Determination of rational values of electrophysical processing parameters affecting on the flax seeds germination

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Abstract: - The article presents studies to determine the rational parameters of the electrophysical treatment of flax seeds affecting on germination. Analysis of response surfaces and two-dimensional sections allows us to establish that in a local area bounded by ranges of factors, the stationary point is close to the largest value. These combinations of factor values are rational, since at these values, in the vicinity of the stationary point, the germination of flax seeds reaches the highest values. Thus, we can recommend the following parameters for treating flax seeds taking into account a confidence interval of at least 95%: with the treating time of flax seeds with the microwave field X1 = 13.987 ± 2 sec; ultrasonic processing time X2 = 19,358 ± 5 min; seed moisture X3 = 17.743 ± 1.2%; germination Y = 87.94 ... 92.35% was obtained..

Key-Words: - flax, pre-sowing treatment, flax seed, treatment methods, electrophysical treatment.

1 Introduction

Flax is a traditional technical culture in Udmurt Republic. Favorable climatic conditions of this region allow cultivation and obtaining high yields of fiber and high quality seeds.

One of the main conditions of the optimal structure formation and obtaining high yield is properly prepared seed for sowing (5, 6). In order to achieve high yield of seed material there are many methods of pre-sowing treatment today. Preseeding treatment methods can be divided into three groups. The first group includes chemical methods. They use chemical substances [9]. The second group includes biological methods based on the use of microorganisms – phytopathogens [1]. The third group of methods is physical, based on the use of thermal, electric, magnetic, electromagnetic fields and other fields and radiations. Start with the last method of presowing seed treatment. Plant materials are complex heterogeneous environments, which, from the point of view of their electrophysical properties, belong to dielectrics with large losses. The most sensitive and subjected of external factors is the seed coat, which contains light-sensitive elements, micropores and water. The action of electrophysical methods of preseeding treatment of seeds is aimed at increasing the activity of the corcle by accumulating energy in the form of free radicals in a multi-level membrane structure of the shell with increased permeability.

Under the action of ultrasonic cavitation, the permeability of the shell is increased mechanically. As a result of the action of ultrasonic vibrations on the environment of a moderately wetted material takes place uniform distribution and binding of moisture by the pectin shell substances and increasing the moisture content of the grain [8].

Electromagnetic oscillations of the microwave range causes more complex molecular processes, such as polarization and the occurrence of conduction currents and displacement. A feature of electromagnetic heating is the simultaneous release of heat in the whole volume [4].

So in the material there are temperature fields that contribute to internal mass transfer, the intensity of heating is determined not only by the thermal resistance of the material, but also by the intensity of the electrical component of the electromagnetic field, as well as the electrical and thermal characteristics of the material [6].

To carry out the process of electrophysical treatment more effectively it is necessary to consider a full-factor analysis of the parameters of ultrasonic and microwave processing that affect seed germination.

The purpose and objectives of the study

The aim of the study is conducting a regression analysis of the process of electrophysical processing and the definition of rational values of the parameters of ultrasonic and microwave processing, which affect on the germination of seeds.

2 Problem Formulation

Regression analysis is carried out according to the results of a full-factor experiment with three factors on three levels of significance.

The following parameters were chosen as input parameters affecting seed germination: X1 - time of flax seed treatment in the microwave field, sec; X2 - ultrasonic treatment time of flax seeds, min; X3 - flax seed moisture, %.

It was decided to conduct the experiment according to the three-level Box-Benkin plan [2; 3; 10]. Box-Benkin plans compared to orthogonal plans are more economical in terms of the number of experiments and possess their properties [2; 3; 10]. The experiment was carried out according to a plan of the second order (i.e., on three levels) in order to obtain an approximated expression that describes the behavior of the function with sufficient accuracy in interested area of change of factors. To describe the area of factor space (regression analysis), a polynomial of the form was used.

$$\begin{aligned} Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + \\ + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + \\ + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2, \end{aligned} \quad (1)$$

where Y is the output parameter, i.e. seed germination,%; - the overall effect of the whole experiment; - effects of factors; - effects of paired interactions; - effects with square terms.

After conducting a series of single-factor experiments, the permissible limits for changing factors were established: the processing time of the microwave field X1 is no more than 30 sec (due to overheating of the material over 40 [Character] C), ultrasonic processing time X2 is no more than 50 min; the moisture content of flax seeds X3 varied within 10 ... 22% [7].

Intervals and levels of variation of the factors are presented in table 1.

Table 1 - Intervals and Variation Levels

Factors	Levels			Variability intervals
	Lower level (-1)	Ground level (0)	Upper level (+1)	
X_1 – processing time of flax seeds in the microwave field, sec	0	15	30	15
X_2 – ultrasonic flax seed treatment time, min	0	25	50	25
X_3 – moisture content of flax seeds, %	10	16	22	6

The planning matrix and the results of the experiments are presented in table.2.

Table 2 - Experiment Planning Matrix

№ Exp.	Processing time of flax seeds in the microwave field, X_1, sec	Ultrasonic flax seed treatment time, min	Moisture content of flax seeds, %	Flax seed germination Y,%
1.	15	0	22	79
2.	30	25	10	85
3.	15	50	22	91
4.	15	25	16	98
5.	15	25	16	76
6.	0	25	22	40
7.	0	50	16	70
8.	0	0	16	78
9.	15	0	10	81
10.	15	25	16	90
11.	0	25	10	73
12.	30	0	16	41
13.	15	50	10	40
14.	30	50	16	70
15.	30	25	22	78

The regression coefficients are calculated using the STATGRAPHIC Plus program. As a result of calculating the coefficients, a mathematical model has been obtained, which relates the influence of these three factors on the germination of flax seeds. The equation of the mathematical model is as follows:

$$\begin{aligned} Y &= 83{,}9306 + 0{,}136111X_1 - 1{,}04333X_2 + \\ &+ 1{,}78472X_3 - 0{,}06X_1^2 + 0{,}0246667X_1X_2 + \\ &+ 0{,}0722222X_1X_3 - 0{,}0156X_2^2 + \\ &+ 0{,}0883333X_2X_3 - 0{,}152778X_3^2. \end{aligned} \quad (2)$$

The significance of the regression coefficients was checked by student's criterion. All model coefficients are significant. The equation of model (2) shows that, in the given ranges of variation of factors, the greatest effect on seed germination causes the pair interaction of ultrasonic treatment and humidity, and also an increase in the processing time of flax seeds in the microwave field adversely affects the germination rate. A negative sign before the coefficient indicates a decrease in the optimization parameter with an increase in the factor being studied, and a positive sign indicates an increase.

3 Problem Solution

Using the STATGRAPHIC Plus program, we obtained graphs of the functional dependence of the germination of flax seeds on processing factors (Figure 1) and graphic images of the response surface, depicting the relationship between the optimization criterion and two independent variables $Y = f(X_1, X_2)$, $Y = f(X_2, X_3)$, $Y = f(X_1, X_3)$.

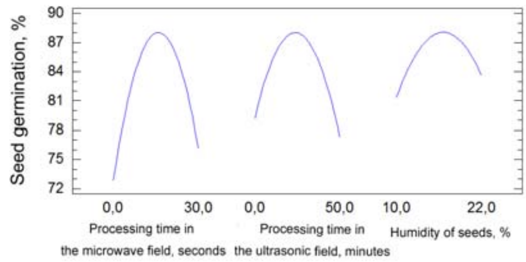

Figure 1– Graph of functional dependence of flax seed germination on factors

The lines shown in the graph show the dependence of the germination of flax seeds on one of the factors with fixed values of the other two factors at the ground level (the average value is within the limits of the factor change). Since all the lines are parabolas whose branches are directed downwards, we can confidently assert that the seed germination function has an optimum in the form of a maximum. His search is a separate task of analyzing the function of several variables.

A visual representation of the appearance of the graph of the function described by expression (2) is impossible in three-dimensional space; therefore, it is replaced by partial variations showing the pairing effect of two controlling factors on the objective function - seed germination, Figures 2-4.

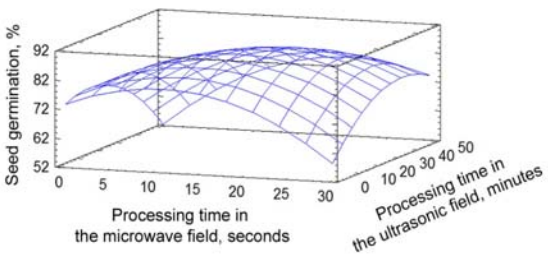

Figure 2 – Graphic display of the response surfaces of the seed germination Y from the processing time in the microwave field X1 and the processing time in the ultrasonic field X2

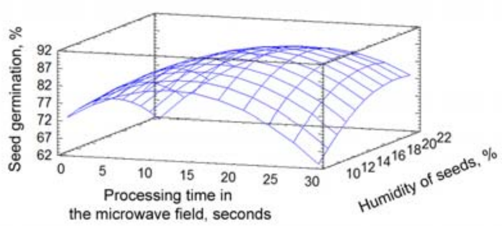

Figure 3 - Graphic display of the response surfaces of the seed germination Y from the processing time in the microwave field X1 and the moisture content of seeds X3

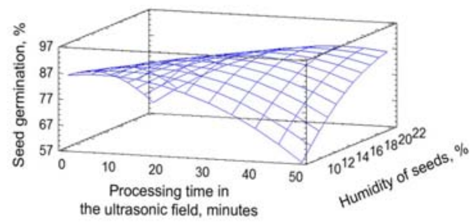

Figure 4 - Graphic display of the response surfaces of the seed germination Y and processing time in the field of ultrasonic X2 and humidity of seeds X3

The response surfaces also indicate the presence of a global maximum of the function in the studied area of change of controlled factors.

Analysis of the surface of the responses, rearranged in Figures 2 ... 4, is more convenient to give with the help of two-dimensional sections presented in Figures 5 ... 7. They show the isolines of the germination of flax seeds depending on combinations of factors.

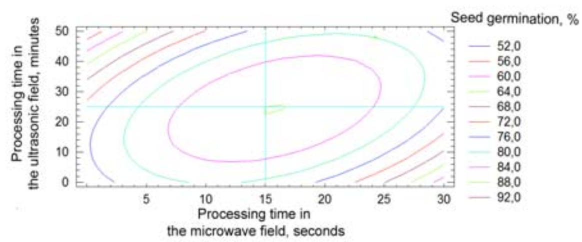

Figure 5 -Graphic display of two-dimensional cross-sections of seed germination Y from the processing time in the microwave field X1 and processing time in the ultrasonic field X2

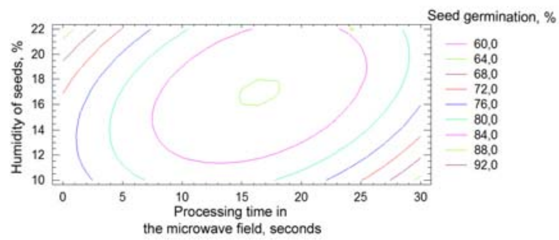

Figure 6 - Graphic display of two-dimensional cross-sections of seed germination Y from the processing time in the microwave field X1 and seed moisture X3

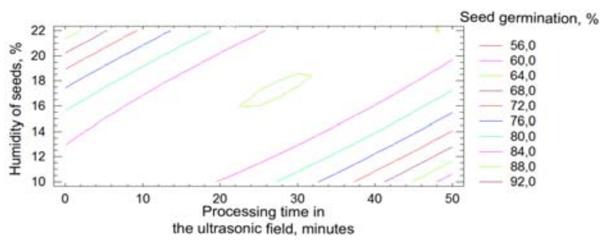

Figure 7 - Graphic display of two-dimensional cross-sections of seed germination Y and processing time in the ultrasonic field X2 and seed moisture X3

Consideration of all possible two-dimensional sections gives a visual representation of the values of the optimization criterion, which it will take when varying levels of a couple of factors.

From the analysis of the data obtained (Figures 2-7) follows that for all factors there is a global extremum of the function inside the study area. The choice of the boundaries of changes in the control factors in the course of single-factor experiments allowed us determination the presence of extremum near the center of the considered region with a high degree of accuracy. Such a choice of boundaries makes it possible to more reliably search for the point of maximum and the value of the maximum of the function.

To determine the numerical values of the factors that ensure the highest germination of flax seeds, an extremum (maximum) function was searched for. For this, partial derivatives of the regression analysis function Y = f (X1; X2; X3) (expression 2) were found and equated to zero for the search for stationary points.

$$\frac{\partial Y}{\partial X_1} = 0,136111 - 0,12 \cdot X_1 + 0,0246667 \cdot X_2 + 0,0722222 \cdot X_3 = 0;$$

$$\frac{\partial Y}{\partial X_2} = -1,0433 + 0,0246667 \cdot X_1 - 0,0312 \cdot X_2 + 0,0883333 \cdot X_3 = 0;$$

$$\frac{\partial Y}{\partial X_3} = 1,78472 + 0,0722222 \cdot X_1 + 0,0883333 \cdot X_2 - 0,305556 \cdot X_3 = 0.$$

After the transformations, we obtain a system of three linear equations, which we solve using the Cramer method in Excel. The stationary point has coordinates X1 = 13.987 sec; X2 = 19,358 min; X3 = 17,743%.

We find all partial derivatives of the second order to prove the presence of a maximum of a function at a stationary point:

$$\frac{\partial^2 Y}{\partial X_1^2} = -0,12; \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_2} = \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_1} = 0,0246667;$$

$$\frac{\partial^2 Y}{\partial X_2^2} = -0,0312; \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_3} = \frac{\partial^2 Y}{\partial X_3 \cdot \partial X_2} = 0,0883333;$$

$$\frac{\partial^2 Y}{\partial X_3^2} = -0,305556; \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_3} = \frac{\partial^2 Y}{\partial X_3 \cdot \partial X_1} = 0,0722222.$$

We make the Hesse matrix

$$H = \begin{pmatrix} \frac{\partial^2 Y}{\partial X_1^2} & \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_2} & \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_3} \\ \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_1} & \frac{\partial^2 Y}{\partial X_2^2} & \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_3} \\ \frac{\partial^2 Y}{\partial X_3 \cdot \partial X_1} & \frac{\partial^2 Y}{\partial X_3 \cdot \partial X_2} & \frac{\partial^2 Y}{\partial X_3^2} \end{pmatrix} =$$

$$\begin{pmatrix} -0,12 & 0,0246667 & 0,0722222 \\ 0,0246667 & -0,0312 & 0,0883333 \\ 0,0722222 & 0,0883333 & -0,305556 \end{pmatrix}.$$

We find the angular minors or determinants "expanding" from the upper left corner:

$$\Delta_1 = \frac{\partial^2 Y}{\partial X_1^2} = -0,12;$$

$$\Delta_2 = \begin{vmatrix} \frac{\partial^2 Y}{\partial X_1^2} & \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_2} \\ \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_1} & \frac{\partial^2 Y}{\partial X_2^2} \end{vmatrix} = \begin{vmatrix} -0,12 & 0,0246667 \\ 0,0246667 & -0,312 \end{vmatrix} = 0,003136;$$

$$\Delta_3 = \begin{vmatrix} \frac{\partial^2 Y}{\partial X_1^2} & \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_2} & \frac{\partial^2 Y}{\partial X_1 \cdot \partial X_3} \\ \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_1} & \frac{\partial^2 Y}{\partial X_2^2} & \frac{\partial^2 Y}{\partial X_2 \cdot \partial X_3} \\ \frac{\partial^2 Y}{\partial X_3 \cdot \partial X_1} & \frac{\partial^2 Y}{\partial X_3 \cdot \partial X_2} & \frac{\partial^2 Y}{\partial X_3^2} \end{vmatrix} =$$

$$= \begin{vmatrix} -0,12 & 0,0246667 & 0,0722222 \\ 0,0246667 & -0,0312 & 0,0883333 \\ 0,0722222 & 0,0883333 & -0,305556 \end{vmatrix} = 0,000456.$$

4 Conclusion

Since $\Delta_1 < 0$, $\Delta_2 > 0$ and $\Delta_3 > 0$, a "saddle" is observed at the stationary point, since the condition for the existence of the maximum or minimum of the function is not met. Analysis of response surfaces and two-dimensional sections allows us to indicate that in a local area bounded by ranges of factors, the stationary point is close to the largest value. These combinations of factor values are rational, since with them, in the vicinity of the stationary point, the germination of flax seeds reaches the highest values. Thus, we can recommend the following parameters for treating flax seeds taking into account the confidence interval: with the treating time of flax seeds by the microwave field X1 = 13.987 ± 2 sec; processing time ultrasonic X2 = 19,358 ± 5 min; seed moisture X3 = 17,743 ± 1.2%; germination Y = 87.94 ... 92.35% was obtained.

Equation (2) itself makes it possible to predict, with a probability of at least 95%, the value of the yield of flax seeds after treatment with a microwave field, an ultrasonic scan and achieved humidity in various modes.

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