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Optimization Of The Duration And Power Parameters Of Ultraviolet Radiation Treatment Of Sunflower Seeds

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Annotation: This study investigated the optimal parameters of ultraviolet (UV) radiation treatment on sunflower (Helianthus annuus L.) seeds. Experiments were conducted on two varieties, Dilbar and Jahongir, to evaluate the effects of radiation intensity (30–90 W), distance (5–15 cm), and exposure time (10–20 minutes) on seed germination as well as seedling root and shoot length using a multi-factor experimental design. Second-order regression equations were developed, and corresponding 3D graphs were constructed. The results identified the optimal conditions for maximum efficiency: total lamp power of 60 W, distance of 10 cm, and exposure time of 15 minutes. The statistical adequacy of the models was confirmed using the Cochran, Student's t, and Fisher criteria.
Keywords: sunflower, ultraviolet radiation, seed germination, seedling growth, multi-factor experiment, regression model, optimization, irradiation parameters

Introduction. Sunflower (Helianthus annuus L.) is one of the widely cultivated plants worldwide due to its high nutritional value and economic importance. Its seeds are used as oilseeds, vitamin-rich feed, and in the food industry. Currently, research focuses on improving seed germination and promoting early seedling growth through various biological and physical methods.

Ultraviolet (UV) radiation treatment is an effective approach to enhance seed physiological activity, improve germination, and stimulate initial seedling growth. UV radiation activates metabolic processes within seed cells, promotes growth hormones, and increases resistance to stress and diseases. At the same time, determining the optimal combination of irradiation parameters (intensity, distance, exposure time) is crucial for maximizing efficiency.

The use of multi-factor experimental designs and regression models allows for a scientific assessment of the effects of UV radiation, identification of optimal conditions, and validation of results through statistical criteria. The aim of this study is to determine the optimal parameters of UV treatment for the Dilbar and Jahongir sunflower varieties and to evaluate their effects on seed germination as well as root and shoot length of seedlings.

Single-factor and multifactor experimental studies were conducted to determine the effective parameters of ultraviolet (UV) radiation treatment of sunflower seeds. During the treatment process, the effects of factors such as radiation power, distance, and exposure duration on seed germination, as well as seedling shoot and root lengths, were investigated.

Material and methods. The optimal values of the parameters studied in single-factor experimental investigations on ultraviolet radiation treatment of sunflower seeds were determined using the method of mathematical design of multifactor experiments [1, pp. 242–243].

The main function of the irradiator is to deliver a specified amount of radiation energy to the receiver [2, pp. 71–82]:

$$Q = \iint_{st} E(\alpha t) dS dt ,$$

Here, S, α, and t represent the irradiation area, direction, and exposure time, respectively.

In conducting the research, the following factors were selected as those affecting the performance characteristics of the ultraviolet irradiation equipment:

– UV irradiation lamp power, W;
– UV irradiation distance, cm;

– UV exposure time, s.

To determine the optimal values of the main dimensions and operating modes of the ultraviolet irradiation equipment for sunflower seeds, a B3 design was used to conduct multifactor experiments in the experimental studies [3, p. 36; 4, p. 58; 5, p. 16; 6, p. 79]. Seed germination, seedling shoot length, and root length of sunflower varieties were adopted as the evaluation criteria for determining the optimal parameters.

Based on the results of preliminary experiments and theoretical studies, the ranges and intervals of variation of the most significant factors were determined.

Table 1 presents the factors, their coded designations, ranges of variation, and levels.

Table 1

Main factors, their levels, and ranges of variation

№	Factors and their units of measurement	Designation	Coded designation		Range of variation	Limits of factor variation		
			Actual	Coded		-1	0	+1
1	**Power of lamps emitting UV radiation, W**	P	X_1	X_1	30	30	60	90
2	**UV irradiation distance, cm**	N_{ubn}	X_2	X_2	5	5	10	15
3	**UV exposure time, s**	t_{ubn}	X_3	X_3	5	10	15	20

They were determined based on the results of the conducted single-factor experiments. The influencing factors were designated as follows:

– X1 – UV lamp power, W;
– X2 – UV irradiation distance, cm;
– X3 – UV exposure time, s.

To simplify the calculations, the factors were coded using the following expression:

$$x_i = \frac{X_i - X_{0i}}{\Delta X_i} \quad , \qquad (1)$$

Where - Xi is the actual value of the factor;
-X0i is the actual value of the factor at the zero level;
- Xi is the coded value of the factor;
- ΔXi is the actual range of variation of the factor.

The effects of the main equipment factors on the technological process of ultraviolet irradiation of sunflower seeds were determined as follows:

$$Y = f(P, H_{убн}, t_{убн}), \qquad (2)$$

Here, Y represents the evaluation criterion, namely the seed germination, seedling shoot length, and root length of sunflower varieties; P, Nubn, and tubn are the input variable factors.

The relationship between the influencing factors and the resulting outcomes was determined in the form of the following regression equation [1, pp. 242–243].

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}{x_1}^2 + b_{11}{x_2}^2 + b_{11}{x_3}^2 \ , \qquad (3)$$

Here, Y is the evaluation criterion; b0, bi, bij, and bii are the values of the regression coefficients; xi are the variable factors.

Cochran's criterion was used to check the repeatability of the experiments, i.e., the homogeneity of variances. Student's t-test was applied to determine the significance of the regression model coefficients. The adequacy of the constructed models was verified using Fisher's criterion, with a significance level of 0.05.

The experiments were conducted on the Dilbar and Jahongir sunflower varieties using UV lamps with wavelengths of $\lambda = 253.7$ nm and $\lambda = 300$ nm.

In the multifactor experiments, the evaluation criteria were as follows: seed germination of the Dilbar sunflower variety (Y1), seed germination of the Jahongir sunflower variety (Y2), seedling root length (Y3), and shoot length (Y4) (Table 2).

Table 2

Evaluation criteria

№	Symbol	Experiment Description
1	Y_1	Seed germination of Dilbar sunflower variety
2	Y_2	Seed germination of Jahongir sunflower variety
3	Y_3	Seedling root length
4	Y_4	Seedling shoot length

To minimize the influence of uncontrolled factors on the evaluation criteria, the sequence of experiments was determined using a table of random numbers.

It was assumed that the influence of the factors on the evaluation criteria is fully described by a second-order polynomial, and the experiments were conducted according to the B3 design [1, pp. 242–243].

The data obtained from the experiments were processed using the program 'Construction of second-order regression models and 3D graphs based on multifactor experimental results' [6, pp. 250–252].

Analysis of research results. The experimental results were processed in the indicated sequence, and the following regression equations, adequately describing the evaluation criteria, were obtained:

For the seed germination of the Dilbar sunflower variety:

$$Y_1 = 100{,}798 - 0{,}507X_1 + 0{,}313X_2 - 1{,}83X_3 - 1{,}948X_1^2 - 0{,}596X_1X_3 + 1{,}9813X_2^2 - 5{,}898X_3^3, \quad (4)$$

For the seed germination of the Jahongir sunflower variety:

$$Y_2 = 100{,}852 + 0{,}36X_1 - 2{,}02X_3 - 4{,}369X_1^2 - 1{,}719X_2^2 - 5{,}402X_3^3, \quad (5)$$

For the seedling root length of the Dilbar sunflower variety:

$$Y_3 = 13{,}727 - 0{,}15X_2 - 0{,}983X_3 - 1{,}36X_1^2 + 0{,}146X_1X_3 - 1{,}16X_2^2 + 0{,}113X_2X_3 - 1{,}76X_3^2, \quad (6)$$

For the seedling shoot length of the Dilbar sunflower variety:

$$Y_4 = 9{,}535 + 0{,}14X_1 - 0{,}093X_2 - 0{,}917X_3 - 0{,}985X_1^2 + 0X_1X_2 + 0{,}079X_1X_3 - 0{,}719X_2^2 + 0{,}792X_2X_3 - 1{,}869X_3^2, \quad (7)$$

For the seedling root length of the Jahongir sunflower variety:

$$Y_3 = 13{,}246 + 0{,}2X_1 + 0X_2 - 0{,}79X_3 - 1{,}113X_1^2 + 0X_1X_2 + 0{,}183X_1X_3 - 0{,}863X_2^2 + 0X_2X_3 - 2{,}096X_3^2, \quad (8)$$

For the seedling shoot length of the Jahongir sunflower variety:

$$Y_4 = 8{,}273 + 0{,}137X_1 + 0X_2 - 0{,}467X_3 - 0{,}74X_1^2 + 0X_1X_2 + 0{,}121X_1X_3 - 0{,}573X_2^2 + 0X_2X_3 - 0{,}89X_3^2, \quad (9)$$

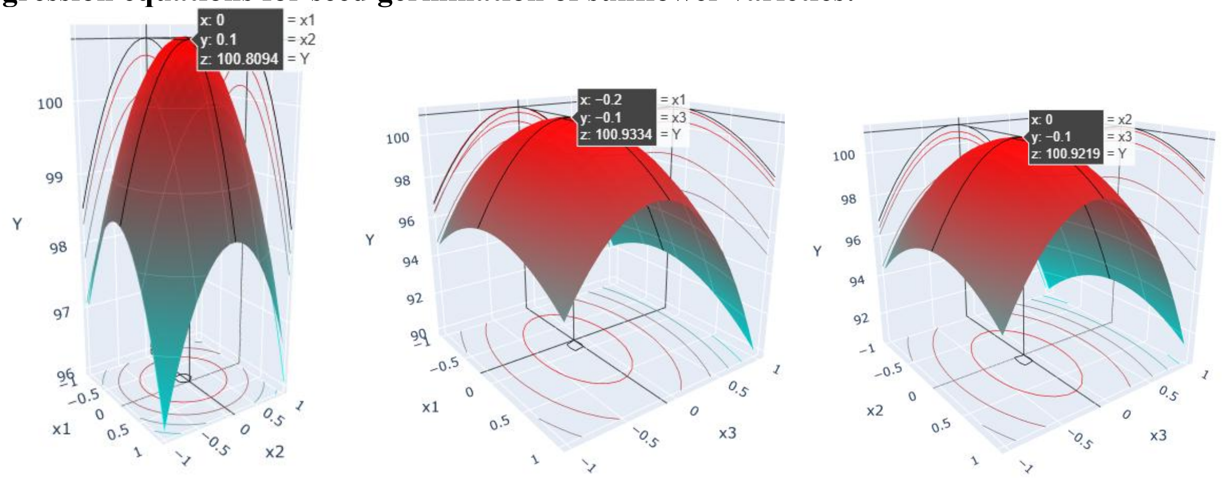
Analysis of regression equations (4)–(9) showed that the factors had a significant effect on the evaluation criteria, namely seed germination, seedling shoot length, and root length of sunflower varieties.

To determine the values of the parameters corresponding to the maximum number of leaves, the regression equations (4)–(9) were solved using the 'Solver' function in Microsoft Excel on a modern computer. The equations were solved under the condition of maximizing the output, which allowed the identification of factor values that satisfy this condition.

A three-dimensional visual analysis was conducted to study the influence of the factors in the obtained regression equations on the output parameters. Analysis of the graphs representing the response surfaces indicated that all factors significantly affected the evaluation criteria. The graphs demonstrated that, under UV treatment with lamps of different powers, at varying distances, and for different exposure durations, the outcomes for seed germination, seedling shoot length, and root length changed accordingly.

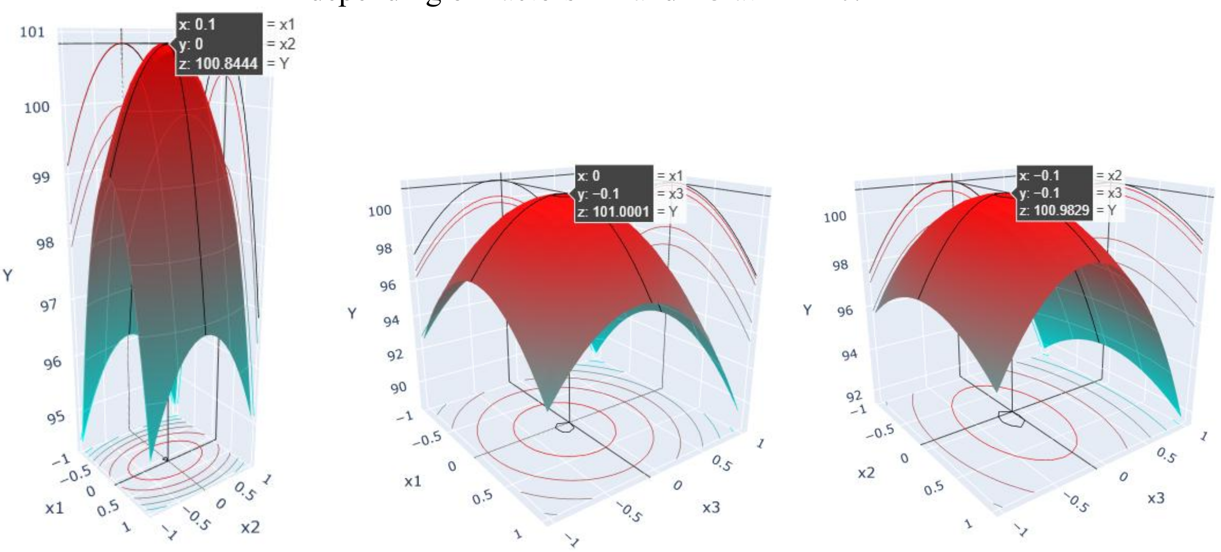
The results for seed germination, seedling shoot length, and root length of sunflower varieties, based on the constructed response surface graphs, are illustrated in Figures 1–6 and are summarized as follows:

1. Constructed graphs representing the response surface of the output parameters according to the regression equations for seed germination of sunflower varieties:



a) b) c)

Figure 1. Seed germination of the Dilbar sunflower variety: (a) variation depending on factors X1 and X2 at X3 = 0; (b) variation depending on factors X1 and X3 at X2 = 0; (c) variation depending on factors X2 and X3 at X1 = 0.



a) b) c)

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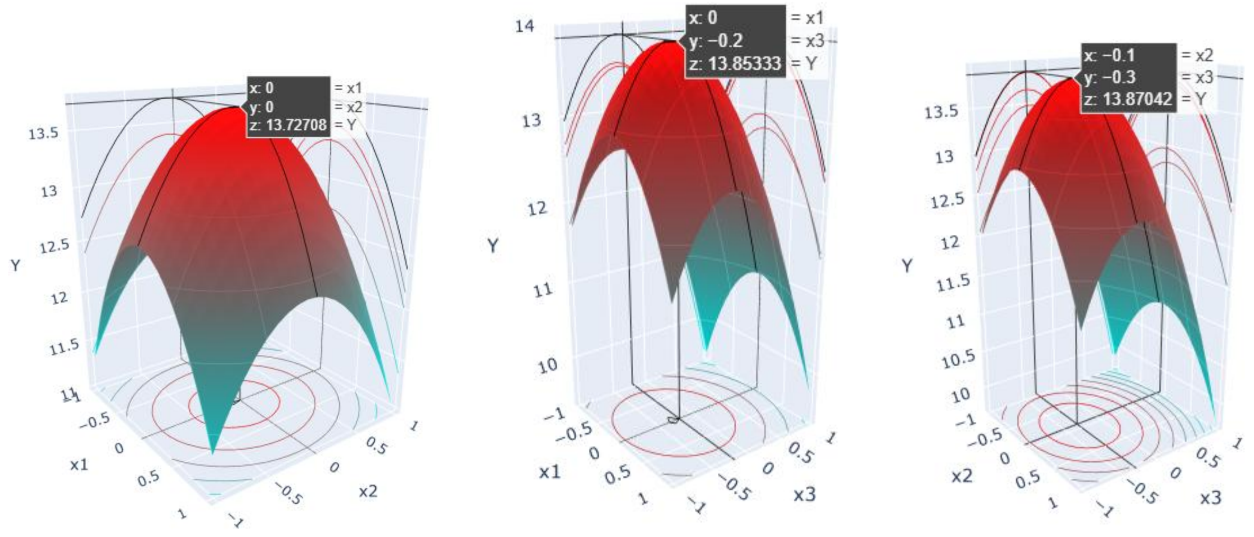
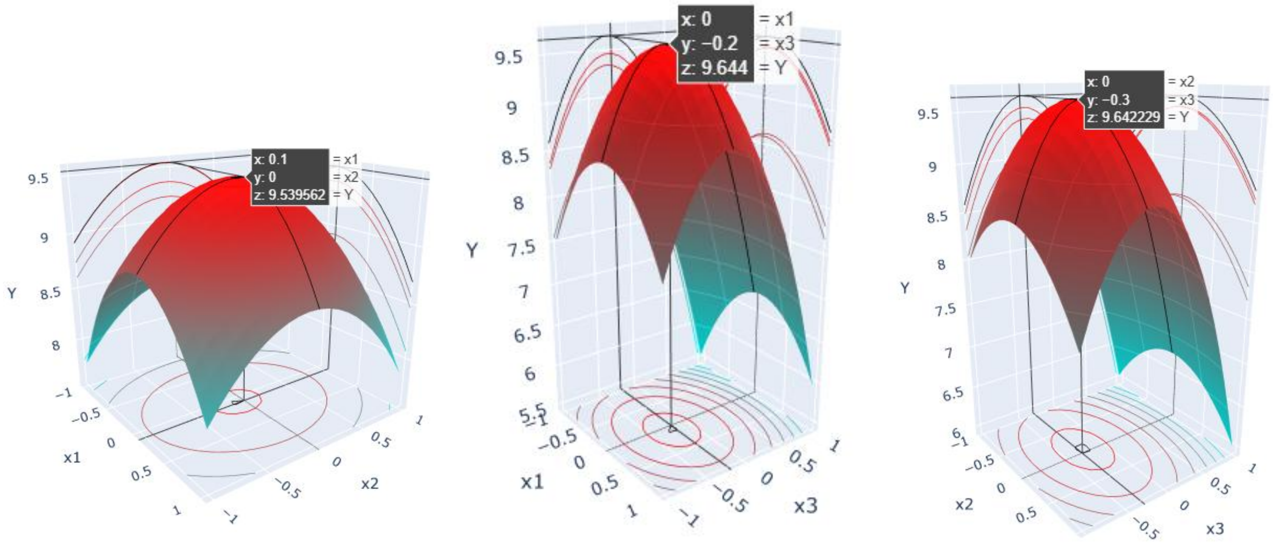
Figure 2. Seed germination of the Jahongir sunflower variety: (a) variation depending on factors X1 and X2 at X3 = 0; (b) variation depending on factors X1 and X3 at X2 = 0; (c) variation depending on factors X2 and X3 at X1 = 0.

2. Constructed graphs representing the response surface of the output parameters according to the regression equations for seedling root and shoot length of the Dilbar sunflower variety:



a) b) c)

Figure 3. Seedling root length of the Dilbar sunflower variety: (a) variation depending on factors X1 and X2 at X3 = 0; (b) variation depending on factors X1 and X3 at X2 = 0; (c) variation depending on factors X2 and X3 at X1 = 0.



a) b) c)

Figure 4. Seedling shoot length of the Dilbar sunflower variety: (a) variation depending on factors X1 and X2 at X3 = 0; (b) variation depending on factors X1 and X3 at X2 = 0; (c) variation depending on factors X2 and X3 at X1 = 0.

3. Constructed graphs representing the response surface of the output parameters according to the regression equations for seedling root and shoot length of the Jahongir sunflower variety:

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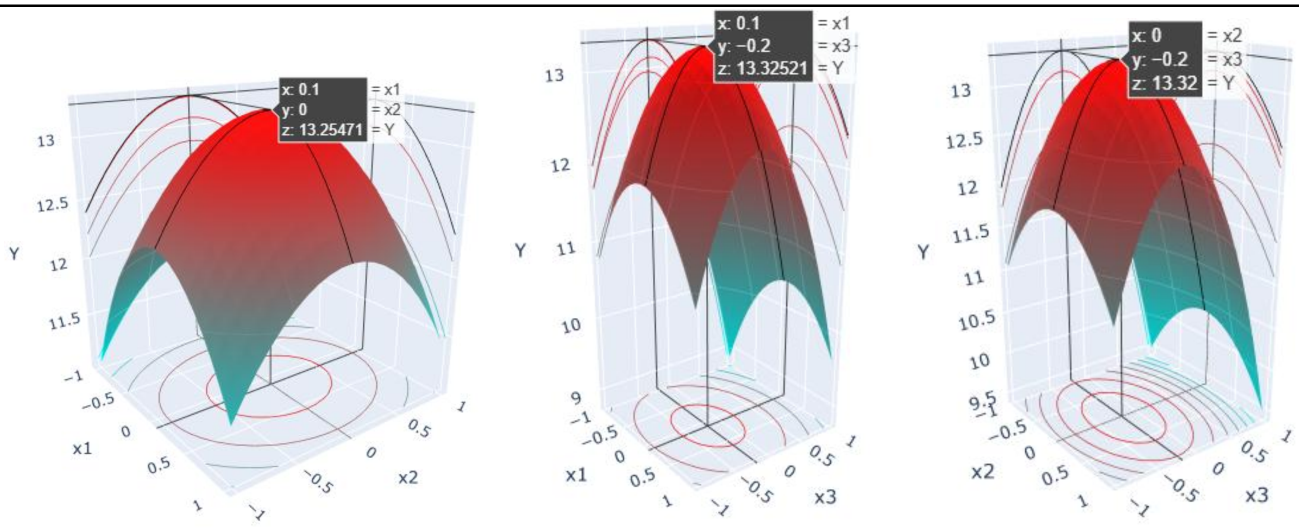
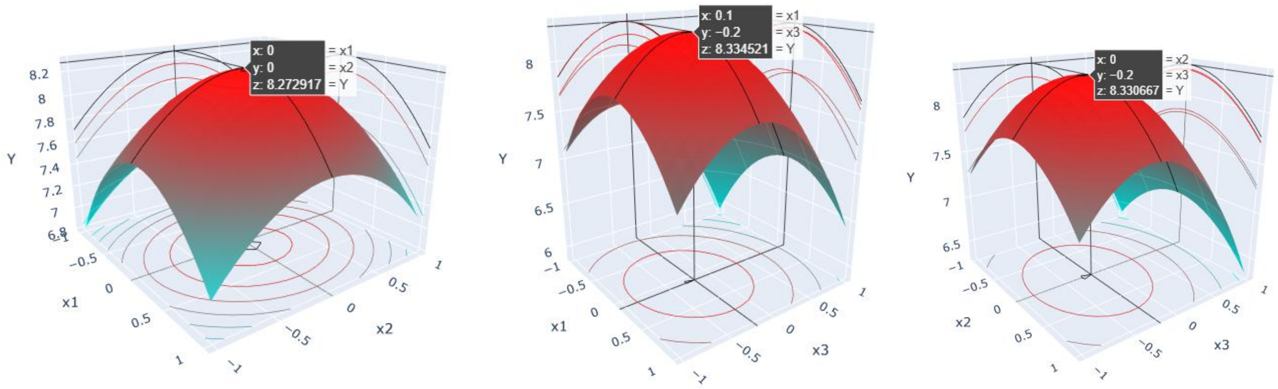


a) b) c)

Figure 5. Seedling root length of the Jahongir sunflower variety: (a) variation depending on factors X1 and X2 at X3 = 0; (b) variation depending on factors X1 and X3 at X2 = 0; (c) variation depending on factors X2 and X3 at X1 = 0.



a) b) c)

Figure 6. Seedling shoot length of the Jahongir sunflower variety: (a) variation depending on factors X1 and X2 at X3 = 0; (b) variation depending on factors X1 and X3 at X2 = 0; (c) variation depending on factors X2 and X3 at X1 = 0.

The values calculated in the above models were compared with the tabulated values of Cochran, Student's t, and Fisher's criteria, and it was determined that the obtained mathematical models fully satisfy the requirements of the criteria, and the equations are adequate.

Analysis of the regression equations (4)–(9) and the constructed graphical relationships (Figures 1–6) showed that the factors have a uniform effect on the evaluation criteria.

Table 3

Optimal values of the factors						
T/r	***X_1***		***X_2***		***X_3***	
	Coded	**Actual**	**Coded**	**Actual**	**Coded**	**Actual**
1	-1	30	-1	5	-1	10
2	1	90	-1	5	-1	10
3	-1	30	1	15	-1	10
4	1	90	1	15	-1	10
5	-1	30	-1	5	1	20

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6	1	90	-1	5	1	20
7	-1	30	1	15	1	20
8	1	90	1	15	1	20
9	-1	30	0	10	0	15
10	1	90	0	10	0	15
11	0	60	-1	5	0	15
12	0	60	1	15	0	15
13	0	60	0	10	-1	10
14	0	60	0	10	1	20

Conclusion

1. The theoretical foundations and practical results of electro-technological treatment of sunflower seeds using UV radiation (UVR) were presented. During the study, the mechanisms of the effects of these physical factors on the biological object, i.e., sunflower seeds, as well as the relationships between exposure duration, energy intensity, and stages of the treatment process, were investigated.
2. Based on single-factor and multifactor experiments, regression equations adequately describing the growth of sunflower seedlings, namely seedling shoot length and root length, were obtained after electro-technological treatment of the seeds.
3. In laboratory conditions, single-factor and multifactor field experiments determined the following optimal parameters for electro-technological treatment of sunflower seeds: UV radiation [(P253.7 + P300) = 60 W; τ = 15 min; h = 10 cm].

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