Influence of the radiation intensity of LED light sources of the red-blue spectrum on the yield and energy consumption of microgreens

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Abstract. The significant interest in microgreens all over the world in recent years is associated with the high nutritional value of these products. At the same time, for most types of microgreens, there are conflicting data on the technology of their cultivation, and, in particular, on the minimum required level of illumination. This study aimed to investigate the effect of different levels of light on the growth and development of radishes, cabbage and basil. The experiment was carried out in triplicate and included variants with irradiation of 50, 100 and 200 µmol m$^{-2}$·s$^{-1}$. In the course of the research, the influence of the radiation intensity on the height of seedlings, the yield of biomass and the energy efficiency of their production was revealed. The highest yield was obtained in variants using light sources with an intensity of 100 µmol m$^{-2}$·s$^{-1}$, while for basil this lighting option was also the most profitable in terms of energy intensity.

1. Introduction
At the moment, the agricultural community has not developed a clear definition of what a "microgreen" is. However, most researchers agree that microgreens are a line of lettuce crops, which are seedlings of agricultural crops with tender cotyledons and the first pairs of true leaves [1]. Currently, the use of microgreens as a valuable source of plant food, vitamins and a wide range of other biologically active substances has become a very popular culinary trend. The current situation has led to the fact that not only small producers and farmers, but rather large greenhouse enterprises are now interested in the production of these products. The main problem they face is the lack and inconsistency of information describing the technology for the production of microgreens and, especially, the requirements for illumination of seedlings of agricultural crops [2-4].

Research is mainly aimed at studying the chemicals and vitamins of microgreens when the spectrum of light changes. In this case, high-intensity radiation is considered (not less than 100 µmol m$^{-2}$·s$^{-1}$) [5-6]. This study aims to investigate the energy intensity of products as an important indicator for commercial manufacturing companies using low and high light intensity. This study was aimed at identifying the dependence of the yield of microgreens of radish, cabbage and purple basil on different lighting intensities.
2. Materials and methods
The studies were carried out from August to December 2020 at the experimental site of the company "Solnyshko" with. Neklyudovo, Borsky district, Nizhny Novgorod region. Microgreens were grown on hydroponic shelving units (figure 1) without access to natural light. Indoor temperature 20-23 °C, humidity 60% - 80%.

One unit consisted of three shelves, each of which contained plastic pallets 1200 × 600 × 60 mm. SPELAND VEGA vegetation mats were placed on the pallets, on the surface of which seeds were sown. On each pallet, vegetation mats were arranged in 2 rows of 12 pieces.

The water supply system consisted of 90 l tanks, OASIS DN 110/6 drainage pumps and an extensive water supply network. The solution was fed automatically 4 times a day for 5 minutes. (00.00; 6.00; 12.00; 18.00).

Plants were irradiated with OTS-01 irradiators of the Solnyshko company (Russia, Nizhny Novgorod). The optical part of the feeds consisted of red and blue LEDs in a ratio of 2:1. The irradiation system was switched on automatically. The photoperiod is 16 hours a day. The distance from the feeds to the irradiated surface was 40 cm.

The following types of crops were used as the object of research: radish, white cabbage, purple basil. Before the experiment, the room was disinfected with ultraviolet irradiators of the OUFB-08 type (Solnyshko, Russia, Nizhny Novgorod) (figure 1). The next day, the seeds of the studied crops were sown. On the third day after sowing the seeds, illumination with blue-red LEDs was switched on. The light sources used two types of LEDs, emitting wavelengths of 450 ± 10 nm and 660 ± 10 nm. The microgreen illumination period was 8 days. The study was carried out for three types of irradiation (table 1).

![Figure 1. General view of the hydroponic rack installation.](image)

| Table 1. Average photosynthetic photon flux densities ± SD delivered from sole-source light-emitting. |
|--------------------------------------------------------------------------------------------------|
| Photosynthetic photon flux density (PPFD) | No (control) | No 2   | No 3   |
| µmol·s⁻¹·m⁻²   |          |        |        |
| 100 ± 13.2     | 50 ± 2.8 | 200 ± 18.1 |

Shoot height was measured with a ruler. The mass from one pallet was measured with a VLKT-500-M laboratory balance (Gosmetr, Russia, St. Petersburg). Then it was recalculated in kg · m⁻² according to the formula (1).
m_1 \cdot \frac{10^{-3}}{S} \quad (1)

m_1 \text{- is the mass of microgreens from 1 pallet, g; } S \text{- pallet area, m}^2.

The calculation of energy consumption (kW \cdot h/kg) was carried out according to the formula (2).

\[ E_F = \frac{W}{m_1 \cdot 10^{-3}} \quad (2) \]

W \text{- is the amount of electricity consumed by the LED system on one pallet, kW \cdot h.}

3. Results

Plant size. For radishes, changes from the control light intensity (100 \mu mol \cdot m^2 \cdot s^{-1}), both downward and upward, resulted in a decrease in seedling height (figure 1 A). With a decrease in intensity to 50 \mu mol \cdot m^2 \cdot s^{-1}, the length of the hypocotyl decreased by 10%; with an increase in intensity to 200 \mu mol \cdot m^2 \cdot s^{-1}, the length of the hypocotyl decreased by 20%.

For cabbage, a decrease in intensity to 50 \mu mol \cdot m^2 \cdot s^{-1} increased the length of the hypocotyl by 10%, an increase in intensity to 200 \mu mol \cdot m^2 \cdot s^{-1} decreased the length of the hypocotyl by 34% (figure 1 A).

For basil, the reaction to a change in light intensity is most pronounced. With a decrease in intensity to 50 \mu mol \cdot m^2 \cdot s^{-1}, the hypocotyl length decreased by 42%; with an increase in intensity to 200 \mu mol \cdot m^2 \cdot s^{-1}, the hypocotyl length decreased by 56% (figure 1 A).

Crop yield. For radishes, changes from the control light intensity (100 \mu mol \cdot m^2 \cdot s^{-1}), both downward and upward, resulted in a decrease in the green biomass of the plant (figure 1 B). With a decrease in intensity to 50 \mu mol \cdot m^2 \cdot s^{-1}, the wet biomass decreased by 12%, with an increase in intensity to 200 \mu mol \cdot m^2 \cdot s^{-1}, wet biomass decreased by 22%.

For cabbage, a decrease in intensity from 100 to 50 \mu mol \cdot m^2 \cdot s^{-1} did not affect the biomass volume. Increasing the intensity from 100 to 200 \mu mol \cdot m^2 \cdot s^{-1} reduced the wet biomass by 28% (figure 1 B).

For basil violet, the response to changes in light intensity was again the most significant. The greatest impact was exerted by a decrease in the radiation intensity. With a decrease in intensity to 50 \mu mol \cdot m^2 \cdot s^{-1}, the wet biomass decreased by 48%, while increasing the intensity to 200 \mu mol \cdot m^2 \cdot s^{-1}, wet biomass decreased by 22% (figure 1 B).

Energy intensity of products. For all micro green cultures, irradiation with a light intensity of 200 \mu mol \cdot m^2 \cdot s^{-1} was found to be the most energy intensive (figure 1 C). Electricity costs for growing 1 kg of products increased by 157% for radish, 180% for cabbage, and 155% for basil. With a decrease in intensity to 50 \mu mol \cdot m^2 \cdot s^{-1}, energy costs for growing 1 kg of products decreased by 44% for radish and 50% for cabbage. For basil, the energy costs for growing 1 kg of products at an intensity of 50 and 100 \mu mol \cdot m^2 \cdot s^{-1} are comparable (-4%).

4. Discussion

From a production point of view, micro greens are a unique product rich in vitamins and obtained in a short period of time. The results are discussed in terms of the effect of light intensity for comparison with similar studies.

When growing radishes, cabbage and basil in our study, the increase in light intensity led to the compactness of the plants. Similar trends are found in other studies. In [7], with an increase in light intensity from 100 to 600 \mu mol \cdot m^2 \cdot s^{-1}, the length of the hypocotyls decreased by 24%, 37%, and 62% for cabbage, arugula, and mustard, respectively. In [8], the length of the hypocotyls decreased to 30% in kohlrabi, mizuna, and mustard with an increase in light intensity from 105 to 315 \mu mol \cdot m^2 \cdot s^{-1}. In 10-day-old mustard, red pak-choy, tatsuoi, kohlrabi, in [9], the decrease in the length of the hypocotyls from 9% to 28% with irradiation of 545 instead of 110 \mu mol \cdot m^2 \cdot s^{-1}. However, the
response to a decrease in light intensity was not uniform for all plants. While in cabbage, a decrease in light intensity contributed to an increase in hypocotyls, in radishes and basil, this caused a reverse reaction. Perhaps this is due to the genotypic characteristics of plants. A similar reaction is observed when growing potato seedlings [10].

![Graphs showing hypocotyl length, fresh weight, and electricity costs for radish, cabbage, and basil at different light intensities.](image)

**Figure 2.** Hypocotyl length (A), fresh weight (B), electricity costs (C) for radish, cabbage and basil at different light intensities, p<0.05.

Fresh weight is most important for commercial industrial production of micro greens, as this figure is critical in the sale of products. In our study, both increasing and decreasing light intensity for radishes and basil resulted in a decrease in vegetative mass. For cabbage, an increase in the radiation intensity from 50 µmol • m$^{-2}$ • s$^{-1}$ to 100 µmol • m$^{-2}$ • s$^{-1}$ did not change the yield of the vegetative
mass. Similar results are obtained by other researchers for Kohlrabi and Mustard when irradiated with a spectrum of light based on red, green and blue LEDs in a ratio of 74: 18: 8 [8]. When growing tatsoi, the greatest mass was achieved at 300 µmol • m$^{-2}$ • s$^{-1}$, and an increase or decrease in light intensity led to a decrease in fresh biomass [11]. An increase in the light intensity from 130 to 280 µmol • m$^{-2}$ • s$^{-1}$ for different varieties of amaranth under irradiation with a red-blue spectrum in a ratio of 70:30 did not lead to significant differences [12]. There are opposite results. With an increase from 100 to 600 µmol • m$^{-2}$ • s$^{-1}$, the increase in yield was 36%, 76%, 82% for cabbage, arugula and mustard, respectively [7]. Various research results are due not only to the culture of plants, but also to the spectrum of light. With the predominance of red light in the composition of the feed, the green and blue spectrum and their combination play an important role [13-15].

Energy intensity is important for the commercial production of micro greens, as this figure affects the cost of production. Reducing the light intensity in our study to 50 µmol • m$^{-2}$ • s$^{-1}$ resulted in a decrease in energy intensity for radishes and cabbage and did not significantly affect basil. Increasing the light intensity from 100 to 200 µmol • m$^{-2}$ • s$^{-1}$ led to a significant increase in energy intensity in all three crops. A 6-fold increase in light intensity for cabbage, arugula and mustard contributed to an increase in biomass by 36%, 76%, 82%, respectively, which increased energy intensity [7]. A 3-fold increase in light intensity in the red-blue spectrum at a ratio of 87:13 for Kohlrabi, Mizuna and Mustard did not lead to a significant increase in biomass.

5. Conclusion
The study of the influence of the intensity of the red-blue spectrum of LEDs on micro greens showed that irradiation with more than 100 µmol • m$^{-2}$ • s$^{-1}$ leads to a decrease in the fresh biomass of micro greens and an increase in the energy intensity of products regardless of the culture. For industrial applications of the red-blue spectrum of LEDs in a ratio of 2:1, the most economical mode is an irradiation intensity of 100 µmol • m$^{-2}$ • s$^{-1}$ for basil and 50 µmol • m$^{-2}$ • s$^{-1}$ for radish and cabbage.

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