Experimental studies to identify the influence of low power monochromatic optical radiation on the seeding qualities of cucumber seeds variety "Feniks+",

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Abstract. A further increase in the volume of cultivated and harvested agricultural products today depends not on the expansion of sown areas, but on scientific achievements aimed at increasing yields. The experimental study presents the results of studying the effect of low-power monochromatic optical radiation on the seeds of cucumbers of the "Fenisk+" variety. The research is based on the principles of refusal to use chemical fertilizers, the use of natural organic substances, and the creation of conditions for the growth and development of plants, identical to the conditions of their natural growth. There are various physical effects, including those based on the use of electrical energy and its transformation into light energy. Monochromatic optical radiation can be attributed to such effects. Based on the analysis of the experimental results, regression equations were obtained for the dependence of the average dry weight of cucumber seedlings on the wavelength of irradiation and exposure, and the optimal range of wavelengths of optical radiation was found: from 565 to 615 nm. At these wavelengths, the best results were obtained in terms of seed germination, the length of shoots and roots, as well as the dry weight of the vegetative part and roots. Based on the results obtained, it is possible to formulate the technological requirements for the design and development of a specialized electrotechnical installation using monochromatic optical radiation in agricultural production with the aim of pre-sowing stimulation of seeds of such a vegetable crop as cucumbers.

1. Introduction
The main purpose of the study was to determine the rational wavelength range of optical radiation for pre-sowing treatment of cucumber seeds with monochromatic optical radiation.

Due to the use of physical factors that have a stimulating effect and activate biophysical processes affecting the growth and development of plants, it becomes possible to increase crop yields, while the products themselves remain environmentally friendly, which is an important task of agricultural production.

There are various methods for improving the sowing qualities of plant seeds, which include methods based on exposure to various physical factors, such as a laser beam, ultraviolet radiation, treatment of seeds with magnetized and ozonized water, electric and magnetic fields [1–9].

The effect of seed stimulation is mainly related to the first stages of plant life, that is, germination and growth energy. For different types of plants, there are different methods and treatment regimes, which differ in intensity and dose. Therefore, when choosing the type of exposure to specific plants, for example, vegetables, it is necessary to know the optimal (rational) exposure parameters.
It is known that oversaturation by impacts cause a general decrease in the productivity of plant seeds; therefore, when applying irradiation to plants, and in some cases to certain varieties, it is necessary to establish rational parameters of the impact.

2. Methods and Equipment

To find the relationship between the sowing qualities of the cucumber seeds and the wavelength, an experimental plan was drawn up [10].

The study involved irradiation with wavelengths of 450, 510, 570, 630 nm. When the seeds were irradiated, an energy dose of 1.5 J was used per 100 seeds. The processing time was constant and equal to 30 s. During the experiment, the seeds were divided into groups of 4 replicates, 100 pieces each. The seeds were selected according to GOST R 52171-2003.

The experiment itself was carried out in accordance with GOST 12038-84. In accordance with it, studies were carried out in the educational-scientific-industrial agro-technological laboratory of the ABSEI at Donskoy State Agrarian University in the city of Zernograd. The samples were warmed up, planted in a moistened filter paper and stored in a container partially filled with water at an average temperature of 25 °C. On the third day after laying the samples, the indicators of germination energy were established, and on the seventh day, the germination of seeds, the length of their shoots and roots were determined.

After determining the sowing qualities of the seeds, the germinated seeds were planted in schools, which were filled with soil. Throughout the experiment, the illumination was maintained at 6.3 klx. For this, low-pressure fluorescent lamps LismaFL 80W – 32/635 with a power of 80 W each were used. The room temperature was maintained at 22 °C.

The final part of the experiment was to determine the dry matter of the vegetative and root systems. The productivity of photosynthesis was assessed by the maximum yield of the dry matter mass of the root part in plants according to the recommended method described by V.V. Kidin [11]:

1. For 20 minutes, the samples were placed between two layers of filter paper in order to remove moisture.
2. Separately, the mass of the green vegetative and root parts of plants was measured on an analytical balance.
3. Each plant was placed in a paper bag and the samples were held in an oven for one hour at a temperature of 110 °C.
4. Then for three days the samples in paper bags were held in an oven with a temperature of 60 °C.
5. Dry biomass was measured on an analytical balance. The vegetative and root parts were weighed separately.

3. Results and Discussion

Based on the results of the research, Table 1 was compiled to determine the germination energy.

Table 1. Results of determining the germination energy of seeds of cucumbers of the "Feniks+" variety after treatment with monochromatic optical radiation in laboratory conditions

| Repeat number | control | Wavelength | Germination [%] |
|---------------|---------|------------|-----------------|
|               |         | 450 nm     | 510 nm | 570 nm | 630 nm |
| I             | 76      | 82         | 76      | 82     | 78     |
| II            | 76      | 78         | 82      | 76     | 62     |
| III           | 74      | 78         | 38      | 76     | 68     |
| IV            | 74      | 37         | 74      | 84     | 66     |
| Average       | 75      | 68.75      | 67.5    | 79.5   | 68.5   |

According to the table and the diagram presented in Figure 1, it can be concluded that optical radiation with a wavelength of 570 nm had a positive effect on the growth and development of seeds, and gave an increase of 4.5%, which is the maximum result in relation to the control (untreated) variant.
However, it should be taken into account that the treatment of seeds with optical radiation with lengths of 450, 510 and 630 nm reduced the growth energy indicators.

![Figure 1](image-url)

**Table 2.** Results of laboratory germination of seeds of "Feniks+" cucumbers after treatment with monochromatic optical radiation

| Repeat number | control | Wavelength | 450 nm | 510 nm | 570 nm | 630 nm |
|---------------|---------|------------|--------|--------|--------|--------|
| I             | 78      | 84         | 74     | 84     | 82     |        |
| II            | 62      | 82         | 84     | 76     | 88     |        |
| III           | 86      | 70         | 80     | 80     | 74     |        |
| IV            | 78      | 86         | 68     | 92     | 72     |        |
| Average       | 76      | 80.5       | 76.5   | 83     | 79     |        |

Based on the results presented in Table 2 and in the diagram (Fig. 2), a pronounced increase in germination rates is observed if the seeds were irradiated with radiation with a wavelength of 570 nm. In this case, the increase was 7% compared to the control variant. Based on the data obtained, we can conclude that optical radiation with a wavelength of 570 nm is the most optimal option for seed treatment.
Figure 2. Influence of pre-sowing treatment on the germination of seeds of "Feniks+" cucumbers

Table 3 shows the results of experimental studies of the length of shoots and roots of cucumbers of the "Feniks+" variety, depending on the wavelength of monochromatic radiation.

Table 3. The results of the effect of low-power optical monochromatic radiation on the length of sprouts/roots of “Feniks+” cucumbers

| Radiation dose [J] | Repeat number | Wavelength | Control | 450 nm | 510 nm | 570 nm | 630 nm | Shoot length [cm] |
|-------------------|---------------|------------|---------|--------|--------|--------|--------|-------------------|
|                   |               |            |         |        |        |        |        |                   |
| I                 | 18            | 0.2        | 2.3     | 2.6    | 1.1    |        |        |                   |
| II                | 0.1           | 1.1        | 3.0     | 2.9    | 2.0    |        |        |                   |
| III               | 2.5           | 0.1        | 2.0     | 2.4    | 2.0    |        |        |                   |
| IV                | 3.4           | 3.7        | 3.0     | 5.8    | 1.0    |        |        |                   |
|                   |               |            |         |        |        |        |        | Root length [cm]   |
| I                 | I             | I          | I       | I      | I      | I      | I      |                   |
| II                | II            | II         | II      | II     | II     | II     | II     |                   |
| III               | III           | III        | III     | III    | III    | III    | III    |                   |
| IV                | IV            | IV         | IV      | IV     | IV     | IV     | IV     |                   |

Table 4. Dependence of the germination energy on the exposure during treatment with radiation with a wavelength of 570 nm (%)

| Exposure       | I   | II  | III | IV  | Average |
|----------------|-----|-----|-----|-----|---------|
| Control (0 s)  | 66  | 28  | 52  | 47  | 48.25   |
| 10 s           | 10  | 20  | 22  | 31  | 20.75   |
| 20 s           | 52  | 70  | 61  | 57  | 60.00   |
| 30 s           | 28  | 60  | 39  | 44  | 42.75   |
| 40 s           | 16  | 34  | 25  | 30  | 26.25   |
| 50 s           | 68  | 62  | 66  | 64  | 65.00   |
| 60 s           | 68  | 46  | 54  | 50  | 54.50   |

Figure 3. Dependence of germination energy on exposure when processing seeds of "Feniks+" cucumbers

The separation of the vegetative part from the root system of the plant has been carried out. The green mass was put into a drying cabinet; a temperature of 60 °C was set using an electric contact.
thermometer; drying was carried out for 48 hours. Then, the dry mass of the plants was measured using an accurate electronic balance. Based on the measurement results, Table 6 was compiled.

**Table 5.** Dependence of the growth energy on the exposure during treatment with radiation with a wavelength of 570 nm (%)

| Exposure | I   | II  | III | IV  | Average |
|----------|-----|-----|-----|-----|---------|
| Control (0 s) | 64  | 68  | 62  | 64  | 64.50   |
| 10 s      | 58  | 64  | 52  | 55  | 57.25   |
| 20 s      | 74  | 72  | 70  | 71  | 71.75   |
| 30 s      | 76  | 60  | 69  | 66  | 67.75   |
| 40 s      | 62  | 72  | 61  | 70  | 66.25   |
| 50 s      | 72  | 74  | 77  | 75  | 74.50   |
| 60 s      | 78  | 66  | 74  | 68  | 71.50   |

**Figure 4.** Dependence of growth energy on exposure when processing seeds of "Feniks+" cucumbers

**Table 6.** Preliminary results of the dependence of the yield of seedlings of "Feniks+" cucumbers on the use of monochromatic optical radiation

|        | Control | 450 nm | 510 nm | 570 nm | 630 nm |
|--------|---------|--------|--------|--------|--------|
| Vegetative part [g] | 46.08   | 42.89  | 57.72  | 56.14  | 52.66  |
| Root system [g]     | 11.08   | 8.89   | 15.73  | 17.17  | 14.39  |
| Vegetative part [g] | 13.05   | 10.68  | 23.06  | 19.13  | 21.21  |
| Root system [g]     | 1.56    | 1.03   | 2.72   | 2.48   | 2.10   |

For a quantitative assessment of the correspondence of theoretical provisions and experimental studies, the following criteria were chosen as indicators with the help of which the validity of the assumptions made in the development of a mathematical model was determined: correlation coefficient, Fisher's criterion, Student's coefficient, and checking the Durbin-Watson autocorrelation [12].

Table 7 shows the factors and levels of variation for them, and the target functions (response). Dry residue of the stem and dry residue of the root, in grams, are indicated in Table 8.

**Table 7.** - Factors and levels of variation

| Factor No. | Factor name     | –1  | 0   | +1  |
|------------|-----------------|-----|-----|-----|
| 1          | Wavelength [nm] | 510 | 570 | 630 |
| 2          | Exposure [s]    | 20  | 30  | 40  |
Table 8. Values of the target function (response)

| No. | x   | y   | M*  | M*root |
|-----|-----|-----|-----|--------|
| 1   | -1  | -1  | 4.48| 0.74   |
| 2   | -1  | 0   | 4.71| 0.8    |
| 3   | -1  | +1  | 4.89| 0.87   |
| 4   | 0   | -1  | 6.46| 0.91   |
| 5   | 0   | 0   | 7.63| 1.37   |
| 6   | 0   | +1  | 7.77| 1.4    |
| 7   | +1  | -1  | 6.01| 1.2    |
| 8   | +1  | 0   | 6.59| 1.4    |
| 9   | +1  | +1  | 6.77| 1.65   |

First, let us choose an experiment design for 2 factors at 3 levels. When planning an experiment at three levels, we get a second order plan. To select an experimental design, we will generate known designs for 2 factors at 3 levels. The plan PFE 3^2, for n = 2, contains 9 experiments. Regression equation coefficients are determined independently of each other. Factors at all levels of variation are controllable.

The table of the experimental design with the initial data will look like Table 9.

Table 9. Table of the experimental design

|      | x   | y   | M*  | M*root |
|------|-----|-----|-----|--------|
| 0    | 510 | 20  | 4.48| 0.74   |
| 1    | 510 | 30  | 4.71| 0.8    |
| 2    | 510 | 40  | 4.89| 0.87   |
| 3    | 570 | 20  | 6.46| 0.91   |
| 4    | 570 | 30  | 7.63| 1.37   |
| 5    | 570 | 40  | 7.77| 1.4    |
| 6    | 630 | 20  | 6.01| 1.2    |
| 7    | 630 | 30  | 6.59| 1.4    |
| 8    | 630 | 40  | 6.77| 1.65   |

To find the optimal value of the response functions and indicate at what values of the factors the desired values are achieved, response surfaces in a three-dimensional plane and their two-dimensional projections were constructed using regression equations (Figures 5 and 6)

Figure 5. Dependence of stem dry weight on wavelength and exposure
The regression equation showing the dependence of the sprout length $M_{st}$ on wavelength $x$ and exposure $y$, obtained from the experimental results, can be written as:

$$M_{st} = -156.369 + 0.552 \cdot x + 0.106 \cdot s - 0 \cdot x^2 - 0.002 \cdot y^2,$$  \hspace{1cm} (1)

where $M_{st}$ is the mass of dry residue, g; $x$ is the wavelength, nm; $y$ - exposure, s.

The quality of the obtained regression model is determined by the coefficient of determination, which in this case is equal to $R^2 = 0.884$, which indicates that 88.4% of changes in dry weight of the stem are due to the values of the factor.

Figure 6. Dependence of root dry mass on wavelength and exposure

The regression equation showing the dependence of the length of the shoots $M_{root}$ on the wavelength $x$ and exposure $y$, obtained from the results of the experiments, can be written as:

$$M_{root} = -2.299 + 0.005 \cdot x + 0.017 \cdot y,$$ \hspace{1cm} (2)

where $M_{root}$ is the mass of dry residue, g; $x$ is the wavelength, nm; $y$ is exposure, s.

The quality of the obtained regression model is determined by the coefficient of determination, which equals $R^2 = 0.661$, which indicates that 66.1% of the response values are explainable by the factor values.

After analyzing the results of experimental studies, we can state that:

1. the analysis of the current state of the process of growing plants, in particular cucumbers, showed the possibility of increasing their productivity, depending on the use of optical radiation, on average by 7-10%;
2. the analytical description of the set of parameters of influencing factors (wavelength and exposure) made it possible to obtain a functioning model— which includes response surfaces—the calculated output for which is 92%;
3. the experimental verification showed an increase in the growth of the mass of the vegetative part by 21.83%, and in the mass of the root system by 54.96%. The dry matter of the vegetative part increased by 46.5%, and the dry matter of the root system increased by 58%;
4. in the course of the experiments, regression equations for the dependence of the average dry weight of cucumber seedlings on the radiation wavelength and exposure were revealed.
5. according to the results of the studies, the rational range of optical radiation is the wavelength from 565 to 615 nm.

### 4. Conclusion

The analysis of the response surfaces allows concluding that the smallest dry residue of the root is observed at an irradiation dose of 1.5 J, a wavelength of 500 nm, and an exposure of 18 to 20 seconds. The greatest dry residue of the stem is observed at an irradiation dose of 1.5 J, a wavelength of over 600 nm and an exposure of more than 33 seconds. At these values, the highest germination capacity was obtained, as well as the length of shoots and roots.
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Conflict of Interest

The authors have no conflict of interest to declare.

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