 a
	Starbuck	3.24 a	3.89 a	3.71 a		3.62 b
Mean for harvest term		3.50 b	4.04 a	3.71 b		

* Suitable like in the first table.

Tab. 4. Effect of harvest term, supplemental lighting and cultivar on total sugars content in fruit (mg 100 g^{-1} FW)

		Term of harvest				
Light source	Cultivar	Dec13, 2010	Jan 4, 2011	Feb 8, 2011	Mean for light source	Mean for cultivar
Control	Komeett	0.89 c	1.54 ab	1.09 c	1.31 c	
	Starbuck	1.46 bc	1.56 ab	1.31 bc		
HPS lamps	Komeett	1.54 ab	1.84 a	1.52 b	1.59 a	
	Starbuck	1.52 b	1.76 ab	1.38 bc		
LED lamps	Komeett	1.06 c	1.64 ab	1.44 bc	1.42 b	1.40 b
	Starbuck	1.54 ab	1.66 ab	1.17 c		1.48 a
Mean for harvest term		1.34 b	1.67 a	1.32 b		

* Suitable like in the first table.

Tab. 5. Effect of harvest term, supplemental lighting and cultivar on potassium content in fruit (mg 100 g^{-1} FW)

		Term of harvest				
Light source	Cultivar	Dec 13, 2010	Jan 4, 2011	Feb 8, 2011	Mean for light source	Mean for cultivar
Control	Komeett	111.58 d	148.81 cd	230.83 b	166.16 b	
	Starbuck	97.84 d	145.55 cd	262.38 ab		
HPS lamps	Komeett	133.50 cd	133.40 cd	287.58 ab	182.78 a	
	Starbuck	139.09 cd	149.63 cd	253.48 b		
LED lamps	Komeett	122.91 cd	170.13 c	279.24 ab	191.83 a	180.74 a
	Starbuck	126.91 cd	146.36 cd	305.45 a		179.77 a
Mean for harvest term		121.97 c	148.98 b	269.83 a		

* Suitable like in the first table.

Tab. 6. Effect of harvest term, supplemental lighting and cultivar on phosphorus content in fruit (mg 100 g^{-1} FW)

		Term of harvest				
Light source	Cultivar	Dec 13, 2010	Jan 4, 2011	Feb 8, 2011	Mean for light source	Mean for cultivar
Control	Komeett	12.06 a	14.83 a	14.51 a	15.66 a	
	Starbuck	20.32 a	16.17 a	16.08 a		
HPS lamps	Komeett	15.37 a	17.64 a	17.61 a	16.96 a	
	Starbuck	16.67 a	17.67 a	16.78a		
LED lamps	Komeett	15.03 a	18.83 a	17.75 a	17.21 a	17.26 a
	Starbuck	16.84 a	15.93 a	18.89 a		15.96 A
Mean for harvest term		16.05 a	16.85 a	16.94 a		

* Suitable like in the first table.

Tab. 7. Effect of harvest term, supplemental lighting and cultivar on nitrate nitrogen content in fruit (mg 100 g^{-1} FW)

		Term of harvest				
Light source	Cultivar	Dec 13, 2010	Jan, 4, 2011	Feb 8, 2011	Mean for light source	Mean for cultivar
Control	Komeett	13.51 b	10.31 b	27.07 a	14.37 a	
	Starbuck	10.54 b	11.08 b	13.70 b		
HPS lamps	Komeett	11.40 b	13.30 b	12.79 b	11.73 b	
	Starbuck	9.76 b	9.38 b	13.76 b		
LED lamps	Komeett	12.18 b	10.08 b	15.16 b	12.20 ab	11.55 b
	Starbuck	11.33 b	10.09 b	14.33 b		13.98 a
Mean for harvest term		11.46 b	10.71 b	16.14 a		

* Suitable like in the first table.

CONCLUSIONS

Marketable yield obtained from plants under LED lamps was lower by 45.84 % compared to HPS lamps usage of and it was 76.10 % higher than control. Supplemental light treatments can significantly increased biomass of plants. Usage of HPS lamps and light emitting diode lamps caused decrease of nitrate nitrogen accumulation in fruit. Supplementary lighting caused higher content of total sugars and potassium in fruit but did not affect accumulation of phosphorus.

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