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OPTIMIZATION OF THE FORMULATION OF A CURD PRODUCT WITH THE ADDITION OF PUMPKIN CRYOPOWDER

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Formulations of structured dairy products that demonstrate good organoleptic properties are considered the most promising in terms of meeting consumer demands, increasing market share, and enhancing the competitiveness of domestic dairy production. The selection of dairy bases (low-fat curd, pumpkin cryopowder, and cream), which possess diverse structural-mechanical characteristics and functional-technological properties, is scientifically justified and aimed at developing a range of structured dairy products containing functional food components. Viscosity was chosen as the target function for optimization, as it is a key indicator characterizing the consistency and structure of viscous products, such as the curd-based product being developed. An analysis of the response surface revealed that the optimal viscosity zone for the curd product is achieved when the mass fraction of curd is 89.6%, the mass fraction of cryopowder is 5.4%, and the fat content in the cream is 31.3%. The characteristic viscosity for curd products ranges from 1400 to 2500 mPa·s. The analysis of prediction error distribution for viscosity values yielded satisfactory results: a significant portion of the data points remained close to the trendline, confirming the adequacy of the model. This indicates the formation of a product structure in which the fermented protein coagulate plays a key role. Therefore, the viscosity, consistency, and consumer properties of the final product largely depend on its concentration.

Keywords: optimization, formulation, curd product, pumpkin cryopowder, low-fat curd, cream, viscosity, Box–Behnken three-level design.

АСҚАБАҚ КРИОҰНТАҒЫ ҚОСЫЛҒАН СҮЗБЕ ӨНІМІНІҢ РЕЦЕПТУРАСЫН ОҢТАЙЛАНДЫРУ

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Жақсы органолептикалық сипаттамалары бар құрылымдық сүт өнімдерінің рецептураларын тұтыну талаптарын қанағаттандыру, нарықтық үлесті арттыру және отандық сүт өнімдерінің бәсекеге қабілеттілігін арттыру үшін ең перспективалы деп санауға болады. Әр түрлі құрылымдық-механикалық сипаттамалары мен функционалдық-технологиялық қасиеттері бар сүт негіздерін (майсыз сүзбе, асқабақ криоұнтағы, кілегей) таңдау ғылыми негізделген және функционалды тағамдық компоненттері бар құрылымдық сүт өнімдерінің желісін жасауға бағытталған. Оңтайландыруға тиісті мақсатты функция ретінде тұтқыр өнімдердің консистенциясы мен құрылымын сипаттайтын көрсеткіш ретінде, сүт өнімін дамытудағы тұтқырлық таңдалды. Алынған жауап бетінің мінез-құлқын талдау көрсеткендей, тұтқырлықтың оңтайлы аймағы, ол сүзбенің массалық үлесі 89,6%, криоұнтақтың массалық үлесі - 5,4% және кілегейдегі майдың массалық үлесі - 31,3% болғанда жетеді. Сүзбе өнімдеріне тән тұтқырлық 1400-2500 мПа·с аралығында болады. Тұтқырлық мәндерінің болжамдық қателіктерінің таралуын талдау қанағаттанарлық нәтижелер көрсетті: көптеген нүктелер айтарлықтай бұрылыссыз түзу сызыққа жақын қалды, бұл алынған модельдің дұрыстығын көрсетеді. Бұл сүт өнімдерінің құрылымын қалыптастыруды білдіреді, мұнда негізгі рөлді ферменттелген ақуыздың түйіршіктері атқарады. Сондықтан оның концентрациясы дайын өнімнің тұтқырлығына, консистенциясына және тұтынушы қасиеттеріне қатты әсер етеді.

Түйін сөздер: оңтайландыру, рецептур, сүзбе өнімі, асқабақ криоұнтағы, майсыз сүзбе, кілегей, тұтқырлық, үш деңгейлі бокс-Бенкен жоспары.

ОПТИМИЗАЦИЯ РЕЦЕПТУРЫ ТВОРОЖНОГО ПРОДУКТА С ДОБАВЛЕНИЕМ КРИОПОРОШКА ТЫКВЫ

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Рецептуры структурированных молочных продуктов, обладающие хорошими органолептическими характеристиками, можно считать наиболее перспективными для удовлетворения потребительских требований, увеличения рыночной доли и повышения конкурентоспособности отечественной молочной продукции. Выбор молочных основ (творог обезжиренный, криопорошок тыквы, сливки), имеющих разнообразные структурно-механические характеристики и функционально-технологические свойства, научно обоснован и направлен на разработку линейки структурированных молочных продуктов с функциональными пищевыми компонентами. В качестве целевой функции, подлежащей оптимизации, была выбрана вязкость, как показатель, характеризующий консистенцию и структуру вязких продуктов, к которым относится разрабатываемый творожный продукт. Анализ поведения полученной поверхности откликов показал, что оптимальной зоной вязкости творожного продукта, которые достигаются, когда массовая доля творога составит 89,6%, массовая доля криопорошка - 5,4% и массовая доля жира в сливках - 31,3%. Характерная вязкость для творожных продуктов составит 1400-2500 мПа·с. Анализ распределения ошибок прогноза значений вязкости дал удовлетворительные результаты: значительные часть точек заметно не отклонились от прямой, что дает адекватность полученной модели. Это говорит о формировании структуры молочных продуктов, где главную роль играет ферментированный белковый сгусток. Поэтому от его концентрации сильно зависит вязкость готового продукта, его консистенция и потребительские свойства.

Ключевые слова: оптимизация, рецептура, творожный продукт, криопорошок тыквы, творог обезжиренный, сливки, вязкость, трехуровний план Бокса-Бенкена.

Abstract. In the current market environment, producers of functional foods face a number of interrelated tasks. They must produce competitive products under import substitution conditions that meet established specifications, while also complying with regulatory requirements related to safety, quality, and the content of functional food ingredients, all while minimizing technological risks. To address this complex set of challenges, a conceptual and systematic approach is required, based on the principle of formulation optimization and the analysis of all factors affecting the quality and safety of products at all stages of their life cycle. This scientific study focuses on implementing the key objectives of the Republic of Kazakhstan in ensuring the population's access to products that comply with the principles of healthy nutrition. One of the relevant directions in the enrichment of dairy products is the use of plant-based raw materials that possess high nutritional and biological value. In recent years, this direction has been actively developing and is based on the justified selection of functional ingredients, taking into account both the nutritional and biological value and the functional and technological properties of the raw materials used. Scientific interest in plant-based raw materials is driven by the presence of biologically active substances that contribute to strengthening the body's protective functions, slowing down aging, and acting as natural structure-forming agents [1].

Materials and methods. The object of the study was a curd-based product with the addition of cryopowder. The formulation components used in the preparation of the curd product included low-fat curd, pumpkin cryopowder, and cream. Experimental research was conducted at the

Agricultural Faculty of the LLP «Kazakh Research Institute of Processing and Food Industry» during 2024-2025.

The study focused on analyzing the combined effect of the main formulation components on the viscosity of the curd product using a three-level Box–Behnken design, implemented through the Statgraphics Centurion 19 software package [2, 3].

Viscosity was selected as the key indicator of the consistency and structure of viscous products and served as the target function for optimizing the formulation of the developed curd product.A key role in the formation of the structure of dairy products is played by the fermented protein coagulate; therefore, its concentration significantly affects the viscosity of the final product, as well as its consistency and consumer characteristics [4, 5].

Three most important parameters in the production of curd products were selected as controllable factors: mass fraction of curd (x_1), mass fraction of cryopowder (x_2), and fat content in cream (x_3). The experimental design involved varying each factor at three levels according to the Box-Behnken design [6], while all other experimental conditions remained constant.

The results of the experiments were characterized by changes in the viscosity of the curd product (y). The number of experimental factors was 3, the number of experiments was 15 (including 3 center points), and the degrees of freedom for error were 5.

The variation levels of the controlled factors were established as follows:

-mass fraction of curd - from 70.0% to 90.0% - determined based on the dominant role of the dairy base in forming the product's structure and the dosage of the cream and cryopowder mixture;

-mass fraction of cryopowder - from 2.0% to 6.0% - established based on the rationale for incorporating functional ingredients;

-mass fraction of fat in cream - from 7.0% to 33.0% - determined based on the existing industrial practices of obtaining and using cream with this concentration in whole dairy production.

The coding and decoding of the factor levels are presented in table 1.

Table 1 - Decoded Values of the Factors

Factor of the Experiment	Designation	X_{min}	X_{i0}	X_{max}	ΔX
Mass fraction of curd, %	x_1	70,0	80,0	90,0	10,0
Mass fraction of cryopowder, %	x_2	2,0	4,0	6,0	2,0
Mass fraction of fat in cream, %	x_3	7,0	20,0	33,0	13,0

The viscosity of the curd product was determined using a Brookfield DV2T rotational viscometer.

Results and discussion. Viscosity studies were conducted on the prepared samples of the curd product, and the results are presented in table 2.

Table 2 - Results of the three-factor experiment for curd product samples with cryopowder

Experiment No.	Levels of controlled factors						Viscosity, mPa·s
	Coded Values			Actual Values			
	x1	*x2*	*x3*	T, %	K, %	C, %	*y*
1	0	0	0	80,0	4,0	20,0	2263,0
2	-1	-1	0	70,0	2,0	20,0	914,0

3	+1	-1	0	90,0	2,0	20,0	985,0
4	-1	+1	0	70,0	6,0	20,0	1062,0
5	+1	+1	0	90,0	6,0	20,0	2810,0
6	-1	0	-1	70,0	4,0	7,0	948,0
7	+1	0	-1	90,0	4,0	7,0	948,0
8	0	0	0	80,0	4,0	20,0	2269,0
9	-1	0	+1	70,0	4,0	33,0	2389,0
10	+1	0	+1	90,0	4,0	33,0	2364,0
11	0	-1	-1	80,0	2,0	7,0	952,0
12	0	+1	-1	80,0	6,0	7,0	961,0
13	0	-1	+1	80,0	2,0	33,0	1042,0
14	0	+1	+1	80,0	6,0	33,0	2501,0
15	0	0	0	80,0	4,0	20,0	2167,0

The analysis of variance for the viscosity of the curd product is presented in table 3.

Table 3 - Analysis of Variance (ANOVA) for the Viscosity of the Curd Product

Values	Sum of Squares	Difference	Mean Square	F-ratio	P-Value
x_1	402305	1	402305,	122,80	0,0080
x_2	1,48006	1	1,48006	451,79	0,0022
x_3	2,51665	1	2,51665	768,21	0,0013
${x_1}^2$	223444	1	223444,	68,21	0,0143
x_1x_2	703082	1	703082,	214,62	0,0046
${x_2}^2$	1,09369	1	1,09369	333,85	0,0030
x_2x_3	525625	1	525625,	160,45	0,0062
${x_3}^2$	389400	1	389400,	118,86	0,0083
Sum of squared deviations	645267	4	161317,	49,24	0,0200
The resulting error	6552,0	2	3276,0	-	-
Total	7,79676	14	-	-	-

The data in table 3 show that the analysis of variance separates the variability in the viscosity of the curd product into individual components for each of the effects. It then tests the statistical significance of each effect by comparing the mean square with the estimate of experimental error [7]. In this case, 8 effects have P-values less than 0.05, indicating that they differ significantly from zero at the 95.0% confidence level.

The lack-of-fit test is intended to determine whether the selected model is adequate for describing the observed data or if a more complex model should be used. The test is performed by comparing the variability of the residuals of the current model with the variability between observations at repeated settings of the factors [8]. Since the P-value for lack of fit in the ANOVA table is less than 0.05, there is statistically significant lack of fit at the 95.0% confidence level.

The R-squared statistic shows that the fitted model explains 91.6399% of the variability in the viscosity of the curd product. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 80.493%. The standard error of estimate indicates that the standard deviation of the residuals is 57.2364. The mean absolute error (MAE) of 172.633 is the average of the residuals. The Durbin-Watson (DW) statistic checks the residuals to determine whether there is any significant correlation based on the order in which they occur in the data file [9]. Since the P-value is greater than 5.0%, there is no indication of serial autocorrelation in the residuals at the 5.0% significance level.

The results of the model fitting for the viscosity of the curd product and the regression coefficients are presented in table 4.

Table 4 - Regression Coefficients

Coefficients	Values
Constant	-12150,4
x_1	332,175
x_2	-652,284
x_3	64,2389
x_1^2	-2,46
x_1x_2	20,9625
x_2^2	-136,062
x_2x_3	13,9423
x_3^2	-1,9216

Based on the regression coefficient, response surfaces and contour lines were constructed to show the influence of the mass fraction of added cryopowder of different types and the mass fraction of fat in the cream on the viscosity of the model mixture, which consists of a dairy base (low-fat cottage cheese, pumpkin cryopowder, cream, respectively).

Thus, the viscosity dependence on the parameters of the curd product with the addition of pumpkin cryopowder can be represented by the regression equation (formula 1):

$$\begin{aligned} y = & -12150.4 + 332.175x_1 - 652.284x_2 + 64.2389x_3 - 2.46x_1^2 \\ & + 20.9625x_1x_2 - 136.062x_2^2 + 13.9423x_2x_3 - 1.9216x_3^2 \end{aligned} \quad (1)$$

The obtained regression equations influence the main recipe parameters, response surfaces, and contour lines showing the impact of the mass fraction of different types of cryopowder and the mass fraction of fat in the cream. When developing the technology and formulations for the product range of structured dairy products with cryopowders, the main focus is on the viscosity of the dairy base, as well as the target and identification quality indicators of the finished products.

Based on the obtained regression equation, a model was constructed in three-dimensional space, representing a plane that characterizes the viscosity dependence on the parameters of the curd product. A visual representation of the contribution of independent factors is provided by the Pareto chart of standardized effects, shown in figure 1.

The standardized effect size indicates the direction and degree of deviation of the effect from the null model [10].

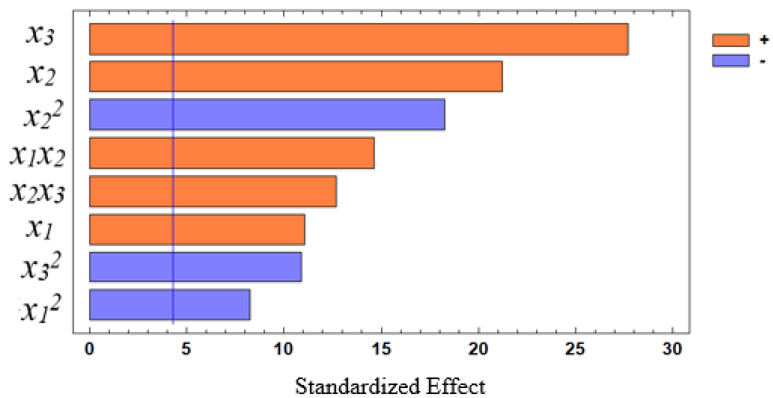

Fig.1 - Pareto Chart of Standardized Effects of Independent Factors on the Viscosity of the Curd Product

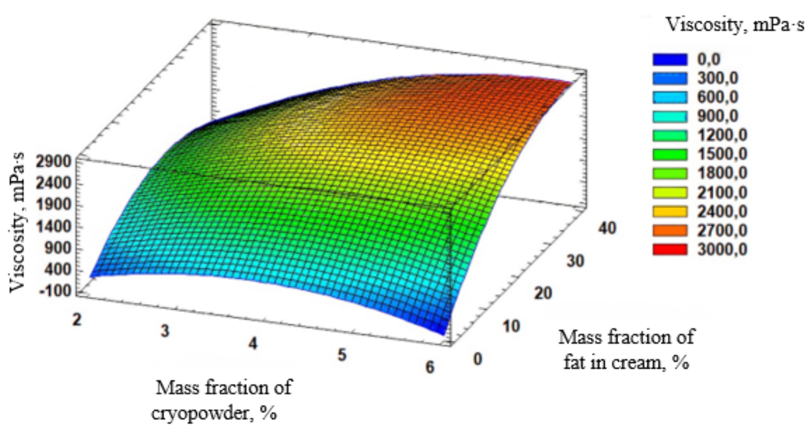

Fig.2 - Response surface of the dependence of curd product viscosity on the mass fraction of cryopowder and fat content in cream

The analysis of the Pareto chart shows the greatest contribution to the viscosity of the curd product from the mass fractions of cryopowder and fat in the cream [11].

Refining the effects of independent factors can be achieved by analyzing the response surfaces, which are 3D graphs of dependencies shown in figures 2-4. These graphs describe the influence of the mass fractions of dairy bases, cryopowders, and the fat content in the cream on the structural-mechanical properties of the model systems, and the response surfaces characterize the patterns of structure formation in products with cryopowders.

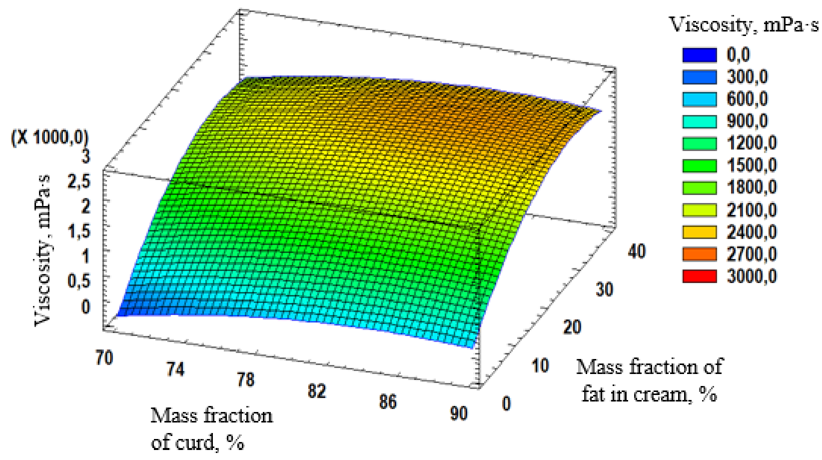

Fig.3 - Response surface of the dependence of curd product viscosity on the mass fraction of curd and fat content in cream

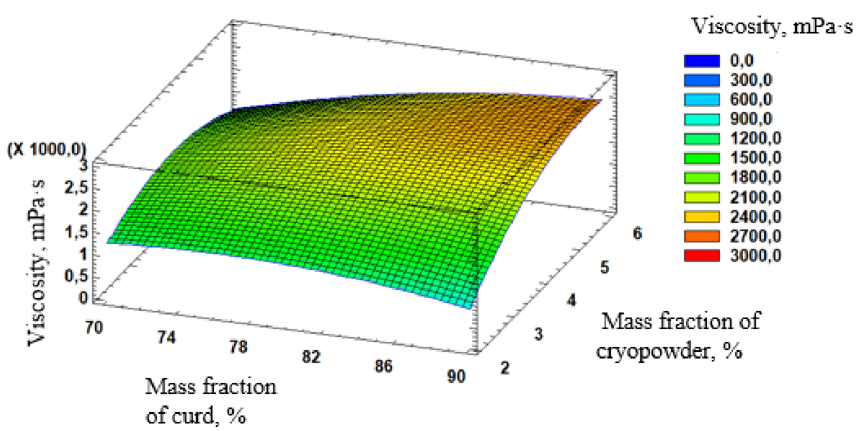

Fig.4 - Response surface of the dependence of curd product viscosity on the mass fraction of curd and cryopowder

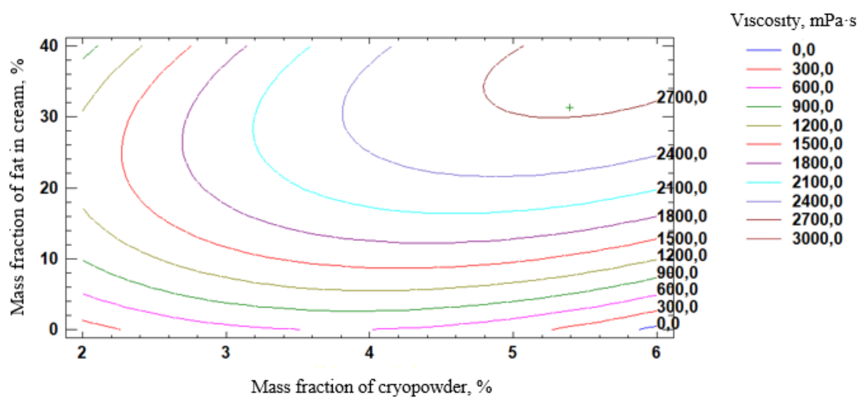

Fig.5 - Sectional projections of the response surface illustrating the dependence of curd product viscosity on the mass fraction of cryopowder and fat content in cream

As seen in figures 2-4, the construction of the response surface for the dependence of curd product viscosity on the mass fraction of curd and cryopowder must take into account that these two components influence the physicochemical properties of the mixture, including viscosity. The optimal ranges of curd product viscosity were established as follows: curd mass fraction - 89.6%, cryopowder mass fraction - 5.4%, and fat content in cream - 31.3%.

Figures 5-8 show sectional projections of the response surfaces illustrating the dependence of curd product viscosity on the mass fractions of cryopowder and fat in cream, which are key quality indicators of the final product.

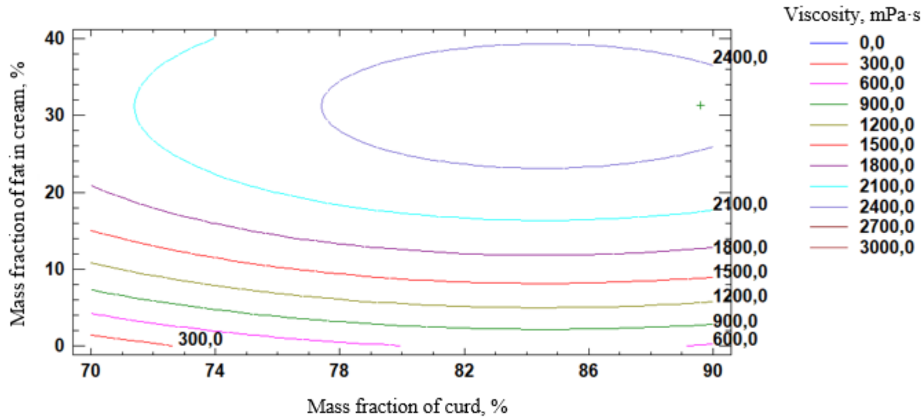

Fig.6 - Sectional projections of the response surface illustrating the dependence of curd product viscosity on the mass fraction of curd and fat content in cream

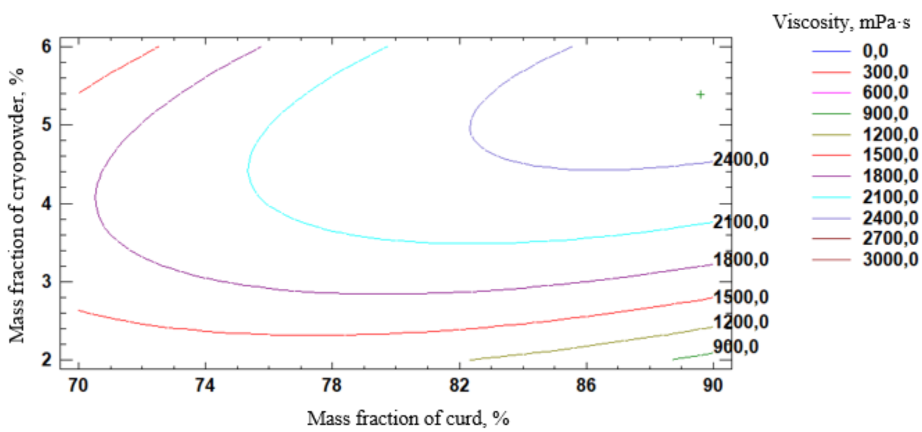

Fig.7 - Sectional projections of the response surface illustrating the dependence of curd product viscosity on the mass fraction of curd and cryopowder

The analysis of the response surface behavior demonstrated that the optimal viscosity range of the curd product is achieved at a curd content of 89.6%, cryopowder content of 5.4%, and cream fat content of 31.3%. The study of the error distribution in viscosity prediction showed that a significant number of points remained close to the line, indicating the accuracy of the developed model. Thus, the obtained results make it possible to determine the optimal formulation parameters of the curd product with the addition of cryopowder based on the developed mathematical model.

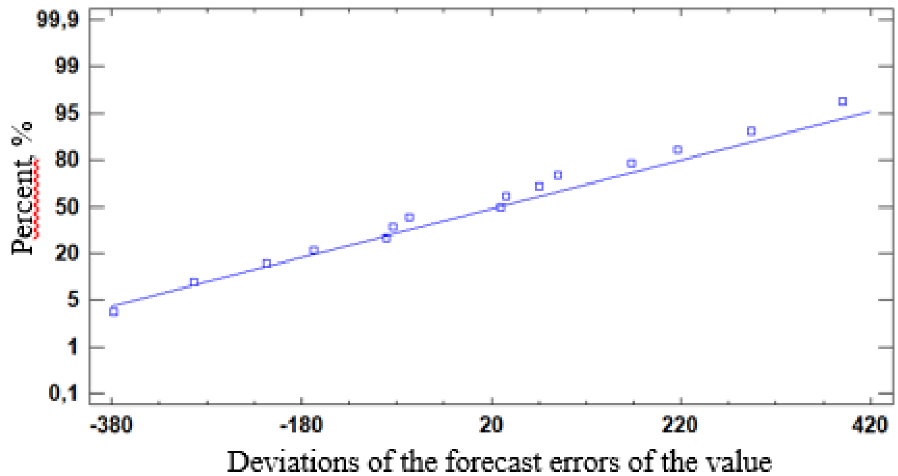

Fig.8 - Diagnostic plot of deviation of predicted viscosity error values from normal distribution

Conclusion. Summarizing the obtained data, the following conclusions can be drawn regarding the impact of the added cryopowders on the curd product:

-on taste, color, and aroma: The amount of cryopowder introduced into the dairy base affects the taste, color, and aroma of the curd product, implying the presence of dosage limitations for cryopowder addition;

-on the content of functional food ingredients: The amount of functional ingredients in the final product directly depends on the amount of added cryopowder;

-on viscosity: The addition of pumpkin cryopowders within the studied ranges provides the sample with a characteristic viscosity (for curd products - 1400-2500 mPa·s) and consistency. Within the studied concentration limits, cryopowders do not distort the product, making it possible and easy to vary their content to ensure the desired high flavor and color characteristics.

The above conclusions highlight the potential of using cryopowders in dairy production as a versatile solution for creating natural products with high nutritional and biological value. This approach also ensures compliance with established standards and target product characteristics, while enabling effective control over these parameters. By adjusting formulation variables such as the mass fractions of the dairy base, cryopowders, and cream (including their fat content), key quality indicators of the final product—such as nutritional value, content of functional ingredients, viscosity, and sensory properties—can be efficiently managed.

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