Development of an ecological lighting device to reduce the growth time of agricultural plants in greenhouses

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Abstract. The use of LEDs in lamps is promising for effective plant growth. Plant growth lamps are designed to create artificial lighting for agricultural crops. This work is devoted to the creation of a smart LED lamp with the ability to adjust the spectral composition of radiation depending on the stage of growth and the type of plant. A number of experiments were carried out to investigate the effect of various radiation parameters on the growth characteristics of dill, parsley, green onion and cucumber seeds. The optimal radiation parameters that contribute to the acceleration of the selected model plants growth were identified. Based on the results obtained, a multi-wavelength LED lamp with an adjustable radiation composition, including blue 440 nm and red 660 nm LEDs, was developed. In the lamp, the possibility of changing the spectral composition of radiation at different stages of growth was realized. Therefore, it is possible to change the light parameters in accordance with the obtained data on the development of crops.

1. Introduction
The reduction in acreage and the increase in cities led [1-8] to the search for new ways to grow plants, especially vegetables. Ecology is an important factor in this case [3, 4, 9-15]. The most common way is to use greenhouses. This requires a lot of light while increasing the cost of energy production [1, 5, 7, 8, 16-23]. To reduce costs, artificial light produced using LEDs is used [24-28]. The use of LEDs for biological processes has important advantages over other existing artificial lighting sources. LEDs have a higher quantum efficiency, longer service life, controlled emission spectrum, safer handling and disposal procedures, and LEDs are also environmentally friendly [11-14, 29-34].

An LED is a type of semiconductor diode that allows the adjusting spectral composition and thereby the adapting photoreceptors of plants to the light intensity to ensure better growth and influence the morphology of plants, as well as various physiological processes such as flowering and photosynthesis efficiency. LEDs are able to create a high luminous flux with a low output radiated heat and maintain the luminous flux efficiency for many years [32-36]. The service life of fluorescent lamps is about 20,000 hours, while for incandescent lamps it is only 1000 hours. LEDs do not have filaments and typically the service life of LEDs is about 30,000 – 50,000 hours or even more. Due to the low production of radiant heat, LEDs can be located near plants [32-37].

Therefore, the task of developing a multi-wavelength LED lamp with an adjustable spectral composition of radiation is extremely relevant for various greenhouses. The developed LED lamp will...
allow one to achieve the optimal spectral composition of the irradiation and the lowest energy consumption when using it. An important factor in the lamp work research will be the plant growth rate and yield.

2. Reasons for choosing LED structures
LED radiation sources for illumination of crops have three main approaches to obtaining the required spectra: the first is a set of monochromatic LEDs, the second is a mixed spectrum of LEDs using luminophores (full-spectrum LED for plants), and the third is a white LED with a luminophor (Fig. 1a).

![Image](image1.png)

Figure 1. Spectra of photodiodes: a) emission of monochromatic LEDs, white and full-spectrum LEDs with a luminophor; b) absorption of the main pigments of green plants.

According to the absorption spectrum of chlorophyll (Fig. 1.b), blue light and red light are important components for efficient photosynthesis. However, some other wavelengths also promote plant growth. For example, green light, along with red and blue light, can participate in the synthesis of pigments that color plants, and can also be used to illuminate the lower leaves, thereby increasing the rate of photosynthesis of the lower leaves.

The absorption of light by chlorophyll-A is concentrated at about 440 nm and about 660 nm, and chlorophyll-B at about 460 nm and about 650 nm. Each plant has a different ratio of chlorophyll A, B and carotenoids, therefore, to determine the most effective spectral composition of radiation for a particular plant, it is necessary to rely on this ratio. Correctly selected spectral composition can stimulate both chlorophylls and increase plant yield.

The most favorable for growing crops are intensities in the range of 150-220 W/m², and the optimal composition of radiation has the following energy ratio in the spectrum: 30% in the blue region (380-490 nm), 15-20% in the green (490-590 nm) and 50-55% in the red region (600-700 nm).

Monochromatic LED has a high efficiency of photosynthetic photon flux, but it is more expensive [32, 33, 38]. In addition, there are advantages to using IR and UV wavelengths for which there are no effective luminophores. Based on all of the above, it is advisable to use a set of monochromatic LEDs in the lamp.

To accelerate seed germination, it is necessary to use LEDs based on GaN/InGaN heterostructures (Fig. 2, b) in the lamp (Fig. 2, a). At a moderate dose of UV and blue radiation, light quanta are able to stimulate the growth and development of plant cells, in connection with which the synthesis processes of biological compounds are activated [38]. The addition of GaAsP-based red LEDs to the lamp (Fig. 2, b) (640-660 nm) increases the germination and flowering of plants. Thus, the use of two types of LEDs in a lamp can activate chlorophylls A, B, carotenoids and other pigments, since the spectral characteristic of the lamp (Fig. 2, d) can best correspond to the absorption spectra of the main photochemical substances.
To study the effect of supplementary illumination of various spectral composition on the development of crops, both monochromatic (blue 440 nm, red 660 nm) and luminous (white 6000 K, full-spectrum LED for plants 400 - 800 nm) LEDs were chosen.

3. Research results

Seeds of dill, parsley, green onions and cucumbers (variety "Zozulya") were selected as the studied crops. These crops are in great demand at buyers and in Russia they are grown in greenhouses.

For the effective cultivation of dill, parsley, green onions, the photosynthetic photon flux density should be from 150 μmol/(m²·s), for cucumbers - from 250 μmol/(m²·s). The operating modes to ensure the required PPFD values were calculated for different types of LEDs. The parameters obtained are shown in Figure 3.

In accordance with the required parameters of light for the germination of leafy vegetables, a germinating box with boxes (Fig. 4, a) was developed, which was illuminated with radiation of various spectral composition. Two germinating boxes with LED lighting (Fig. 4, b-c) contained 24 cells each, where seeds were placed in boxes.

The electrical circuit contains eight current stabilizers to obtain the required density of the photosynthetic photon flux. The current stabilizers are based on the LM317 microcircuits. Each circuit
contains 8 LEDs connected in series. The circuit is powered from two sources. The power parameters are matched to the maximum power dissipation of the LM317, which is 3 W.

![Image of LED lamps](image)

**Figure 4.** Appearance of a) germinating box and b), c) lamps for research.

To study the effect of supplementary illumination using different spectral composition on seed growth, two germinating boxes and 12 boxes with dimensions of 8.5 × 6 cm were used.

Each culture was subjected to supplementary illumination with full-spectrum LEDs 400-800 nm, white LEDs 6000 K, red LEDs 660 nm, blue LEDs 440 nm, simultaneously red and blue LEDs in a PPFD ratio of 30%B + 70%R and vice versa 30%R + 70%B. The seeds were germinated in each box on 4 layers of filter paper with a timely supply of 2-3 ml of filtered water.

For the crops, seed germination energy and germination capacity were measured. Also, during the research, such parameters as the average and maximum hypocotyl length, the appearance (absence) of the first green leaf, the average and maximum root length were monitored.

It was found that to accelerate the growth of dill requires: PPFD is not less than 150 μmol/(m²s); on the 1st day of germination, illumination is not required; from the 2nd to the 4th day, LED illumination of 660 nm (R) is required; from the 4th day, acceleration was observed under illumination of 30%R/70%B 440 nm. Accelerated growth of parsley requires: PPFD is not less than 150 μmol/(m²s); germination from the 1st to the 5th day does not require supplementary illumination; from the 6th to the 20th day, lighting of 30%R/70%B is required. Accelerated growth of green onions requires: PPFD is not less than 250 μmol/(m²s); from the 1st to the 10th day, active growth was observed under illumination of 100%R. 70%B/30%R was required from the 11th to the 18th day. Accelerated growth of cucumbers requires: PPFD is not less than 250 μmol/(m²s); from the 1st to the 3rd day, the type of lighting did not affect growth; from the 3rd to the 7th day, the growth acceleration was observed with irradiation of 100%B. From the 7th to the 18th day, it was observed under illumination of 70%B/30%R

4. Circuit design solution for creating a multi-wavelength lamp

Based on the data obtained on the cultivation of some crops, it was found that to increase plant growth, two types of LEDs are required in different ratios of the photosynthetic photon flux density at different stages of development. These are blue 440 nm and red 660 nm [32–34].

To enable the control of the spectral composition of radiation and the observation of a 16-hour photoperiod, an LED lamp containing 16 blue 440 nm and 16 red 660 nm LEDs was developed. Each LED circuit is powered by dimmable LED drivers.

The lamp contains two dimmable programmable LED drivers: MOSO LDP - 105M062 and MOSO LUP - 120M062. They include three dimming functions and are designed with programmable and constant power, with adjustable output current. The lamp operating modes are recorded in the IR Programmer software.

The developed lamp with an adjustable spectral composition of radiation, shown in Figure 5, is intended for irradiation of plants in industrial greenhouses and other cultivation facilities in protected
ground. This lamp works in 220 V AC networks. The efficiency of the device in the phased array region is at least 2.0 μmol/(s·W).

![Figure 5. Developed lamp with adjustable spectral composition of radiation.](image)

The efficiency of the device in the phased array region is at least 2.0 μmol/(s·W). The maximum heating temperature of the lamp body does not exceed 60 °C. The device is made of anodized aluminum, which acts as a heat dissipator. The overall dimensions of the lamp are 355 × 230 × 60 mm.

5. Conclusions
As a result of the work, on the basis of the obtained spectral energy and temperature characteristics of LEDs, an installation for growing crops with LED lighting of various spectral composition was created. During the experiments, the main indicators of crop growth were established: germination energy, capacity, the appearance of primary leaves, the average and maximum length of the hypocotyl and roots.

The optimal radiation parameters that contribute to the acceleration of the selected model cultures were identified. Based on the results obtained, an LED multi-wavelength lamp with an adjustable composition of radiation, including blue 440 nm and red 660 nm LEDs, was developed. The lamp has the ability to change the spectral composition of radiation at different stages of plant growth. The electromagnetic component [39, 40] from the lamp, which influences negative changes in plants, is extremely small. The infrared component of these light sources, measured with special instruments [41-44] is also small.

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