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Plant growth parameters of *Cucumis sativus* L. cv Cornish Paris changes under the conditions of seeds irradiation with LED lasers.

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Abstract:
The problems of increasing plant productivity are among the leading at the present stage of human development. Most often, chemicals are used to achieve this goal, which leads to a deterioration in the environmental situation. An alternative is the use of physical means, in particular the use of laser systems to stimulate plants. One of the most promising areas is the use of LED lasers, which at the same radiation power have smaller dimensions and use much less energy than He-Ne or other lasers.
The results of studies of the influence of seed irradiation Cucumis sativus L. are presented in the paper. cv Cornish Paris LED lasers emitted red (wavelength 635 nm) and blue (wavelength 405 nm) light. Irradiation was carried out according to the scheme of a complete factor experiment, which made it possible to detect the action of each of the light sources and their complex action. Determination of growth parameters was carried out using standard methods. The area of the leaves was determined after scanning them on a tablet scanner.
The results showed a significant positive effect of irradiation of seeds on the growth processes of experimental plants. Irradiation with red light with an energy of 51.10 mJ/cm2 and complex irradiation improved oral parameters such as root length by 25.0-42.5%, shoot height by 19.4-77.4% compared to plants grown from non-irradiated seeds. In experimental plants, the leaf area increased significantly and by 22.4-41.5% the total leaf area grew.
Studies have also revealed a significant positive effect of seed irradiation on the plant pigment complex. In plants grown from irradiated seeds, the content of chlorophyll A is 25.5-30.9%, and chlorophyll B is 754.0-105.5% higher than in control plants. The ratio of chlorophyll A to chlorophyll B under these conditions was not likely to change.
Studies have shown the prospects of using laser irradiation using LED laser systems to improve the growth, development and productivity of agricultural plants.
Keywords: *LED laser, seeds irradiation, growth parameters*

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I. Introduction

The use of chemicals aimed at improving plant productivity (artificial growth additives, inhibitors, mineral fertilizers, etc.) can cause environmental pollution, deterioration of living organisms and decreased product quality [1, 2, 3]. The safety of fresh products in the economy requires the development and implementation of new methods of quality assurance. The influence of physical factors such as microwave and laser radiation, magnetic field and ultrasonic irradiation is an alternative to soil additives and fertilizers. Replacement of chemical improvement by physical can reduce the content of toxins in raw materials and increase food safety. Given these conditions, there is an important problem of non-toxic agents that stimulate growth, which can affect the processes of plant development without harming the environmental situation [4, 5]. However, the most promising methods of regulating plant growth parameters, characterized by the slightest impact on the environment, are physical methods of influence on plants [1, 6, 7]. For this purpose, pre-sowing treatment of seeds often uses low red light, which is emitted by He-Ne lasers [8, 9]. It has been found that shortwave coherent red light with a wavelength of 620-660 nm increases the germination rate and germination rate of seeds [6,10, 11, 12, 13]. Laser irradiation of Nd-Yag at 532 nm wavelength caused Glycin max L. cv. Giza 111 increase seedling growth potential, change in the structure of protein strips of leaf pools [14]. The results showed that the irradiation with a laser beam of the seed shell yielded perforation in one or more positions. Typically, increasing the energy and duration of He-Ne laser light exposure increased the level of endogenous stimulants (GA and IAA) and reduced the level of endogenous inhibitors (ABA and phenol) in seed shells [15]. Plants grown from irradiated seeds had increased activity of growth stimulants (indoluxic acid, gibberellins, cytokinins); simultaneously reduced activity of growth inhibitors [10, 16,17].Improved morphological characteristics of such plants [12], activity of photosynthetic agents, enzymes responsible for amino acid synthesis, lipid synthesis and carbohydrate synthesis [14, 18, 19],as well as the intensity of photosynthesis [20]. Plants grown from laser-stimulated seeds made better use of elements of mineral nutrition [21]. The positive effect of red-light laser radiation was also observed when plants were exposed to elevated levels of ultraviolet radiation. [6, 22, 23, 24].

It was also found that red light laser irradiation contributed to the restoration of sap and increased PCNA expression for damage from UV-B[15].

However, He-Ne lasers require significant power energies and are characterized by lack of mobility. He-Ne lasers are also limited in their spectral characteristics. LED laser systems can be used to overcome these shortcomings, as they require less energy to provide the same radiation power and are characterized by small size and mass, as well as high efficiency effects on plant organisms. [25, 26, 27]. In particular, seed irradiation before sowing LED lamps with a wavelength of 620-625 nm and exposure of 1-14 hours demonstrated greater fertilization, better growth, average height and greater homogeneity [25]. Laboratory studies have shown that red-diode lasers at 650 nm wavelength after seed treatment for 15 minutes of the plant had the highest concentration of total soluble sugar, common soluble aminoacids and common soluble indoles [28]. It is also observed that the red diode laser increased the concentration of macro elements (N, P, K, Na and Mg) and raw protein.

In this regard, the effects of radiation red (wavelength 635 nm) and blue (wavelength 405 nm) investigated LED lasers light on the growth parameters of individual species of Poaceae plants.

II. Material And Methods

Investigation of the effect of LED seed irradiation by lasers on the growth parameters of Cucumis sativus L. Vasyl "Stus Donetsk National University. The seeds were irradiated with LED lasers, sprouted on filter paper, and planted in the soil. Cultivation of plants was carried out during 1 month after germination in light 10000 lx and temperature 22-25 ° C. The plants determined the length of the main root, the height of the shoot, the square of leaf plates and the total square of leaves on the plant.

Methods of seeds irradiation.

For seed irradiation were used BRP-3010-5 with a 635 nm red wavelength radiation and BBP-3010-5 with the radiation of the blue spectrum at a wavelength of 405 nm (BOB LASER Co., China)LED lasers. Irradiation was carried out according to the scheme of a complete factor experiment [29]. Conditions of irradiation of seeds and irradiation energy are given in Table 1.

Table 1:Seed irradiation scheme

Variant	Red Laser (635 nm)		Blue Laser (405 nm)	
	Irradiation term, sec	Irradiation energy, mJ/cm^2	Irradiation term, sec	Irradiation energy, mJ/cm^2
1	0	0	0	0
2	5	25.05	0	0
3	10	51.10	0	0
4	0	0	5	25.05
5	5	25.05	5	25.05
6	10	51.10	5	25.05
7	0	0	10	51.10
8	5	25.05	10	51.10
9	10	51.10	10	51.10

Method of determining the leaves square.

To measure the square of the leaves, the technique developed by Prysedskyi and Shuntov[30] was used. For this, leaves collected from one plant were placed on the glass of a tablet scanner and scanned images with a resolution of 100 ppm. The scanned image was stored in bmp format. Images obtained after saving were analyzed in a specially designed program. The resulting results were recorded automatically in a text file and daoi were used for statistical processing.

Statisticalanalysis.

All studies were conducted in three or ten repetitions. Statistical analysis of research results was carried out by methods of dispersion analysis. Comparison of mean values and the probability of difference between manure was performed by the method of multiple comparisons by Dannet[29, 31].

III. Result and Discussion

Studies have made it possible to conclude that there are significant differences in changes in the growth parameters of *C. sativus* under the conditions of irradiation of seeds with red (635 nm), blue (405 nm) lasers and their complex action. Plant reactions also depended heavily on radiation energy.

Analysis of the influence of seed irradiation revealed a significant positive effect on seed germination processes. In particular, a significant acceleration of seed germination was established, as evidenced by the known statistically probable (Fischer's criterion for red laser action was 28.74 and for complex irradiation - 25.04. corresponding standard values 3.55 and 2.93) increase in germination energy. In control plants grown from non-irradiated seeds, this figure was 42.3%. Exposure to red and blue lasers increased this figure by 48.8-72.5% compared to control plants (Table 2). The best results were given by complex irradiation of seeds with red (radiation energy 51.10 mJ/cm^2) and blue laser with radiation energy 51.10 mJ/cm^2.Under these conditions, the germination energy was 72.67 and 73.0% respectively. Complex irradiation with red and blue lasers (var. 9) reduced germination energy compared to other experimental options. But under these conditions, the energy of germination of experimental plants did not differ from this indicator of control plants.

Table 2: germination energy and germination of seeds under the conditions of complex irradiation with LED lasers

Variant	Germination energy, %				Seed germination, %			
	M±m	D	D^D	% to control	M±m	D	D^D	% to control
1	42.33±2.48			100.0	73.333±3.12			100.0
2	63.00±2.8	20.67	8.55	148.8	97.00±1.41	23.67	9.08	132.3
3	63.33±3.19	21.00	8.55	149.6	87.67±2.28	14.33	9.08	119.5
4	72.00±3.24	29.67	8.55	170.1	88.00±3.94	14.67	9.08	120.0
5	68.33±2.68	26.00	8.55	161.4	90.67±2.68	17.33	9.08	123.6
6	72.67±2.86	30.33	8.55	171.7	93.67±2.16	20.33	9.08	127.7
7	73.00±2.55	30.67	8.55	172.5	95.67±2.94	22.33	9.08	130.5
8	67.33±1.78	25.00	8.55	159.0	91.33±3.19	18.00	9.08	124.5
9	49.33±4.14	7.00	8.55	116.5	68.00±2.12	-5.33	9.08	92.7

Note: in tables M – mean, m – error representativeness, D – difference between test and control averages, D^D – least significant difference according to the Dannet test

Seed germination by blue and red lasers also increased statistically from 73.3% in control to 87.7-97.0% in experimental variants. Statistical analysis has shown a significant impact on the studied parameter of all variants of irradiation. Thus, the Fischer criterion for exposure to red radiation was 5.68 (standard value - 3.55). The best result was obtained for irradiation by a red laser with radiation energy of 25.05 mJ/cm2 - 97.0% (var.2). The exposure of seeds by a laser with a wavelength of 405 nm also had a probable effect (the calculated value of the Fischer criterion is 15.70). For irradiation with a blue laser, the best result was obtained by energy 51.10 mJ/cm^2 (var. 7). Under these conditions, seed germination increased 30.5% to the control level. Complex irradiation (simultaneous action of red and blue lasers) led to statistically probable changes (Fischer criterion value 29.04). At the same time, these changes depended on the energy dose of irradiation. With the combination of low energies (25.05 mJ/cm2) and one source of irradiation at a low level, and the other at a high level (51.10 mJ/cm^2), the germination of seeds likely increased 19.5-27.7% compared to the similarity of non-irradiated seeds. The combination of red and blue lasers with radiation energy 51.10 mJ/cm^2 led to a 7.3% decrease in seed germination compared to control. Thus, from the results of the research, it can be concluded that by regulating the irradiation regimes, the process of germination of seeds C can be significantly accelerated. sativus.

Plant growth parameters reacted to irradiation depending on the wavelength and energy of the modes used (table 3). On the growth processes of root systems, the probable effect was exposure by a red laser (the calculated value of the Fischer criterion was 3.93, which exceeded the standard - 3.55). Seed irradiation with a blue laser and complex irradiation (red + blue lasers) did not lead to statistically likely changes in the growth parameters of the root. However. For irradiation of seeds by a blue laser with energy 25.05 mJ/cm^2 (var.4) and complex irradiation by red (25.05 and 51.10 mJ/cm^2) and blue (radiation energy 51.10 mJ/cm^2) by lasers (var. 7 and 8) caused a tendency to increase the length of the main root by 25.0-42.4% compared to the same parameter of plants grown from non-irradiated seeds.

Table 3: Effect of seeds laser irradiation on growth parameters of *Cucumis sativus* L. cv Cornish Parisian

Variant	Root length, cm				Stem height, cm			
	M±m	D	D^D	% tocontrol	M±m	D	D^D	% tocontrol
1	4.0±1.2			100.0	3.1±0.7			100.0
2	3.3±0.8	-0.7	2.8	82.5	3.3±0.8	0.2	2.0	106.5
3	3.8±0.7	-0.1	2.8	95.0	3.7±0.4	0.6	2.0	119.4
4	5.0±0.7	1.0	2.8	125.0	4.1±0.7	1.0	2.0	132.3

5	2.3±0.4	-1.7	2.8	57.5	2.4±0.4	-0.6	2.0	77.4
6	3.8±1.3	-0.2	2.8	95.0	4.7±0.4	1.6	2.0	151.6
7	5.7±0.8	1.7	2.8	142.5	4.0±0.7	0.9	2.0	129.0
8	5.0±0.4	1.0	2.8	125.0	5.5±0.6	2.5	2.0	177.4
9	4.7±0.8	0.7	2.8	122.5	3.2±0.5	0.1	2.0	103.2

On the height of the above-ground parts of plants, almost all variants of irradiation had a positive effect. At thesame time, changes in the growth parameters for irradiation of seeds with a blue laser were not likely. For this calculated value, the Fischer criterion was 0.05, which is less than its standard value (3.55). In the version with irradiation by a blue laser with energy 51.1 mJ/cm^2 there was a significant inhibition of the growth processes of the above-ground parts of plants C. sativus. Corresponding indicator under irradiation (var. 5) was 2.4±0.4 cm, which was 77.4 % of the level of control plants. At the same time, irradiation with a blue laser had a statistically probable positive effect if it was combined with exposure by a red laser. The Fischer criterion for the interaction of factors was 5.91, far exceeding the standard value (2.93). Under conditions of complex irradiation (var. 6-8) the height of plant stems significantly exceeded the corresponding indicator of control plants. The most effective was irradiation by a red laser with an energy of 25.05 mJ/cm^2 in combination with irradiation by a blue laser with an energy of 51.10 mJ/cm^2 (var. 7). This variant of irradiation caused an increase in stem height by 77.4% compared to rolls grown from non-irradiated seeds. Red laser irradiation had a less significant effect.

Thus, seed irradiation causes a significant improvement in the growth processes of *C. sativus*. The data obtained coincides with the data. Obtained earlier for oilseeds [26] and research by other authors [10, 14].

An important indicator of the state of plants is their photosynthetic activity. Plant productivity, its photosynthetic activity characterizes a variety of parameters, including the photosynthetic surface [7]. In this regard, the effect of LED exposure by lasers on the square of leaf plates and the total square of C leaves was studied. sativus (Table 4). Studies have allowed us to conclude that there is no statistically probable link between the irradiation of seeds and the square of individual leaf plates. The calculated values of Fischer's criteria were 0.13 for red laser irradiation, 0.03 for blue laser irradiation (the corresponding standard value is 3.09) and 1.38 for complex irradiation (the standard value is 2.46). this may have been due to a significant divergence in the square of individual leaves and, accordingly, a large error of representation. However, the analysis of the materials of the table made it possible to conclude the positive effect of irradiation of seeds on the square of leaf plates. Thus, exposure to red and blue lasers and complex irradiation, in addition to high energies of red and blue rays (var. 8, 9), caused a significant average increase in the square of leaf plates, which ranged from 25.5 % to 54.2 % compared to control. The largest increase in the square of leaf plates was observed for irradiation with a blue laser (var. 7) with energy51.10 mJ/cm^2. Under these conditions, the square of leaf plates was 213.6±2.7 cm^2, whereas in control this figure was 15.5 cm^2. A significant increase in the square of leaf plates was also observed for the irradiation of seeds by a red laser with an energy of 25.05 mJ/cm^2. Under these conditions, the square of leaf plates of experimental plants was 145.1 % of the control level.

Table4: Effect of seeds laser irradiation on the leavessquare of *Cucumis sativus* L. cv Cornish Parisian

Variant	Leaves square, cm^2				Total square of plants leaves, cm^2			
	M±m	D	D^D	% tocontrol	M±m	D	D^D	% tocontrol
1	15.3±4.7			100.0	55.9±7.6			100.0
2	22.2±3.5	6.9	13.4	145.1	71.7±9.1	15.8	20.3	128.2
3	19.7±4.0	4.4	13.4	128.7	72.7±3.9	16.7	20.3	130.0
4	19.2±3.8	3.9	13.4	125.5	70.6±3.7	14.6	20.3	126.3
5	21.1±3.3	5.9	13.4	137.9	79.1±6.6	23.1	20.3	141.5
6	19.6±3.4	4.3	13.4	128.1	68.4±3.8	12.3	20.3	122.4
7	23.6±2.7	8.3	13.4	154.2	75.4±9.5	19.4	20.3	134.9
8	15.0±3.3	-0.3	13.4	98.0	47.3±5.2	-8.6	20.3	84.6
9	17.1±3.3	1.9	13.4	111.8	54.5±1.1	-1.5	20.3	97.5

Exposure to seed C. sativus on the total leaf surface of plants with a red laser and complex irradiation proved statistically likely. Thus, for exposure to a red laser, the Fischer criterion value was 5.43 (standard – 3.55), and for a complex action – 6.388 (standard value – 2.93). The effect of the blue laser was not statistically likely (the calculated value of the Fischer criterion was 0.14, the standard value was 3.55). However, it should be noted that in almost all regimes of irradiation of seeds in plants grown from it, the total leaf area was 122.6–141.5 % of the corresponding indicator of plants grown from non-irradiated seeds. In variants using blue radiation with an energy of 50.05 mJ/cm^2 in combination with irradiation with a red laser (var. 8 and 9) statistically probable impact on the total leaf area has not been detected, although there has been a tendency to decrease this figure by 2.5–15.4 % compared to control plants. This is most likely due to excess radiation energy. Similar results were obtained by other researchers [28, 31], who reported a decrease in the positive effect of factors for increasing the duration of their impact, that is, an increase in impact energy.

Another important factor that determines the photosynthetic activity and productivity of plants is the state of the pigment complex. It was noted that the exposure of seeds by red lasers can significantly improve this figure [7, 13, 20, 26, 27]. In this regard, the effect of irradiation of seeds C. sativus on the content of chlorophyll in their leaves (Table. 5).

The results of determining the amount of chlorophyll A showed that in most variants of irradiation there was a probable increase in the amount of this pigment in the leaves of experimental plants compared to this parameter of plants grown from non-irradiated seeds. Moreover, the most likely effect on the content of chlorophyll A is the combined action of both sources of laser radiation (the calculated value of the Fischer criterion is 15.39, the standard is 2.62). The greatest positive effect on the content of chlorophyll A was irradiated by a red laser with an energy of 25.05 and 51.10 mJ/cm^2. Under these conditions, the amount of chlorophyll A in plant leaves increased by 27.3 and 25.0 % compared to the pigment content in control plants. Exposure to the blue laser at an energy of 25.05 mJ/cm^2 did not have a probable effect on the content of chlorophyll A, while at an irradiation energy of 51.10 mJ/cm^2 the amount of this pigment increased by 30.9 %. Under the conditions of complex action of laser irradiation of seeds in variants with low radiation energy (var. 5, 6 and 8) the content of chlorophyll A exceeded a similar indicator of control plants by 14.5-20.0 % the amount of this pigment in plants grown from non-irradiated seeds. With complex irradiation, the level of pigment decreased compared to other experimental variants and did not differ from the corresponding parameter of control plants. We can assume that such a combination of radiation energies is somewhat redundant for this plant species.

Table 5: Influence of LED laser irradiation on Chlorophyll Content in Leaves of C. sativus

Variant	Chlorophyl A Content, mg/g				Chlorophyl B Content, mg/g				Ratio A/B
	M±m	D	D^D	% to control	M±m	D	D^D	% to control	M±m
1	0.55±0.03			100.0	0.20±0.01			100.0	1.861±0.121
2	0.70±0.03	0.14	0.06	127.3	0.36±0.02	0.06	0.04	180.0	1.906±0.078
3	0.69±0.01	0.13	0.06	125.5	0.36±30.01	0.07	0.04	180.0	1.913±0.115
4	0.62±0.03	0.07	0.06	112.7	0.35±0.01	0.05	0.04	175.0	1.759±0.053
5	0.66±0.02	0.11	0.06	120.0	0.36±0.01	0.06	0.04	180.0	1.829±0.059
6	0.66±0.01	0.11	0.06	120.0	0.36±0.01	0.07	0.04	180.0	1.820±0.055
7	0.72±0.01	0.16	0.06	130.9	0.41±0.01	0.11	0.04	205.0	1.764±0.027
8	0.63±0.01	0.08	0.06	114.5	0.40±0.01	0.10	0.04	200.0	1.601±0.045
9	0.60±0.01	0.04	0.06	109.1	0.28±0.01	-0.02	0.04	140.0	2.110±0.085

Changes in chlorophyll B content were similar. Exposure to chlorophyll B was statistically probable as a red laser (Fischer's criterion was 3.34). and under the conditions of using a blue laser (the calculated value of the Fischer criterion was 8.60, the standard – 3.25). In variants with red or blue lasers, the content of chlorophyll B ranged from 0.35±0.1 to 0.41±0.01 mg/g, which at 75.0–105.0 % exceeded the level of control plants. Complex radiation had a more significant effect on the content of chlorophyllB. The calculated value of the Fischer criterion for this indicator was 23.75 (standard –2.62). At the same time, it should be noted that the combination of high radiation energies (51.10 mJ/cm^2 exposure to red laser and 51.10 mJ/cm^2 exposure to blue laser at the same time) caused a significant decrease in the content of chlorophyll B compared to other experimental variants.

An important indicator of the quality of the pigment complex is the ratio of the content of chlorophyll A to chlorophyll B. Studies have established that in all research plants, this indicator does not undergo significant changes and ranges from 1.60±0.04 to 2.11±0.08. This indicates the stability of the state of the pigment complex, which allows effective photosynthetic function of experimental plants.

IV. Conclusion

Based on the results of experiments, we can conclude that the significant positive effect of LED seed irradiation with red and blue light lasers on the development and growth parameters of Cucumis sativus L. cv Cornish Parisian. Plants grown from irradiated seeds had 25-42% longer main root length, 19.4-77.4% higher shoot height and 25-41% larger leaf area on plants. Studies have also revealed a significant positive effect of seed irradiation on the plant pigment complex. In plants grown from irradiated seeds, the content of chlorophyll A is 25.5-30.9%, and chlorophyll B is 754.0-105.5% higher than in control plants. The ratio of chlorophyll A to chlorophyll B under these conditions was not likely to change.At the same time, for the practical use of the given stimulation techniques, further studies are needed aimed at the most effective selection of mitigation regimes.

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