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Advances in Space Research 53 (2014) 1574–1581

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Biochemical, photosynthetic and productive parameters of Chinese cabbage grown under blue–red LED assembly designed for space agriculture

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Received 7 November 2013; received in revised form 1 March 2014; accepted 3 March 2014
Available online 14 March 2014

Abstract

Currently light emitting diodes (LEDs) are considered to be most preferable source for space plant growth facilities. We performed a complex study of growth and photosynthesis in Chinese cabbage plants (*Brassica chinensis* L.) grown with continuous LED lighting based on red (650 nm) and blue (470 nm) LEDs with a red to blue photon ratio of 7:1. Plants grown with high-pressure sodium (HPS) lamps were used as a control. PPF levels used were about 100 μmol/(m^2 s) (PPF 100) and nearly 400 μmol/(m^2 s) (PPF 400). One group of plants was grown with PPF 100 and transferred to PPF 400 at the age of 12 days. Plants were studied at the age of 15 and 28 days (harvest age); some plants were left to naturally end their life cycle. We studied a number of parameters reflecting different stages of photosynthesis: photosynthetic pigment content; chlorophyll fluorescence parameters (photosystem II quantum yield, photochemical and non-photochemical chlorophyll fluorescence quenching); electron transport rate, proton gradient on thylakoid membranes (ΔpH), and photophosphorylation rate in isolated chloroplasts. We also tested parameters reflecting plant growth and productivity: shoot and root fresh and dry weight, sugar content and ascorbic acid content in shoots. Our results had shown that at PPF 100, plants grown with LEDs did not differ from control plants in shoot fresh weight, but showed substantial differences in photophosphorylation rate and sugar content. Differences observed in plants grown with PPF 100 become more pronounced in plants grown with PPF 400. Most parameters characterizing the plant photosynthetic performance, such as photosynthetic pigment content, electron transport rate, and ΔpH did not react strongly to light spectrum. Photophosphorylation rate differed strongly in plants grown with different spectrum and PPF level, but did not always reflect final plant yield. Results of the present work suggest that narrow-band LED lighting caused changes in Chinese cabbage plants on levels of the photosynthetic apparatus and the whole plant, concerning its development and adaptation to a varying PPF level.
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Keywords: LED-based light unit; Space agriculture; Photosynthesis; Plant yield; Biomass quality; Chinese cabbage

1. Introduction

Growing plants in space vessels is important for research purposes, the astronauts' diet improvement and for air regeneration inside biological life support systems.

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http://dx.doi.org/10.1016/j.asr.2014.03.003
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Thus, it is important to develop plant growth facilities for space applications (Berkovich et al., 2004). Currently light emitting diodes (LEDs) are considered to be most preferable source for space plant growth facilities. After the possibility to grow plants with light emitting diode (LED) lighting was experimentally demonstrated, many works were dedicated to testing LEDs for a number of crops, including space plant growth units. The first LED light sources contained only 1–2 types of LEDs and allowed limited regulation of lighting parameters (Bula et al., 1991; Hoenecke et al., 1992; Goins et al., 1997; Hahn et al., 2000). Over the last 10 years the power and cost-effectiveness of LEDs has sufficiently increased. Today lighting sources for plant growing usually include 1 to 3-watt LEDs. Efficiency of the LED light sources is higher than that of sodium lamps; external quantum efficiency of the best LEDs exceeds 50% (Tamulaitis et al., 2005). The use of luminophores allows forming various wide-band spectra of lighting sources, along with narrow-band spectra. Thus, it is now possible, when growing plants with artificial lighting, to implement nearly any light spectrum in the visible range, and to add ultraviolet and infrared light if necessary.

However, despite the technical advances in LED-based light sources, the effects of LED light on various aspects of plant physiology remain poorly studied. Firstly, in the majority of works concerning the effect of LED light on plants, the plants were grown at a low photosynthetic photon flux (PPF) level, no higher than 200–250 μmol m^{-2} s^{-1}. Such low PPF levels lead to a significantly decreased plant growth rate, irrespective of the type of light source, which makes it harder to reveal the effects of other lighting parameters on plant growth. Secondly, in works aimed at assessing the quality of LED light according to the needs of the plant, usually very few parameters are tested. These parameters are often limited to shoot fresh and dry weight, chlorophyll content, and photosystem II (PSII) parameters (Jao and Fang, 2004; Olvera-Gonzalez et al., 2013). However, photosynthesis is a complex process involving many reactions. Light is first absorbed by photosynthetic pigments, chlorophylls and carotenoids. Then the energy of the absorbed light is transformed into an electrochemical gradient of protons on the thylakoid membrane (ΔpH) through the functioning of the chloroplast electron transport chain. The energy of the ΔpH is then used to form chemical bonds in adenosine triphosphate molecules (ATP), through the functioning of a protein complex called ATP synthase. The process of ATP synthesis by the ATP synthase with the use of light energy is called photophosphorylation. The energy stored in ATP is then used to produce carbohydrates from atmospheric CO_2; these carbohydrates serve as the material for plant growth and biomass accumulation. Various environmental stimuli, including light spectrum, can lead to an imbalance in individual steps of photosynthesis, so measuring of a limited number of the photosynthetic parameters may not allow a correct estimation of plant photosynthetic performance and growth (Maxwell and Johnson, 2000). Also, the plants are often studied during a very limited period of ontogenesis (Wang et al., 2009; Hogewoning et al., 2010). Such data could be insufficient to assess the plant physiological state properly and predict their further growth and development.

The aim of our work was to study the relationship between selected parameters of the plant photosynthetic apparatus (PSA) and plant growth and development at different ages in Chinese cabbage (*Brassica chinensis* L.) grown with a LED light source at PPF levels of 100 and 400 μmol m^{-2} s^{-1}, as well as a “variable” PPF level. Some preliminary data were presented and discussed in Avercheva et al., 2009, 2010.

2. Lighting sources and experimental design

Experiments were performed with Chinese cabbage (*Brassica chinensis* L.), cv. Vesnyanka, bred at the All-Russia Research Institute for Vegetable Crop Breeding and Seed Growing. This cultivar has good taste and high Vitamin C content, and was recommended as a supplement in the cosmonauts’ diet (Erokhin and Berkovich, 2005).

The experiments were performed on a lab bench. Plants were grown on porous tubes connected with a reservoir filled nutrient solution as described in (Berkovich et al., 2002). 0.5-strength Chesnokov mineral solution with added Hoagland micronutrients was used in the experiments (Chesnokov et al., 1960). Water potential at tube axis level was (−1.0) kPa. Temperature in the room was controlled with an air conditioner. Temperature and humidity measurements were taken twice a day; average air temperature was (25 ± 1) °C, and average relative humidity was (15 ± 5)%.

We tested a lighting source based on red and blue LEDs, constructed at the Centre for LED and Optoelectronic Technology, of the NAS of Belarus. The passport emission maxima of the LEDs used were 650 and 470 nm, respectively. The red to blue photon ratio was 7:1 (Fig. 1A). As a control, we used a DNaT-400 high-pressure sodium (HPS) lamp (Fig. 1B) to provide good yields in green crops (Sager and McFarlane, 1997). Plants were grown with a 24-h photoperiod. PPF levels at the top leaf were 107 ± 9 μmol/(m^2 s) (further in the article – PPF 100, low PPF) and 391 ± 24 μmol/(m^2 s) (further in the article – PPF 400, moderate PPF). One group of plants grown with PPF 100 was transferred to PPF 400 when they were 12 days old (“variable” PPF). PPF level was measured with a Li-250A light meter equipped with a Li-190SA quantum sensor (Li-COR Biosciences, USA). HPS lamps and LEDs were isolated from each other and from daylight with screens.

Plants were harvested at the age of 15 and 28 days after planting. About 20 plants per experimental group were sown in each experiment, with spacing of about 2–3 cm. About 10 of these plants were harvested at 15 days without changing the spacing. The rest of the plants were left to grow to 28 days. Growth, photosynthetic parameters,

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