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Characteristics of mucous-forming polysaccharides extracted from flax seeds

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ABSTRACT

The research used the seeds of long flax of the "Vruchy" variety and oil-curly flax of the "Original" variety. To extract mucus, whole flax seeds were hydrated for 3 hours. in tap water, at a ratio of 1:20 and a temperature of 18 – 20 °C with constant stirring with a magnetic stirrer. This study aimed to evaluate the effect of temperature and duration of extraction on the yield of mucilaginous polysaccharides in aqueous solution from flaxseed. Change range: the temperature is selected in the range from 0 °C to 100 °C with a step of 20 °C; with a duration, ranging from 10 min to 140 min in 10 min increments. The yield of polysaccharides from flax seeds was determined for each combination of controlled factors. It was established that in the first 10 – 20 min. there is an increase in the yield of polysaccharides and the rate slows over time. For 90 min. equilibrium occurs at a temperature of 80 °C. This period of the process is optimal for the extraction of mucilage-forming polysaccharides from flaxseed. The mass of the extracted polysaccharides, from the mass of the seeds after a time of 95 min was 5.74%, and 6.00% at a temperature of 80 °C. A package of applied statistical programs was employed during the research to process the experimental data. A mathematical model of the process of extracting mucus-forming polysaccharides in an aqueous solution of flax seeds was built using regression analysis methods. The obtained regression equations determined the optimal regimes of the sought values in terms of temperature (80 – 85 °C), time (85 – 90 min) and conducted in compliance with the prescribed amount of water of 200 cm^3. Within 10 – 20 min the formation of a transparent gel capsule around the flax with a phase separation boundary under seed contact with water, which does not change further. This indicates the completion of the hydration process.

Keywords: flax seeds, polysaccharides, mucus, extraction, additive

INTRODUCTION

Today there is a great challenge to the problems that often arise and human faces. The main ones are the high-quality provision of food to the population, energy provision, raw materials, including water, ecological and radiation safety of inhabitants, and protection of the person against the results of negative activity **[1]**. To a large extent, nutrition determines a person's health and life expectancy. The current rather complex ecological situation **[2]** dictates new approaches to processing natural raw materials: the ways of their fullest use are necessary.

Provision of the population with quality food is one of the most important tasks for Ukraine and any other country. Food affects the human body from birth and determines the development of the body. After all, getting into a human body, **[3]**, **[4]** at the expense of difficult biochemical transformations, during a metabolism, creates structural elements of cells. The body is provided with energy that is necessary for physiological and mental activity. In addition, nutrition determines the health, activity, and protected life expectancy of a person with the ability to reproduce. Thus, the state of nutrition is and remains one of the most important factors determining the nation's health **[5]**.

Food should provide the body not only with nutrients but also contribute to the prevention and treatment of diseases. Bakery and confectionery products with the use of raw flour are a component of the daily human diet. Therefore, giving them the properties of a health product is an important problem today, because the chemical composition they are not sufficiently balanced with important ingredients **[6]**.

Flax is one of the most universal and valuable industrial crops and one of the most promising in dynamic development. Demand for flax and flax products in Ukraine and other countries is characterized by high interest in its use in medicine, cooking, and cosmetology **[7]**, **[8]**. Ukrainian food producers do not often use this type of raw material, although it has a unique biochemical composition and pharmacological properties. They are due to the high content of substances in the provision of preventive measures and treatment of cardiovascular, gastrointestinal, cancer, and many other diseases. Therefore, food manufacturers have begun to pay special attention to the extraordinary benefits of flax seeds for health prevention and treatment.

One of the ways to ensure healthy nutrition is to enrich basic products with non-traditional types of raw materials, particularly flax seeds. Flax seeds are a promising raw material for normalizing the fatty acid composition of food products, enriching them with water-soluble polysaccharides and flax lignans.

Despite the rapid development of scientific and technological progress and a mass of artificial fabrics, resins, and oils, economic interest in flax as an oil and yarn crop is not decreasing, but increasing sharply **[9]**. In recent years, the cultivation of oilseed flax in Ukraine has grown dynamically. Flax has several advantages over other crops due to stable yields (14 – 24 kg/ha) and early maturity (the end of July). Flaxseed's main components are oil (41%) and protein (21%). However, depending on the variety, growing environment, and processing methods, the ratio of these components in flaxseed can vary significantly **[10]**. In addition, flax is an important medicinal plant. Flaxseed oil is used in the diet of patients with disorders of fat metabolism, atherosclerosis, coronary heart disease, brain, hypertension, diabetes, liver cirrhosis, hepatitis, fatty liver disease, skin diseases, and various inflammatory processes.

Nowadays, only oil is produced from flax seeds on an industrial scale, using one of the traditional mechanical methods. In terms of biological value, flaxseed oil ranks first among other edible vegetable oils. It contains a lot of useful substances for the body (polyunsaturated acids, vitamins F, A, E, and K, and saturated fatty acids (10% of the composition), which is shown in Figure 1.

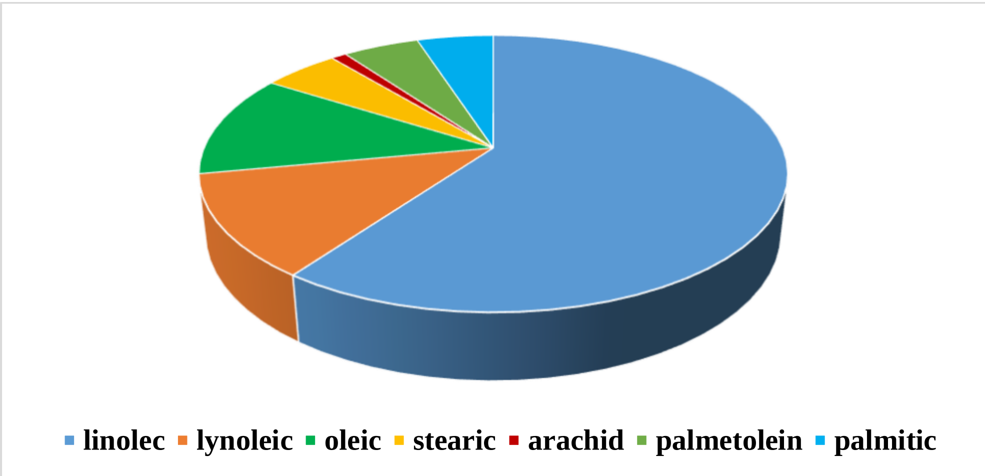

Figure 1 Fatty acid composition of linseed oil.

In scientific works **[11]**, **[12]** it was proved that linseed oil contains a large amount of unsaturated fatty acids, the consumption of which with food lowers the level of cholesterol. Based on the results of research presented in the manuscripts **[13]**, **[14]**, it was established that substances in flax seeds are effective in treating various types of tumors. The following scientific works **[15]**, **[16]** were devoted to the study of the properties of linseed oil, in which the author teams studied the content of polyunsaturated α-linolenic acid, which is part of almost all cell membranes, is an indispensable acid in the human diet and contains a large amount of vitamin E. The use of domestic raw materials of plant origin, which has a high potential for biologically active substances, allows you to purposefully create products with functional properties, as well as allows you to expand the range of products, and increase their nutritional and biological value. Flax seeds contain a significant amount of protein (about 25%), fat (30 – 48%), which contains 35 – 45% glycerides of linolenic acid, 25 – 35% linoleic acid, 15 – 20% oleic acid and a small number of glycerides of palmitic and stearic (8-9%) acids.

Flax seeds are an excellent source of valuable polyunsaturated fatty acids ω-3 and ω-6. These are vital acids the human body cannot produce on its own, and should only be obtained from the foods we consume. The content of w 75.00% (of the total mucus content) of the most viscous neutral polysaccharide with a molar mass of 1.2C3.75% of acid polysaccharide AF1 with a molar mass of 6.5.10 5 g/mol; 21.55% acid polysaccharide AF2 with a molar mass of 1.7.10 4 g/mol. Flax seeds contain vitamins D, B2, B3, B4, B6, and B9, tocopherols, β-carotene, macro- and microelements: potassium, calcium, magnesium, iron, manganese, copper, chromium, selenium, aluminum, iodine, zinc **[17]**.

The authors **[23]**, **[24]**, present the characteristics of the insoluble fiber fraction. It consists of cellulose and complex polymeric compounds such as lignin. These fiber forms are valuable food components due to their physiological action. They promote bowel function, prevent atherosclerosis and improve lipid metabolism. Fiber is about 28% of the dry weight of non-fat flaxseed.

Note that a distinctive feature of carbohydrates is the content of water-soluble polysaccharides. When wet, they can form mucus on the surface of the seeds. Their number is 2-7% of the total mass. All other biologically active seed ingredients, such as mucus, are not so widely used due to the lack of rational and efficient technologies for their production.

It should be noted that the mucus of flax seeds is rich in macro-and micronutrients such as potassium, calcium, magnesium, iron, manganese, copper, zinc, chromium, aluminum, selenium, nickel, iodine, boron. According to **[18]** the mucous substances of flax seeds contain fibrous materials diameter of 18-45 nm **[19]** which are stretched in the presence of water, and are connected with the same fibers of seeds nearby (Figure 3). Hydrophilic groups of mucous molecules retain water in the middle of the cells of this grid, thus creating the effect of "freezing". According to various information data **[20]**, **[21]**, flax seeds can retain water in a multiplicity of 7 to 27 units, about its mass. This is a prerequisite for the use of flax seeds not only as enrichment but also to regulate the technological characteristics of food products.

Anatomomorphological studies of cross-sections of flax seeds **[22]** showed that the shiny, dry state, surface of the shell is determined by a vitreous layer of dehydrated mucus-forming polysaccharides

The study aimed to analyze the process of extracting mucilage-forming polysaccharides from flax seeds. To evidence their composition and properties and to develop a method of dehydration to form a dry powdered additive with structure-forming properties.

Scientific Hypothesis

This hypothesis is aimed at determining the technological influence of the main factors of moisture absorption and moisture release in the germination process of "Vruchiy" and "Original" flax seeds with the disclosure of the extracted characteristics of the complex of mucilaginous polysaccharides with further use in the bakery industry. Taking into account the complex process accompanied by mechanical, physical, and chemical phenomena, the influence of factors on the germination of flax seeds is mathematically described using the methods of regression and correlation analysis. This analysis helps to establish optimal modes of germination of flax seeds.

MATERIAL AND METHODOLOGY

Samples

Long-term flax seeds of the "Vruchiy" variety and oil-curly flax of the "Original" variety were used for research. Flaxseeds were cleaned thoroughly to free them from dust, dirt, and other foreign matter.

Damaged seeds were discarded. Previous studies **[23]** found that these varieties have the best biochemical composition and are promising raw materials in the production of dietary supplements and healthy and functional foods. Flax seed carbohydrates are of particular interest. Fibre and mucus-forming polysaccharides stand out among them. Figure 2 clearly shows that flax seed fiber consists of insoluble and water-soluble fractions. The insoluble fiber fraction is characterized by cellulose and complex polymer compounds such as lignins. These forms of fiber are valuable components of food products due to their physiological benefits.

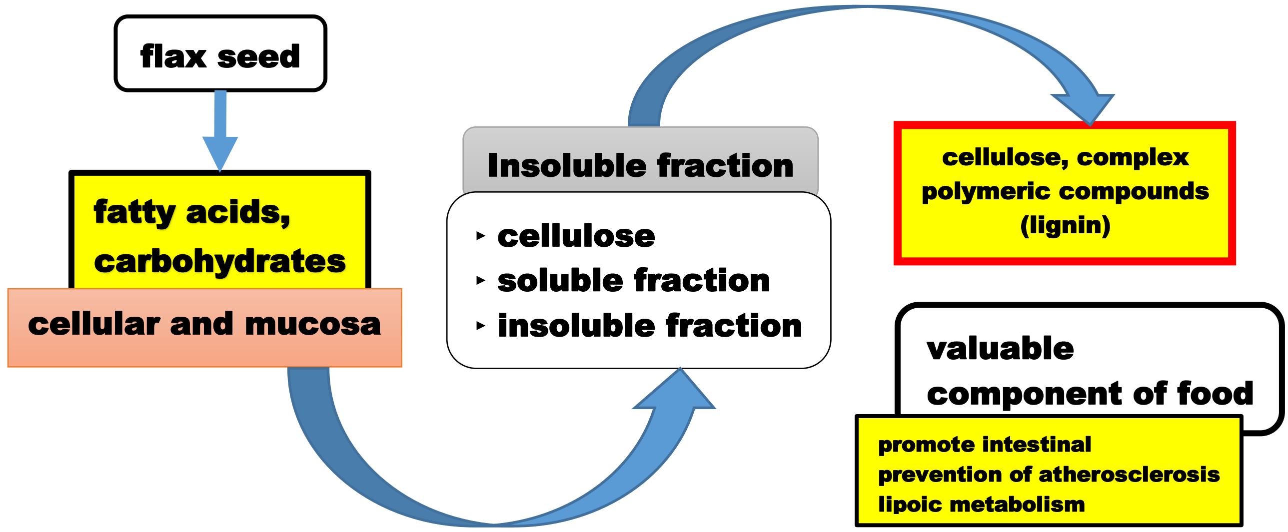

Figure 2 Scheme of the physiological action of carbohydrates of flax seeds.

The main physical and mechanical properties and physicochemical parameters of seed quality are presented in Table 1.

Table 1 Quality indicators of different varieties of flax seeds.

Grade	Humidity, %	Oil content, %	Bulk density, kg/m^3	Weight of 1000 seeds, gr
Vruchiy	8.6	33.82	712	6.62
Original	8.7	38.75	752	4.73

All methods of isolating polysaccharides from flax seeds are based on extraction processes with water or salt solutions. The extraction is carried out either from intact flax seeds or directly from the shell separated from the core. The polysaccharide product is isolated from the extracts, mainly by precipitation by alcohol (ethyl or isopropyl) **[24]**, then it is dried using a lyophilic or spray dryer.

Chemicals

Water (chemical formula H_2O) was used to soak different flax seed varieties during extraction. Water corresponds to the national standard DSTU ISO 7887:2003 **[25]**. A salt solution extracted polysaccharides from flax seeds (1% NaCl solution).

Animals, Plants, and Biological Materials

Flax seeds of the following varieties were used for experimental research: Gladiator (producer: Sofia farm, Vinnytsia region, Ukraine); Hetman (producer Sofia farm, Vinnytsia region, Ukraine); Monk springs (supplier: Svitanok Farming, Rivne Region, Ukraine), which are recommended for cultivation in the Polissia and Forest Steppe zones.

Instruments

Drying of flax is performed on the drying cabinet SECH-3MK. Flax drying was carried out at a temperature of no more than +65 °C and heating of seeds 35 – 45 °C. To control the temperature of the seed during its drying period, samples are taken every 20 – 40 minutes for 10 hours. Photographs of samples using a microscope Bresser Biolux LCD 50x-2000x at a magnification of × 300 times. The temperature was measured with a thermometer TLS Ukrainian manufacturer "Glass Device". The obtained results were statistically processed using the standard Microsoft Office software package.

Laboratory Methods

Sampling was performed according to DSTU ISO 4803:2013 GUEST 4803:2013 **[26]**, Organoleptic evaluation "Descriptive (qualitative) method of profile analysis" DSTU ISO 4910:2008 **[27]**. The extraction efficiency is influenced by the following factors: the ratio of raw material and solvent (hydromodule), temperature, and time of the extraction process. When selecting a rational hydro module, it was taken into account that an increase in the mass fraction of the extractant leads, on the one hand, to an increase in the driving force and, on the other hand, to a decrease in the concentration of extracted substances. Irrational selection of the hydraulic module increases the cost of the target product, as it will require a larger volume of extractant or a longer process of their concentration. In this case, a decrease in the mass of the extractant leads to an increase in the viscosity of the solution, which also leads to an increase in power consumption. The optimal and economical hydraulic module for the process on an industrial scale, as defined by the authors **[28]**, is a hydraulic module in the range of 18-20, which we used in research.

To remove mucus, whole flax seeds were hydrated for 3 h in tap water, at a hydromodule of 1:20 and a temperature of 18 – 20 °C with constant stirring with a magnetic stirrer. Water as an extractant is associated with its food and pharmaceutical applicability. Before extraction, the raw material was not subjected to any pre-treatment. The resulting mass was poured into boxes and dried at a temperature of 50 °C for 10 h in SECH-3MK. According to the method **[29]**, the dried mucus was separated from the seeds by rubbing through a sieve No. 40 with a through mesh of 0.42 mm. Using an Oswald viscometer, the viscosity of the resulting solution was measured, and the dry residue was determined.

The resulting dry residue was weighed and redissolved in a volume of water equal to the original (taken for extraction). The viscosity of the solution's polysaccharides is reduced, which is important in using dry polysaccharides. In fig. 3 shows the localization of mucus-forming polysaccharides in flax seeds based on an enlarged fragment of the cross-section of the seed, × 200. The arrows show a vitreous layer of dehydrated mucus-forming polysaccharides.

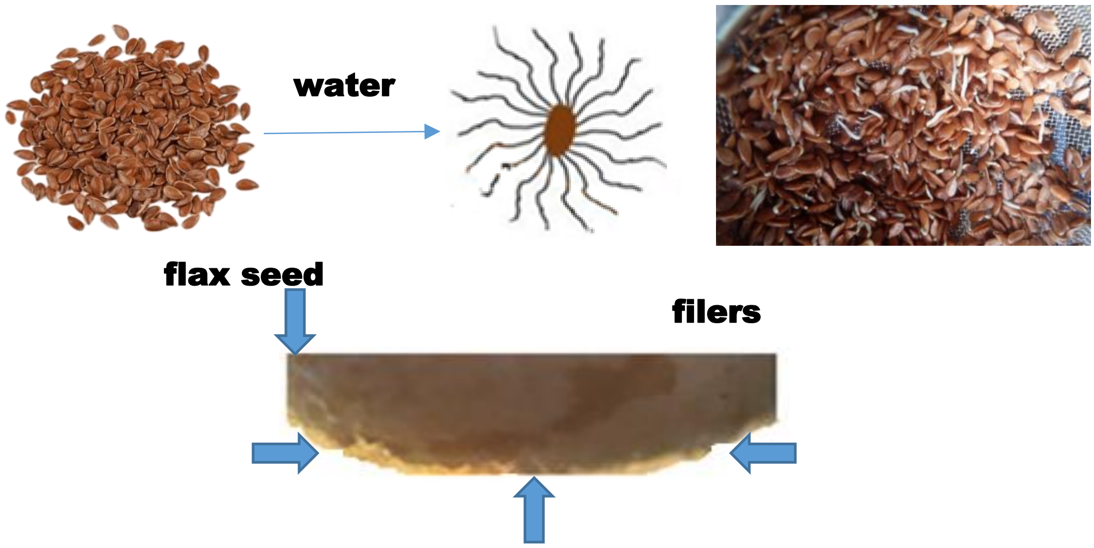

Figure 3 Modern ideas about the mechanism of gelation of mucous membranes substances of flax seeds.

Using salt solutions to extract polysaccharides from flax seeds (1% NaCl solution) facilitates the process. Thus, the viscosity of the extracts is reduced by almost three times, and the yield of the final product is increased **[30]**. However, in the product the carbohydrate part decreases and the content of protein and ash elements increases. Therefore, we used water in our research.

Methods for determining the study data: Sampling of flax seeds was performed by DSTU ISO 8837:2019 **[31]**. The mass fraction of moisture was determined by the method of accelerated drying in an oven SECH-3MK **[32]**.

Flax seeds' swelling dynamics were evaluated on a microscope Bresser Biolux LCD 50x-2000x at a magnification of × 300 times. The ability of flax seeds to retain water was determined by the amount retained in the sample after infusion and centrifugation of the appropriate suspension. The ratio of flax seeds: to water in suspension was 1:10. The indicator's value was determined as a percentage by the ratio of the difference between the amount of water used and the weight of the obtained supernatant to the weight of the sample **[33]**.

Description of the Experiment

Sample preparation: The dependence of the extraction of mucus from flax seeds by extraction over time and in tap water at a temperature of 18 – 20 °C sets the study's parameters. The influence of parameters on extraction was constructed by the method of the planned experiment. The zones of rational extraction parameters according to the direction of the process are established by the method of a planned experiment.

Number of samples analyzed: 5 samples of each of 3 hundredths of flax, weighing 0.1 kg, were selected for research.

Number of repeated analyses: All measurements of instrument readings were performed 5 times.

Number of experiment replication: The number of repetitions of each experiment to determine one value was also 5 times.

Design of the experiment: Variable factors, optimization criteria, and the area of definition of factors are found. The choice of factors influencing the water extraction process of polysaccharides from flax seeds was carried out according to the parametric scheme (Figure 4).

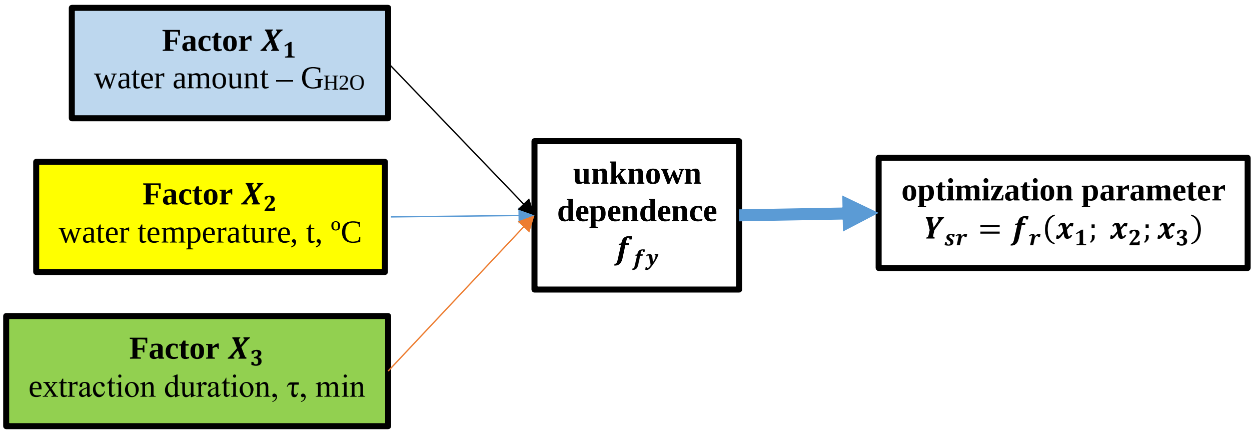

Figure 4 Scheme of the model of the planned experiment of PFE 3^3.

The main factors influencing the process are: water quantity - G_{H2O}, cm^3; water temperature – t, °C; extraction duration – τ, min The extraction efficiency was evaluated by the amount of dry matter transferred to the extract from 100 g of flax in terms of dry matter (Y_{sr},%). Independent variables were taken: the amount of water – G_{H2O}, cm^3, which was encoded by the index; water temperature – t, °C, which was coded by the index; extraction duration – τ, min, which was encoded by the index.

The reliability of the evaluation of the results of experimental studies with effective extraction by the amount of dry matter was ensured by the minimum number of measurements of the above indicators, the method of which is described in **[34]**.

After coding the factors, a planning matrix of the PFE 3^3 experiment was compiled for the total number of experiments N = 3^3. Thus, an approximate mathematical model in the form of a functional dependence $Y_{sr} = f_Y$ (x_1; x_2; x_3) was chosen to study dry matter Y_{sr}. The response function, namely the optimization parameter, was taken as a complete square polynomial, which describes the real experimental process:

$$T = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$$

Where:
Y_{sr}, is the experimental value of the dry matter; b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33} are regression coefficients that correspond to the corresponding values of the input factors; – input coded factors.

The coefficients of the approximating polynomial, represented as a complete quadratic equation under orthogonality and symmetry, were determined by known formulas **[34]**. According to the method **[34]**, the reproducibility of the obtained values from the experimental array was checked at the same number of repeats for each experiment performed according to Cochren's criterion. At the same time, after checking the adequacy of the distribution of random variables to the real process, the statistical significance of the regression coefficients was assessed using the Student's t-test. We used the statistical software package for the PC "Statistics 6.0" to build and analyze the obtained dependencies.

Statistical Analysis

Statistical processing of the results of experimental studies was carried out using the program (STATISTICA 12) from the company StatSoft for a series of parallel measurements (n = 4-5, *p* <0.05). During the optimization of technological parameters, the method of an incomplete factorial experiment with the formulation of a regression equation and optimization by the method of "least squares" using the Mathcad package of applied mathematical calculations is used. Approximation of the results, presented in the form of three-dimensional diagrams, was carried out using polynomial regressions. The importance of influencing factors on the dynamics of hydration of mucus-forming polysaccharides is the creation of objective control. It is aimed at economical use of material and energy resources. At the level of probability *p* = 0.95 and the value of the t-alpha criterion equal to 2.365, the following statistics were obtained (Figure 5): coefficient of multiple determination D = 0.926; coefficient of multiple correlation R = 0.962; standard deviation of the estimate s = 0.084; Fisher's F-test is 10.776. The coefficient D is significant with a probability level of P = 0.99961.

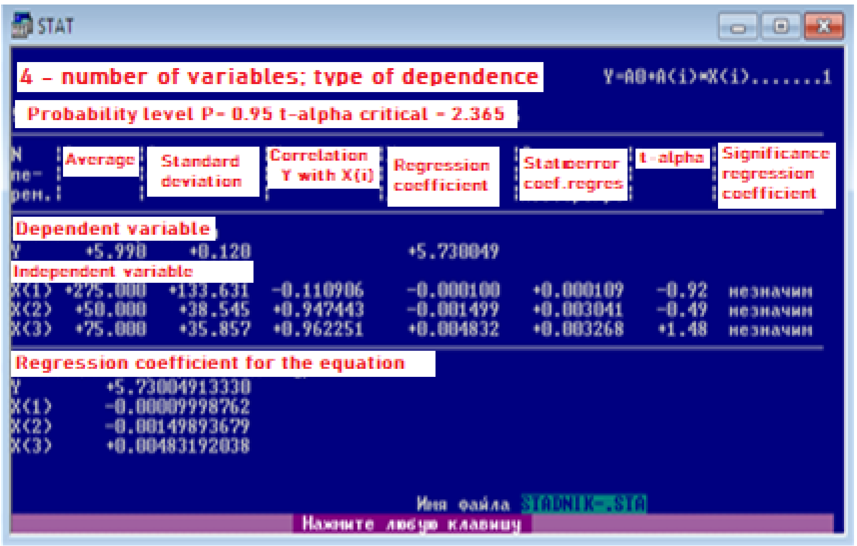

Figure 5 Statistical evaluation.

RESULTS AND DISCUSSION

Based on the results of the obtained calculations, which were performed using a package of applied statistical processing programs, as well as analysis of experimental research results, the obtained regression equations were recorded for a personal computer, and the spatial dependences of the response surfaces of the required dry matter values (Y_{sr}, %). They were determined from the obtained values of the amount of water – G_{H2O}, cm^3, water temperature – t, °C, the duration of extraction – τ, min.

The obtained regression equations characterizing the functional change of the required values of dry matter (Y_{sr}) in natural values for flax "Vruchiy" and "Original":

by temperature:

$$Y_{1tsr} = 5{,}73 - 0{,}99\ 10^{-4}\ G_{H2O} - 1{,}5\ 10^{-3}\ t + 4{,}83\ 10^{-3}\ \tau$$
$$Y_{2tsr} = 5{,}7 - 0{,}42\ 10^{-3}\ G_{H2O} - 0{,}33\ 10^{-2}\ t + 6{,}83\ 10^{-2}\ \tau$$

by time:

$$Y_{1\tau\ sr} = 4{,}55 - 0{,}99\ 10^{-3}\ G_{H2O} + 0{,}036\ t - 0{,}013\ \tau$$
$$Y_{2\tau\ sr} = 3{,}99 - 1{,}47\ 10^{-3}\ G_{H2O} + 0{,}038\ t - 0{,}86\ 10^{-2}\ \tau$$

When constructing the response surfaces of the influence of two independent values of factors on the change of dry matter (Y_{sr}, %), the third was assumed to be constant, giving it an average value from the corresponding range of the lower and upper limits. These regression equations characterize the change in dry matter (Y_{sr}, %) depending on the parameters within the following limits of change of input factors:

X_1, – $G_{H2O,}$ $см^3$(400-150); X_2 – t, °C (20-110); X_3 – τ, min (10-120).

According to the equations, the response surfaces of (Figure 6) are constructed.

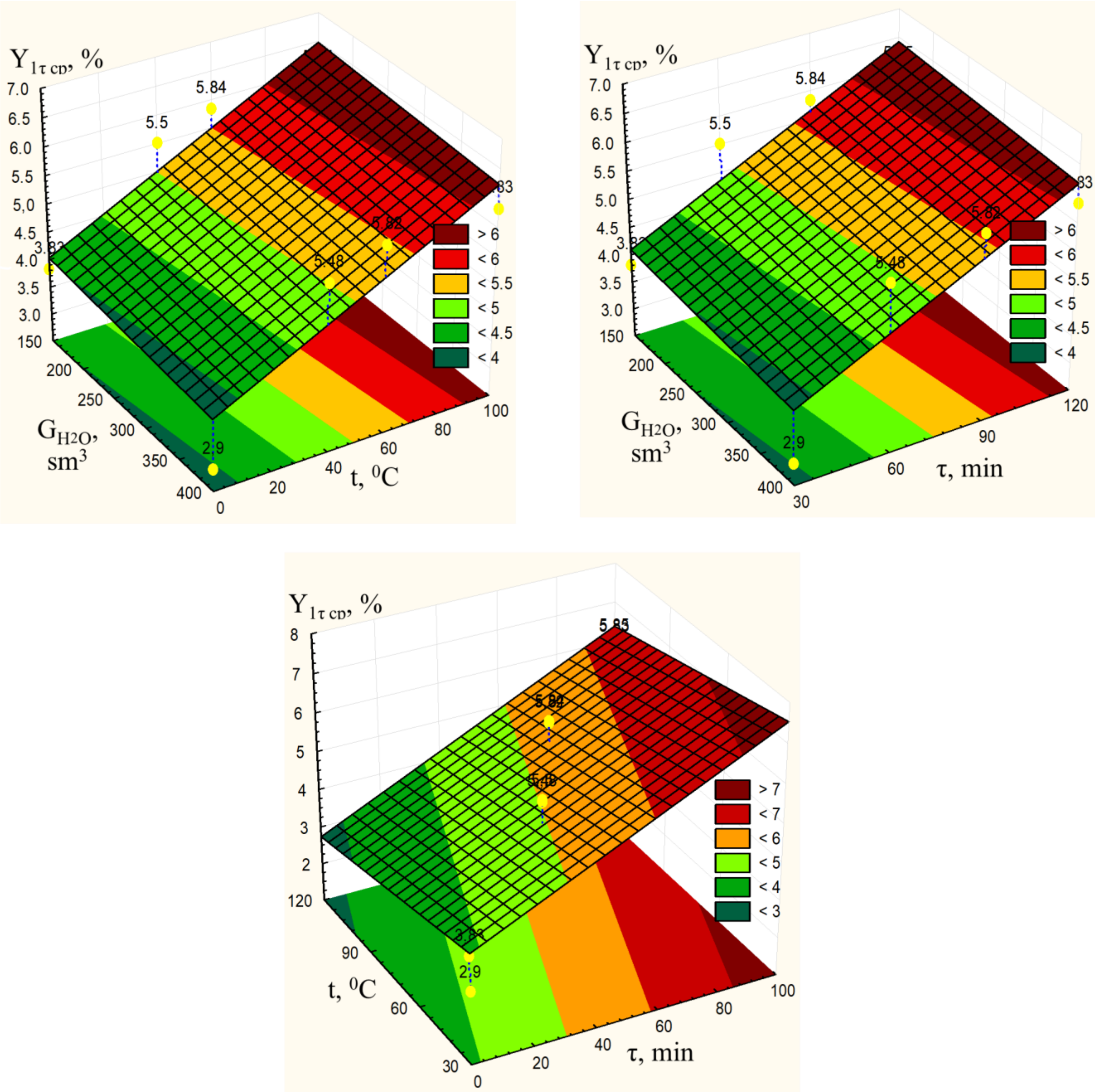

Figure 6 Surface response change of dry matter depending on water and temperature; water and time; temperature and time.

Figure 6 clearly shows the effect of parameters on the quantitative yield of mucus-forming polysaccharides. Determination of the effect of duration and temperature on extraction found that during the first minutes, there is a sharp increase in the yield of polysaccharides from flax seeds. This process period slows down over time, and equilibrium occurs after 70 minutes of water contact with flax seeds. Equilibrium occurs when the set amount of water is 200 cm^3, significantly playing during extraction. Therefore, these parameters can be optimal for extracting mucus-forming polysaccharides from flax seeds.

The interaction of water, duration, and temperature indicates a positive effect of hydration on the intensity of its dispersion. So, the response surface (Figure 6) shows that the influence parameters are important for establishing and determining the area of their influence. The interaction of the parameters depends on the percentage formation of polysaccharides. Thus, achieving the optimum mucilage-forming polysaccharides in flax seeds begins with a hydration time of 60 minutes. at a temperature of 75 – 85 ºC while maintaining the amount of H_2O 200 cm^3. their uniform connection. We can note that the beginning of mucus formation is already at 50 min showing 5.19% polysaccharides. Polysaccharides reach their maximum at 5.9% at parameters: t = 90 0C, G_{H2O} =

200 sm^2, and time τ = 80 min. Thus, without increasing the consumption, the effectiveness of the hydration dynamics of mucus-forming polysaccharides in flax seeds was achieved.

In scientific manuscripts **[35]**, **[36]**, **[37],** the authors conducted a study of the amino acid composition and polysaccharide complexes of the above-ground and underground parts of the spring primrose. Fractions of water-soluble polysaccharides and pectin substances were isolated from the studied raw materials, and their quantitative content was determined. It should be used (gas chromatography method) to determine free sugars' qualitative composition and quantitative content.

Indeed, the authors presented and disclosed in the paper **[38]**, **[39]** that molecules simultaneously interact with proteins and non-starch polysaccharides of seeds. The insoluble fraction of non-starch polysaccharides of flax seeds is 20-22% of its mass and consists mainly of cellulose, a small amount of lignin, and hemicelluloses **[40]**, **[41]**. Scientific works **[42]**, **[43]** noted that many hydroxyl groups and a developed system of thin submicroscopic capillaries characterize cellulose. Therefore, it gives high retention properties to the liquid.

Research devoted to the application of ultrasonic vibrations in chemical technology is quite promising: in many cases, they provide the exceptionally high intensity of the technological process, which cannot be achieved with the help of such widespread methods as mechanical mixing, application of high temperatures and pressures, etc. **[44]**, **[45]**. Therefore, the problem of using ultrasound in the processes of chemical technology deserves serious attention. In our opinion, it can be used to determine the qualitative composition and amount of free sugars.

Soluble non-starch flaxseed polysaccharides are represented by mucous substances (4-6% by weight of seeds) **[46]**, **[47]**, which are well hydrated in cold water with the formation of a mobile gel. In the cellular structures of the first three layers of the seed coat, after 1 min of hydration, the gel passes through the microscopic holes in the seed coat and becomes visible, forming a transparent capsule with a fairly clear phase boundary (Figure 7).

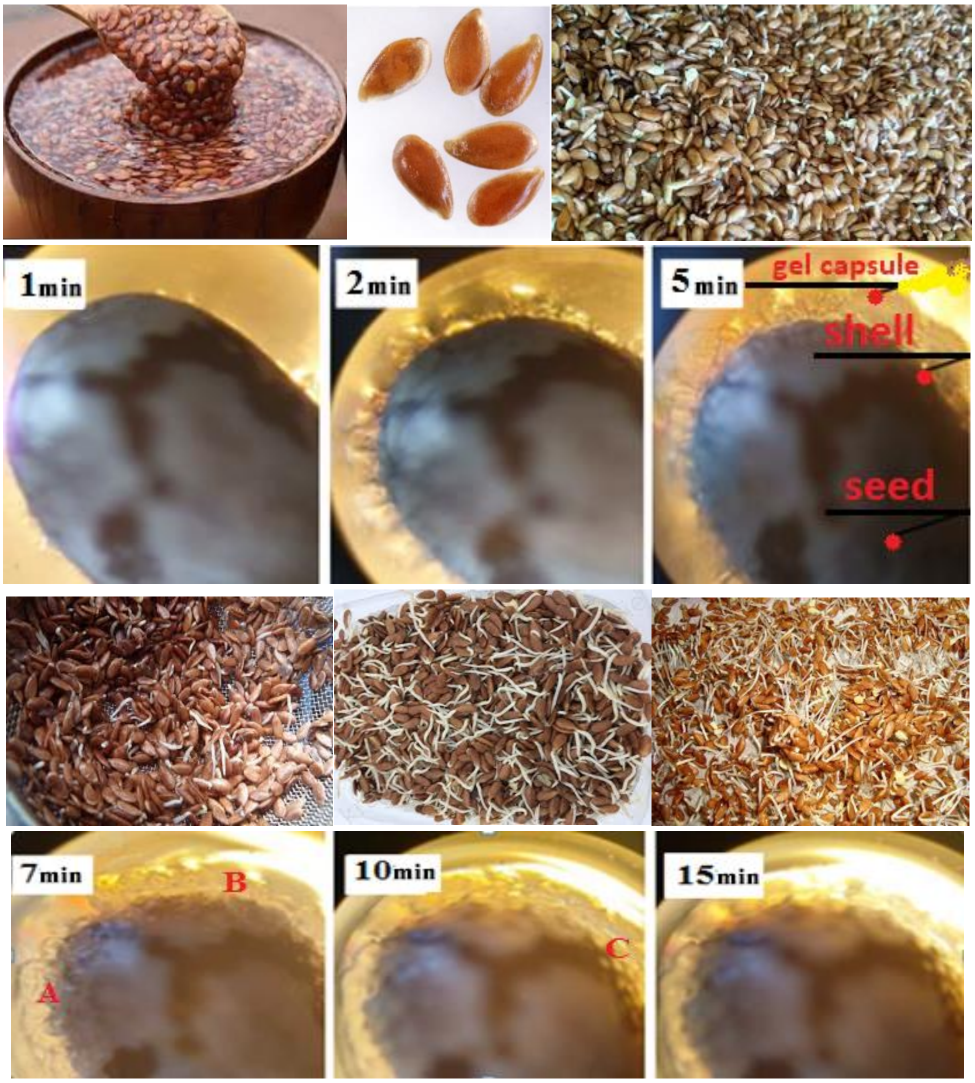

Figure 7 Features of the initial dynamics of hydration of mucus-forming polysaccharides in flax seeds with different duration of contact with water (x300).

The thickness of the gel capsule increases when the seeds come into contact with water for up to 10 minutes, and if the process of soaking the seeds is continued for up to 25 minutes, the size of the capsule does not change.

Figure 7 shows the volume A occupied by low molecular weight mucus formed above the surface of the shell at 7 minutes and 10 minutes of the process. Accordingly, B is a light loop-like strand of more high molecular weight mucus in a low molecular weight mucus solution. The formation of C – spheroidal formation of the highest molecular weight mucus.

Modeling allowed us to confirm our idea about the state of influence of the main factors on the dynamics of hydration of mucus-forming polysaccharides. In general, the hydration of flax seeds allowed us to isolate several fractions of mucus-forming components of polysaccharide nature with different physicochemical properties, in particular, with different hydration rates. At the same time, it is quite obvious that the biggest technological problems in various production operations with flax seeds are created by the low-molecular slime-forming component, which quickly hydrates even with a slight increase in the moisture content of the seeds.

The mucus fraction is presented as translucent (in micrographs – light) loop-shaped strands. These strands gradually increase in size and occupy the entire primary mucus area. The zone was previously formed around the flaxseed shell by a fraction of rapidly hydrating polysaccharides. Therefore, the polysaccharide nature of mucus formation is confirmed by a qualitative reaction to the influx of a weak aqueous solution of methylene blue. Blue gives a blue-violet color in the presence of polysaccharides (in Figure 6 – dark loose formations in the area of mucus).

Similar series of experimental studies are described in scientific works **[48]**, **[49]**, **[50]. The** author's teams investigated the properties of polysaccharides, which were obtained by extracting different types of oilseeds (sunflower, soybean, and rapeseed). But in the works mentioned above, there is no comparative analysis of the chemical composition of the obtained polysaccharides.

In the conducted studies and the given features of the initial dynamics of hydration of mucilage-forming polysaccharides in flax seeds (Figure 7), changes in the location, intensity, and shape of bands of the main functional groups that characterize protein, carbohydrate, and lipid complexes are visible. The periodicity of the processes occurring on the change in the intensity of the functional groups' main bands depends on the hydration and temperature duration. In our research, the intensity of breaking down protein and polysaccharide substances, which are few in the literature in this aspect, is reflected.

In the scientific literature, there is a large amount of information devoted to the study of the properties of polysaccharides, which were obtained by various methods:

Extraction from natural sources. This method involves harvesting the plant material, processing it, and extracting the polysaccharide using solvents or physical methods **[51]**.

Biosynthesis by bacteria or fungi. Some bacteria and fungi can be used for the biosynthesis of polysaccharides. For example, xanthan gum, used in the food industry, can be produced using the bacterium *Xanthomonas campestris* **[52]**.

Fermentation. In some cases, polysaccharides can be obtained by fermentation. This process uses living microorganisms, such as fungi or bacteria, to break down carbohydrates in substrates and form polysaccharides **[53]**.

Chemical synthesis. Some polysaccharides can be synthesized chemically using organic chemistry. This method involves stepwise reactions leading to the formation of the desired polysaccharide **[54]**, **[55]**.

Biotechnological methods. With the help of biotechnological methods, it is possible to use genetically modified organisms for the production of polysaccharides. This involves genetically engineering bacteria or fungi to produce the desired polysaccharide **[56]**.

The choice of method for obtaining polysaccharides depends on their natural source, properties, and application needs. Each method has its advantages and limitations, and the specific situation and research or production need to determine its use.

In general, the hydration of flax seeds allowed us to identify several fractions of mucus-forming components of polysaccharide nature with different physical and chemical properties, in particular, with different rates of hydration. It is quite obvious that the biggest technological problems in various production operations with flax seeds are created by the lowest molecular weight mucus-forming component, which is quickly hydrated even with a slight increase in seed moisture.

Flaxseed mucus is a mixture of water-soluble polysaccharides **[57]**, **[58]**, which include mainly L-lactose, D-xylose, L-rhamnose, and D-galacturonic acid. Mucus polysaccharides form two main fractions: neutral and acidic. The neutral fraction contains almost no galacturonic acid, xylose is the basis of this fraction. The acidic fraction is dominated by galacturonic acid and xylose residues are detected. According to the authors, the relative content of the neutral fraction in the composition of mucus polysaccharides **[59]**, **[60]**, is 75%. The ratio of these fractions depends on the genotype of flax and largely determines the properties of polysaccharides of flax mucus, including rheological.

Chemically, the mucus is dominated by pentosans (up to 90%). Its complete solubility in water characterizes the physical properties of mucus. The mucous substances of flaxseed are complex chemical compounds of monosaccharides.

We see that the latter hydrate the most high molecular weight polysaccharides. We believe this is because they are localized in the inner layers of the seed coat and the endosperm. At the initial stage of hydration, these mucus are visually identified as small spheroidal translucent structures. Macromolecular mucus takes the form of transparent annular formations against the background of dark cell walls.

We obtained this result by compressing the flooded seed coat between the slides and the cover glasses. The inner surface of the flax shell with translucent annular structures of macromolecular mucus is reflected against the background of dark cell walls for 10 minutes. after the influx of water.

The effect of the duration of extraction on the quantitative yield of mucus-forming polysaccharides found that during the first 10 – 20 minutes there is a sharp increase in the yield of polysaccharides from flax seeds. In the future, the speed of the process slows down, and after 90 minutes of water contact with flax seeds equilibrium occurs. Therefore, this time can be considered optimal for removing mucus-forming polysaccharides from flaxseed. The research results are given in Table 2.

Table 2 Dependence of quantitative yield of mucus-forming polysaccharides from flax seeds on the duration of extraction.

Duration, min	Weight of extracted polysaccharides,% by weight of seeds	
	Vruchiy	Original
10	2.09	1.95
20	3.83	3.45
40	4.86	4.62
60	5.48	5.21
80	5.76	5.53
100	5.82	5.74
120	5.82	5.74
140	5.82	5.74

The Table 3 presents the results of the effect of temperature on the yield of mucus-forming polysaccharides from flax seeds. The extraction time is 100 minutes.

Table 3 Dependence of quantitative yield of mucus-forming polysaccharides on temperature.

Temperature, °C	Weight of extracted polysaccharides,% by weight of seeds	
	Vruchiy	Original
20	5.82	5.74
40	5.91	5.86
60	6.08	5.93
80	6.10	6.00
90	6.12	6.00
100	6.12	6.00

The results indicate that the increase in the amount of extracted polysaccharides depends more on the duration of the extraction process than on temperature. Because the increase in temperature requires energy consumption and also causes denaturation of flaxseed protein. We consider it inexpedient to increase it during the process of extraction of mucus-forming polysaccharides from flax seeds.

It can be noted that even simple visual observations of the dynamics of mucus formation in the case of hydration of flax seeds allow us to distinguish several fractions of mucus-forming components of polysaccharide nature. These fractions have different physicochemical properties, particularly with different hydration rates. The lowest molecular weight mucus-forming component creates the biggest technological problems in various production operations with flax seeds. It quickly hydrates even with a slight increase in seed moisture. Therefore, all the mucus-forming components when moistened flax seeds are successively hydrated and go into solution, which indicates a gradual increase in its concentration.

We offer the following method of processing flax seeds to obtain a food additive with gel-forming properties. The raw material is brought into contact with water at room temperature and a hydraulic module of 1:3.

CONCLUSION

The hydration parameters and mechanism were studied to substantiate the technology for releasing mucilage-forming polysaccharides in an aqueous solution from flax seeds. The effect of temperature and duration of extraction on the yield of mucus-forming polysaccharides in an aqueous solution from flax seeds was evaluated. Based on all the investigated parameters in this study, the best for hydration will be recommended to be carried out with water at room temperature (18 – 20 °C) and ratio 1 : 3 for 90 min. It was determined that the maximum amount of polysaccharides released in the aqueous solution is observed at 10-20 min, it remains unchanged after that. From 85 min, equilibrium occurs at a temperature of 80 °C, which indicates the optimality of the process for extracting mucilage-forming polysaccharides from flax seed. With the proposed ranges of temperatures and time, the best result was observed in the mass of extracted polysaccharides from the mass of seeds: at a temperature of 80 ºC – 6.00% and at a time of 95 minutes – 5.74%. Microscopic studies have established that low-molecular fractions of polysaccharides are hydrated on the surface of the shell. When flax seeds come into contact with water for a few minutes, high-molecular polysaccharides enter the hydrated state.

It is also necessary to mention that flax mucilage polysaccharides can be used as a thickener, stabilizer, and moisture-retaining agent while providing a protective effect to the digestive system. The obtained results make it possible to use the soaking of flax seeds, under the established parameters, in the food industry, particularly in the technologies of bakery and flour confectionery products. Flax seed polysaccharides and lipids and proteins included in its composition have practical significance and can be used in pharmacy as:

- structure formers;
- water-retaining agents;
- stabilizers.

Nevertheless, further studies are needed to evaluate the yield of mucilaginous polysaccharides.

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