**UDC 637.3.04**

**МРНТИ 65.63.03**

**M.V. Temerbayeva 1\*, T.I. Uryumtseva1, L.S. Komardina1**

1Innovative University of Eurasia, Kazakhstan

(e-mail: marvik7@yandex.ru)

**Mathematical modeling of experimental data in the design of formulas for dairy products**

**Аbstract**

*Main problem:* the article is devoted to the issue of designing basic recipes for dairy products using mathematical modeling methods. The author analyzed the problems in the field of food technology and concluded that mathematical modeling is used in the following areas: clarification of technological process modes, designing recipes and assessing the quality of finished products, as well as predicting the shelf life of new products when they are put into production. The use of dihydroquercetin as a drug that prevents the oxidation of milk fat in the design of dairy products is substantiated. Mathematical modeling was carried out on the basis of experimental and analytical material obtained in laboratory and production conditions. Based on the maximum value of the objective functions, the optimal normalized mixtures and the maximum allowable concentration of dihydroquercetin were selected. The analysis of the received mathematical dependences and models is carried out, the system of linear equations is made.

*Purpose:* to study the effect of natural bioflavonoid antioxidant on the oxidative processes of milk fat and the viability of lactic acid cultures and their associations by mathematical modeling in order to use it in the technology of a new product; conduct an analysis of mathematical dependencies and models, compose a system of linear equations.

*Methods:* the article uses the method of mathematical analysis and the matrix method.

*Results and their significance:* a mathematical model was developed for the dependence of the viability of probiotic cultures on the mass fraction of dihydroquercetin when designing recipes for a creamy-protein curd product, a matrix of the chemical composition of dairy ingredients was presented, and a system of linear equations for basic recipes was compiled. In the course of the study, the spatial configurations of dihydroquercetin, as well as its effect on the oxidative processes of milk fat, were studied. Mathematical modeling of experimental data on the study of the effect of dihydroquercetin on the viability of microorganisms with probiotic properties was carried out. The normalization of the complex of obtained results on the study of the influence of the mass fraction of dihydroquercetin on the fermentation process was studied. Controlled factors characterizing the process of fermentation of model media with dihydroquercetin have been determined. A rationing of the dihydroquercetin complex of more than 0.50% was established; the target function decreases to its minimum value of

0.53 with a mass fraction of dihydroquercetin of 1.00%.

*Keywords:* mathematical modeling, dihydroquercetin, concentration, objective function, controlled factors, controlled factors.

**Introduction**

In the food industry, the use of mathematical methods has significantly expanded. This is due to the complication of technological processes, when any technically and economically unjustified solution leads to significant material losses. It is possible to avoid miscalculations in modern production conditions only by applying a strict quantitative assessment of technological processes based on mathematically described patterns of occurring phenomena. The translation of technological problems into a mathematical form allows not only to clarify the essential aspects of the problem itself, but also to significantly reduce the time and cost of solving it. Various mathematical methods are used both in the study and optimization of modes and parameters of various technological processes [1].

A large number of antioxidants of various activity and origin are known in the world. Dihydroquercetin, a biologically active flavonoid from Siberian larch, is known among them. Dihydroquercetin is currently the reference product, i.e. the product with the highest antioxidant activity.

Dihydroquercetin is presented as vitamin P and has the following characteristics: chemical formula - С15Н12О7; molecular weight - 304.26; it contains 2,3 - dihydro - 3,5,7 - trihydroxy - 2- (3,4

- dihydroxyphenyl) - 4H - 1 - benzopyran - 4 - OH. The chemical formula of dihydroquercetin is shown in Figure 1.



Figure 1 – Chemical formula of dihydroquercetin С15Н1207

There are four spatial configurations of dihydroquercetin – R, R; R,S; S,S; S,R (Figure 2).



Figure 2 – Spatial configurations of dihydroquercetin

As a substance with a high degree of biological activity, dihydroquercetin, as a P-vitamin, enhances capillary permeability, has a whole range of positive effects on metabolic reactions and the dynamics of various pathological processes in the human body. The doses of dihydroquercetin recommended by doctors, physiologists and biologists as a prophylactic agent in the composition of dietary supplements or food products are 140-160 mg per day [2].

Dihydroquercetin is non-toxic, harmless to humans, has high activity at low concentrations. It does not add extraneous tastes and odors and does not change the color of products, it is resistant to thermal and mechanical influences used in the manufacture of products, that is, it meets all the requirements for all food additives in general and, in particular, for antioxidants. Dihydroquercetin is included in the list of food additives that do not have a harmful effect on human health when used for food preparation [3].

The use of dihydroquercetin as a drug that prevents the oxidation of milk fat must be studied for each dairy product individually, taking into account its chemical composition, the amount of fat component and the production process, since dihydroquercetin can affect their effectiveness. In the technology of curd products, milk fat during heat treatment and mixing comes into contact with atmospheric oxygen, equipment walls, which lead to a decrease in its quality due to the development of oxidative processes. Least of all, this process has been studied in milk cream and fermented products, as a result of which the task was to investigate the effect of a natural bioflavonoid antioxidant on the oxidative processes of milk fat and the viability of lactic acid cultures and their associations in order to use it in the technology of a new product.

Given the above, the topic of this scientific study is relevant and timely.

**Materials and methods**

Normalization of the complex of the obtained results on the study of the influence of the mass fraction of dihydroquercetin on the fermentation process was carried out according to the maximum value of a homogeneous indicator according to the formula:

, (1)

The objective function was determined by the formula:

, (2)

Given that the duration of fermentation should be minimal, then the normalized value will enter the objective function with a minus sign [4]. Based on the maximum value of the objective functions, the normalized mixtures optimal for further research and the maximum allowable concentration of dihydroquercetin were selected, at which the optimal quality indicators and technological properties of the normalized mixtures are ensured.

**Results**

Mathematical modeling was carried out on the basis of experimental and analytical material obtained in laboratory and production conditions.

Rationing was carried out according to the following controllable factors presented in Table 1.

Table 1 – Controlled factors characterizing the process of fermentation of model media with dihydroquercetin

|  |  |  |  |
| --- | --- | --- | --- |
| Уi | Name of factors | Units of measurement | Optimal meaning |
| У1 | Fermentation time | in hours | ≤ 8,5 |
| У2 | Organoleptic evaluation | in points | → max (15) |
| У3 | Logarithm of the total number of microorganisms with probiotic properties | Colone-forming units/gram | Not < 8,0 |

The summary results of experimental studies to determine the main qualitative indicators characterizing the process of fermentation of model media in the presence of dihydroquercetin are shown in Table 2.

Table 2 – Summary of Experimental Data on Fermented Model Media

|  |  |  |
| --- | --- | --- |
| Experienced sample | Regulated factors | Controlled factors |
| Х1 (mass fraction ofdihydroquercetin, %) | У1 | У2 | У3 |
| Experience 1 | 0,000 | 8,0 | 10,0 | 9,991 |
| Experience 2 | 0,063 | 8,0 | 11,5 | 8,908 |
| Experience 3 | 0,125 | 8,2 | 12,0 | 8,903 |
| Experience 4 | 0,250 | 8,3 | 13,0 | 8,875 |
| Experience 5 | 0,375 | 8,5 | 13,5 | 8,778 |
| Experience 6 | 0,500 | 8,7 | 14,5 | 8,732 |
| Experience 7 | 0,625 | 9,0 | 14,0 | 8,000 |
| Experience 8 | 0,750 | 9,2 | 13,5 | 7,903 |
| Experience 9 | 0,875 | 9,3 | 13,5 | 7,778 |
| Experience 10 | 1,000 | 9,6 | 11,0 | 7,681 |

The calculation results of the objective function are presented in the form of Table 3.

Table 3 – Normalization of complex experimental data and calculation of the objective function

|  |  |  |
| --- | --- | --- |
| Position | Rationing of controlled factors | *F*13 |
| У1 | У2 | У3 |
| Experience 1 | 0,83 | 0,69 | 1,00 | 0,86 |
| Experience 2 | 0,83 | 0,79 | 0,89 | 0,85 |
| Experience 3 | 0,85 | 0,83 | 0,89 | 0,86 |
| Experience 4 | 0,86 | 0,90 | 0,89 | 0,92 |
| Experience 5 | 0,89 | 0,93 | 0,88 | 0,92 |
| Experience 6 | 0,91 | 1,00 | 0,87 | 0,97 |
| Experience 7 | 0,94 | 0,97 | 0,80 | 0,83 |
| Experience 8 | 0,96 | 0,93 | 0,79 | 0,76 |
| Experience 9 | 0,97 | 0,93 | 0,78 | 0,74 |
| Experience 10 | 1,00 | 0,76 | 0,77 | 0,53 |

Analyzing the results obtained, the values of the objective function, we can conclude that the optimal concentration of dihydroquercetin is observed in experiment 6 and is 0.50 %. It can be noted that with a mass fraction of dihydroquercetin of more than 0.50 %, the objective function decreases to its minimum value of 0.53 with a mass fraction of dihydroquercetin of 1.00 % Thus, in a normalized mixture, the mass fraction of dihydroquercetin in an amount of 0.50 % is optimal and maximum allowable.

The subject of further analytical studies is to study the dependence of the influence of the mass fraction of dihydroquercetin on the activity and viability of lactic acid microorganisms (L. bulgaricus, S. thermophilus) and bifidobacteria (Bifidobacterium lactis).

Based on a set of experimental data on the process of fermentation of model media, a model of the effect of dihydroquercetin on the activity of cultures with probiotic properties has been developed.

The mathematical description of the established dependence has the form:

f (x, y) = a + b·x + c·y + d·x·y + f·x2 + g·y2, Where х – mass fraction of dihydroquercetin, %; у – fermentation time, hours;

f (x,y) – logarithm of the total amount of microflora; a, b, c, d, f, g – coefficients.

At the next stage, the formulations of the dairy product were designed. A feature of the technology of the new product is the naturalness of its components: dairy and vegetable. The design of the basic recipe consisted of determining the quantitative ratio of dairy ingredients to ensure that the mass fraction of protein in the new product is at least 10%, the mass fraction of fat is from 5 % to 15 %. To solve this problem, ingredients were used, the chemical composition of which is given in Table 4.

Table 4 – Dairy Ingredients Chemistry Matrix

|  |  |  |
| --- | --- | --- |
| Ingredients | Mass fraction, % | Хi |
| drysubstances | including |
| fat | protein | carbohydrates |
| Milk protein concentrate | 20,0 | 3,11 | 10,0 | 4,3 | Х1 |
| Cream with a mass fraction of fat 25 % | 32,0 | 25,00 | 3,0 | 4,0 | Х2 |
| Cream with a mass fraction of fat 35 % | 42,0 | 35,00 | 3,0 | 4,0 | Х3 |
| Skimmed milk powder | 94,0 | 1,00 | 36,0 | 53,0 | Х4 |

Based on the data given in Table 4, a system of linear equations was compiled for the first basic product recipe (using milk cream with a fat mass fraction of 25%):- by fat (У1): 0,311Х1 + 0,25Х2 + 0,01Х4;

– for proteins (У2): 0,10Х1 + 0,03Х2 + 0,36Х4;

– by carbohydrates (У3): 0,043Х1 + 0,040Х2 + 0,53Х4;

– on dry matter (У0): 0,20Х1 + 0,32Х2 + 0,94Х4.

The following conditions are accepted in the basic recipe.

For a product with a mass fraction of fat 5 %:

У1 = 5 %;

У2 = 10 %;

У3 – not standardized, that is, in fact;

У0 = 32-33 %.

For a product with a mass fraction of fat 10 %:

У1 = 10 %;

У2 = 10 %;

У3 – not standardized, that is, in fact;

У0 = 38-39 %.

For a product with a mass fraction of fat 15 %:

У1 = 15 %;

У2 = 10 %;

У3 – не not standardized, that is, in fact;

У0 = 45-47 %.

The composition of the recipe in kg/ton is determined by the weight participation of the components and can be represented by the following equation:

Z0 = Х1 + Х2 + Х4 = 1000 (kilogram)

For the second version of the basic recipe for a new product in the equations, instead of cream with a mass fraction of fat 25 %, used cream with a mass fraction of fat 35 %:

– by fat (У1): 0,311Х1 + 0,35Х3 + 0,01Х4;

– for proteins (У2): 0,10Х1 + 0,03Х3 + 0,36Х4;

– by carbohydrates (У3): 0,043Х1 + 0,040Х3 + 0,53Х4;

– on dry matter (У0): 0,20Х1 + 0,42Х3 + 0,94Х4.

After determining the main recipe, the composition of the recipes will be determined in the assortment with the introduction of functional and flavoring additives.

**Discussion**

The effect of natural bioflavonoid antioxidant on the oxidative processes of milk fat and the viability of lactic acid cultures and their associations was studied by mathematical modeling in order to use it in the technology of a new product. Mathematical relationships have been established that characterize the viability of cells of probiotic microorganisms on the amount of dihydroquercetin in model media. The analysis of mathematical dependencies and models was carried out, a system of linear equations was compiled.

**Conclusion**

Analysis of the obtained mathematical dependencies and models allows us to draw the following conclusions:

For lactic acid microorganisms (L. bulgaricus, S. thermophilus), the optimal number of cells is observed in areas of response surfaces corresponding to the mass fraction of dihydroquercetin in the fermentation medium of 0.2-0.6 %.

The optimal amount of bifidobacteria (Bifidobacterium lactis) in the fermented medium is observed in areas of the response surfaces corresponding to the mass fraction of dihydroquercetin in the fermented medium in the range of 0.2-0.5 % during fermentation for 7.5-8.0 hours.

Based on the results of normalization of experimental data and analysis of mathematical models, the optimal mass fraction of dihydroquercetin (0.5 %) was established, which does not reduce the viability of microorganisms involved in the fermentation of the protein base (L. bulgaricus, S. thermophilus, Bifidobacterium lactis). Therefore, the level of dihydroquercetin in the composition of the product should not exceed the prescribed amount, which will ensure its quality and functional properties.

Thus, on the basis of the ingredients established experimentally, recipes will be drawn up that meet the regulatory requirements for a new product.

**THE LIST OF SOURCES**

1 Бочарова-Лескина А.Л. Математическое моделирование в технологии и оценке качества пищевых продуктов / А.Л. Бочарова-Лескина, Е.Е.Иванова // Научный журнал КубГАУ. – 2017. – № 125 (01). – С.1-10.

2 Леонтьева Н.В. Дигидрокверцетин – природный антиоксидант: учеб. пос. / Н.В.Леонтьева. – СПб: СЗГМУ им.И.И. Мечникова, 2016. – 36 с. – Режим доступа: https://dkv99.ru/images/ lbr/dkv2015.pdf

3 Костыря О.В. О перспективах применения дигидрокверцетина при производстве продуктов с пролонгированным сроком годности / О.В. Костыря, О.С.Корнеева // Вестник ВГУИТ. – 2015. –№ 4. – С.165-170.

4 Rebezov M.B. Mathematical modeling of the results of experimental studies of the influence of the type and dose of cheese melting salt on the qualitative indicators of melted cheeses /

**REFERENCES**

1 Bocharova-Leskina, A.L. (2017). Matematicheskoe modelirovanie v tekhnologii i ocenke kachestva pishchevyh produktov [Mathematical modeling in technology and food quality assessment]. Nauchnyj zhurnal KubGAU – KubSAU Scientific Journal, 125(01),1-10 [in Russian].

2 Leontieva, N.V. (2016). Digidrokvercetin – prirodnyj antioksidant [Dihydroquercetin is a natural antioxidant] . Saint-Petersburg: NWSMU named after I.I. Mechnikov [in Russian].

3 Kostyrya, O.V. (2015). O perspektivah primeneniya digidrokvercetina pri proizvodstve produktov s prolongirovannym srokom godnosti [On the prospects of using dihydroquercetin in the production of products with a prolonged shelf life] . Vestnik VGUIT – VGUIT Bulletin, 4,165-170 [in Russian].

4 Rebezov, M.B. (2020). Mathematical modeling of the results of experimental st**u**dies of the influence of the type and dose of cheese melting salt on the qualitative indicators of melted cheeses [Mathematical modeling of the results of experimental st**u**dies of the influence of the type and dose of cheese melting salt on the qualitative indicators of melted cheeses] . Vestnik Innovacionnogo Evrazijskogo universiteta – Bulletin of the Innovative Eurasian University, 3, 108-117.

**М.В. Темербаева1\*, Л.С. Комардина1, Т.И. Урюмцева1, Б.К. Дюсеналин1**

1Инновациялық Еуразия университеті, Қазақстан

Сүт өнімдерінің формулаларын жобалау кезінде эксперименттік деректерді математикалық модельдеу

Мақала математикалық модельдеу əдістерін қолдана отырып, сүт өнімдерінің негізгі формулаларын жобалау мəселесіне арналған. Автор тамақ технологиялары саласындағы мəселелерді талдап, математикалық модельдеу келесі бағыттарда қолданылады деген қорытындыға келді: технологиялық үрдістердің режимдерін нақтылау, формулаларды жобалау жəне дайын өнімдердің сапасын бағалау, сондай-ақ оларды өндіріске қою кезінде жаңа өнімдердің жарамдылық мерзімдерін болжау. Мақсатты функциялардың максималды мəніне сүйене отырып, оңтайлы қалыпқа келтірілген қоспалар жəне дигидрокверцетиннің шекті рұқсат етілген концентрациясы таңдалады. Алынған математикалық тəуелділіктер мен модельдерге талдау жасалды, сызықтық теңдеулер жүйесі жасалды.

Пробиотикалық дақылдардың өміршеңдігінің дигидрокверцетиннің массалық үлесіне тəуелділігінің математикалық моделі кремді ақуызды сүзбе өнімінің формулаларын жобалау кезінде жасалды, сүт ингредиенттерінің химиялық құрамы матрицасы ұсынылды, негізгі формулалардың сызықтық теңдеулер жүйесі жасалды. Зерттеу дигидрокверцетиннің кеңістіктік конфигурацияларын, сондай-ақ оның сүт майының тотығу үрдістеріне əсерін зерттеді. Дигидрокверцетиннің пробиотикалық қасиеттері бар микроорганизмдердің өміршеңдігіне əсерін зерттеу бойынша эксперименттік деректерді математикалық модельдеу жүргізілді. Дигидрокверцетиннің массалық үлесінің ашыту үрдісіне əсерін зерттеу бойынша алынған нəтижелер кешенінің қалыпқа келуі зерттелді. Дигидрокверцетинмен модельдік ортаны ашыту үрдісін сипаттайтын басқарылатын факторлар анықталды. Дигидрокверцетин кешені 0,50% - дан жоғары нормалау белгіленді, мақсатты функция оның ең төменгі мəні 0,53-ке дейін төмендейді.

Түйін сөздер: математикалық модельдеу, дигидрокверцетин, концентрация, мақсатты функция, басқарылатын факторлар, бақыланатын факторлар.

**М.В.Темербаева1\*, Л. С. Комардина1, Т.И. Урюмцева1, Б.К. Дюсеналин1**

Инновационный Евразийский университет, Казахстан

Математическое моделирование экспериментальных данных при проектировании рецептур молочных продуктов

Статья посвящена вопросу проектирования базовых рецептур молочных продуктов с применением методов математического моделирования. Автором проанализированы проблемы в области пищевых технологий и сделан вывод, что математическое моделирование применяется в следующих направлениях: уточнение режимов технологических процессов, конструирование рецептур и оценка качества готовых продуктов, а также прогнозирование сроков годности новых продуктов при постановке их на производство. На основании максимального значения целевых функций выбраны оптимальные нормализованные смеси и предельно допустимая концентрация дигидрокверцетина. Проведен анализ полученных математических зависимостей и моделей, составлена система линейных уравнений.

Разработана математическая модель зависимости жизнеспособности пробиотических культур от массовой доли дигидрокверцетина при проектировании рецептур сливочно- белкового творожного продукта, представлена матрица химического состава молочных ингредиентов, составлена система линейных уравнений базовых рецептур. В ходе исследования изучены пространственные конфигурации дигидрокверцетина, а также его влияние на окислительные процессы молочного жира. Проведено математическое моделирование экспериментальных данных по исследованию влияния дигидрокверцетина на жизнеспособность микроорганизмов с пробиотическими свойствами. Исследовано нормирование комплекса полученных результатов по изучению влияния массовой доли дигидрокверцетина на процесс ферментации. Определены управляемые факторы, характеризующие процесс ферментации модельных сред с дигидрокверцетином. Установлено нормирование комплекс дигидрокверцетина более 0,50 % происходит снижение целевой функции до ее минимального значения 0,53 при массовой доле дигидрокверцетина 1,00 %.

Ключевые слова: математическое моделирование, дигидрокверцетин, концентрация, целевая функция, управляемые факторы, контролируемые факторы.

**Сведения об авторах:**

**Темербаева М.В.** –техника ғылымдарының кандидаты, Инновациялық Еуразия университетінің профессоры, Павлодар қ., Қазақстан Республикасы.**Темербаева М.В. -**кандидат технических наук, профессор Инновационного Евразийского университета г. Павлодар, Республика Казахстан. **Timerbayeva, M.** – Candidate of Technical Sciences, Professor of Innovative Eurasian University, Pavlodar, Republic of Kazakhstan. E-mail: marvik75@yandex.ru.

**Урюмцева Т.И.** – ветеринария ғылымдарының кандидаты, Инновациялық Еуразия университетінің профессоры, Павлодар қ., Қазақстан Республикасы. **Урюмцева Т.И.** – кандидат ветеринарных наук, профессор Инновационного Евразийского университета г. Павлодар, Республика Казахстан. **Uryumtseva, T**. – Candidate of Veterinary Sciences, Professor of Innovative Eurasian University, Pavlodar, Republic of Kazakhstan. E-mail: vbh2@mail.ru.

**Комардина Л.С.** – Биология ғылымдарының кандидаты, Инновациялық Еуразия университетінің профессоры, Павлодар қ., Қазақстан Республикасы.**Комардина Л.С. -**кандидат биологических наук, профессор Инновационного Евразийского университета г. Павлодар, Республика Казахстан. **Komardina, L** – Candidate of Biological Sciences, Professor of Innovative Eurasian University, Pavlodar, Republic of Kazakhstan. E-mail: komardina57@mail.ru.

**Date of receipt of the manuscript to the editor:**