SECTION 3. FOOD AND LIGHT INDUSTRY TECHNOLOGY

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3.1 Optimisation of drying of Sorbus aucuparia fruit processing derivatives using the response surface methodology

Abstract. In any food production process, it is important not only to produce a high quality product, but also to minimise production waste and reduce energy consumption. In recent years, customers have also been paying particular attention to biological value, which has led to an increase in the popularity of natural products. Finding new types of unconventional raw materials and choosing a rational way to process them is an important task for scientists. **The object of study** in this case was the fruit of Sorbus aucuparia. **The purpose of the study** was to determine the influence of the interdependence of technological parameters and to establish the optimal parameters for rowan drying using the method of mathematical modelling, namely the response surface methodology. The process of processing Sorbus aucuparia fruit included preliminary freezing, defrosting, osmotic dehydration, drying and grinding. **Research methods.** The modelling and processing of experimental data was performed using the Statistica 10 package, namely, the construction of the experiment planning matrix in the form of a table, the finding of response functions, regression and analysis of variance models. The method specified in DSTU 8004:2015 was used to determine the mass fraction of moisture. The content of vitamin C in the experimental powder samples was studied using the HPLC method (high-performance liquid chromatography). **Results.** According to the solved model for all the presented rowan fruits, the optimal value is the drying temperature (50...55)°C, at which the maximum desirable value of moisture content, vitamin C content in products and attractive appearance are observed. A factor that affects the drying of wild berry derivatives is the duration of the process. The optimal value is a drying time of 110...120 minutes.

Conclusion. Using the method of mathematical modelling, namely, the methodology of response surfaces, the influence of the interdependence of

technological parameters and the establishment of optimal parameters for rowan drying were determined.

Keywords: Sorbus aucuparia; food additive; drying; osmotic dehydration; mathematical model

3.1.1 Introduction

One of the priorities of the food industry is to extend the shelf life of plant-based products and preserve their biological value.

Traditional methods of processing plant materials include heat treatment at high or low temperatures, dehydration and enzymatic preservation.

In the process of high-temperature heat treatment, changes occur in the structural-mechanical, physicochemical, biochemical, chemical, microbiological, organoleptic properties, nutritional and biological value of raw materials [79].

Fresh berries, which contain biologically active compounds, are perishable under natural conditions. Drying is one of the most effective processing methods that can extend the shelf life of berries, while retaining nutrients and active ingredients to a large extent. However, the taste and texture of the final product largely depend on the drying method [80].

Berry crops have a high water content (80–90 %). In addition to water, berries contain cell sap, which consists of undissolved nutrients and biologically active substances, nitrogenous substances, carbohydrates, vitamins, mineral salts and aromatic compounds. About 10...15 % of the total water is retained by plant colloids and requires significant energy consumption for its removal [81].

An experimental study [82] of drying viburnum berries at different temperatures of the drying agent (55, 70, and 85 °C) and air circulation rate (0.5 m/s) showed that the samples obtained almost did not differ in most physical properties, except for skin hardness and elasticity. However, a significant difference was found in the drying time of the berries. At a hot air velocity of 0.5 m/s, the drying time for viburnum fruit was more than 44 hours at 55 °C and approximately 7 hours at 85 °C.

In modern practice, infrared dryers are increasingly being used to dry food products, which have several advantages. These include shorter process times due to high drying speeds, energy savings, greater control over temperature conditions, improved product quality, lower environmental impact, and the ability to combine with other dehydration methods. The combination of infrared radiation with other drying methods is a very promising area, as it not only speeds up the process but also preserves the quality of products [83].

The infrared drying method is based on the use of infrared radiation properties. Its safety for the environment and humans is a primary advantage. Infrared rays of a certain wavelength are absorbed not by the tissues of the fruit, but by the water contained in them, which allows moisture to be removed at low temperatures (up to 50 °C). This approach prevents cell destruction, which makes it possible to preserve almost all the content of vitamins and other biologically active substances up to 90 % of the original raw material. In addition, this method ensures that the natural aroma and colour of the product is preserved [84].

There are already studies on the impact of different drying conditions on strawberry quality. The drying time decreased with increasing infrared power, temperature and air speed. Increasing the power from 100 W to 300 W, the temperature from 60 to 80 °C and the speed from 1.0 m/s^1 to 2.0 m/s^1 reduced the fruit colour quality index. In terms of total phenol and anthocyanin content, 300 W, 60 °C and 1.0 m/s^1 were superior to the other experimental conditions. Drying processes increased the content of N, P and K and decreased the content of Ca, Mg, Fe, Mn, Zn and Cu. The optimal conditions for nutrient retention during infrared drying of strawberries were 200 W, 100 °C and 1.5 $m.s^1$ [85].

Osmotic dehydration is an effective method of preliminary preparation of raw materials before drying, which allows improving the quality of dried products and preserving their sensory properties and biological value [86].

During osmotic dehydration, plant materials are immersed in a hypertonic solution, where they absorb exogenous fluid. This process partially removes water from the cells, which facilitates the subsequent removal of moisture during drying [87].

As a result of osmotic dehydration, the concentration of valuable substances in the raw material increases and the drying time decreases, which helps to maintain product quality [88].

Known methods of drying wild berries require the use of high temperatures, which can cause significant losses of nutrients, which can range from 20 % to 80 % [89].

In [90], infrared drying tests were carried out at temperatures of 60, 70, 80 and 90 °C to assess the drying rate, as well as the colour and texture of the finished product.

There is also a study of Ugni molinae Turcz berries to determine the drying characteristics and compare the quality of the dried product under convective and combined convective-infrared conditions at temperatures of 40, 50 and 60 °C and power of 400-800 W [91].

There are also results of a study where the optimal conditions for drying grapes and goji berries were infrared heating at a temperature of 65 °C, with a drying time of about 720 minutes for grapes and 450 minutes for goji berries [92].

Pointing et al. [93] were the first to develop osmotic dehydration of food products.

Vial [94] and Heng et al. [95] studied the kinetics of osmotic dehydration of papaya and kiwi in sucrose and glucose solutions.

Torregianni [96] investigated the quality of osmotically treated cherries and analysed sugar content, colour, acidity, vitamin C content, pH and organoleptic characteristics.

Mass transfer during osmotic dehydration of pineapple was studied by Beristain et al. [97].

Pragati et al. [98] investigated the effect of drying methods on the nutritional composition of dehydrated amla fruit (Emblica officinalis Garten) during storage. The fruits were dried using different methods, namely air drying, direct sun drying, indirect sun drying and oven drying. It was observed that the air drying method resulted in better preservation of nutrients such as ascorbic acid and sugar. Tannin levels were found to be lower in air-dried amla compared to other drying methods.

El-Aouar et al. [99] studied the effects of two different osmotic agents (sucrose and corn syrup) on the osmotic dehydration of papaya (Carica papaya L.) slices. The dehydration in sucrose solutions was higher than in corn syrup solutions, which is explained by their higher viscosity and polysaccharide content.

Haj Najafi et al. [100] studied the effect of the osmotic dehydration process on the mass transfer and quality characteristics of red pitaya (Hylocereus polyrhizusis) using a sucrose solution at 35ºC. The sucrose solution was used at concentrations of 40, 50 and 60 per cent. It was observed that increasing the sucrose concentration and dehydration time resulted in softer tissue of the dehydrated product and a discolouration compared to fresh red pitaya.

Ibitwar et al. [101] studied the effect of different osmotic agents (sugar and sugar glycerol) on the increase in dry matter and water loss during osmotic dehydration of plums. Drying was carried out at 45, 55 and 65°C. It was found that osmotic dehydration followed by air drying resulted in a shorter drying period and a reduction in total convective dehydration time by 240 min and 120 min in sugar and sugar-glycerol solutions, respectively, compared to convective air drying. The drying rate curves did not have a constant period and showed a linear decrease in rate throughout the drying process.

Taking this into account, the aim of the work was to the purpose of the study is to determine the influence of the interdependence of technological parameters and to establish the optimal parameters of rowan drying using the method of mathematical modelling, namely, the response surface methodology.

3.1.2. Experimental part

3.1.2.1. Procurement of Raw Materials. The raw material for the production of food powdered additives from berry processing derivatives is the fruit of the common rowan (Sorbus aucuparia), which is harvested in Sumy region. Vegetable powders made from berry derivatives are produced from high-quality fruit and berry raw materials that are not damaged by diseases and pests. Processing of fruits and berries with signs of decay is not allowed. Fruits were harvested at the state of consumer ripeness, when they are fully formed, have acquired the colour, taste, aroma and dense flesh characteristic of the variety.

3.1.2.2. Pretreatment of Raw Materials – osmotic dehydration. We have developed a technology [102] that involves the processing of wild berries into functional powders. It differs from other methods of powder production by using osmotic dehydration before drying. Preliminary dehydration of berries takes place in a concentrated (70 %) sugar solution. After separation from the osmotic solution, the berries are dried in infrared dryers at 50 °C to a moisture content of 7–10 %. This method reduces energy consumption by shortening the drying time.

3.1.2.3. Development of dry wild berries and their powders. The dried berries are crushed to a powdered structure and then sorted into fractions of different degrees of dispersion. The dried material is ground to a powdered structure using a laboratory disc mill LZM-1 and sieved using a set of brass sieves № 045, № 035 and № 016.

3.1.2.4. Experimental design for optimization of drying Sorbus aucuparia L.

The optimisation of the parameters of drying rowan fruit derivatives consisted in choosing the most effective variant of technological processes.

The optimal parameters for drying rowan fruit derivatives were determined by analysis of variance and regression. The method of mathematical modelling, in particular, the methodology of response surface on the data of a full-factorial experiment, was used.

Temperature (t, °C) and duration (τ, min) were chosen as controlling factors (independent variables). The control parameters (dependent variables) are humidity (φ, %), vitamin C content (C, mg/100 g), and appearance (A, point).

To create an experiment planning matrix, we plan to change the control factors at three levels: X_o, -X; +X, with a variation step of ±Δ . The levels of variation of the control factors of the full-factor experiment are presented in Table 1.

Table 1.

Levels of variation of controlling factors in the system of drying rowan fruit processing derivatives

Operation	Designation	Control parameters	
		t, °C	τ, min
Variation interval	±Δ	5	30
Levels:			
zero	0	55	90
lower	–1	40	30
upper	+1	70	150

The modelling and processing of experimental data was performed using the Statistica 10 software (Statsoft Inc., USA), namely, the construction of the experiment planning matrix in the form of a table, the finding of response functions, regression and variance analysis of models.

The adequacy of the developed models was checked by the method of analysis of variance. For the adequacy of the models, the level of significance of the loss of consistency for the models should be $p \leq 0.05$ and the value of the determination coefficients (R^2, R^2_{adj}) should be close to one, the calculated Fisher's criterion ($F_{calculated}$) should be greater than the tabulated one (F_{table}).

3.1.2.5. Physicochemical analysis of wild berries powders.

To determine the mass fraction of moisture, the method defined in DSTU 8004:2015 was used. A pre-dried and weighed burette with a glass rod, lid, and sand was used to weigh a crushed PPR sample weighing 5 grams. The burette with the sample was placed in a drying oven heated to a temperature of (105 ± 2) °C. The drying time was started when the thermometer read 105 °C. After 40 minutes of drying, the bays with the sample were loosely covered with lids, placed in an evaporator for 20 minutes, and then tightly closed with lids and weighed.

The mass fraction of moisture (x) in percent was calculated by the formula:

$$W = \frac{m1 - m2}{m1 - m3} * k, (1)$$

where m_1 is the mass of the burette with lid, stick, sand and suspension before drying, g;

m_2 is the mass of the flask with lid, stick, sand and suspension after drying, g;

m_3 is the mass of the flask with lid, stick and sand, g;

K - correction factor.

The content of vitamin C in the experimental powders samples was studied using the HPLC method (high-performance liquid chromatography). For this purpose, an Agilent Technologies 1200 apparatus with a UV-Vis Abs detector was used, which operated at λ = 240 and 300 nm. The column used for the analysis was a C18 (Zorbax SB-C18) with dimensions of 4.6 × 150 mm and a 5 µm mesh. The mobile phase consisted of methanol and 0.02M KH2PO4 solution in a ratio of 20:80. The analysis was performed using isocratic processing with an elution rate of 1 mL/min and an analytical column temperature of 40 °C. The injection volume was 20 µl.

Samples were extracted by adding 20 ml of mobile phase to powdered samples weighing 1 gram and liquid samples in a volume of 5 ml. After extraction, the samples were centrifuged three times for 10 minutes at 10,000 rpm using an OPN-12 centrifuge. The extracts were filtered using an Agilent PTFE filter with a mesh size of 0.45 µm.*2.6.*

Statistical Analysis.

In order to avoid systematic errors, the study was conducted in a randomised manner – the experiments were conducted not sequentially as specified in the plan, but in a random order. Each series of experiments (N = 9) was repeated 3 times.

The mathematical and statistical processing of the obtained results was carried out on a computer using Statistica 10 software (Statsoft Inc., USA). The determined value of the reliability of the deviation (p) does not exceed 0.05, which indicates that the value of the accuracy indicator (P) of the results is more than 0.95.

3.1.3. Research results and their discussion

Since the design of a full-factorial experiment creates a matrix of two control factors (t, τ) at three levels of change (X_o, -X; +X), the experiment will be carried out according to the number of sufficient experiments, which is calculated by Eq:

$N=3^n=3^3=9$. Thus, 9 experiments are sufficient to implement all possible combinations of changes in the control factors. The matrix-plan of the full-factorial experiment and the averaged results of moisture content (φ, %), vitamin C content (C, mg/100 g) and appearance (A, point) under the determined control factors are shown in Table 2.

Table 2.

Matrix-plan of a full-factor experiment of the influence of controlling factors on control parameters and averaged research results in the system of drying rowan fruit processing derivatives

No. of experiment	**Indication of the level of change of factors**		**Controlling factors**		**Control parameters**		
	t, °C	**τ, min**	**t, °C**	**τ, min**	**φ, %**	**C, mg/100 g**	**A, point**
1	-1	-1	40	30	33,5	12,1	2,1
2	-1	0	40	90	27,2	8,5	2,3
3	-1	+1	40	150	16,7	4,1	3,2
4	0	-1	55	30	23,5	7,5	2,5
5	0	0	55	90	7,5	1,7	4,5
6	0	+1	55	150	6,0	1,4	4,0
7	+1	-1	70	30	18,5	6,5	2,8
8	+1	0	70	90	7,5	1,4	4,0
9	+1	+1	70	150	4,5	1,0	3,9

At the first stage of mathematical processing of the experimental results, the significance of individual components of the mathematical model – regressors – was assessed, and the adequacy of the obtained mathematical model for obtaining powders of rowan fruit derivatives was evaluated.

The analysis of variance of the influence of controlling factors on the control parameters of obtaining powders derived from the processing of rowan fruit is presented in Table 3.

Table 3

Dispersion analysis of mathematical models for drying rowan fruit processing derivatives

Controlling factors		SS	d*f*	MS	Fisher's criterion	
					$F_{calculated}$	F_{table}
Moisture, %	Temperature, °C	430,447	2	215,223	25,719	5,99
	Duration, min.	407,420	2	203,710	24,343	5,99
	Net error	33,473	4	8,368		
	SS	871,340	8			
	R^2	0,962				
Vitamin C content, mg/100 g	Temperature, °C	50,149	2	25,074	17,832	5,99
	Duration, min.	68,936	2	34,468	24,513	5,99
	Net error	5,624	4	1,406		
	SS	124,709	8			
	R^2	0,955				
Appearance, point	Temperature, °C	2,362	2	1,181	5,111	5,99
	Duration, min.	2,816	2	1,408	6,091	5,99
	Net error	0,924	4	0,231		
	SS	6,102	8			
	R^2	0,849				

The variance analysis confirmed the significance of the selected control factors according to the Fisher's criterion: $F_{calculated} > F_{table}$, where $F_{calculated}$ is the calculated Fisher's criterion, F_{table} is the critical Fisher's criterion. Accordingly, according to the analysis of variance, the control factors for which the value of the calculated Fisher's criterion is greater than the critical value ($F_{calculated} \geq F_{table}$ (5.99)) are considered significant, that is, capable of influencing and effectively moving the drying process towards the goal – the maximum of the control parameters. Thus, the duration and temperature of drying are significant factors for the presented mathematical models of drying rowan fruit derivatives.

The adequacy of the mathematical models was checked by the determination coefficient R^2, which numerically expresses the proportion of variations in the dependent variables – the higher the R^2 value, the greater the proportion of variations explained by the variables included in the mathematical model.

The coefficient of determination (R^2) in the mathematical models (Table 3) is as close as possible to one, so the studied mathematical models are adequate and suitable for calculating the optimal values of the control factors.

The regression analysis performed in Statistica software in the mathematical models of drying rowan fruit processing derivatives was used to calculate the coefficients for the variables of the regression equation and to determine their significance. The results are summarised in Table 4.

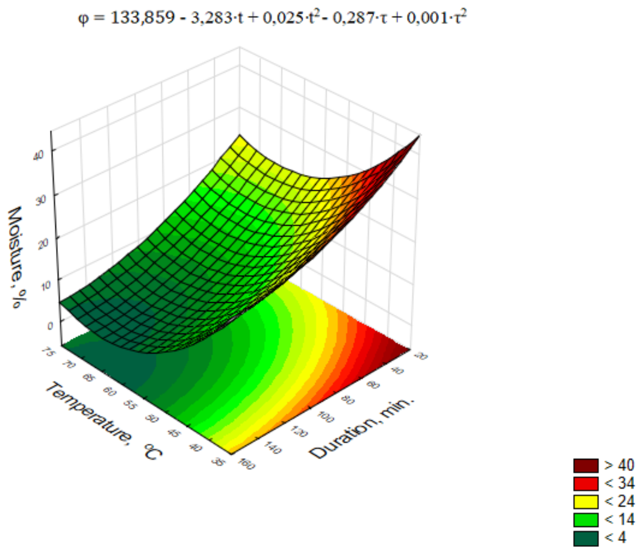
Table 4.

Regression analysis of mathematical models for drying rowan fruit processing derivatives

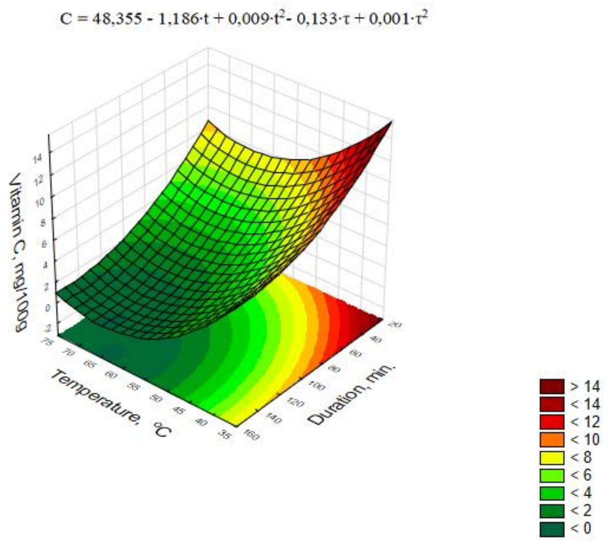
Controlling factors		**Control parameters**				
		Mean / Interc.	**t**	**t^2**	**τ**	**$τ^2$**
Moisture, %	Coefficient on variables (b)	133,859	-3,283	0,025	-0,287	0,001
	Standard errors of estimates (S_b)	26,767	1,003	0,009	0,104	0,001
	Student's criterion (t – criterion)	5,001	-3,273	2,762	-2,752	1,491
	Significance level (p)	0,007	0,031	0,005	0,005	0,021
Vitamin C content, mg/100 g	Coefficient on variables (b)	48,355	-1,186	0,009	-0,133	0,001
	Standard errors of estimates (S_b)	10,972	0,411	0,004	0,043	0,001
	Student's criterion (t – criterion)	4,407	-2,884	2,465	-3,110	1,868
	Significance level (p)	0,012	0,045	0,006	0,036	0,014
Appearance, point	Coefficient on variables (b)	-8,262	0,336	-0,003	0,036	-0,001
	Standard errors	4,448	0,167	0,002	0,017	0,001

Controlling factors		Control parameters				
		Mean / Interc.	t	t^2	τ	τ^2
	of estimates (S_b)					
	Student's criterion (t – criterion)	-1,857	2,015	-1,814	2,086	-1,519
	Significance level (p)	0,013	0,011	0,014	0,011	0,020

The mathematical equations of the mathematical models and a visual representation of the response functions, which depicts the nature of the influence of control factors on the drying of wild berry processing derivatives, are shown in Fig. 1.



a



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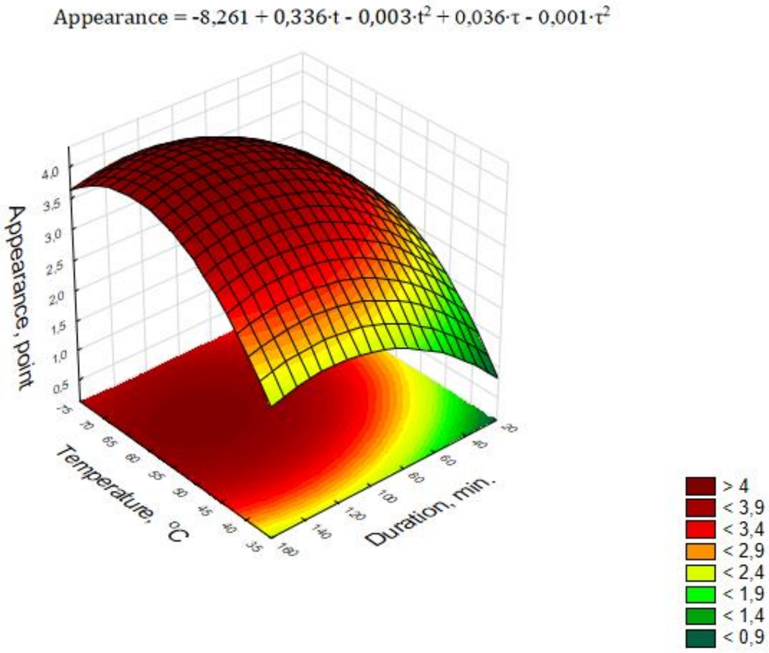

c

Figure 1 - Changes in control parameters from controlling factors during drying of rowan fruit derivatives:

a) moisture content, %; b) vitamin C content, mg/100g; c) appearance, point

Determining the optimal rational drying parameters means selecting such modes that will ensure the minimum duration and energy consumption of the process, and the output will be a product with the highest possible technological properties, nutritional and biological value.

The constructed response surfaces (Fig. 1 a) show that the minimum moisture content in the powders of rowan fruit derivatives is observed in the temperature range (60...70)°C. The optimum drying temperature was chosen taking into account energy consumption and product quality indicators. From the point of view of energy consumption, the shorter the drying time, the higher the degree of heat utilisation, but product quality is also strongly influenced by the temperature. Therefore, the drying temperature was selected to ensure that the drying time was kept to a minimum and the resulting powder was of the highest quality. The analysis of the response surfaces in Fig. 1b shows that high temperature values contribute to a decrease in the vitamin C content. At low temperatures and at high temperatures, the appearance of the resulting dry products is not satisfactory, characterised by low scores. According to the solved model for all the presented rowan fruits, the optimal value is the drying temperature (50...55)°C, at which the maximum desired value of moisture content, vitamin C content in products and attractive appearance are observed.

A factor that affects the drying of wild berry derivatives is the duration of the process. If the time is not rationally chosen, energy consumption increases, and vice versa, if the process is not carried out sufficiently, the quality of the finished product decreases. The analysis of the response surfaces in Fig. 1b show that with an increase in drying time, the moisture and vitamin C content decrease, the latter being undesirable. The optimal value for solving this model is the drying time (110...120) min.

Rowan berries (Sorbus aucuparia) are known for their high vitamin C content, making them a valuable addition to the diet for boosting immunity and overall health. Rowan is reported to contain three times more ascorbic acid than oranges [103].

The results of the study of the vitamin C content in powdered food supplements and raw materials are shown in Figure 2.

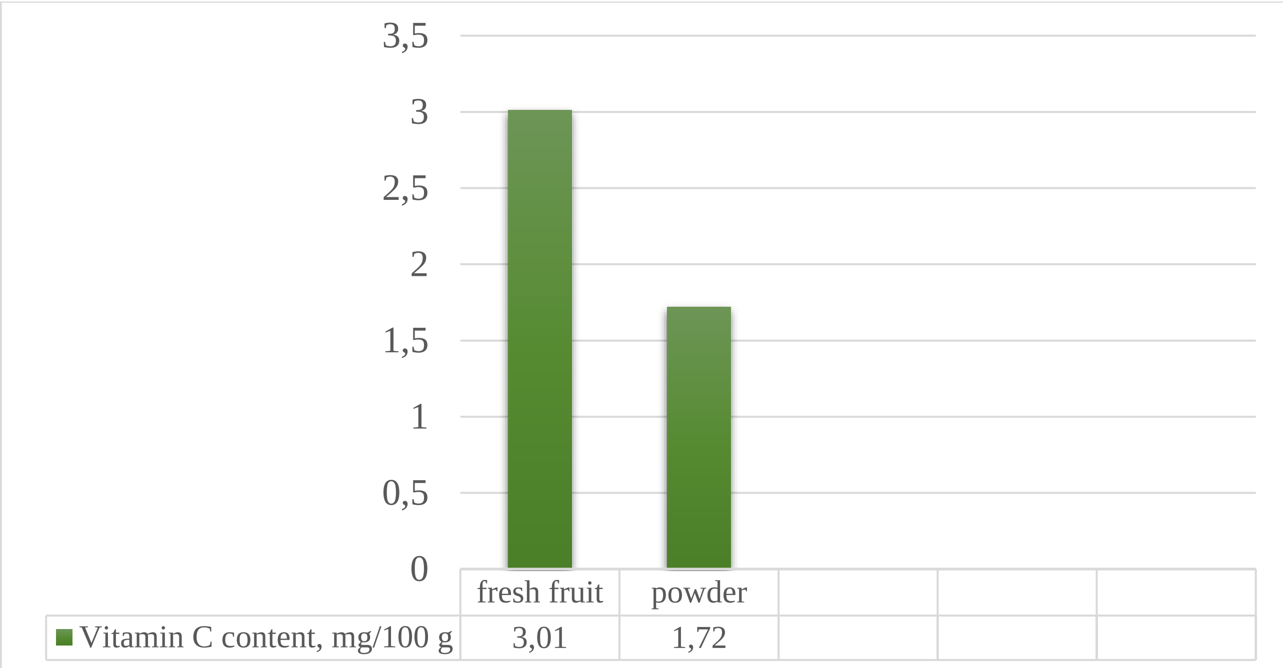

Figure 2 - Vitamin C content in fresh rowan fruit and powders

The proposed method of processing rowan fruit, using osmotic dehydration, allows preserving the content of vitamin C in their processed products by 72%.

According to some scientists [104], the content of ascorbic acid in rowan fruits and their processed products is about 0.10-0.42 mg/g. The recommended intake of ascorbic acid is 60 mg per day. When freshly frozen rowan berries are stored in a starch-sugar mixture, the vitamin C content decreases by 33-40% [105], and the shelf life of such berries is only 6 days. Using our proposed processing method, the shelf life of the powders is 12 months.

3.1.4. Conclusion

Osmotic dehydration is an important stage in the production of dried food products, which allows improving the quality and preserving the valuable properties of raw materials.

Using the method of mathematical modelling, namely, the methodology of response surfaces, the influence of the interdependence of technological parameters and the establishment of optimal parameters for rowan drying were determined.

Summarising the results of the experimental data, planning the experiment with the establishment of an adequate mathematical model and its solution, the optimal technological parameters for drying rowan fruit derivatives and obtaining powders were determined in the final version: temperature – (50...55) °C; duration – (110...120) min.