The LED phyto lighting for improving the environmental friendliness of growing and productivity of lettuce varieties with red and green leaves

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Abstract. The intensively developing area of modern phytophysiology is the ecological plants physiology, which important section is the ecology of photosynthesis, by which we understand the intensity and photosynthesis productivity dependence on environmental factors, primarily on optical radiation. The urgent problem of growing plants under artificial conditions is to increase energy efficiency, reduce energy intensity and degree of environmental impact. Using LED irradiators with the function of controlling the spectral composition and optical radiation power, it is possible to increase photosynthesis efficiency and vegetable crop productivity in greenhouses. The comparative study of the effect of sodium lamp radiation and LED irradiators with different spectral composition on the growth and productivity lettuce varieties with red leaves (Anthony, Lolo-Rossa) and with green leaves (Levistro, Lifli), was conducted. The research results showed the different susceptibility of lettuce varieties to the spectral composition of radiation. For the Anthony, Levistro and Lolo-Rossa lettuce varieties, LED radiation application provided the positive effect on plant productivity (8-20%) compared to sodium lamps, and simultaneous reduced in energy consumption of the irradiation system by 40 - 50%. Diodes emission increase in the blue region of the spectrum had a significant positive effect on the synthesis of anthocyanins in the culture of lettuce varieties with red-leaves, compared to sodium lamps. For these varieties, a variable irradiation regime is necessary with a change in the spectrum and increase in the proportion of blue radiation towards the end of growth.

1 Introduction

The intensively developing area of modern phytophysiology (at the junction of plant physiology and ecology), considering the processes of plant life in relation to environmental conditions, is the ecological plant physiology, an important section of which is the photosynthesis ecology, which is understood as the intensity and productivity dependence of photosynthesis on environmental factors, primarily optical radiation [1, 2].

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The main sources of lighting for plants in greenhouses are still high pressure sodium (HPS) and metal halide lamps, but they have a significant drawback associated with the problem of their recycling. Mercury-containing lamps utilization is currently one of the acute problems associated with the increase in the level of pollution of the environment with heavy metals.

The actual problem of growing plants in artificial conditions is to increase energy efficiency, reduce energy intensity and the environmental impact degree. Compared to other artificial light sources used in plant cultivation, LEDs have several advantages, such as high light output, low heat generation and low weight long service life and the possibility of their recycling. In addition, the LEDs are available with different radiation options from ultraviolet to infrared, therefore, it is possible to optimize the light quality in order to improve both the yield and the quality of the products obtained. Using LED irradiators with the function of controlling the spectral composition and power of optical radiation, it is possible to increase the energy efficiency of growing and the productivity of vegetable crops in greenhouses [3].

It is known that red and blue LEDs are effective for improving plant photosynthesis since chlorophyll a and b efficiently absorb radiation in the blue and red spectral regions [4]. So, under the red LED light, the leaf surface index of lettuce plants increases. Conversely, the increase in blue light levels negatively affects the lettuce growth. However, at high ratios of blue light emitting diodes, the chlorophyll content, total phenol concentration, flavonoid concentration, and antioxidant capacity are significantly higher [5]. At the same time, narrow-band radiation of red and blue LEDs alone leads to inhibition of the generative development of the plant, which was also confirmed by researches [6, 7]. Blue, green and red are the primary colors that have a positive effect on plant productivity, growth and nutrient quality. Sometimes other radiation, such as far red and ultraviolet UV-A, is useful in certain situations [8]. The wet weight of leafy vegetable crops can be increased by additional green light and far red light, which can be accompanied by plant elongation [9]. The concentration of ascorbic acid increases under green and blue light, while the nitrate concentration in plants decreases under blue and red light [10].

Red-leaved lettuce contains various types of health benefits. In particular, phenolic compounds, which are one of the most common phytochemicals that have some physiological properties, such as antioxidant activity [11]. In low light conditions in a greenhouse, such as in northern Russia, red lettuce leaves often remain green and not visually attractive to consumers. Red lettuce pigmentation can also be increased using LEDs [12]. An increase in the blue component of the spectrum at the end of cultivation can stimulate the biosynthesis of anthocyanins [13]. It is also useful to add UV-A radiation to the main light during the growing period [14].

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Despite the abundance of researches on the use of LEDs irradiation in growing leafy vegetables, there is no universal recipe for irradiation. In addition, each crop has its own characteristics for a particular variety and can react differently to the spectral composition of optical radiation.
2 Methods

We have carried out researches to study the effect of radiation from LEDs irradiators with different spectral composition on the growth and leaf lettuce productivity of various varieties.

For research, we chose industrial varieties of leaf lettuce: red leaf hybrids Anthony F1 and Lollo rossa and green hybrids - Levistro F1 (type Lollo bionda), LiFli F1 of Enza Zaden breeding company. Seeds were sown in a mixture of high-moor peat with coconut flakes as a substrate. A nutrient solution for irrigation was prepared on the basis of deionized water according to the formulation known for lettuce. The pots were placed in phytotrons with the same microclimatic parameters.

Phyto-irradiators with LEDs in various combinations LED1, LED 2 were used as radiation sources. The following LED combinations were selected: Bl (445nm) + Rt (660nm) + FRt (730nm). Part of the Bl (445) radiation was reradiated by the luminophore in the Gr region (480-600 nm).

The selected spectral composition of the radiation of these LED combinations correlates well with the absorption spectrum of pigments and chromophores involved in the photosynthetic apparatus work [4]. The influence of the composition of spectral radiation on the elongation of internodes and an increase in leaf area is also known, that is, phytochromic reactions of plants to red and far red light, the synergistic nature of which is explained by the Emerson effect and the addition of a far red component to the photosynthetically active radiation (PAR) (700-750nm) can stimulate the growth of leaf area and enhance photosynthesis [15]. Therefore, the phytoradiator LED was also supplemented with LEDs with a wavelength of 730 nm. The high pressure sodium lamp (HPS) was used as a control. Irradiation in all phytotrons was set ~ 250 μmol s⁻¹ m⁻² at the 18-hour light period, as the most optimal for growing lettuce [16].

To measure the PAR irradiation and analyze the radiation spectrum, we used a TKA-Spectrum PAR spectrophotometer. A climate computer was used to control heating, ventilation, carbon dioxide enrichment, humidity, lighting, and recording environmental conditions. The irradiation and microclimate parameters are presented in Table 1.

Table 1. Parameters of illumination and microclimate.

| Spectrum composition, % | Illuminant |
|-------------------------|------------|
|                         | LED 1  | LED 2  | HPS |
| Bl (445)                | 20     | 14     | 7   |
| Gr (480-600nm)          | 40     | 31     | 64  |
| Rt (660nm)              | 40     | 55     | 29  |
| FRt (730nm)             | 15     | 11     | 6   |
| Power consumption, W    | 220    | 220    | 440 |
| Total photosynthetic photon flux density, μmol s⁻¹ m⁻² | 250 |
| Day temperature, ºC     | 25     |
| Night temperature, ºC   | 20     |

The photosynthesis intensity was assessed by the content of chlorophyll a and b (Chl) in dry leaves. Chlorophyll was extracted from the leaves by grinding and keeping them in 95% ethanol (ET) in a water bath at 50-70 ºC. Absorption density (D) of chlorophyll solution in ET at wavelengths of 440.5; 664 and 649 nm were measured on the Specord M-40 spectrophotometer in a 1-cm-thick cuvette. The total concentration of Chl a+b (C_a+b) and carotenoids (C_car) in the extract was calculated using the Smith and Benitez formulas:
\[ C_{a+b} (\text{mg/l}) = 5.24 \cdot D_{664} + 22.24 \cdot D_{649} \]  
\[ C_{\text{car}} (\text{mg/l}) = 4.69 \cdot D_{440.5} - 0.268 \cdot C_{a+b} \]  

The Chl content and carotenoids (mg/g) in plant material dry weight was calculated by the formula:

\[ A = \frac{C \cdot V}{P \cdot 1000}, \]  

where, \( C \) - pigment concentration (mg/l); \( V \) - pigment extract volume (ml); \( P \) - plant material weight (g); \( A \) - the pigment content in plant material (mg per 1 g of dry weight).

Anthocyanins (An) were extracted from leaves in a solution of water / ethanol = 1 / 1 + HCl (1%). Concentration of anthocyanins \( (C_{\text{An}}) \) was determined by the formula:

\[ C_{\text{An}} (\text{mg/g}) = \frac{D_{530} \cdot \mu}{P \cdot \varepsilon} \]  

where, \( D_{530} \) - the optical density of the anthocyanin solution at a wavelength of 530 nm, \( \mu \) - the molecular weight of An (449), \( \varepsilon \) - the molecular extinction coefficient equal to 27000.

The average chlorophyll content index (CCI) in each leaf was determined at ten points using an Apogee MC-100 portable chlorophyll meter. The experiment was carried out in three repetitions. For all measurements, the arithmetic mean and standard deviation were calculated.

3 Results and Discussion

The research results show the different lettuce susceptibility of different varieties to the spectral composition of radiation. Thus, Lifly lettuce had the highest green weight under LED 1, while other varieties had the highest productivity under LED 2 (Table 2). For lettuce Anthony F1, Levistro, Lollo rossa, the radiation of LEDs gives a positive effect in the plant productivity (8-20%) with a simultaneous decrease in energy consumption by the irradiation system by 40 ÷ 50% in comparison with a sodium lamp.

| Lettuce varieties | Wet weight, g | Dry weight, g | CCI      |
|-------------------|--------------|--------------|----------|
|                   | LED 1 | LED 2 | HPS | LED 1 | LED 2 | HPS | LED 1 | LED 2 | HPS |
| Lollo rossa       | 23.08 | 28.36 | 20.64 | 1.44  | 1.61  | 1.25 | 2.8   | 2.0   | 2.5 |
| Lifli F1          | 25.30 | 22.70 | 19.76 | 1.25  | 1.56  | 1.37 | 2.5   | 2.2   | 2.0 |
| Anthony F1        | 29.80 | 30.48 | 33.45 | 1.56  | 1.72  | 1.48 | 2.6   | 2.2   | 2.4 |
| Levistro F1       | 24.20 | 30.19 | 28.20 | 1.06  | 1.45  | 1.35 | 2.6   | 2.4   | 2.3 |

The results of leaves biochemical analysis showed that the synthesis of anthocyanins in the leaves of Anthony lettuce under LED irradiators is higher than under HPS (Table 3). For red-leaved lettuce under the HPS irradiator, due to the small fraction of blue light, anthocyanins practically didn't accumulate, lettuce leaves didn't acquire a characteristic red color, which reduced the commercial quality of the product (Figure 1). An increase in the proportion of blue light in LED radiation from 14% to 20% didn't significantly affect the
biosynthesis of anthocyanins. However, the decrease in proportion of green radiation in the LED 2 version led to the decrease in the concentration of carotenoids, the absorption spectrum of which lies in the blue and green radiation regions.

Table 3. Concentration of photosynthetic pigments of lettuce 'Anthony'.

| Illuminant | Chlorophyll a, mg/g | Chlorophyll b, mg/g | Carotenoids, mg/g | Anthocyanin, mg/g |
|------------|---------------------|---------------------|------------------|------------------|
| LED 1      | 0.50 ±0.11          | 0.22 ±0.06          | 3.89 ±0.86       | 0.07 ±0.01       |
| LED 2      | 0.45 ±0.09          | 0.24 ±0.05          | 1.46 ±0.35       | 0.09 ±0.01       |
| HPS        | 0.51 ±0.12          | 0.22 ±0.05          | 3.27 ±0.72       | 0.01 ±0.01       |

Fig. 1. Lettuce Anthony F1 (from left to right – LED1, LED2, HPS).

It is known that the anthocyanins (red pigment) synthesis of red-leaved green crops is significantly influenced by UV and blue radiation (320-470 nm) [17, 18]. However, a high proportion of blue radiation slows down the leaf plate growth, which ultimately reduces the yield of green crops [19]. So, for all studied hybrids except Lifli F1, the maximum wet weight was under the LED 2 irradiator with the 14% share of blue radiation. Also, in previous researches, it was found that as a result of green light screening by the anthocyanin absorption, the biosynthesis of which activates blue LEDs light, the efficiency of Zn extraction in lettuce decreases compared to HPS [20].

Thus, in a series of LED irradiators, the best option for growing red-leaved lettuce is a composition of LEDs emitting in the blue and red spectrum regions, and blue radiation is most effective at the final stage of growing lettuce [12, 13].

The Lifli F1 lettuce variety, when irradiated with HPS, was distinguished by its compact size and less weight (Figure 2).

Fig. 2. Lettuce Lifli F1 (from left to right – LED1, LED2, HPS).
In other varieties, no significant differences were found in appearance and morphological characteristics. There were no significant differences in the chlorophyll concentration in all researched hybrids under different irradiation.

4 Conclusions

A comparative study of the radiation effect from a sodium lamp and LEDs with different spectral composition on the growth and productivity of leaf lettuce showed a difference in the susceptibility of different lettuce varieties to the spectral composition of radiation. The dependence of lettuce yield on various combinations of blue, green and red light in the total irradiation spectrum was revealed. It is necessary to select a radiation spectrum for a specific lettuce variety, while the red-leafed Lollo rossa group varieties require a variable irradiation mode with the spectrum changing at the end of growth towards an increase in the proportion of blue radiation of 450 nm.

LED radiation application provide the positive effect on plant productivity (8-20%) compared to sodium lamps, reduce energy consumption of the irradiation system, doesn't require special disposal, and more environmentally friendly, then other plant artificial light sources.

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