INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/3/2014, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1377–1385
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2014.4.3.103

INFLUENCE OF SUPPLEMENTARY LIGHTING ON GROWTH AND PHOTOSYNTHETIC ACTIVITY OF TOMATO TRANSPLANTS

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Summary

The objective of the study was to examine the influence of supplemental lighting with sodium light and LED on leaf gas exchange and growth of tomato transplants. During cultivation period (September – October) the transplants received supplemental artificial lighting provided by standard high-pressure sodium lamps (HPS) or high-power solid-state lighting modules with red, blue and far-red LEDs. Quantum irradiance in both combinations was maintained at the same level. The third group of plants (control combination) was grown under the natural light (without supplemental lighting). The following measurements were taken: leaf gas exchange (net photosynthesis and transpiration rate) and selected morphological parameters (fresh weight of plant organs, leaf surface area, plant height). The results showed that supplemental illumination using LED or HPS light sources affected growth and physiological responses of tomato plants. The higher rates of leaf gas exchange were found in the plants supplementary lighted (compared to the control ones). Supplemental lighting also resulted in enhanced plant growth, however no significant differences were found between the plants lighted with HPS or LED. The obtained results showed that HPS lamps can be replaced by LEDs in greenhouse lighting systems for tomato transplant production during periods with insufficient natural light.

Key words: *Lycopersicon esculentum,* gas exchange, photomorphogenesis

INTRODUCTION

Light is one of the most important environmental factors strongly affecting plant growth and development (Blom and Ingratta 1984, Hendriks 1992, Liu *et al*. 2011). Light is used by plants in two general ways: as a source of energy during photosynthesis and as a trigger for a number of developmental events (photomorphogenesis). These independent of photosynthesis processes occur throughout the whole life cycle of plants, from germination through vegetative growth (shoot elongation, leaf development), generative development until the senescence. Many studies revealed an existence of relationship between light availability and productivity of plants (Selga *et al*. 1983, Massa *et al*. 2008). Insufficient amount and/or inadequate spectral composition of light can cause not only the reduction of yield but also the deterioration of its quality (Starck *et al*. 1995).

Poland is located in the temperate climate zone, characterized by a deficit (considering crop requirements) of natural sunlight in autumn, winter and early spring. Energy inputs (heating and lighting) range from 10 to 30% of total production costs for the greenhouse industry (Mitchell *et al*. 2012). Most energy used in greenhouse production is derived from the fossil fuels, which is criticized for its negative impact on the environment. Therefore, new lighting technologies that significantly reduces consumption of electricity for crop lighting are of interest to crop growers.

Currently in horticultural production high pressure sodium lamp (HPS) is mostly used, which presents a high luminous efficacy and a relatively long life (Brazaitytė *et al*. 2010, Puternicki 2010). Adverse economical conditions (high cost of energy) limit, however, to a large extend the introduction of those lamps to a wide crop production. It should also be noted that the spectrum of light in those lamps is determined by their construction and is difficult to modify. Moreover, these lamps emit large amounts of heat which (when the lamps are improperly used) might cause thermal injury to plants.

In recent years, semiconductor light sources (light-emitting diodes, LED) have become more popular in practical lighting solutions (Puternicki 2010). The main advantage of this solution over the other artificial light sources is the possibility to optimize the spectrum of LED modules easily. The use of light-emitting diodes allow to build lighting modules of any spectral characteristics, which can be adjusted to the needs of any species cultivated. Other advantages of using LEDs are: small sizes of a single light source, high durability and reliability, minimal heat emission (Massa *et al*. 2008, Puternicki 2010, Mitchell *et al*. 2012). All these characteristics suggest that the widespread use of LEDs in greenhouse technologies is only a matter of time.

Tomato is commercially one of the most important vegetable crop worldwide, often grown under covers. Tomato is a plant with high thermal and light requirements. The quality of planting material is a key factor determining the quality and quantity of crops produced. At the northern latitudes tomato transplants are produced under unfavorable conditions of insufficient natural light. In such conditions supplemental lighting is often used from autumn to spring to enhance the growth of seedlings and promote yielding (Głowacka 2002, Gajc-Wolska *et al*. 2010).

In the available literature there are few data concerning the possible use of supplemental lighting for tomato cultivation. Study performed by Lu *et al*. (2012) revealed that white and red LEDs were effective in enhancing tomato yield. Several experiments were done to assess the effect of blue light on growth and quality of tomato planting material. Addition of blue LEDs (supplemental to HPS lamps or red LEDs) increased photosynthetic performance and plant biomass accumulation (Liu *et al*. 2011, Samuolienė *et al*. 2012). However, in other studies no positive effect of additional blue light on early growth of tomato seedlings was found (Hernandes and Kubota 2012). Further research in necessary to determine the optimal light spectra for the growth of specific crops when LEDs are used as supplementary light source. The aim of the study was to examine the influence of supplemental lighting with sodium light and LED on leaf gas exchange and growth of tomato transplants.

MATERIAL AND METHODS

The study was performed in a greenhouse of the Research Institute of Horticulture in Skierniewice, Poland. On September 17th 2013 tomato seedlings (cv. 'Growdena') were transplanted to 1.2 dm^3 pots filled with a 1:1 mixture of peat substrate and coco substrate, and placed on potting benches in greenhouse chambers equipped with different lighting systems:

- standard high-pressure sodium lamps of 400 W (LADYBIRD 400, Lucalox LU400W/PSL light source).
- high-power solid-state lighting modules of 110 W (DAPLON-plus, constructed at the Electrotechnical Institute), emitting light in the spectral ranges: red 642 and 666 nm (68.5%), blue 445 nm (28.4%) and far red 731 nm (3.1%).

Two LED lamps (over one potting bench) were necessary to obtain similar level of surface irradiance as for one HPS lamp. This configuration caused that the power consumption in the chamber lighted with HPS was higher (by approx. 80%) compared to the one in which LED lamps were used. The quantum irradiance in the supplementary lighted chambers, measured after planting on the level of the upper leaves of tomato seedlings was 170 ± 20 μmol m^{-2} s^{-1} (measured during a cloudy day). Supplemental lighting was automatically turned on during daytime (hours 6 – 18) when the natural light intensity reaching the greenhouse was lower than 100 W m^{-2}. Plants growing under the natural light (without supplemental lighting) served as the control group.

Growing conditions were monitored by a computerized system (Priva, Holland) controlling the temperature and air humidity. The plants were irrigated by a drip system (Netafim, Israel) according to growing medium moisture measurements carried out using capacitance probes (EC-5, Decagon Devices, USA). The experiment was prepared in 20 replicates, each comprising one plant.

In order to assess the physiological status of the plants the measurements of gas exchange rate (photosynthesis and transpiration) were carried out. The measurements were performed twice during the experiment (3 and 6 weeks after planting). Gas exchange was measured using LCpro+ analyser (ADC BioScientific, UK).

Morphological characterization involved measurement of fresh weight of stem, leaves and roots, plant height, number of leaves, shoot diameter (measured below the first leaf) and leaf area. Measurements were performed at the end of the experiment (end of October). The leaf surface area was measured using a WinDIAS image analysis system (Delta-T Devices, UK).

All data were statistically elaborated using analysis of variance, followed by means separation using Duncan's multiple-range t-test at $P < 0.05$. All calculations were performed with the help of the Statistica software package (StatSoft, Poland).

RESULTS AND DISCUSSION

Unfavorable light conditions occurring during autumn-winter and early spring periods limit the rate of CO_2 assimilation and hence negatively influence the growth and development of crop plants. The introduction of an additional light source to cultivation can affect the efficiency of photosynthetic apparatus (Gajc-Wolska *et al*. 2013). In the present experiment, three weeks after planting only minor (not significant) differences in the intensity of photosynthesis between the control plants and the ones supplementary lighted were recorded (Table 1). Similarly, intensity of transpiration was not affected by the light regimes. This might be due to the relatively high amount of natural light the plants received during the first 3 weeks of experiment (the lighting system was running only for 55 h during that period, within 195 h of the whole experimental period). Significant variations in leaf gas exchange rates were observed in the second sampling date (six weeks after planting) (Table 1). Plants supplementary lighted with LEDs were characterized by a higher photosynthesis compared to the control combination. A similar tendency was noted while observing transpiration, a dominant process in plant water relations (Klamkowski and Treder 2002). Positive effect of supplementary lighting on the CO_2 assimilation rate of tomato plants was also showed by Gajc-Wolska *et al*. (2013). However, these authors observed higher photosynthesis in case of plants lighted with HPS lamp (compared to LEDs). In the present experiment, in neither measurement period significant differences were noted between the plants lighted with a different light source. This suggests a similar efficiency of the photosynthetic apparatus of the plants from both lighted combinations.

Table 1. Effect of supplementary lighting on leaf gas exchange of tomato transplants.

	First sampling date		Second sampling date	
Treatment	Net photosynthesis ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	Transpiration rate ($mmol\ H_2O\ m^{-2}\ s^{-1}$)	Net photosynthesis ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	Transpiration rate ($mmol\ H_2O\ m^{-2}\ s^{-1}$)
HPS lamp	17.65 a	4.43 a	8.03 ab	2.45 b
LED lamp	16.07 a	3.98 a	9.42 b	2.80 b
control	15.97 a	3.89 a	7.79 a	2.03 a

Source: own research data

Means in the columns followed by the same letter are not significantly different according to Duncan's multiple-range t-test at $P < 0.05$.

There have been some studies on the effect of light spectral quality on gas exchange of various horticultural plants (Johkan *et al*. 2012, Liu *et al*. 2011). Although the effect of light quality on stomata characteristics has not been clearly determined, stomatal development could be associated with the increase of gas exchange rates. The stomata regulate gas exchange between the inside of the leaf and the atmosphere. Therefore, they are the main means of regulating water relations and carbon assimilation in plants (Hetherington and Woodward 2003). A reduced rate of CO_2 uptake in the leaves of tomato plants which were not supplementary lighted indicate a poorly developed photosynthetic apparatus, which resulted in the inhibition of their growth.

Plants are able to detect changes in light quality due to the presence of photoreceptor system responsive to specific light signals, which in consequence initiates certain developmental changes (Ward *et al*. 2005). High quality tomato transplants should have a compact habit, thick stem, well-developed green leaves and strong root system. This guarantees optimal development of plants after transplanting, and enables to obtain an early, high quality crop (Głowacka 2002). The production of tomato transplants usually takes place in winter time when there is insufficient light availability, which can result in growth inhibition and developmental disorders (Atherton and Rudich 1986). In the current study, growth inhibition was observed in the plants grown without additional lighting

(Table 2, 3). Low photosynthetic efficiency made these plants grew shorter, had thinner shoots and their leaf area was reduced in comparison with the plants grown under supplemental lighting. No differences were stated in the morphology of tomato plants grown under supplemental artificial lighting produces by various sources. The only exception was the height of the plants. The transplants lighted with HPS lamps were taller.

Table 2. Effect of supplementary lighting on morphology of tomato transplants.

Treatment	Fresh weight of leaves (g plant^{-1})	Fresh weight of stem (g plant^{-1})	Fresh weight of roots (g plant^{-1})
HPS lamp	36.34 b	50.39 b	3.95 b
LED lamp	36.26 b	47.36 b	3.53 b
control	25.86 a	27.08 a	2.12 a

Source: own research data
Means in the columns followed by the same letter are not significantly different according to Duncan's multiple-range t-test at P<0.05.

Table 3. Effect of supplementary lighting on morphology of tomato transplants.

Treatment	Leaf surface area (cm^2 plant^{-1})	Stem diameter (mm)	Plant height (cm)
HPS lamp	1227.96 b	8.33 b	89.25 c
LED lamp	1235.23 b	8.09 b	82.75 b
control	939.18 a	7.34 a	59.50 a

Source: own research data
Means in the columns followed by the same letter are not significantly different according to Duncan's multiple-range t-test at P<0.05.

A vigorous and healthy root system is essential for water and nutrient uptake and therefore is crucial for proper plant development (Nicola 1998). The ability of transplants to quick establishment in the field depends on the quality of their root system. In the present study, total root weight of the transplants supplementary lighted with HPS or LED lamps was significantly increased compared to the control ones (Table 2). However, no significant differences in root biomass between the plants grown under different light sources were recorded.

In the previous study on tomato (Klamkowski *et al.* 2012), significant changes in the morphology of plants caused by light quality (HPS or LED light sources) were found. The observed differences in plant response may result from the external conditions prevailing during the experimental period. In 2011, the production of tomato transplants started in November (approx. 2 months later compared to the investigation described here) (Klamkowski *et al*. 2012). During that period, the amount of solar energy reaching the plants was approx. 4 times lower compared to the period described in the present study (data not presented). In such conditions the influence of supplemental lighting on tomato was more pronounced and significant variations in morphology of plants cultivated under different light sources were detected (Klamkowski *et al*. 2012).

Investigations carried out by several authors revealed the importance of spectral quality of light used for supplemental lighting of crop plants. For example, supplementing the emitted spectrum with blue light increased the accumulation of biomass of cucumber (Menard *et al*. 2006), pepper (Brown *et al*. 1995), and stimulated the development of strawberry plants (Samuolienė *et al*. 2010). In the studies performed by Brazaityte *et al*. (2009 2010), the photomorphogenic response of vegetable crops depended on the spectral characteristic of the light. These authors stated a positive influence of supplemental lighting with diodes emitting the green light on growth of cucumber transplants and the opposite effect (growth inhibition) when the light spectrum was supplemented with UV radiation (Brazaitytė *et al*. 2009). A different response was observed in tomato. The addition of UV radiation enhanced the growth of tomato transplants but supplementing the light spectrum with green light was not suitable for the development of young tomato plants (Brazaitytė *et al*. 2010). It seems that due to a variety of photomorphogenic responses, the spectral range of the emitted light should be adjusted to a particular crop or even cultivar, what was confirmed by Klamkowski *et al*. (2014) on strawberry plants.

CONCLUSIONS

Tomato transplants grown in late autumn under natural light were characterized by decreased leaf gas exchange rates and reduced growth. Introduction of additional light source caused an increase of the intensity of photosynthesis and transpiration. Supplemental lighting also resulted in an enhanced plant vigor. In general, no differences in the efficiency of photosynthetic apparatus and growth between the plants grown under different light sources were recorded. The study showed that the energy-efficient LED light source can be successfully used in production of tomato transplants instead of the less efficient high-pressure sodium lamps.

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