Effect of LEDs on the growth and physiological responses of sweet basil (Ocimum basilicum L.)

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Abstract. Sweet basil Ocimum basilicum L. belongs to the mint family and grows wild in tropical and subtropical climates. Basil is an important culinary and essential oil crop grown and used throughout the world. In areas with insufficient natural light for optimal plant growth and productivity, high pressure sodium light sources are widely used. However, these lamps are considered energy-intensive, and they also generate a large amount of thermal radiation. Therefore, there is great interest in replacing sodium lamps with new, more efficient light sources in the form of light emitting diodes (LEDs). In this work, the influence of two light sources (white LED light and red-blue together with white LED light) on the growth, development and physiological parameters of two varieties of sweet basil was studied - green basil of the "Anisoviy aromat" variety and red basil of the "Opal" variety. Illumination with red-blue light in combination with white LED light had a clear advantage in almost all growth and development parameters measured for both varieties of basil. Plants of green basil cultivar "Anisoviy aromat" and red basil cultivar "Opal" at both stages of crop accounting were taller, had larger mass and larger leaves. with white light in red basil plants allowed to surpass the control plants by about one and a half times. At the same time, white LEDs initiated a more effective photoprotective mechanism during long-term cultivation of green basil plants.

1. Introduction
Year-round cultivation of aromatic crops has been widely practiced for a long time. In the middle temperate latitudes in winter, natural daylight hours last 7-8 hours, which is clearly not enough for the normal growth and development of most plants, and beyond the Arctic Circle at this time there is natural light. To obtain high-quality green mass, additional illumination of 40-60 W per 1 sq.m. is needed. and a light period of at least 12 hours. Recently, LED lamps have been widely used as a source of illumination. Along with economic advantages (energy saving, long service life, quick payback) in LED panels and lamps, it is possible to change the qualitative composition of light. Various combinations of narrow-spectrum light make it possible to change the direction and intensity of metabolic processes in plant cells. This contributes to the activation of the adaptive potential of plants, the formation of protective reactions, which ultimately leads to the optimization of the production process [1-2]. Dominance in the spectrum of red light stimulates the synthesis of chlorophyll and carotenoids, affects the activation of carbohydrate metabolism enzymes, and the synthesis of secondary metabolites. Blue light inhibits cell elongation, reduces the number of stomata,
that is, the plant habitus changes [3]. These changes are certainly important when growing green and aromatic crops to increase the amount of high-quality green mass.

In addition, long-wave radiation (red light) contributes to the suppression of pathogens [4]. Thus, LED panels not only allow to extend the light period, improve the quality of vegetable products, but also contribute to environmentally friendly infection control.

The use of monochrome light can have a negative impact on the growth and development of plants, and, consequently, on obtaining good yields of green mass [5].

In our previous work, we used LED panels as a supplement to natural light. The purpose of this work is to study the effect of illumination only with LED panels with different spectral composition of light on the growth and development of green-leaf and red-leaf varieties of basil when grown in winter - spring (February-April).

2. Materials and methods

Two varieties of contrasting basil leaves, green basil 'Anise aroma' (O. basilicum 'Anisoviy aromat') and red basil 'Opal' (O. basilicum 'Opal'). Basil seeds were sown in a universal soil and, at the stage of the second pair, true leaves, seedlings were transferred to a phytotron chamber at a temperature of 22±3 °C and a relative humidity of 65 ±5%, and the plants were grown under conditions of 16/8-hour light/dark mode in two modes: control - lighting only with white LEDs (50 W, EPISTAR, Taiwan); option 1 - simultaneous illumination with white LED light and LED lamps (50 W, E24 Sind 57-30, China) with emission spectra in two maxima [blue spectral region (450 nm): red spectral region (660 nm) = 30%:70 %]. The lamps were placed at a height of 85 cm from the top edge of the cassette, the photon flux density was 180 µmol/m² sec.

In control and experimental plants, after 30 and 60 days of illumination, physiological and photosynthetic parameters were measured. The shoot height, leaf weight, leaf area, chlorophyll content, carotenoids, total flavonoids, phenolcarboxylic acids (chlorogenic, caffeic) were determined [6-8]. The results of the experiment were statistically processed using the Excel 2010 and Past V 3.0 programs. The mean value of the indicators (M) of 40 plants in the sample, the standard errors of the mean (± SEM) and the confidence interval at the 95% confidence level were determined. Differences between the variants were significant at P≤0.05.

3. Results and Discussion

It was noted that both in the green cultivar "Anisoviy aromat" and in the red cultivar "Opal" red-blue light in combination with white light had no significant effect on plant height. At the same time, the stage of accounting for plant yield has a significant effect on plant height ((p ≤ 0.05), while taller plants were observed at the end of the experiment. Thus, the height of green basil plants in the variant of the combination of white and red-blue light was 1.1 times higher, than in the plants of the control variant both in the middle of the experiment (on the 30th day) and at the end of the experiment, while the height of the plants during the experiment in the control and variant 1 increased by 2.7 times (table 1). of the experiment was 1.3 and 1.2 times compared with the control in the middle and at the end of the experiment, respectively. At the same time, the growth rate of red basil was higher - during the experiment, the height of the plants increased by 2.85 times, both in the control and in the variant of the combination of white and The accelerated growth of basil under LED lighting has been reported in previously published papers for both sweet basil (Ocimum basilicum L.) and bush basil (Ocimum minimum L.) was noted earlier [1;9-11].

In both varieties of sweet basil, a significant effect of additional illumination with red-blue light in combination with white light and the phase of plant development on the leaf area was observed (p ≤ 0.001). The optimal leaf area was observed in plants of both "Anisoviy aromat" and "Opal" varieties grown under red-blue LEDs, at the end of the experiment - the leaf area of plants of the experimental variant increased by 2.1 and 1.6 times and exceeded control plants by 1.7 and 1.3 times in green basil cultivar "Anisoviy aromat" and red basil cultivar "Opal", respectively (table. 1).
Table 1. Influence of different light sources and plant development phases of two varieties of sweet basil (*Ocimum basilicum* L.) on the morphological and physiological parameters of plants.

| Indicator                        | Green basil variety "Anisoviy aromat" | Red basil variety "Opal" |
|----------------------------------|--------------------------------------|--------------------------|
|                                  | The control                          | Experience variant       | The control                          | Experience variant       |
|                                  | 30 days                              | 60 days                  | 30 days                              | 60 days                  |
|                                  | 30 days                              | 60 days                  | 30 days                              | 60 days                  |
| Plant height, cm                 | 5.6±0.5                              | 16.2±0.2                 | 6.3±0.7                              | 17.7±0.7                 | 11.4±1.8                 | 32.1±0.6                 | 13.5±2.6                 | 35.6±1.1                 |
| Leaf area, cm²                   | 10.0±0.8                             | 12.6±0.7                 | 10.3±0.6                             | 21.2±1.1                 | 7.7±0.4                  | 12.3±0.4                 | 10.1±0.5                 | 16.5±0.8                 |
| Aboveground fresh mass, g        | 1.25±0.11                            | 1.27±0.09                | 1.30±0.10                            | 1.43±0.11                | 1.18±0.10                | 1.22±0.07                | 1.23±0.07                | 1.30±0.09                |
| Content of chlorophyll a+b, mg/g | 1.77±0.08                            | 1.73±0.06                | 1.82±0.08                            | 1.86±0.07                | 2.23±0.10                | 2.10±0.09                | 1.94±0.11                | 2.29±0.10                |
| Content of carotenoids, mg/g     | 0.22±0.04                            | 0.25±0.03                | 0.12±0.02                            | 0.23±0.03                | 0.30±0.04                | 0.31±0.04                | 0.25±0.03                | 0.31±0.03                |
| Content of total flavonoids, mg/g| 4.5±0.2                              | 1.6±0.1                  | 2.6±0.1                              | 1.1±0.2                  | 4.9±0.2                  | 1.3±0.2                  | 4.9±0.1                  | 1.7±0.1                  |
| Content of chlorogenic acid, mcg/g| 3.94±0.25                           | 1.82±0.55                | 2.38±0.05                            | 1.79±0.13                | 0.88±0.07                | 2.42±0.1                 | 1.17±0.07                | 2.53±0.13                |
| Content of caffeic acid, mcg/g   | ≤ 0.1                                | ≤ 0.1                    | ≤ 0.1                                | 7.86±0.37                | ≤ 0.1                    | 5.07±0.36                | ≤ 0.1                    | 3.43±0.25                |

Illumination with red-blue light in combination with white light had an insignificant effect on the wet weight of plants of both varieties of sweet basil. The maximum mass was observed in green basil plants of the "Anisoviy aromat" variety at both stages of accounting for the plant yield, it was 1.1 times higher with additional illumination compared to the control. Whereas the mass of plants of red basil variety "Opal" in the variant of the experiment with additional illumination exceeded the control plants only 1.05 times, both in the middle and at the end of the experiment.

Comparison of the dynamics of accumulation of chlorophyll *a* and *b* under additional illumination with red-blue light in combination with white light revealed varietal differences (table 1). In green basil plants of the "Anisoviy aromat" variety in the experimental variant, the content of chlorophyll *a* and *b* at both stages of accounting for plant yield was higher than in control plants (table 1). At the same time, by the second phase of accounting for the yield of plants in the control, a decrease in the content of chlorophyll *a* and *b* was recorded - by 1.06 times. In "Opal" cultivar red basil plants, the content of chlorophyll *a* and *b* was 1.15 times higher in control plants compared to the supplementary illumination with red-blue light in combination with white light on the 30th day of the experiment. However, by the end of the experiment, the content of chlorophyll *a* and *b* in red basil plants decreased by 1.06 times in the control. And with additional illumination with red-blue light in combination with white light, an increase in the content of chlorophyll *a* and *b* by 1.18 times was recorded (table 1).

The content of carotenoids in the leaves of the control plants of both varieties of basil was significantly different, it was higher in the plants of red basil of the variety "Opal" at both stages of accounting for the plant yield (table 1). Illumination with red-blue light in combination with white light also revealed varietal differences in the dynamics of changes in the content of carotenoids, but at the same time, in both varieties, carotenoid synthesis was inhibited compared to the original control. In green basil plants, by the middle of the experiment, the content of carotenoids decreased by 1.8 times compared to the control, and in red basil plants only by 1.2 times. With an increase in the duration of light exposure (by the end of the experiment), the content of carotenoids increased and was almost at the control level in both varieties.

An increase in carotenoids in response to exposure to red-blue light is an important adaptive mechanism present in basil plants, since carotenoids are an effective defense mechanism [12].

With regard to the total content of the sum of flavonoids in the leaves of control plants, varietal differences were not recorded. In both varieties of basil, the content of the total flavonoids was in the range of 4.5–4.9 mg/g (on the 30th day of the experiment), by the end of the experiment it significantly decreased by 2.8 (green basil) and 3.3 times (red basil) and amounted to 1.6–1.5 mg/g.
(table 1). Illumination with red-blue light in combination with white light of green basil plants of the variety "Anisoviy aromat" by the middle of the experiment reduced the content of flavonoids by 1.8 times compared to the control; in plants of red basil variety "Opal" such a decrease was not recorded - the content of the total flavonoids was at the level of control plants. By the end of the experiment, in experimental plants of both varieties, a decrease in the content of this indicator was observed and it was practically at the level of control plants. It is known that the content of flavonoids positively correlates with the antioxidant activity in O. basilicum plants [13]. A decrease in the content of flavonoids in both varieties by the end of the experiment may indicate that basil plants are protected from light by other antioxidants, possibly phenolcarboxylic acids, which are closely associated with the formation of adaptive and protective reactions to environmental conditions [14].

It is obvious that phenolcarboxylic acids, in particular chlorogenic and caffeic acids, play a more important role in red basil plants of the "Opal" variety - at both stages of accounting for the yield of plants with supplementary illumination with red-blue light in combination with white light, the content of chlorogenic and, especially, caffeic acids, higher than in control plants. In green basil plants, phenolcarboxylic acids are only partially involved in the initiation of protective mechanisms.

4. Discussion

Thus, the quality of light influenced the growth and physiological characteristics of the two varieties of sweet basil. The use of red-blue light in combination with white LED light for supplementary illumination showed a clear advantage over using white LED light alone. Green basil cultivar "Anisoviy aromat" and red basil cultivar "Opal" at both harvest stages were taller, heavier and had larger leaves when red-blue light was used in combination with white light for supplementary illumination. Our results are consistent with the concept that carotenoids, flavonoids, and phenolcarboxylic acids play an important role in the adaptation of basil plants to high-intensity light. The high content of carotenoids, flavonoids and chlorogenic acid serves as a more effective photoprotective mechanism in the long-term cultivation of photophilous green basil plants using only white LEDs. On the contrary, these same compounds provide high adaptive potential for red-basil plants of the "Opal" variety when supplemented with red-blue light in combination with white light, and especially when narrow-band light is used for a long time.

Our LED research has great practical application for the commercial production of sweet basil in areas where natural light is not sufficient for optimal growth and productivity of light-loving plants.

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