Features of technological processing of seeds with an electromagnetic field of microwave before sowing

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Abstract. To increase the efficiency of crop production in the arsenal of the agronomic service there is a number of techniques, methods and technologies that reveal the potential of agricultural plants for all stages of production, starting with soil preparation, selection and preparation of seeds for sowing, agrotechnological measures during the growing season, harvesting technologies, storage and processing of products. The article presents the results of experimental studies on the use of the energy of ultra-high frequency electromagnetic fields for pre-sowing treatment of lupine seeds in order to increase their germination. Revealed the relationship between the parameters of microwave exposure and seed germination. The areas of modes where microwave treatment allows to increase germination, as well as areas of modes in which the impact does not reach the planned effect, or has a negative (depressing) effect, have been determined. Recommendations are given for ensuring the optimal modes of microwave processing and ensuring control of the parameters of the technological process. Based on the results obtained, it can be reliably asserted that the region of microwave treatment of lupine seeds, with a result exceeding the control values, is observed at exposure in the range from 50 to 60 s and at a specific microwave power of exposure from 1.0 to 1.17 kW/kg. The best result of an increase in germination by 1.5% was obtained at 60 s and 1.17 kW/kg. When treating seeds, it is recommended to maintain an average microwave heating rate of 0.50 °C/s until an average microwave heating temperature of 51.5 °C is reached.

1. Introduction
The efficiency of crop production is formed at all stages of production, including soil preparation, selection and preparation of seeds for sowing, agro-technological measures during the growing season, harvesting technologies, storage and processing of products. All the accumulated experience and an arsenal of agrotechnical techniques are aimed at unlocking the potential of agricultural plants and reducing production costs and reducing product losses. The use of promising technological methods, methods and technical means in each specific case allows you to get the maximum effect. A very important stage of production is the preparation of seeds for sowing. It is carried out for the purpose of disinfection, pre-sowing stimulation, removal of seeds from dormancy, etc. When preparing seeds for sowing, chemical treatment and physical methods of exposure are used. One of the technological methods of preparing seeds for sowing can be the use of the energy of electric, magnetic and electromagnetic fields [1-10].

Treatment of seeds with the energy of an electromagnetic field of ultrahigh frequency, in comparison with other electrophysical methods, has its own specifics. The microwave effect is manifested at the...
cellular level and is accompanied by heating of the seeds. Therefore, it is necessary to impose strict requirements on the treatment regimes in terms of exposure power and exposure. As shown by numerous studies, during microwave treatment, not only a stimulating effect can be observed, but also a negative (depressing) effect. In addition, it is necessary to develop a simple and reliable way to ensure and control the modes of microwave seed treatment. These circumstances require the establishment of a reliable relationship between the exposure parameters and the treatment effect. The significance and influence of each of the influencing factors can be unambiguously estimated only on the basis of statistical processing of the experimental results with obtaining regression equations (models) and subsequent analysis of the results.

2. Results

Below are the results of experimental research on pre-sowing microwave treatment of lupine seeds. In the experiment, lupine seeds with a moisture content of 10.25% were studied. Seeds were treated with continuous radiation at a frequency of 2450 ± 50 MHz. During the experiments, the specific microwave power of exposure and the treatment time (exposure) were recorded, and the initial and final temperatures of microwave heating of seeds were measured. After microwave treatment, seed germination was assessed. Sample processing was carried out in accordance with Kono's plan for a 2-factor experiment. The coded values and the interval of variation of the influencing factors are shown in Table 1. Studies in 4-fold repetition at each of the 4 points of the experimental design.

| Table 1. Coded and natural values of influencing factors. |
|---------------------------------|-----------------|----------------|
| Factor name | Factor coded values | Variation interval, Δ |
| Specific power, kW/kg, X1 | -1 0.83 | +1 1.17 |
| Exposition, c, X2 | 40 | 50 60 | 10 |

The main results of the experiment and indicators of energy and germination of lupine seeds are shown in Table 2.

| Table 2. Results of processing lupine seeds. |
|---------------------------------|-----------------|----------------|
| N | Specific power P, kW/kg | Exposure τ, s | Seed germination, % |
| | Average | Difference with control |
| 1 | 0.83 | 40 | 87.0 | +0.5 |
| 2 | 1.17 | 40 | 85.5 | -1.0 |
| 3 | 0.83 | 60 | 86.5 | 0.0 |
| 4 | 1.17 | 60 | 88.0 | +1.5 |
| 5 | 0.83 | 50 | 84.5 | -2.0 |
| 6 | 1.17 | 50 | 87.5 | +1.0 |
| 7 | 1.00 | 40 | 86.0 | -0.5 |
| 8 | 1.00 | 60 | 87.5 | +1.0 |
| 9 | 1.00 | 50 | 86.0 | +0.5 |
| 10 | The control | | 86.5 | |

The reproducibility of the experiments was assessed using the Cochran test at the significance level α=0.05 and the number of degrees of freedom f2 = 12. The calculated value of the Cochran test G_calc did not exceed the permissible values G0.05 (3.9) (0.08≤0.40).

The regression equation describing the effect of specific microwave power (kW/kg) and exposure (s) on seed germination in coded variables has the form:

\[ Y = B_0 + B_1X_1 + B_2X_2 + B_{12}X_1X_2 + B_{22}X_2^2, \]
where $X_1$ - specific microwave power, p.u. (-1≤$X_1$≤1), $X_2$ - exposure, p.u (-1≤$X_2$≤1); $B_0=86.00$; $B_1=0.50$; $B_2=0.58$; $B_{12}=0.50$; $B_{22}=0.75$.

The significance of the coefficients was checked by the Student's test ($t_{cr}$) at the significance level $\alpha = 0.05$ and the number of degrees of freedom $f_2 = 27$. All coefficients in equation (1) are significant; therefore the factors are sufficiently correlated with each other. The adequacy of the model was assessed by Fisher's criterion at a significance level of $\alpha = 0.05$. The calculated value of the Fisher criterion $F_{calc}$ did not exceed the permissible values $F_{0.05}(5, 27) (1.69 \leq 2.69)$.

As mentioned earlier, during the experiment, the initial and final temperatures of microwave heating of seeds were measured. The main results of the experiment and indicators of germination of lupine seeds are shown in Table 3.

### Table 3. Results of treatment of lupine seeds.

| N  | Final seed temperature, °C, $t_k$ | Heating rate, °C, $|\Theta|$ | Seed germination, % | average difference from control |
|----|---------------------------------|-----------------------------|---------------------|-------------------------------|
| 1  | 44                              | 0.59                        | 87.0                | +0.5                          |
| 2  | 34                              | 0.34                        | 85.5                | -1.0                          |
| 3  | 54                              | 0.56                        | 86.5                | 0.0                           |
| 4  | 49                              | 0.48                        | 88.0                | +1.5                          |
| 5  | 42                              | 0.43                        | 84.5                | -2.0                          |
| 6  | 45                              | 0.49                        | 87.5                | +1.0                          |
| 7  | 39                              | 0.46                        | 86.0                | -0.5                          |
| 8  | 52                              | 0.53                        | 87.5                | +1.0                          |
| 9  | 45                              | 0.49                        | 86.0                | +0.5                          |
| 10 | The control                     |                             | 86.5                |                               |

The reproducibility of the experiments was assessed using the Cochran test at the significance level $\alpha =0.05$ and the number of degrees of freedom $f_2 = 12$. The calculated value of the Cochran test $G_{calc}$ did not exceed the permissible values $G_{0.05}(3.4) (0.18 \leq 0.68)$.

The experimental data were approximated by an incomplete second-order regression equation that takes into account the effect of the final temperature and microwave heating rate on the germination capacity of seeds in the range of final temperatures from 43 to 51.5 °C at microwave heating rates from 0.46 to 0.51 °C/s.

The regression equation for the effect of the final temperature and microwave heating rate on the germination of lupine seeds in coded variables is:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{12}X_1X_2,$$

where $Y$ - ability of seeds to germinate, %; $X_1$ - factor of the final temperature of microwave heating, p.u. (-1≤$X_1$≤1); $X_2$ - factor of the microwave heating rate, p.u (-1≤$X_2$≤1); $B_0=86.50$; $B_1=1.00$; $B_2=0.50$; $B_{12}=-0.75$.

The significance of the coefficients was checked by the Student's test ($t_{cr}$) at the significance level $\alpha =0.05$ and the number of degrees of freedom $f_2 = 12$. All the coefficients in equation (1) are significant; therefore, the factors are sufficiently correlated with each other. The adequacy of the model was assessed by Fisher's criterion at a significance level of $\alpha =0.05$. The calculated value of the Fisher criterion $F_{calc}$ did not exceed the permissible values $F_{0.05}(1, 12) (0.20 \leq 4.75)$.

### 3. Process analysis

Figure 1 shows the calculated surface of the change in the germination of lupine seeds relative to the control, depending on the natural values of the exposure time (s) and the specific microwave power (kW/kg). The germination rate of the control seeds was 86.5%.
Figure 1. Changes in lupine seed germination compared to control after microwave treatment.

Analysis of the surface of changes in seed germination shows that the exposure time is most pronounced at high values of the specific microwave power. The area of microwave treatment of lupine seeds during stimulation should be limited to an exposure of 50 to 60 s at a specific microwave power of exposure from 1.0 to 1.17 kW / kg.

Figure 2 shows the calculated surface of the germination ability for lupine seeds, depending on the natural values of the microwave heating rate (°C / s) and the final temperature (°C). The germination rate of the control seeds was 86.5%.

Analysis of the surface of changes in seed germination shows that the microwave heating rate is most pronounced at temperatures close to 50 °C. According to the results obtained, to control the processing modes, it is most advisable to use the accompanying microwave treatment, heating the seeds and limit the microwave heating rate - from 0.50 to 0.56 °C/s, and maintain the final microwave heating temperature in the range from 47.0 to 51.5 °C.

4. Conclusion

The results of experimental studies on the use of the energy of ultra-high frequency electromagnetic fields for pre-sowing treatment of lupine seeds in order to increase their germination are presented.

It was found that an increase in seed germination compared with control is observed at exposure of 50 - 60 s and at a specific microwave power of exposure from 1.0 to 1.17 kW / kg. The best result of an increase in germination by 1.5% was obtained at 60 s and 1.17 kW / kg. When treating seeds, it is recommended to maintain an average microwave heating rate of 0.50 °C / s until an average microwave heating temperature of 51.5 °C is reached.
Figure 2. Changes in lupine seed germination in comparison with control after microwave treatment.

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