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OPTIMIZATION OF THE TECHNOLOGICAL PROCESS OF FLAX SEED GERMINATION

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Abstract. In the world, demand for flax seeds and its processed volumes are increasing. Flax seeds are classified as natural functional food products. This is confirmed by the Ministry of Health of many countries, in particular Canada and the United States of America. Flax germination makes flax seed components biologically available. Each type of plant has its own set of germination requirements consisting of both internal and external factors. This research was aimed at studying the effect of various external factors (temperature, humidity.etc.) affecting flax seed germination energy. The temperature varied in the range 16°C to 30°C, in increments of 2°C, as further increasing the temperature requires additional equipment and, consequently, additional energy consumption. The ambient humidity was maintained at 40, 60, 70, and 95%. The flax seeds were germinated for 36 hours till seedlings, up to 3 mm long, appeared. The germination energy was determined for each combination of the controlled factors. A mathematical model of the flaxseed germination process was constructed using the regression and correlation analysis methods. The model obtained determines the optimum germination modes. In the course of the experimental research, we applied experimental design techniques and mathematical processing of the experimental data. Using the computer programmes MathCad and Microsoft Excel optimized the flax seed germination and set its optimum modes. The constructed mathematical model makes it clear that the maximum germination energy 99.64% is achieved at the temperature 27.5°C and humidity 95%. The experimental and statistical models of germination of flax seeds have been obtained, describing the process with the correlation coefficient R = 0.96–0.99. The data obtained can be used to predict the quality parameters of flax seedlings and the energy consumption to obtain them.

Key words: flax, seedlings, determination, experimental and mathematical modelling, regression analysis.

Introduction. Formulation of the problem

Today's topical task is providing people with quality food of high nutritional value. Due to the modern environmental conditions and the rhythm of life, the diet should contain a sufficient amount of naturally occurring biologically active substances (vitamins, macro and microelements, essential amino acids, polyunsaturated fatty acids, dietary fibres) that can increase the resistance of the human organism. An important area of developing new functional health food products is the creation of combined products [1].

The use of flax seeds in combined foods is promising because these seeds contain a wide range of biologically active substances (vitamins, minerals, unsaturated fatty acids, lignans, etc.), and germination allows using all their anatomical parts [2,3].

Analysis of recent research and publications

Linseed, or common flax (Linum usitatissimum L.) [2,4,5], belonging to the family *Lineaceae*, has regained its popularity as a natural functional food product due to its biochemical composition and biological value. Flax seeds are recognized as a potential source of functional ingredients due to their bioactive components; ω-3 fatty acids, lignans, dietary fibre, and complete protein. The seeds have a clear, chewy texture and a pleasant, nutty taste [1,6,7]. Flax is the best and the only source of ω-3 fatty acids for a vegetarian diet [8,9]. Using natural sources to make nutrition healthier is becoming popular.

Germination is a technological technique widely used as it helps reduce the level of anti-nutritional factors in seeds and improve the taste and the availability of biologically active substances. Germinated flax seeds are widely used in food technology to improve the nutritional value of products [1,6,10]. Flax seedlings are used to increase the content of ω-3 polyunsaturated fatty acids and to reduce cholesterol in chicken eggs [2,11,12]. From germinated flax seeds, lignans are derived to combat a number of diseases, including oncological [9,10,13].

Most scientific publications devoted to germination or hydrothermal treatment of certain types of plant raw materials consider the grain of cereals, legumes, nuts, vegetable seeds, and oilseeds [14-16]. A lot of studies used the traditional parameters of the germination process that are characteristic of the malt production technology, and the purpose of research was to establish the biochemical composition of the obtained products [16-18]. The optimum parameters of the germination process using the methods of mathematical modelling were established for wheat grains [19], oats [20], triticale [21].

In our previous studies [22], it was determined how the germination temperature effected on the time a flax sprout required to reach the optimum length. However, in the literature on the subject, there are no complex studies of how to optimize the technological parameters of obtaining bioactive flax seeds. That is why, the scientific novelty of the work consists in developing a mathematical model of flax seed germination, using regression and correlation analysis to establish the optimum technological parameters of the process.

Purpose and objectives of the research. The purpose of the research is to determine the optimum modes of germination of flax seeds.

Objectives of the study:

– to establish the dependence between the input and output parameters of flax seed germination;

– using the regression-statistical modelling method, to construct empirical dependences of flax seed germination energy on the temperature at constant humidity;

– on the basis of the experimental data obtained [1,18], to build an experimental-statistical model of the process of flax seeds bioactivation, suitable to predict the optimum modes of germination and energy consumption;

– based on the model constructed and on the response surface of the flaxseed germination process for a random temperature and humidity range, set the optimum bioactivation modes.

Research materials and methods

The research used flaxseeds of the variety *Vruchy*, harvested in 2018, grown in the village of Chabany, Kyiv Region, at the National Scientific Centre “Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine.” The regression and correlation analysis techniques were used to obtain and validate a mathematical model of the germination process, which quantitatively describes the relationship between the input parameters (temperature, humidity) and the response (germination energy).

All the factors that influenced the process can be divided into three groups [23]:

– the monitored and controlled factors are those for which not only their level can be registered, but their possible values can be pre-set in each experiment as well;

– the monitored, but uncontrolled factors are those that can only be registered, but it is practically impossible to set their certain values in each experiment;

– the uncontrollable factors are those that the experimenter does not register and can even have no idea of.

The monitored and controlled factors include the temperature and humidity. During germination, the temperature was changed from 16°C to 30°C, in increments of 2°C. A further increase in the temperature can only be achieved by forced heating, which requires energy and additional equipment. That is why, the temperature was within a range that did not exceed 30°C. The humidity was set and maintained at the following values: 40%, 60%, 70%, 95%. Uncontrolled factors were not taken into account in the modelling process.

The germination process can be studied and analysed by changing the input factors and observing the outputs, or the responses (Fig. 1). The input parameters are the temperature and humidity of the environment, the response is the energy of germination.

Fig. 1. The flowchart of germination (the factors and the response)

Germination energy is the ability of crops to sprout up quickly together. It is defined as the number of seeds that have sprouted over a certain period of time, and it is expressed as a percentage of the total number of seeds [24].

The analysis is carried out on the seeds of the main crop. To do this, a random selection of 400 seeds is taken, by 100 or (for large-seeded crops) 50 seeds in each cycle of the analysis. The seeds are evenly placed on moistened filter paper. Filter paper is used for the two variants of the analysis: “on paper” and “in paper.” To moisten the paper, it is dipped in water, taken out, and the excess water is allowed to trickle down. During the analysis “on paper,” the seeds are spread on two or more layers of moistened paper placed in Petri dishes. During the analysis “in paper,” the seeds are spread between two layers of moistened paper (it is recommended to place them in rows in order to facilitate visual assessment of seedlings). Paper can be used in the form of envelopes, rolls, corrugations having different profiles. For better ventilation, it is recommended to put cold-proof plates or frames between the paper layers.

The device with the seeds thus prepared is placed in the germination chambers, vessels, or directly on the shelves of the thermostat. The flax seeds were germinated for 36 hours before the appearance of normal seedlings up to 3 mm long, whole and healthy, with the most important structures well and proportionately developed, according to DSTU (State Standard) 4136-2002 "Crop seeds. Quality determination method."

The idea of the modelling is detecting the existence of a dependence between the germination energy P and the germination temperature t, with the given humidity w. The objective of the modelling is building a mathematical model of this dependence in the form of a functional.

$$P(t,w) = f(t,w), \qquad (1)$$

Results of the research and their discussion

The analytical dependence (1) was determined by the regression analysis.

The regression analysis is a method of modelling measured data and studying their properties. The data consist of pairs of values: the dependent variable (response) and the independent variable (factor). The regression model is a function of the independent variable. The model parameters are determined from the condition of minimizing the relative error.

$$\varepsilon = \min_i \left(\frac{|y_i^o - y_i^m|}{y_i^o} * 100\% \to \min\right), \qquad (2)$$

where, y_i^o, y_i^m are the average values of the experimental measurements and the modelling results, respectively.

Another criterion for the quality of the approximation [3] is the correlation coefficient

$$R^{o-m} = \frac{\sum_i (y_i^o - \overline{y^o}) * (y_i^m - \overline{y^m})}{\sqrt{\sum_i (y_i^o - \overline{y^o})^2} * \sqrt{\sum_i (y_i^m - \overline{y_m})^2}}, \qquad (3)$$

which shows the degree of correlation between the experimental measurements and the modelling results. R is a dimensionless value that varies from -1 to 1. When variables are varied independently, with no relationship between them, R = 0. Positive values indicate a positive (direct) dependence (i. e., with the increase of the values of one variable, the average values of the other variable increase, too). Negative values indicate a negative, or inverse, dependence (with the increase of one variable, the other decreases).

Regression dependences of the germination energy on the temperature (t), at the set humidity (w), were obtained in laboratory experiments using the CureyExpert programme:

$$P(t,w) = a(w)e^{-\frac{(b(w)-t)^2}{2c(w)^2}}, \qquad (4)$$

The values of the coefficients a, b, c of the equation (4) are given in Table 1.

Table 1 – Values of the parametric coefficients of the regression solution for the process of flax seed germination

Coefficients	Air humidity, %			
	40	60	70	95
a	75.2616	90.2110	92.697209	99.64231
b	27.1922	28.4679	27.06270	27.56552
c	28.8494	25.2223	20.03569	17.64323

The method of regression-statistical modelling has allowed obtaining empirical dependences of the germination energy on the temperature at a constant humidity (Fig. 2), where t is temperature, a, b, c are coefficients.

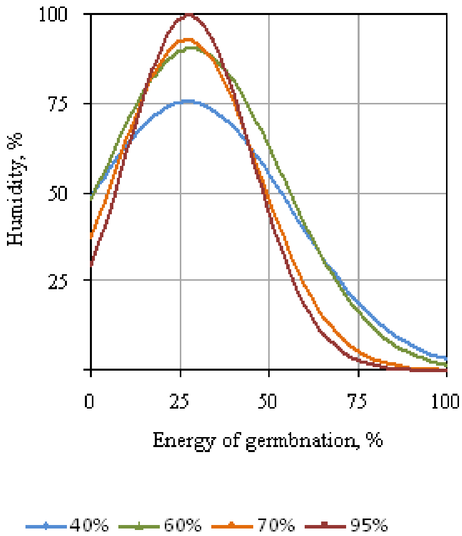

Fig. 2. Dependence of the changes in the germination energy on the temperature and humidity

The results of the analysis show that the statistical-regression models obtained describe the experimental data with sufficient accuracy. Thus, the correlation coefficient for flax seeds is: R = 0.96–0.99.

Since the coefficients a, b, c (Table 1) are functions of the temperature at a constant humidity, then by approximating the coefficients (Fig. 3, 4, 5)

a – by the linear equation

$$a(w) = a_{1i} + a_0, \qquad (5)$$

b, c – by the 4th degree polynomials

$$b(t) = b_4 t^4 + b_3 t^3 + b_2 t^2 + b_1 t + b_0, \qquad (6)$$

$$c(t) = c_4 t^4 + c_3 t^3 + c_2 t^2 + c_1 t + c_0, \qquad (7)$$

we obtain a general model of the flax seed germination process. This model contains the equations (4-7).

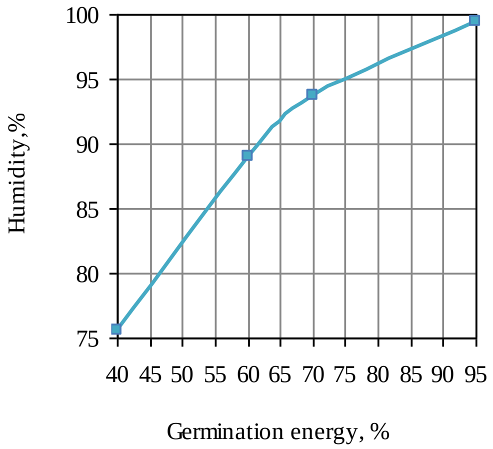

Fig. 3. Dependence of the coefficient *a* on the humidity during flax seed germination

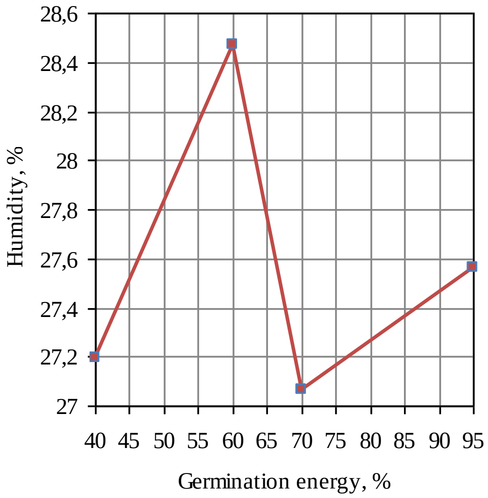

Fig. 4. Dependence of the coefficient *b* on the air temperature during flax seed germination

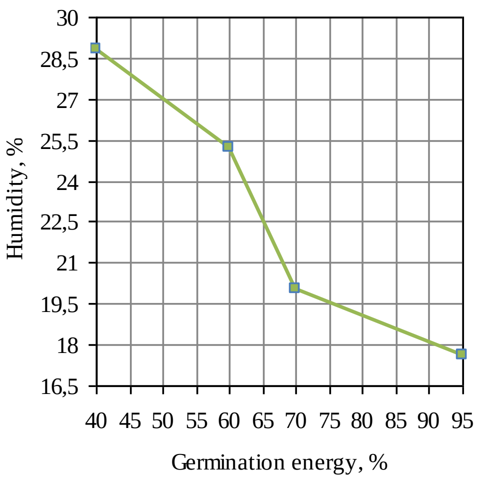

Fig. 5. Dependence of the dispersion – the coefficient *c*

According to the results of the analysis of the data shown in Fig. 3-5, the maximum germination energy at a given humidity is in the range 75–100%, and the optimum temperature at a given humidity is observed in the range 27–28.5°C:

The equations 4-7 represent a generalized model of the process of germinating flax seeds for a random range of temperatures and humidity. The results of the computational experiment by this model are shown in Fig. 6 and Fig. 7.

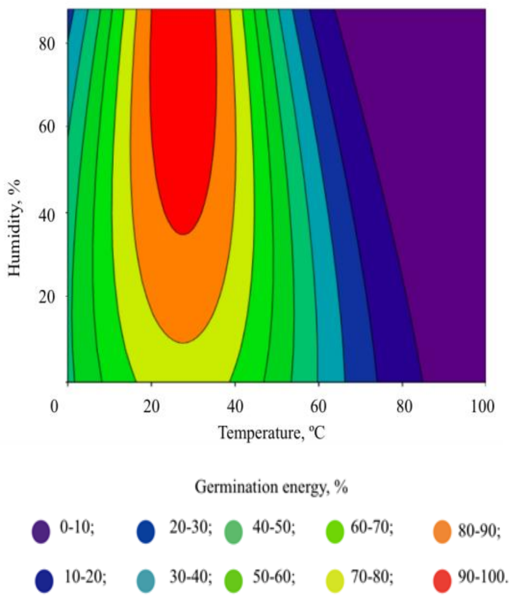

Fig. 6. Model of the process of flax seed germination for a given range of temperatures and humidity

As can be seen from Fig. 2-7, there are significant differences in the course of flaxseed germination, which is explained by quite a wide range of the input factors (pre-set temperatures and humidity). From the constructed mathematical model, it follows that the maximum germination energy is 99.64%, and it is reached at the temperature 27.5°C and the humidity 95%.

Approbation of the research results. According to the results of the research, utility model patent of Ukraine UA No. 128341 "Method of obtaining biologically active products" has been granted.

Conclusion

It has been established that at the humidity 95%, the temperature range providing the germination energy not lower than 99% is 25–34°C. When the temperature is decreased to 24°C, the response is 98%, at 22°C 95%, and at 20°C – 91%. In our opinion, the permissible range of germination energy values is 90 to 100%. Therefore, in the production environment, flax seed germination at the temperatures 20 to 30°C is possible, if the ambient humidity is 95 %. When the humidity is lowered to 70%, the temperature range providing the energy of flax seed germination within 90–100% is 22–32°C.

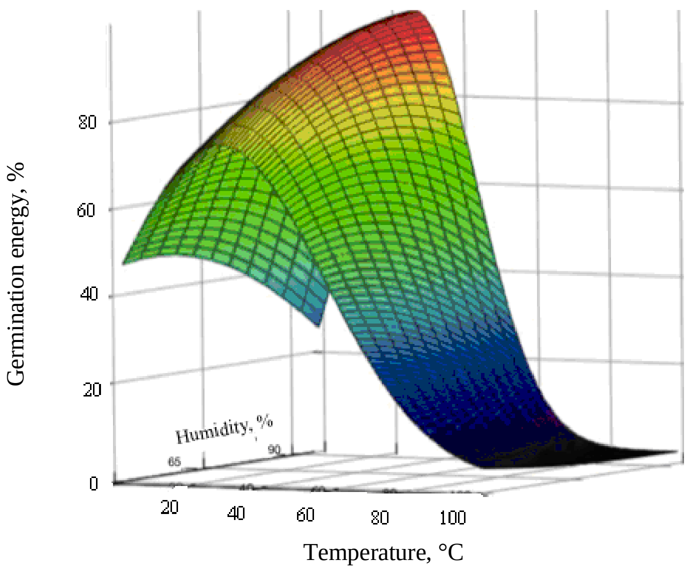

Fig. 7. The response surface of the model of the flax seed germination process for a given temperature and humidity range

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ОПТИМІЗАЦІЯ ТЕХНОЛОГІЧНОГО ПРОЦЕСУ ОТРИМАННЯ БІОАКТИВОВАНОГО НАСІННЯ ЛЬОНУ

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Анотація. У світі спостерігається підвищення попиту на насіння льону та зростання обсягів його переробки. Насіння льону відносять до категорії природних функціональних харчових продуктів. Цей факт підтверджують Міністерства охорони здоров'я багатьох країн, зокрема Канади та Сполучених Штатів Америки. Пророщування льону дозволяє досягти біологічної доступності компонентів насіння льону. Кожен вид рослин має свої власні передумови для проростання, що складаються як з внутрішніх, так і з зовнішніх факторів. Метою даного дослідження було вивчення впливу деяких зовнішніх чинників, таких як температура та вологість навколишнього середовища, на енергію проростання насіння льону. Діапазон зміни температур був обраний у межах від 16°С до 30°С з кроком 2°С, оскільки подальше підвищення температури вимагає примусового нагрівання шляхом використання додаткового обладнання, що призведе до зростання витрат енергоносіїв. Вологість навколишнього середовища задавали та підтримували при значеннях 40, 60, 70 та 95%. Процес пророщування насіння льону проводили протягом 36 годин до появи проростків довжиною до 3 мм. Для кожної комбінації контрольованих факторів визначали енергію проростання. Було побудовано математичну модель процесу пророщування насіння льону з використанням методів регресійного та кореляційного аналізу. За допомогою отриманої моделі визначено оптимальні режими пророщування. Під час проведення експериментальних досліджень застосувались методи планування експерименту і математичної обробки експериментальних даних. За допомогою комп'ютерних програм MathCad та Microsoft Excel проведено оптимізацію процесу пророщування насіння льону та встановлено оптимальні режими. З побудованої математичної моделі випливає, що максимальна енергія проростання 99,6% досягається при температурі 27,5°С та вологості 95%. Отримані експериментально-статистичні моделі процесу пророщування насіння льону описують перебіг процесу з коефіцієнтом кореляції R = 0,96-0,99, і можуть бути використані для прогнозування якісних показників готового напівфабрикату й енерговитрат на його отримання.

Ключові слова: льон, проростки, пророщування, експериментально-математичне моделювання, регресійний аналіз.

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