RESEARCH OF RATIONAL MODES OF DRYING RAPE SEED
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ДОСЛІДЖЕННЯ РАЦІОНАЛЬНИХ РЕЖИМІВ СУШІННЯ НАСІННЯ РІПАКУ

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ABSTRACT
Determination of rational drying modes of seed grain is related to the kinetics of the drying process and qualitative indicators. Changing the drying conditions affects the drying process duration and also affects the seed germination. The mathematical processing of experimental data on the drying of rape seeds is based on experimental studies and the compilation of an experiment matrix based on three factors: the temperature and velocity of the heat carrier, the initial moisture content of the material. Selected variation levels or the boundary conditions of these factors are based on qualitative indicators, initial seed conditions before drying. Studies carried out on increasing the temperature of the coolant from 50° to 80°C increase the drying rate by 2.4 times, but reducing the germination of the material indicates the advisability of drying at 50°C. The obtained regression equations of duration and germination characterize the processes, proceeding from the effect of three factors with the exception from the equation of non-significant coefficients of the regression according to Stewdent's criterion. It also examines the adequacy of the mathematical model that corresponds to the real object. The change in the acid number substantially increases at the coolant temperature of 80°C, but it is normal.

РЕЗЮМЕ
Визначення раціональних режимів сушіння насіннєвого зерна пов'язаний з кінетикою процесу сушіння та якісних показників. Зміна режимів сушіння впливає на тривалість процесу сушіння, а також впливає на схожість. Математична обробка експериментальних даних сушіння насіння ріпаку основана на проведені експериментальних досліджень та складанні матриці експерименту від дії трьох факторів: температури та швидкості руху теплоносія, початкової вологості матеріалу. Вибрані рівні варіювання або граничні умови зазначених факторів основані на якісних показників, початкових умов насіння перед сушіння. Проведені дослідження із підвищення температури теплоносія від 50 до 80°C підвищують інтенсивність сушіння в 2,4 рази, але зниження схожості матеріалу вказує на доцільність сушіння при 50°C. Отримані регресійні рівняння тривалості та схожості характеризують процеси, що відбуваються від дії трьох факторів із виключення з рівняння не значимих коефіцієнтів регресії за критерієм Стьюдента. А також йдеться перевірка адекватності математичної моделі, що відповідає реальному об’єкту. Зміна кислотного числа істотно збільшується при температурі теплоносія 80ºC, але знаходиться в нормі.

INTRODUCTION
Drying is the main technological process for bringing the seeds to a stable equilibrium state. The technology of drying seeds involves the knowledge of the biological properties of the grain mass, as the object of drying, the heat resistance of the grain, the laws of evaporation of moisture, the determination of drying modes and equipment for the implementation of the process.

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Application of high temperatures at the beginning of the drying wet grain process, leads to a rapid dehydration of its surface, which makes the shells less penetrating to moisture (the phenomenon of thermal "quenching" of the grain). Under these conditions, water vapour forms in the surface layer, the output of which becomes complicated.

MATERIALS AND METHODS

Drying seeds of different crops is associated with certain limitations. As it is known, high temperatures have a negative effect on the seed's quality, reducing its germination energy and germination itself, as well as degrading the quality of the material for technological purposes. (*Stankevich G. M., Strahova T.V.*, *1997; Matkivska I.Ja., Atamanyuk V.M., Symak D., 2014; Podpryatov G.I., Nasikovsky V.A., 2005; Snyezhkin YU.F., Shapar R.O., Chalayev D.M., 2010; Gaponyuk O.I., Ostapchuk M.V, Stankevich G.M., 2014; Kovalenko O.A., Kosovska N.V., 2012)*

So, it is recommended to dry the seeds at relatively soft temperature modes. In soft mode, drying does not have a complete guarantee of preserving the seed properties, so at long-lasting low temperature drying (depending on the environmental parameters) the formation of the mould on the surface is possible and, as a result, the spoil of the seed material.

The main parameters that determine the choice of drying mode and the achievement of high-quality indicators of dried seed are the temperature of the coolant, the drying rate and the initial moisture content of the seeds.

Recommended modes of rape seeds drying show that, depending on the initial moisture content of the material, the maximum allowable temperature of the coolant is 55° – 65°C. However, these recommendations do not provide complete information on the effect of drying modes on qualitative characteristics of the seeds. *(Stankevich G. M., Strahova T.V., 1997; Beregova O. M., Stankevich G.M., 2001; Snezhkin Yu.F., Paziuk V.M., Shapar R.A., Mikhailik T.A., Petrova J.A., 2008; Snezhkin Yu.F., Pazyuk V.M., 2009; Snezhkin Yu.F., Paziuk V.M., Petrova Zh.O., 2011).*

RESULTS

That's why, to determine the characteristics of drying rape seeds, we carry out drying with the coolant temperature of 50° - 80°C on an experimental convective drying stand in the elementary layer. The drying intensity of rape seeds rises 2.4 times from a certain temperature increase (Fig. 1) (*Paziuk, V.M., Liubin, M.V., Yaropud, V.M., Tokarchuk, O.A., Tokarchuk, D.M.*, 2018; *Snezhkin YU.F., Paziuk V.M., Petrova Zh.O., Chalaev D.M.*, 2012; *Snezhkin Yu.F., Petrova Zh.O., Paziuk V.M.*, 2016; *Snezhkin Yu.F., Paziuk V.M., Petrova Zh.O., Samoilenko K.M.*, 2019).

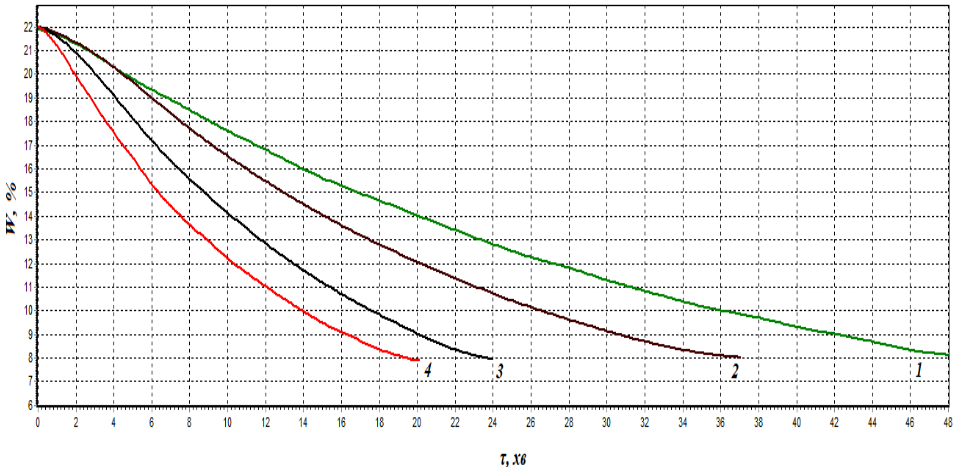


Fig. 1 - The influence of the coolant temperature on the drying process kinetics of "Black Giant" variety rape seeds V = 1.5 m/s, d = 10 g/kg:
1 - 50°C, 2 - 60°C, 3 - 70°C, 4 - 80°C

The curves of the drying rate of the "Black Giant" variety rape seeds showed that warming up and removal of moisture from the material occur simultaneously (Fig. 2).

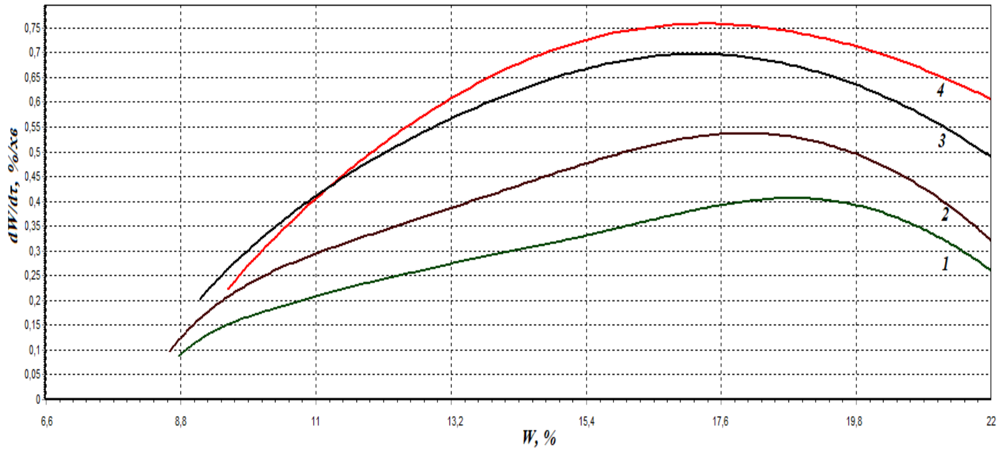


Fig. 2 - Curves of the speed of drying rape seeds
of the "Black Giant" variety V = 1.5 m/s, d = 10 g/kg s, Wn = 22%:
1 - 50°C, 2 - 60°C, 3 - 70°C, 4 - 80°C

The drying rate increases with the increasing of the coolant temperature from 50 to 80°C, so the drying rate is almost 1.9 times higher in the drying regime of 80°C, compared with the drying regime of 50°C.

Visually, the effect of the coolant temperature on the germination, at the initial moisture content of the rape seeds of 22%, can be estimated from the presented photos (Fig. 3), so active germination is carried out at a temperature of 50°C, but at 80°C it almost does not happen (*State Standard* 4138 – 2002, 2003).

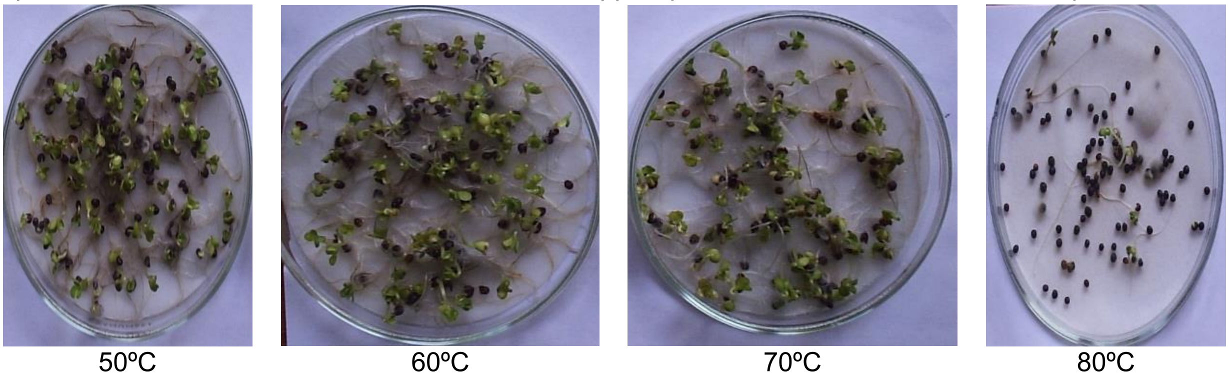


Fig. 3 - The influence of coolant temperature on the rape seeds of "Black Giant" variety at an initial moisture content of 22%

Research on the rape seeds' initial humidity influence on the time of drying at a temperature of 50°C, at different values of the initial humidity, is presented in Fig. 4.

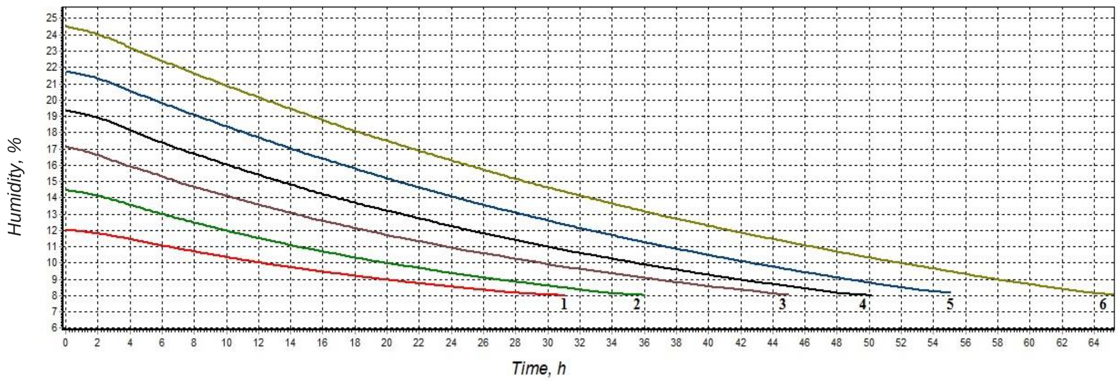


Fig. 4 - Curves of drying rape seeds. Influence of initial humidity
at a temperature of the drying agent of 50°C at a speed of 0.5 m/s:
1 - 12%; 2 - 14.5%; 3 - 17%; 4 - 19.5%; 5 - 22%; 6 - 24.5%

When drying rape seeds in the elementary layer on the convective drying stand, the following drying stages are characteristic: heating of the material to the maximum drying rate and then comes a period of falling drying rate to the equilibrium moisture content of the material to 8%.

The curves of drying rape seeds have a look, typical for colloidal capillary-porous materials.

The graphs of the process of drying rape seeds influenced by the speed of the drying agent are shown in Fig. 5.

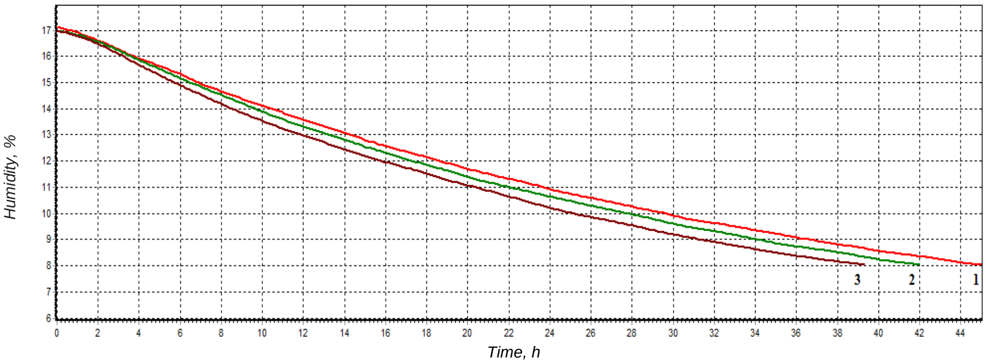


Fig. 5 - Curves of drying rape seeds. Influence of drying agent's speed at a temperature of 50°C:
1 - 0.5 m/s; 2 - 1.0 m/s; 3 - 1.5 m/s

According to the research, the following results were obtained. When the speed changes from 0.5 to 1.5 m/s, the intensity of the process decreases by 15%, when the initial humidity changes from 24 to 12% in 2.25 times, and with an increase in temperature from 50 to 80ºC - in 2.4 times.

Conducted research of the drying regime influence on the quality parameters of the "Black Giant" variety rape seeds at different temperatures and initial moisture content of the grain are shown in table 1.

Table 1

Influence of temperature and initial humidity on the quality of rape seeds of the "Black Giant" variety at a coolant speed of 1.5 m/s

№	Process parameters			Quality parameters		
	Coolant temperature *t*, ºC	Initial moisture content of rape W_n, %	Duration of drying, *τ*, m	Germination energy, *E*, %		Germination to 7th day, *G*,%
				3-th day	5-th day	Absolute / Ref.
1.	Outgoing rape			84	85	94/100
2.	50	12	24	82	83	91/97
3.	50	17	39	80	84	91/97
4.	50	22	48	80	81	91/97
5.	60	12	18	76	79	83/89
6.	60	17	27	78	80	82/87
7.	60	22	37	74	78	81/86
8.	70	12	12	62	64	75/80
9.	70	17	20	61	63	73/78
10.	70	22	24	60	62	70/75
11.	80	12	7	50	55	68/72
12.	80	17	16	18	25	27/29
13.	80	22	20	2	4	4/4

The best germination of rape seeds is observed at a coolant temperature of 50ºC, the germination is at 97% and the influence of initial humidity does not occur. The increase of temperature to 60°C reduces the qualitative parameters of the seed material to 89% and at the same time, the effect of the initial moisture content of the seeds on the germination is noticeable; it is reduced by 3%. At 70°C, the germination is 80%, at 80°C the germination decreases at 72% and there is a sharp decrease in the quality of the seeds when drying the material with high humidity. So, with the initial moisture content of 22% and a coolant temperature of 80ºC, the seed germination is at a level of 4%.

The influence of coolant temperature on the acid number in the range of 50-70°C is not significant and is 3 - 5% (Fig. 6). At a coolant temperature of 80ºC, a sharp increase in the acid number is observed, compared with the other drying conditions by 71 - 75% (at the top of the table - the normative value of the acid number for rape seeds 4 mg/g of oil (GOST 30418-96) (*State Standard* 30418-96, 1996).

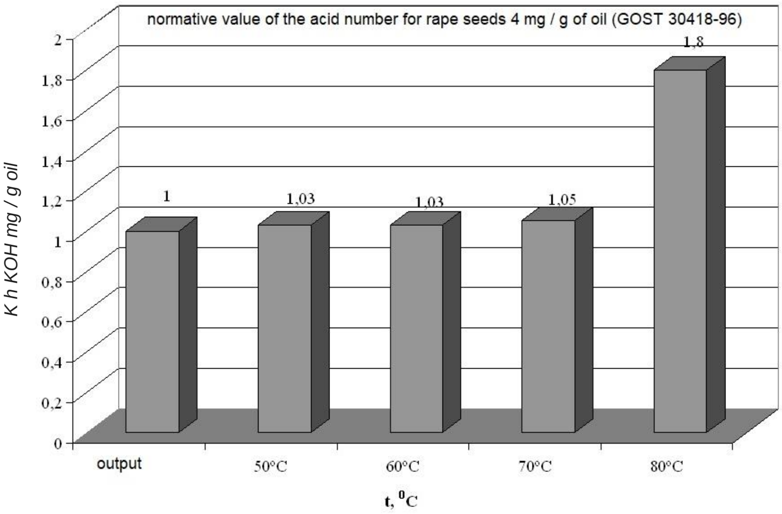


Fig. 6 - Effect of coolant temperature on acid number of rape seeds

All these drying modes meet the regulatory requirements for the acid number, which provides the quality of rape seeds. For a mathematical description of the process of drying rape seeds in the elementary layer, a three-factor experiment on the second order orthogonal compositional plan was carried out. In orthogonal central planning, the criterion for optimality of the experiment plan is the orthogonality of the planning matrix columns.

Due to the orthogonality of the planning, all the coefficients of the regression equation are determined independently of each other. The core of the composite plan is the plan of full factor experiment PFE (*Yantsevich A.A, Aleksandrov Yu.A.*, *2004)*.

The values of the factors and variation levels are selected based on the experimental studies (Table 2).

Table 2

Factors and levels of variation affecting the process of drying rape seeds

Indexes	Factors		
	Heat carrier		Material
	Temperature, *t*, °C	Speed, *V*, *м/с*	Initial humidity, *W*, %
Upper (+1)	80	1,5	22
Average (0)	65	1,05	17
Lower (-1)	50	0,6	12
Variable interval	15	0,45	5
Code notation	x_1	x_2	x_3

According to the plan, the research was done using the three levels for each factor - upper (+1), zero (0) and lower (-1), the code values of which were determined by the formula:

$$x_1 = \frac{t - t_0}{\varepsilon_1} = \frac{t - 65}{15}; \qquad x_2 = \frac{V - V_0}{\varepsilon_2} = \frac{V - 1,05}{0,45}; \qquad x_3 = \frac{W - W_0}{\varepsilon_3} = \frac{W - 17}{5},$$

where:

t_0, V_0, W_0 - the factors of the main level, respectively, the temperature and velocity of the coolant, the initial humidity and height of the rape layer; ε_1, ε_2, ε_3 - interval of variation of factors.

The mathematical models of the process were constructed in the form of regression equations:

$$\overset{\frown}{y} = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_{11} x_1^2 + a_{22} x_2^2 + \\ + a_{33} x_3^2 + a_{12} x_1 x_2 + a_{13} x_1 x_3 + a_{23} x_2 x_3 \qquad (1)$$

The coefficients of regression can be determined by the following formulas:

$$a_0 = \frac{1}{N}\sum_{k=1}^{N} y_k - q\sum_{i=1}^{N} a_{ii}; \qquad a_i = b_1 \sum_{k=1}^{N} x_{ik} y_k; \qquad a_{ij} = b_2 \sum_{k=1}^{N} x_{ik} x_{jk} y_k; \qquad a_{ii} = b_3 \sum_{k=1}^{N} (x_{ik}^{\prime 2} - q) y_k, \qquad (2)$$

where: *q* – the value that provides the orthogonality of composite plans:

$$q = \frac{1}{N}(2^n + 2R^2) = \frac{1}{15}(2^3 + 2\cdot 1,215^2) = 0,73$$

b_0, b_1, b_2, b_3 – elements of the dispersion matrix of the plan:

$$b_0 = 0,0667;\ b_1 = 0,0913;\ b_2 = 0,125;\ b_3 = 0,2298$$

The results of a three-factor experiment on an orthogonal compositional plan of the second order allowed obtaining the equation of quadratic regression in the code variables for the duration of the drying process in the elementary layer:

$$\overset{\frown}{y} = 31,11 - 11,212x_1 - 2,087x_2 + 8,61x_3 - 0,328x_1^2 - 0,669x_2^2 - 2,709x_3^2 + 0,5x_1x_2 - 3x_1x_3$$

for the germination of rape seeds is the quadratic regression equation:

$$\overset{\frown}{y} = 78 - 27x_1 - 0,86x_2 - 16,14x_3 - 11,73x_1^2 - 0,17x_2^2 - 2,21x_3^2 - 0,125x_1x_2 - 15,625x_1x_3 + 0,125x_2x_3$$

According to the results of the performed calculations, the statistical data were obtained and the reproducibility of the regression equation experiment was checked, significant regression coefficients and adequacy of the model of the real object were determined (Table 3).

Table 3

Obtained indicators of statistical data

Indicators of static data	Duration of drying	Germination	Conclusion
Coherent Criterion	G_{max} = 0.087 < < $G_{кр}$ = 0.3346	G_{max} = 0.111 < < $G_{кр}$= 0.3346	Reproducibility of the experiment
Stewdent's Criterion Non-significant coefficients of regression	$t_{кр}$ = 2.04 a_{11} = -0.328, a_{23} = 0	$t_{кр}$ = 2.04 a_{12} = 0.125, a_{22} = 0.17, a_{23} = 0.125	The significant coefficients in the regression equation are determined
Fisher's Criterion	F_p = 0.87 < $F_{кр}$ = 2.35	F_p = 0.13 < $F_{кр}$ = 2.27	The model is adequate to the real object

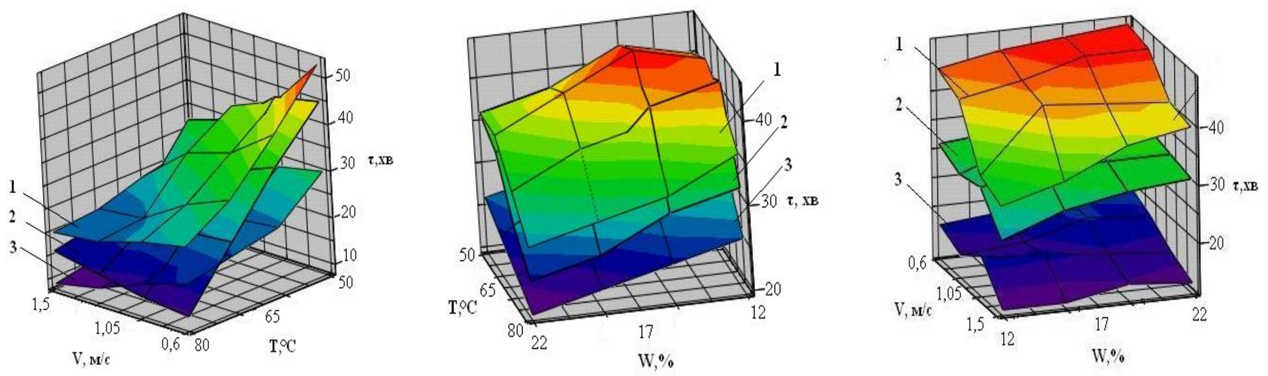
Let's turn to the quadratic regression equation from coded factors x_i to the corresponding physical quantities. The equation of quadratic regression for the duration of rape seeds drying:

$$\tau = 51,096 - 0,148\cdot t - 9,45\cdot V + 4,32\cdot W - 3,3\cdot V^2 - 0,108\cdot W^2 - 0,074\cdot t\cdot V - 0,04\cdot t\cdot W \quad (3)$$

Equation of quadratic regression for germination of rape seeds:

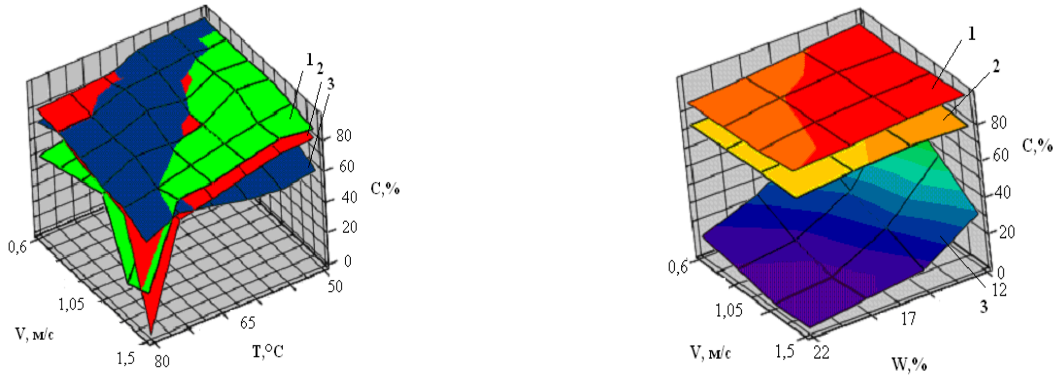
$$C = 267,4 + 1,6\cdot t - 1,91\cdot V + +10,32\cdot W - 0,052\cdot t^2 - 0,088\cdot W^2 - 0,21\cdot t\cdot W \quad (4)$$

On the obtained regression equation of the rape seeds' drying and germination duration, in the elementary layer, the surfaces of response for the action of three factors are found and built in the graphical program Mathcad (Fig. 7, 8).



a) b) c)

Fig. 7 – Surfaces of response of the duration of rape seeds drying in the elementary layer depending on the following factors:
a) temperature: 1 - 50°C; 2 - 65°C; 3 - 80°C; b) speed: 1 - 0.6 m/s; 2 - 1.05 m/s; 3 - 1.5 m/s; c) initial humidity: 1 - 12%; 2 to 17%; 3 - 22%



a) b)

Fig. 8 – The surface of the response of rape seeds' germination, obtained by the equations of quadratic regression from the effects of the following factors:
a) temperature: 1 - 50°C; 2 - 65°C; 3 - 80°C;
b) initial humidity: 1 - 12%; 2 - 17%; 3 - 22%

For the resulted surfaces of response, described in the orthogonal composition plan of the second order, it is possible to find intermediate values of the drying time, depending on the factors mentioned.

The obtained empirical mathematical models can be used as a basis for determining the duration and germination of the process of drying rape seeds influenced by the drying parameters: temperature and coolant velocity, the initial moisture content of rape seeds.

CONCLUSIONS

Experimental studies on kinetics of seed rape drying on a convective drying stand gave the opportunity to work out the rational modes of drying on the elementary layer in order to obtain the best quality of seed material.

The mathematical description of the drying process according to the second order orthogonal compositional plan and the obtained quadratic regression equations confirm the correctness of the selected technological drying modes.

The obtained regression equations of durability and germination of rape seeds drying give a detailed description of the influence of both individual and joint effects of factors; the significance of these parameters is determined by the corresponding coefficients according to Stewdent's criterion.

Also, the adequacy of the mathematical model according to Fisher's criterion, which corresponds to the real object, is tested.

The construction of the response surfaces of the duration and germination of the rape seed drying indicates the nature of the effect of these factors in the given range of variation.

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