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PHOTOSYNTHESIS AND PRODUCTIVITY OF BASIL PLANTS (*Ocimum basilicum* L.) UNDER DIFFERENT IRRADIATION

M.N. POLYAKOVA[1], Yu.Ts. MARTIROSYAN[1], T.A. DILOVAROVA[1], A.A. KOSOBRYUKHOV[1, 2]

[1]*All-Russian Research Institute of Agricultural Biotechnology,* Russian Academy of Agricultural Sciences, 42, ul. Timiryazevskaya, Moscow, 127550 Russia, e-mail yumart@yandex.ru, dilovarova@yandex.ru, kromashka@gmail.com;
[2]*Institute of Basic Biological Problems*, Russian Academy of Sciences, Pushchino, Moscow Province, 142290 Russia, e-mail kosobr@rambler.ru
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A b s t r a c t

Improving the efficiency of growing plants in phytotrons is largely linked to the introduction of advanced technologies, providing the optimization of the light conditions. The use of modern light sources such as light emitting diodes (LEDs) or induction lamps can reduce the energy consumption for growing plants due to the high light output, long work and control of the spectrum of irradiation. Comparative studies of growth processes and activity of the photosynthetic apparatus of plants of Basil (*Ocimum basilicum* L.) variety Ararat, when using LEDs and induction lamps with an energy capacity of 64 and 150 W, respectively were done. The light intensity was 80-85 μmol photons $\cdot$ m$^{-2}\cdot$ s^{-1} under LEDs white light and 240-260 μmol photons $\cdot$ m$^{-2}\cdot$ s^{-1} under induction lamps. CO_2 gas exchange, the content of pigments and growth processes in plants grown in hydroponic conditions were estimated. The rate of photosynthesis under induction lamp was more than 2 times higher than under LEDs (2.6±0.4 and 1.2±0.3 μmol $CO_2\cdot$ m$^{-2}\cdot$ s^{-1}, respectively), although there was a slight decrease in the content of the chlorophylls (a + b) to 0.71±0.01 mg/g dry weigh compared to 0.83±0.03 for LEDs. More than twofold increase in the rate of photosynthesis did not result in the same increase in the accumulation of plant biomass that may be connected with different light saturation of growth processes and photosynthesis. The efficiency of biomass accumulation per 1 W of energy power for a period of 40 days under LEDs was 1.7 times higher than under the irradiation of induction lamp. Significant difference in photosynthetic efficiency was not detected. At elevated concentrations of CO_2 the rates of photosynthesis were comparable as a result of higher values of the quantum yield of photosynthesis, activity ribulose-1,5-bisphosphate carboxylase/oxygenase (RUBISCO) and the efficiency of carboxylation in LEDs plants. The investigation of structural and functional parameters of the photosynthetic apparatus and growth processes under the action of different light intensity showed the complex nature of the changes of some processes during long-term exposure to light of different intensity and spectral composition.

Keywords: basil, photosynthesis, LED.

Numerous basil (*Ocimum basilicum* L.) varieties enjoy well-deserved popularity in Russia. The leaves and stems of some basil species contain flavors and therefore are used both fresh and dried as a spice. At the same time, this plant is valued as a source of antioxidants contributing to human organism protection under various unfavorable conditions [1].

Improving the efficiency of plant cultivation under artificial lighting is largely linked to the introduction of the advanced technologies providing, in particular, the optimization of light conditions. Luminaries with sodium and mercury lamps are widely used now; they have maximum absorption in the area of 550-600 and 450 nm [2, 3]. The use of modern light sources, such as Light Emitting Diode (LED) illuminators, makes it possible to drastically reduce energy requirements for plant cultivation due to high luminous efficiency, long operating life and adjustable radiation spectrum. LEDs can serve as supplementary illuminators or completely replace conventional light sources in plant cultivation [4, 5]. Positive results with the use of LEDs have been obtained for various crops [6-9].

Induction lamps also become more common in plant growing under artificial lighting. The operating principle of these energy-saving light sources is based on electromagnetic induction and gas discharge for generation of visible light. The key difference of these lamps from the existing gas discharge lamps is in the electrodeless design, which significantly extends their operating life. As compared to diode illuminators (operating life of 50,000 hours), the induction lamp is designed for 100,000 hours of operation. A technique has been developed for the manufacture of special high-efficiency induction lamps with high luminous flux in the red and blue spectral regions needed for plants.

The reported data are mainly referred to the study of the effect of LEDs with various spectral distributions on growth processes and photosynthetic characteristics [10-12], as well as the influence of light of various intensity on the production process of plants [13]. Nevertheless, in spite of significant interest in the problem, there is still a lack of information about the effect of modern illumination sources on plant growth and development, photosynthetic apparatus activity and, finally, yielding capacity.

The purpose of this work was to carry out a comparative study of growth processes and photosynthetic apparatus reactions for basil plants in case of the use of a LED illumination source and an induction lamp.

Techniwue. The experiments were carried out on basil (*Ocimum basilicum* L.) plants of variety Ararat. Seeds were preliminary dipped in weak solution of potassium permanganate for 10 min and solution of biopreparation Albit (NPF Albit LLC, Russia) (1 g/ml) for 3 h and then sown directly in hydroponic units developed by us (All-Russia Research Institute of Biotechnology).

The plants were cultivated using nutrient solution of our own formulation including all necessary macro- and microelements. Room air temperature was maintained at 24-26 °C. Relative air humidity ranged from 60 to 75 %. Concentration of CO_2 during cultivation was 380-400 $\mu mol \cdot mol^{-1}$. Full plant growth cycle from sprouts to harvesting was 38-40 days on average.

The light sources were induction and LED illuminators with energy capacity of 150 and 64 W, respectively. The light intensity of the white-light LED illuminator (Focus LLC, Russia) and induction lamp (GK BSKA LLC, Russia) was 80-85 μmol photons $\cdot m^{-2} \cdot s^{-1}$ and 240–260 μmol photons $\cdot m^{-2} \cdot s^{-1}$, respectively. Each variant included 15 plants for analyses.

The rate of CO_2 gas exchange in leaves was measured in situ, at plant growth sites, using an $LCPro^+$ portable photosynthetic system (ADC BioScientific Ltd., Great Britain). In order to plot carbon-dioxide curves, carbon dioxide concentration in air was set within 0-1,600 $\mu mol\ CO_2 \cdot mol^{-1}$ using the microprocessor of the gas analyzer. The carbon-dioxide curve of CO_2 gas exchange was analyzed based on the model proposed by G.D. Farquhar et al. [14] in modification [15-17]. The dependence of apparent photosynthesis rate (Φ_B) on light intensity was determined within the range of Photosynthetically Active Radiation (PAR) from 0 to 1,600 μmol photons $\cdot m^{-2} \cdot s^{-1}$ at CO_2 concentration in air equal to 400 $\mu mol \cdot mol^{-1}$. In order to determine the light dependence of CO_2 gas exchange in leaves, light intensity was gradually increased from 0 to 1200 μmol photons $\cdot m^{-2} \cdot s^{-1}$. The light curve was approximated using the model proposed by J.L. Priol and P. Chartier (18).

The pigment content was estimated after homogenization of leaves in a porcelain mortar with addition of $CaCO_3$ and pigment extraction with 80 % acetone. The chlorophyll absorption was registered using a Spekol-11 spectrophotometer (Carl Zeiss, Germany) at wave lengths of 662 nm (chlorophyll a), 644 nm (chlorophyll b) and 470 nm (carotenoids) and was calculated as described [19].

A total of 15 plants in each variant were collected in order to determine growth parameters. The plants were separated into aboveground and underground parts, weighed and dried at 70 °C.

The tables and figures show arithmetic mean values with a standard error. The significance of differences was determined based on Student's *t*-test at P = 0.95.

Results. The basil plants grown under illumination with the induction light source were characterized by greater activity of the photosynthetic apparatus. The photosynthesis rate for the leaves of 30-day plants was more than 2 times higher than that for the plants grown under the LED illuminator (2.6±0.4 and 1.2±0.3 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, respectively).

In the conditions which did not limit the process with regard to CO_2 (at increased CO_2 concentration in air), the photosynthesis rate was the same (Table 1).

1. The parameters of approximation of carbon-dioxide curves for CO_2 gas exchange in the leaves of the basil (*Ocimum basilicum* L.) of variety Ararat with the use of the model proposed by G.D. Farquhar et al. [9] ($X \pm x$)

Parameter	Induction lamp	LED's
Maximum CO_2 absorption rate, μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$	8.78±2.53	8.02±1.61
CO_2 dark release rate, μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$	1.05±0.04	3.27±0.80
Maximum carboxylation rate, μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$	7.20±0.82	9.65±0.40
Carboxylation efficiency, μmol $CO_2 \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$	0.10±0.04	1.74±0.30
Light-saturated electron transport rate, μmol $\cdot m^{-2} \cdot s^{-1}$	21.6±0.5	14.9±2.2
Triosophosphate utilization rate, μmol $\cdot m^{-2} \cdot s^{-1}$	4.32±0.60	1.74±0.40
Carbon dioxide compensation point, μmol $CO_2 \cdot mol^{-1}$	124±10	230±12

Note: The energy capacity of the induction lamp and LED illuminator is 150 W and 64 W, respectively. The light intensity of the white-light LED illuminator (Focus LLC, Russia) and induction lamp (GK BSKA LLC, Russia) was 80-85 μmol photons $\cdot m^{-2} \cdot s^{-1}$ and 240-260 μmol photons $\cdot m^{-2} \cdot s^{-1}$, respectively.

The same photosynthesis rate at increased carbon dioxide concentration (1,200 μmol $CO_2 \cdot mol^{-1}$) could be associated with higher quantum yield for plants under the LED illuminator (i.e. 0.088 μmol $CO_2 \cdot$ μmol^{-1} photons against 0.056 μmol $CO_2 \cdot$ rmol^{-1} photons for the plants grown with the induction lamp). Thus, one of explanations with regard to the observed comparable values of plant photosynthesis rates in both variants may be the increase in quantum yield at higher CO_2 concentration in the intercellular space of plants under the LED illuminator. In addition, the light of different intensity and spectral distribution had different effects on the activity of light and dark reactions in the photosynthetic apparatus of plant leaves. Under LED illumination, maximum carboxylation rate and carboxylation efficiency were higher than similar parameters for the plants grown under the induction lamp, although electron transport and triosophosphate utilization rates turned out to be lower (see Table 1).

As a result, in spite of relatively low values of light intensity under LED illumination as compared to the induction lamp, photosynthesis rates of these plants at increased CO_2 concentration were comparable due to higher quantum yield of photosynthesis, as well as high activity of ribulose bisphosphate carboxylase/oxygenase (RBPC/O) and carboxylation efficiency in case of the plants illuminated by LED's. Along with changes in the functional activity of the photosynthetic apparatus under LED illumination conditions, some increase in the sum of chlorophylls a + b took place (0.83±0.03 as compared to 0.71±0.01 mg/g dry weight under the induction lamp). The ratio of chlorophylls a + b was also higher (4.73±0.31 under the LED illuminator and 4.47±0.22 under the induction lamp). At the same time, reduction in carotenoid content was observed: 0.12±0.01 as compared to 0.16±0.01 mg/g dry weight under the induction lamp.

In spite of some decrease in chlorophyll content when plants were cultivated under the induction lamp, biomass accumulation in this case was higher

2. The accumulation of fresh and dry biomass and growth parameters for the variety Ararat basil (*Ocimum basilicum* L.) plants grown under LED and induction illuminators

Variant	Weight, g						Plant height, cm	Number, pcs		Root length, cm
	leaves		stems		roots			leaves	nodes	
	fresh	dry	fresh	dry	fresh	dry				
Induction luminary	1.538±0.134	0.143±0.024	0.531±0.056	0.041±0.005	0.667±0.159	0.057±0.009	17.43±1.19	28.27±3.82	5.53±0.23	13.73±1.80
White LEDs	0.997±0.106	0.102±0.014	0.545±0.112	0.039±0.011	0.615±0.171	0.048±0.008	14.17±0.70	23.27±0.93	5.40±0.16	8.51±0.74

N o t e: The energy capacity of the induction lamp and LED illuminator is 150 W and 64 W, respectively. The light intensity of the white-light LED illuminator (Focus LLC, Russia) and induction lamp (GK BSKA LLC, Russia) was 80-85 μmol photons $\cdot$ $m^{-2} \cdot s^{-1}$ and 240-260 μmol photons $\cdot$ $m^{-2} \cdot s^{-1}$, respectively than that for the plants grown under LED illumination due to the higher activity of the photosynthetic apparatus, as well as due to the formation of larger leaf surface (Table 2). Alongside with that, more than double increase in photosynthesis rate did not lead to equivalent increase in biomass accumulation in plants, which may be associated with different light saturation of growth processes and photosynthesis as noted as early as in the study by N.N. Protasova and V.I. Kefeli [20]. In addition, relatively higher plant productivity at low light intensities may be explained by the X.G. Tooming's concept [21] regarding maximum productivity at adaptation radiation intensity when maximum efficiency of incident radiation utilization is observed.

In assessing the effect of various sources of illumination, it is important to determine their energy efficiency. In our situation, higher efficiency of light energy utilization by plants was observed in case of cultivation under the LED source of illumination.

So, the following indices were obtained with the use of the induction lamp (240 μmol photons $\cdot$ $m^{-2} \cdot s^{-1}$) and LED illuminator (80 μmol photons $\cdot$ $m^{-2} \cdot s^{-1}$): plant biomass was 1,538±134 and 997±106 mg, respectively, efficiency of leaf biomass accumulation per 1 W for 40 days was 7.70±0.7 and 13.3±1.4 mg, respectively, photosynthesis was 2,600±400 and 1,200±300 nmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, respectively, and photosynthetic efficiency of energy capacity utilization (per 1 W) was 13±2 and 16±4 nmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, respectively. I.e. the efficiency of leaf biomass accumulation per 1 W of energy capacity for a period of 40 days under the LEDs was 1.7 times higher than under the induction lamp. We have not found significant differences in photosynthetic efficiency of energy capacity utilization.

Thus, we have revealed the regularities of productivity formation in basil plants under different illumination conditions using the LEDs and induction lamp. Increase in light intensity due to the use of the induction lamp led to greater biomass accumulation as compared to that for the LED source of illumination, however, the energy efficiency in the latter case was higher. The study of the structural and functional indicators of the photosynthetic apparatus and growth processes depending on lighting conditions has shown a complex behavior of the part of them during long-term exposure to the light of different intensity and spectral distribution.

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