COMPARATIVE APPLICATION EFFICIENCY OF OPTICAL FLUX DELIVERED FROM LED AND GAS-DISCHARGE SOURCES IN INDOOR PLANT CULTIVATION

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Abstract. Optical radiation energy (OR) is the basis of photosynthesis processes and indoor cultivation of useful plants. Its application in hothouse vegetable growing puts forward special requirements to efficiency of power and material resources use. The major drawback of traditional OR sources is their poor conversion of electrical energy into the energy of optical flux. The comparative efficiency of LED and sodium lamps was assessed in the experiment on supplementary lighting of seedlings of Parthenocarpic cucumber hybrid F1 Courage and determinate tomato hybrid F1 Blagovest. Under the LED lamps the compact tomato plants with a powerful felted stalk developed, are featuring higher dry matter content compared to the plants grown under sodium lamps. Supplementary lighting of cucumber seedlings by LED sources resulted in earlier development of lateral shoots, thicker root collar and shorter interstices. In terms of electricity inputs the LED sources demonstrated better efficiency: energy saving was 38.8 % and 40.3 % compared to the sodium lamps. The experiment outcomes have proved the LED sources to be more promising for intensive indoor plant growing.

Keywords: indoor plant cultivation, optical radiation, LED, energy efficiency.

Introduction

Plant cultivation under artificial light is currently used in glasshouse horticulture in many countries of the world, especially in the regions with the deficit of daylight. The indoor plant cultivation makes extensive use of the gas-discharge optical flux sources (OFS), such as high pressure sodium lamps SON-T, ДНаЗ/Reflux, Planta Star and others, with the optimized for plants spectrum of flux and high luminous efficiency (up to 130-150 $lm \cdot W^{-1}$). Their major drawback is poor conversion efficiency of electric energy into optic flux energy [1]. Improvement of power efficiency of indoor plant cultivation is especially urgent now that highly effective but expensive LED sources of optical flux have appeared on the market. These sources allow for flexible flow control on different phases of plant growth and have a higher luminous efficiency. Many research studies focus on the effect of various spectrum parts and supplementary lighting modes, but these studies are a long way still from being complete [2].

Materials and methods

In a specially equipped facility in SZNIIMESH, Saint-Petersburg, the comparative efficiency of LED and gas-discharge lamps was assessed when providing supplementary lighting of cucumber and tomato seedlings. Gas-discharge sodium lamps Reflux S 400 served as reference.

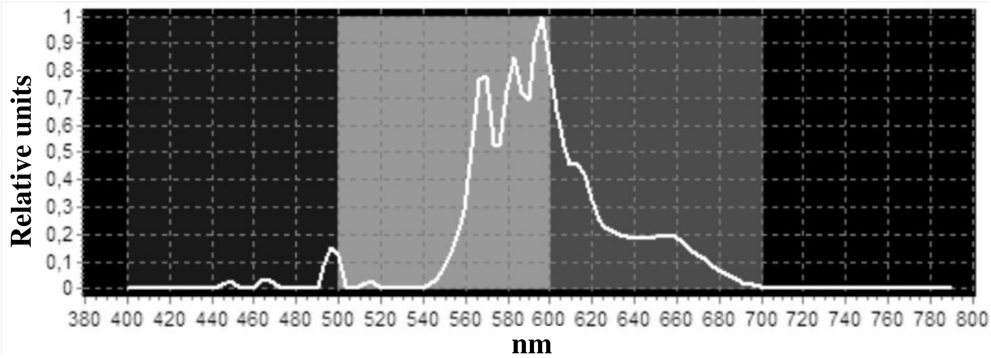
Radiation ranges of the applied OFS, shown in Fig. 1, were measured by the TKA-PKM VD/04 device and estimated according to our method [3].

Parthenocarpic cucumber hybrid F1 Courage and determinate tomato hybrid F1 Blagovest intended for growing in hothouses were selected for the experiments. These hybrids have high requirements for light. The used substrate was highbog-peat, neutralized by chalk to pH 6.0 and fertilized to the following nutrient levels, $mg \cdot l^{-1}$: NO_3 – 240, NH_4 – 12, P_2O_5 – 60, K_2O – 300, Ca – 180, Mg – 80, Mn – 0.50, Mo – 0.05, Cu – 0.05. Tomato seedlings were pricked off into cups of 663 cm^3, cucumber seedlings – into cups of 412 cm^3. The cups with cucumber seedlings were rearranged 14 days after the seedling emergence (25 plants per 1 m^2). The cups with tomato seedlings were rearranged twice: after closing the seedlings rows and two weeks before the end of the experiment at the age of 40 days from sowing (25 plants per 1 m^2).

The seedlings were top-dressed with fertilizing solutions of K_2SO_4, $MgSO_4$, KH_2PO_4 and $Ca(NO_3)_2$. The concentration of the nutrient solution was maintained in the range of fertilizer conductivity 1.8-2.5 $mS \cdot cm^{-1}$.

Phenological records and observations over the growth and development of tomato and cucumber seedlings were performed every 3-4 day. The substrate moisture content in the cups was maintained at the level of 75-80 % of minimum moisture-holding capacity by the metered rate of water with the temperature of 24-25 ºC. The air temperature in the plant growing room was maintained at 23-25 ºC by forced ventilation. Integrated irradiance was measured by the illumination value, which was 7 to 8 klx for tomatoes and 5 to 6 klx for cucumbers.

a)



b)

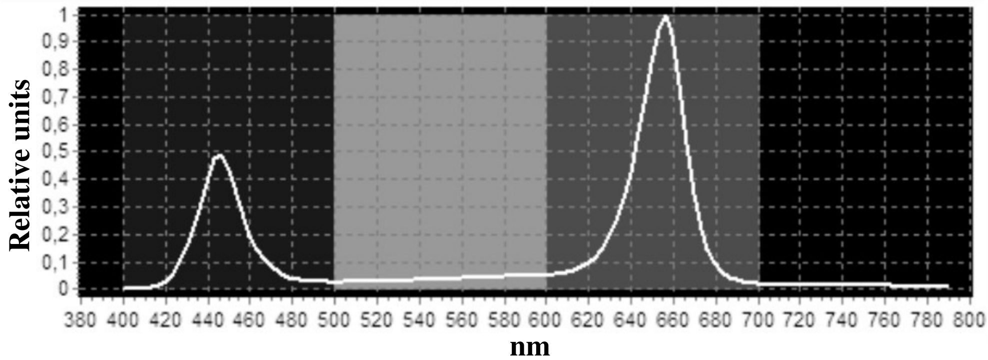


Fig. 1. **Ranges of radiation for sodium lamps (a) and LED (b)**

Results and discussion

Supplementary lighting of tomato seedlings with sodium lamps accelerated the growth of the plants. The height of 55-days-old seedlings was 79.35 cm, and the number of leaves was 12.45 pieces per plant due to the excessive infrared irradiation of sodium lamps.

Truss initiation started on the 48th to the 50th day after sowing. On the 53rd day all the plants had a formed truss. The stalk diameter was 6.92 mm average, wet weight of one plant was 53.8 g, dry matter content was 5.69 %.

Under the LED lamps the compact tomato plants with a powerful felted stalk and dark leaves with violet veins developed.

The height of 55-days-old seedlings was 43.5 cm average, number of leaves was 11 pieces per plant, stalk diameter was 8.57 mm, dry matter content in the plant herbage was 8.8 %. On the leaves there were single brown spots, but as a whole they did not indicate any disease. On the plants the first mature truss formed above the 8th leaf on the 44th day after the sowing. By the 55th day two blossoming trusses had developed.

The characteristics of tomato and cucumber seedlings grown under supplementary lighting are presented in Tables 1 and 2.

Development of the cucumber plants under the sodium lamps had a vegetative orientation.

The height of the plants on the 25th day after sprouting was 27.8 cm average, number of leaves was 5.75 pieces per plant, stalk diameter was 6.28 mm. Lateral shoots on cucumber seedlings were observed to form on the 23rd day after the emergence of seedlings.

Growth and development of the cucumber seedlings under the LED sources had the generative orientation, resulting in dark-green leaves, thicker root collar and shorter interstices.

Lateral shoots on the plants appeared on the 18th day after the emergence of seedlings. The values of wet weight of plants (30.25 g) and dry matter content (7.97 %) were higher compared to those of the plants grown under the sodium lamps – 24.7 g and 6.0 %, respectively.

Table 1

Characteristics of 55-days-old tomato seedlings additionally lit by sodium lamps and LED sources

Indices	Average	Standard deviation	Variation coefficient, %	Average relative error %
Sodium lamps				
Plant height, cm	79.35 ± 1.21	5.39	6.80	1.52
Number of leaves, piece	12.45 ± 0.15	0.69	5.51	1.23
Stalk diameter, mm	0.92 ± 0.18	0.49	7.08	2.6
Wet weight of a plant, g	53.80 ± 1.9	5.02	9.33	3.53
Dry matter content, %	5.69 ± 0.34	0.58	10.2	5.89
LED				
Plant height, cm	3.50 ± 0.84	3.73	8.59	1.92
Number of leaves, piece	11.30 ± 0.16	0.73	6.48	1.45
Stalk diameter, mm	8.57 ± 0.38	1.02	12.60	4.43
Wet weight of a plant, g	51.20 ± 1.15	3.05	5.92	2.24
Dry matter content, %	8.80 ± 0.52	0.89	10.14	5.85

Table 2

Characteristics of 25-days-old cucumber seedlings additionally lit by sodium lamps and LED sources

Indices	Average	Standard deviation	Variation coefficient, %	Average relative error %
Sodium lamps				
Plant height, cm	27.85 ± 0.83	3.70	13.30	2.97
Number of leaves, piece	5.75 ± 0.12	0.55	9.57	2.14
Stalk diameter, mm	6.28 ± 0.18	0.49	7.76	2.93
Wet weight of a plant, g	24.70 ± 1.01	2.69	10.80	4.08
Dry matter content, %	6.00 ± 0.39	0.68	14.36	6.56
LED				
Plant height, cm	15.40 ± 0.61	2.72	17.68	3.95
Number of leaves, piece	5.75 ± 0.10	0.44	7.73	1.73
Stalk diameter, mm	8.40 ± 0.30	0.80	9.52	3.57
Wet weight of a plant, g	30.25 ± 0.97	2.58	8.52	3.20
Dry matter content, %	7.97 ± 0.30	0.53	6.59	3.80

Fig. 2 shows the growth dynamics of the cucumber and tomato plants under different OFS. The intensity of physiologically active irradiance under the sodium lamps (12.82 and 14.85 $W \cdot m^{-2}$) was insufficient and the intensive growth of the plants was due to excessive heat from the lamps and general temperature conditions in the room.

Fig. 3 shows the tomato and cucumber seedlings under supplementary lighting with sodium lamps and LED emitters.

The intensity of the active irradiance for tomato and cucumber plants should be at least 20-25 $W \cdot m^{-2}$ [4].

Under LED sources the intensity of active irradiance reached 40.05 $W \cdot m^{-2}$ and 40.72 $W \cdot m^{-2}$ P.A.R., resulting in the active emergence of lateral shoots on the cucumber and tomato plants that is probably due to the red and blue color of the light emitted by LED.

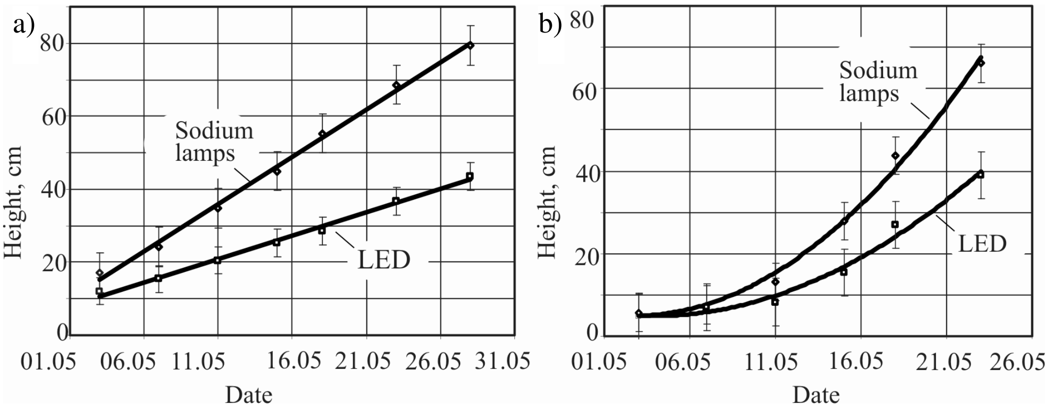


Fig. 2. **Growth dynamics of seedlings under sodium lamps and LED for tomatoes (a) and cucumbers (b)**

In terms of electricity inputs when growing the cucumber and tomato seedlings the LED sources demonstrated better efficiency: energy saving was 38.8 % and 40.3 % compared to the sodium lamps (Table 3).

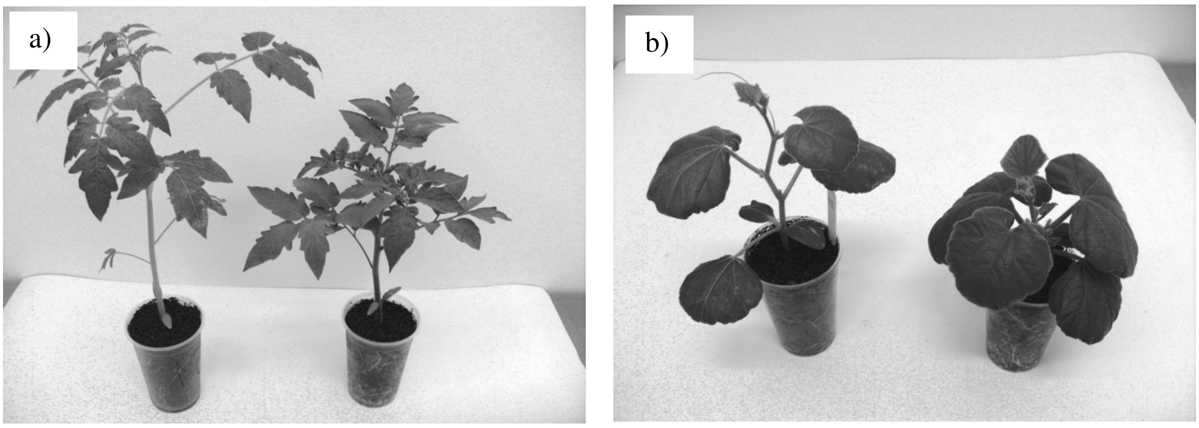


Fig. 3. **Tomato (a) and cucumber (b) seedlings grown under sodium lamps (left) and LED emitters (right)**

Table 3

Energy assessment of supplementary illumination of vegetable seedlings by different sources of optical flux

Indices	**Cucumber**		**Tomato**	
	LED	Sodium lamps	LED	Sodium lamps
Specific power of an illumination facility, $W \cdot m^{-2}$	58.00	58.00	70.00	80.00
Duration of supplementary illumination, $h \cdot day^{-1}$	12.00	12.00	12.00	12.00
Total duration of supplementary illumination, days	18.00	18.00	31.00	31.00
Intensity of the physiologically active plant irradiance, $W \cdot m^{-2}$	40.05	12.82	40.72	14.85
Dry matter output, $g \cdot m^{-2}$	60.27	37.05	112.64	77.04
Specific electric power consumption, $KWh \cdot m^{-2}$	12.50	12.50	26.04	29.76
$MJ \cdot m^{-2}$	45.00	45.00	93.70	107.13
Specific electric power consumption, $MJ \cdot g^{-1}$ of dry matter	0.74	1.21	0.83	1.39
Electric power saving, %	38.80	-	40.30	-

Conclusions

Application of LED sources for supplementary lighting of the tomato seedlings allowed to avoid leggy plants and to grow the seedlings with a powerful stalk and smaller number of leaves. The trusses formed earlier and had bigger dry matter content compared to the plants grown under sodium lamps.

Under the LED sources the cucumber seedlings featured earlier formation of lateral shoots, the root collar of the plants was thicker, interstices were shorter. The seedlings also had bigger dry matter content. The energy saving when growing the cucumber and tomato seedlings under the LED sources was 38.8 % and 40.3 % against the sodium lamps. The experiment outcomes have proved the LED sources to be more promising for indoor plant growing under intensive artificial lighting but further investigations are needed to determine the optimum radiation spectrum and illumination modes of different crops and different plant development phases.

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