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Mathematical Modeling and Optimization of Technological Modes for Obtaining Pectin from Melon

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ABSTRACT
The article presents the results of studies of pectin-containing melons from melon crops of the Torpedo variety, the most common in the southern region of Kazakhstan, including Kyzylorda, Turkestan, Zhambyl, Almaty, and Zhetysu regions. Melons, after ripening, require special processing and storage conditions; under unfavorable conditions, they quickly deteriorate and become unfit for consumption. In this regard, there is a need to reduce melon losses to a minimum using resource-saving integrated technology for processing melons into components: peel, pulp, and seed materials. Based on their deep processing, it will receive nanostructured powders from these components. Studies of the content of pectin and other chemicals allow us to scientifically substantiate the principles of constructing a technological scheme for processing melons and the effective use of component powders for food production, depending on the content of pectin and other chemical elements. In this article, the effects of different hydromodule ratios on pectin yield are studied in detail. At the same time, special attention is paid to the content and production of pectin under optimal conditions of the hydromodule (1:10), taking into account the influencing technological factors such as acidity (K, deg) temperature (t, ℃) and the duration of pectin extraction (τ, hour). The article presents the scientific and practical values of pectin substances from melon and comprehensively analyses all areas of influence and technological factors on 12 quality and safety indicators from y_1 to y_{12} pectin extract. Regression models have been developed to describe their changes. For the first time, mathematical modeling and optimization of technological modes of pectin obtained from extracts of the melon variety "Torpedo" were built.

Keywords: Melon, Hydro Modulus, Pectin, Mathematical Modeling, Optimization of Extract Modes.
Article type: Research Article.

INTRODUCTION
Pectins are natural compounds that are widely used in industry. In the food industry, they are used to produce marshmallows, marmalade, jams, jams, sausages, juices, yogurts, and some other products. In medicine and pharmaceuticals - in the production of baby granules, suspensions, and gels- to add viscosity to emulsions, bind heavy metal ions, treat wounds, develop nutrient media, etc. In the cosmetic industry, they are used to produce some face masks and gels. The traditional technology of pectin involves using caustic mineral acids, alkalis, ethyl alcohol, and other chemical and explosive substances, which fails to ensure environmental cleanliness and waste-free production and increases the requirements for equipment (Donchenko & Firsov 2006). Modern technologies for producing pectin can fundamentally differ in the method of conducting the process, unique methods of extraction (ultrasound, freezing, electric field), and instrumentation (from the use of standard equipment to the use of specially designed equipment). It should be noted that the world's leading pectin producers use specially designed or modified equipment. Methods for extracting pectin substances with high-quality indicators without aggressive media have been developed (Iskakova *et al.* 2021). The development of a technology for extracting

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pectin products with desired properties from various plant raw materials of Kazakhstan will allow in the future to organize the production of pectin products and biological products with high physiological activity for their use not only under conditions of acute exposure to metals but also with their long-term intake into the body, which is just typical for ecological the load of residents of industrial regions and the modern metropolis (Kizatova *et al.* 2020). The isolation of pectin from the composition of the melon is a complex technological process, and it is necessary to establish the optimal conditions of the hydromodule for the maximum extraction of pectin-containing substances from the pomace of the melon. The object of the study is the most common melon variety, "Torpedo," in the South of the country. Therefore, our earlier study made it possible to establish that this variety is suitable for obtaining a pectin-containing extract. The results of studying the optimal technological regimes (hydraulic modulus, pH, temperature, extract time) made it possible to establish the maximum level of pectin yield in the range from 0.68% to 0.72% (Donchenko 2000; Uikassova *et al.* 2022). The paper presents in detail the study's results on the following values of the hydromodulus: 1:4, 1:6, 1:8, 1:10, 1:12, 1:14, and 1:16, depending on the pH environment, extract temperature, and exposure time in hours. In all experiments, the optimal conditions for the isolation of pectin extracts from the pomace of the melon "Torpedo" refer to the hydromodulus 1:10 (Iskakova *et al*. 2021; Uikassova *et al.* 2022). Taking into account the obtained data on optimal conditions, we developed mathematical modeling and optimized technological modes for obtaining pectin from the marc of the melon variety "Torpedo" with a hydro modulus of 1:10. A matrix of the planned PFE experiment was compiled -2^3, containing eight experiments. For each experiment, identifying such indicators as:

y_1, mass fraction of pectin%, y_2 mass fraction of vitamin C, mg/%, y_3 – mass fraction of carotene, mg/%; y_4- total sugar, %, y_5- glucose, fructose, %, y_6- sucrose, %, y_7- vitamin A mg/100g, y_8- vitamin E, mg/100, y_9- potassium mg/100g, y_{10}- iron, mg/100g, y_{11}- QMAFAMnM, CFU, 10^{-3}/g, y_{12}- mold, CFU/g (Jyotsana & DelGiorno 2022; Kulazhanov *et al.* 2021). We have obtained regression models for all these indicators that describe the change in their value from technological regimes (from acidity K, deg, temperature t ℃, and extraction time, τ hour). Linear and non-linear optimization models were compiled based on regression models. As an objective function, in one option, the maximum yield of pectin (y_1), and in another embodiment, the minimum content of microorganisms (y_{11}). Restriction functions were the remaining indicators y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9, y_{10}, y_{12}. Solutions of the optimization models made it possible to establish the optimal technological regimes for extracting pectin substances from the pomace of the melon variety "Torpedo." Based on the preceding, the work aims to establish the best conditions for the hydro module to maximize the extraction of pectin extracts from the pomace of the melon variety "Torpedo," the compilation of mathematical modeling and optimization of technological modes for obtaining pectin from melon.

To achieve the goal of scientific work, we considered the following tasks:

- Study the optimal technological regimes (hydraulic modulus and pH - environment) when obtaining a pectin-containing extract from the pomace of melon variety "Torpedo."
- Study the optimal technological regimes (hydraulic modulus, temperature) when obtaining a pectin-containing extract from the pomace of the melon variety "Torpedo."
- Studies the optimal dose and exposure time for the enzyme complex during the enzymatic extraction of pectin from the pomace of melon variety "Torpedo"
- conducting a study based on full factorial experiments (PFE-2^3) and developing regression mathematical models describing the change in pectin indicators from technological modes (K-acidity, deg, t^0C- extract temperature, τ – extraction time, hour).
- Creation of optimization mathematical models of technological pectin extraction modes from the melon's pomace "Torpedo."

MATERIAL AND METHODS

We have used the following standards in our research for experiments on " Torpedo " melon varieties." Within the framework of this goal, the physicochemical composition of biochemical parameters from the melon variety "Torpedo" was studied. The content of vitamins was determined according to GOST R 54635-201, the content of potassium, sodium, and magnesium, according to GOST R 51429.99, the content of iron, according to GOST 30178-96, and the content of phosphorus, according to GOST 26657-97. The quantitative content of QMAFAnM was determined according to GOST 10444.15-94. The method for determining the amount of mesophilic aerobic and facultative anaerobic microorganisms was carried out by inoculation into agar nutrient media and is based on inoculation of the product or dilution of a sample of the product into a nutrient medium, incubation of the cultures, and counting of all grown visible colonies. Methods for detecting and counting the number of molds and yeasts were established according to GOST 10444.12-2013 (XIE 2012; Vatsa *et al.* 2021). The research results showed their safety and compliance with the requirements of TR CU 021/2011 Technical Regulations of the Customs Union "On Food Safety." They proved that the safety indicators of the melon variety "Torpeda" fully coincide with TR CU 021/2011. As a result of the selection of rational modes for the extraction of pectin substances from the pomace of the melon variety "Torpedo" (temperature 40-41℃, the dose of the polygalacturonase enzyme preparation was 2.0%, the pH of the medium was 6.0 and the exposure time was 4-5 hours), a pectin-containing extract with a volume of 1000 ml, the resulting extract was concentrated by vacuum evaporation using an RV 05 basic 2-B apparatus at a mode of 58-60oC and a vacuum discharge of 0.5-0.7 atm., to a pectin content of 2.40-2.52 ± 0.02% and soluble solids 22.0-24.0 ± 0.02%. Specific research methods were used to study the condition for extracting pectin extracts from melon at various values of the hydromodulus and with a pH environment, the temperature of the extract, and the exposure time depending on the concentration of the enzyme preparation. To establish the optimal technical regimes for extracting extraction from melon pomace, mathematical methods for planning multifactorial PEFs of type 2^3 were used, and based on their results, regression and optimization linear models were compiled.

RESULTS

Based on previous studies, it was found that the melon variety "Torpedo" is quite suitable for obtaining a pectin-containing extract in terms of the content of total pectin and the yield of pomace. Table 1 shows the results of studying the optimal technological regimes (hydraulic modulus and pH environment) for obtaining a pectin-containing extract from the pomace of the melon variety "Torpedo".

Table 1. The results of the study of the optimal technological regimes (hydro modulus and pH-environment) when obtaining a pectin-containing extract from pomace of melon variety "Torpedo".

Hydraulic module index	**Medium pH**			
	The content of pectin in the enzymatic extract melons (%)			
	4.0	5.0	6.0	7.0
Hydromodule 1:4	0.52	0.54	0.58	0.54
Hydromodule 1:6	0.57	0.60	0.63	0.61
Hydromodule 1:8	0.60	0.62	0.67	0.64
Hydromodule 1:10	0.62	0.64	0.72	0.68
Hydromodule 1:12	0.61	0.62	0.70	0.67
Hydromodule 1:14	0.58	0.60	0.68	0.62
Hydromodule 1:16	0.55	0.57	0.63	0.60
M+m	0.02	0.01-0.02	0.02-0.03	0.02-0.03

As a result of studying the optimal technological regimes, the hydromodulus and the pH medium, when obtaining a pectin-containing extract from the pomace of the melon variety "Torpedo" by the enzymatic method (enzyme polygalacturonase), it was found that the optimal pH medium for the enzymatic extraction of pectin from the pulp of the melon "Torpedo" is pH - medium at the level of 6.0 and hydromodule 1:10 (pectin content 0.68-0.72%), since at pH-medium: 4.0, 5.0 and 7.0 and in hydro modules 1:4, 1:6, 1:8, 1:12, 1:14 and 1:16 the resulting extracts contained pectin at a lower concentration (Table 1). Table 2 shows the results of studying the optimal technological regime (temperature) for obtaining a pectin-containing extract from the pomace of the melon variety "Torpedo." As a result of studying the optimal technological regime: the temperature of the extract, it was found that the optimal temperature of the extract during the enzymatic extraction of pectin from the pomace of the Torpedo melon variety is the temperature 40-410C (content 0.69-0.71%), which is unfavorable for many obligate microorganisms, which undoubtedly has a positive effect in the technological process, at a hydromodulus of 1:10, while at temperatures: 38-39 0C and in hydromodules 1:4, 1:6, 1:8, 1:12, 1:14 and 1:16 the resulting extracts contained pectin in a lower concentration (Table 2). The results of determining the optimal dose and exposure time for the enzyme complex during the enzymatic extraction of pectin from pomace of the Torpedo melon variety are shown in Table 3. When determining the optimal dose and exposure time for the enzyme complex during the enzymatic extraction of pectin from pomace of melon variety "Torpedo", it was found that at the recommended temperature 40-410 ℃, pH = 6.0, hydromodule 1:10, the optimal dose of the enzyme in the enzymatic extraction of pectin from pomace of melon variety "Torpedo" is a dose of 2.0% and an exposure time of 4-5 hours (pectin content -0.85 - 1.05%). The results of physicochemical and biochemical parameters from melon and pectin products are shown in Table 4.

Table 2. Results of the study on the optimal technological regime (temperature), when obtaining a pectin-containing extract from pomace of melon variety "Torpedo"

Hydraulic module index	**Extract temperature** **Content of pectin in the enzymatic melon extract (%)**			
	38 ℃	39 ℃	40 ℃	41 ℃
Hydromodule 1:4	0.52	0.53	0.55	0.56
Hydromodule 1:6	0.57	0.59	0.62	0.60
Hydromodule 1:8	0.61	0.63	0.67	0.65
Hydromodule 1:10	0.64	0.66	0.71	0.69
Hydromodule 1:12	0.62	0.64	0.68	0.67
Hydromodule 1:14	0.58	0.62	0.66	0.64
Hydromodule 1:16	0.56	0.58	0.64	0.61
M+m	0.02	0.01-0.02	0.02-0.03	0.02-0.03

Table 3. Results of determining the optimal dose and exposure time for the enzyme complex during the enzymatic extraction of pectin from pomace of melon variety "Torpedo"

Hydromodule	**Exposure time in hours** **Concentration of the enzyme preparation / Content of pectin in the enzymatic melon extract (%)**						
	1	2	3	4	5	6	12
	1.0% enzyme preparation concentration						
1:10	0.22	0.39	0.70	0.75	0.72	0.71	0.69
	2.0% enzyme preparation concentration						
1:10	0.28	0.51	0.75	1.05	0.85	0.80	0.75
	3.0% enzyme preparation concentration						
1:10	0.25	0.50	0.67	0.72	0.70	0.65	0.63
M+m	0.01-0.02	0.01-0.02	0.01-0.02	0.01-0.03	0.01-0.02	0.02-0.03	0.01-0.02

Table 4. The physicochemical and biochemical parameters from melon and pectin products

№ п/п	**Name of indicator**	**Ref use from melon**	**Melon pectin extract**
1	Carotene content (mg/kg)	0.40	0.28
2	Vitamin A content (mcg)	67.00	46.5
3	Vitamin B12 content (mg)	0.04	0.002
4	Vitamin B6 content (mg)	0.20	0.14
5	Vitamin C content (mg)	20.00	10.00
6	Vitamin E content (mg)	0.10	0.007
7	The content of vitamin PP (mg)	0.50	0.35
8	Na content (mg)	32.00	22.40
9	K content (mg)	118.00	82.60
10	Mg content (mg)	13.00	8.85
11	Ca content (mg)	16.00	11.20
12	P content (mg)	12.00	8.20
13	Fe content (mg)	1.00	0.55
14	Cu content, (μg)	47.00	31.50
15	Zn content (mg)	0.009	0.006

Since one of the criteria for the quality of pectin is the content of pure pectin in a commercial sample, additional studies were carried out on raw materials and pectin products for the presence of sugars, which are ballast substances in relation to pectin. Experimental data on the total content and fractional composition of sugars are shown in Fig. 1. In the data figure, it follows that almost all samples of the studied raw materials contain sugars. This necessitates the preparation of these types of raw materials for hydrolysis-extraction of pectin substances. To assess the quality indicators of pectin-containing extracts from pomace of melon variety "Torpedo", its analytical characteristics were determined. The results of the analytical characteristics of pectin-containing extracts from pomace of melon variety "Torpedo" are shown in Fig. 2. It shows analytical characteristics of pectin products from melon pomace, % in terms of absolutely dry weight.

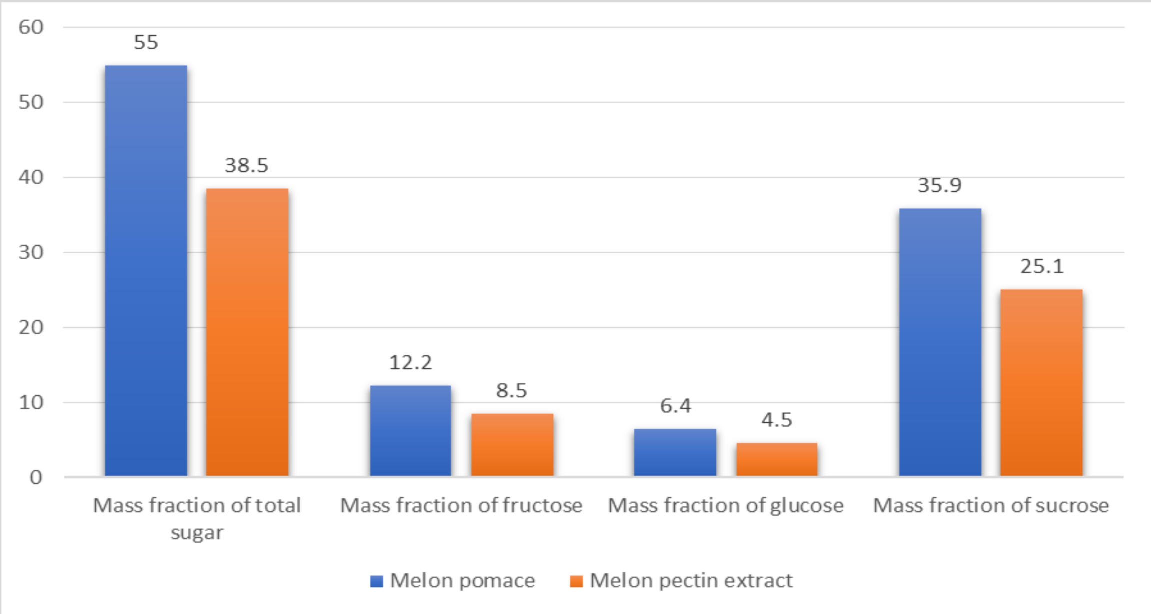

Fig. 1. Mass fraction of sugars, % in terms of absolutely dry mass.

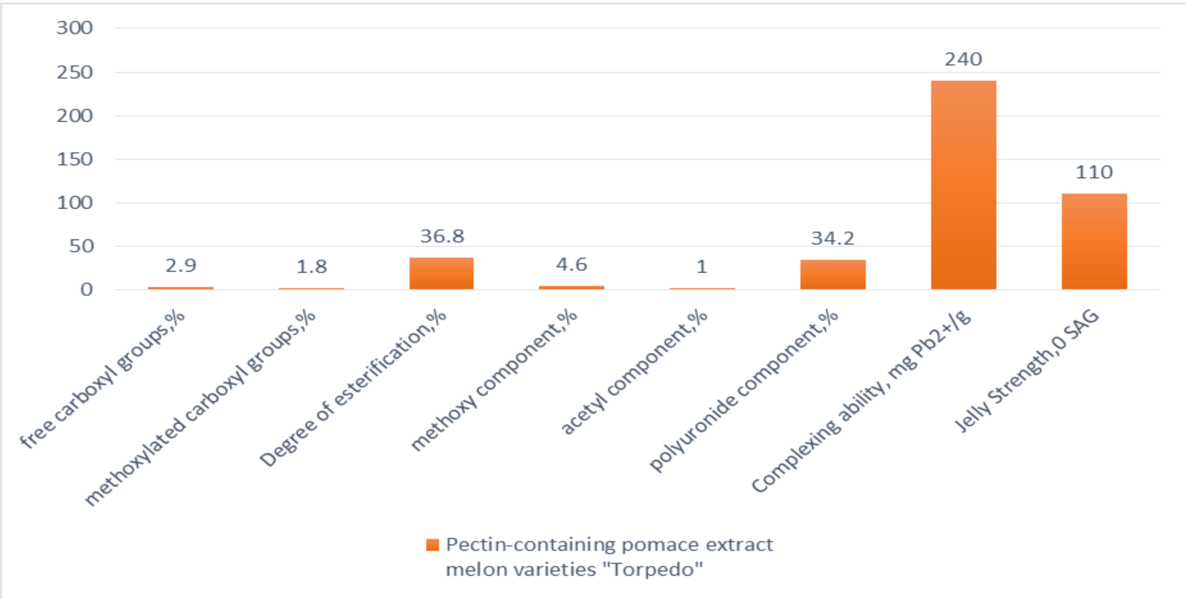

Fig. 2. Pectin-containing extract from pomace of melon variety "Torpedo".

Thus, the content of free carboxyl groups corresponds to 3.0 and 2.9%. In comparison, the degree of esterification was 36.8% (melon), respectively, corresponding to a lower value of the complexing ability of the pectin-containing extract from melon 240 mg Pb2+/g. At the same time, the acetyl component's content does not affect pectin's purity, the same - 1.0%. Based on the results of the studies, the output of pectin from melon varieties "Torpedo" is obtained with a hydromodulus of 1:10 studied and isolated the main factor K, t, which determines the yield of pectin extract. To establish the relationship of factors with the quality indicators of pectin extract, it is necessary to draw up plans for a complete factorial experiment. When selecting technological modes (hydraulic modulus, temperature, pH-environment) to obtain a pectin-containing extract from pomace of melon variety "Torpedo" before the introduction of an enzyme preparation (polygalacturonase), the raw material was preliminarily swollen in water at a temperature of 48-50ºC for 12-15 hours. Pectin extracted from pre-swollen raw materials has higher quality indicators. Enzymatic treatment of vegetable raw materials was carried out with a minimum dose of 0.5% at temperature ranges from 38.0 to 41.0 ºC, pH of the medium from 4.0 to 7.0, at a weight

ratio of raw materials and water in hydromodules: 1:4, 1:6, 1:8, 1:10, 1:12, 1:14 and 1:16, adjusting the initial natural environment of the extract pH=5.3-5.9 with 0.1N NaOH and 1N solutions of acetic acid. The duration of the enzymatic treatment of plant materials was determined by carrying out the enzymatic extraction for 3 hours. At the end of fermentation, the extract is filtered and centrifuged at 8000 rpm for 15 minutes to purify and clarify the extract, after which the enzyme in the extract is inactivated at a temperature of 75-77^{0}C for 30 minutes, followed by cooling of the extract. As a result, during the enzymatic extraction of pectin from the pomace of melon variety "Torpedo", it was found that at the recommended temperature 40-41^{0}C, pH=6,0, hydromodulus 1:10, the optimal dose of the enzyme in the enzymatic extraction of pectin from the pomace of melon variety "Torpedo" is a dose of 2.0% and an exposure time of 4-5 hours (pectin content - 0.85 - 1.05%). An assessment of the quality indicators of pectin-containing extracts from pomace of the melon variety "Torpedo" is given. Obtaining pectin from various vegetables and fruits is a complex technological process whose results depend on the influence of many mechanical, thermal, and technological factors. Its mathematical description is also complex. It would help if you first drew up its mathematical description to determine the optimal technological modes for obtaining pectin from melon varieties "Torpedo". To do this, it is necessary to experimentally determine the dependence of the pectin yield and its quality indicators on technological modes. Acidity (K, deg.), temperature (t, °C), and duration of melon processing (τ, h). Many indicators evaluate the quality of melon. In the studies, the following indicators were determined:
y_1: Mass fraction of pectin (%);
y_2: Mass fraction of vitamin C (mg/%);
y3: Mass fraction of carotene (mg/%);
y_4: Total sugar (%);
y_5: Glucose, fructose (%);
y_6: Sucrose (%);
y_7: Vitamin A (mg/100 g);
y_8: Vitamin E (mg/100 g);
y_9: Potassium (mg/100 g);
y_{10}: Iron (mg/100 g);
y_{11}: QMAFAnM (CFU × 10^{-3}/g);
y_{12}: Mold (CFU/g).
Given the need for many experiments, mathematical methods for planning multifactorial experiments were applied. For the above three factors K, t, and τ, a matrix of a complete factorial experiment of the PFE-2^3 type was compiled, containing 8 experiments. The levels of factors (experimental conditions) and the obtained experimental values of the above melon quality indicators y_1 – y_{12} are given in Table 5.

Table 5. Planning matrix and results of study experiments quality indicators of the extract of melon variety "Torpedo", obtained under various technological conditions.

N	**Modes**			**Quality indicators**											
	***K*, (*deg.*)**	***t* (°C)**	**τ (h)**	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	$y_{11}\cdot10^{-3}$	y_{12}
1	7	41	5	0.89	8.35	0.23	24.5	12.5	12.0	0.022	0.06	5.80	0.21	2	2
2	4	41	5	0.84	8.42	0.24	24.8	12.8	12.2	0.012	0.035	6.67	0.29	5	1
3	7	38	5	0.86	8.49	0.25	24.4	13.3	11.2	0.034	0.03	6.23	0.42	4	2
4	4	38	5	0.84	8.43	0.21	24.5	13.2	11.3	0.042	0.04	5.42	0.37	3	2
5	7	41	2	0.45	8.40	0.18	24.0	12.8	11.2	0.009	0.08	6.81	0.13	8	1
6	4	41	2	0.41	8.46	0.22	25.0	13.0	12.3	0.011	0.05	7.12	0.61	7	2
7	7	38	2	0.44	8.50	0.24	24.2	13.1	11.1	0.032	0.03	5.18	0.54	4	3
8	4	38	2	0.42	8.49	0.20	24.6	13.2	11.4	0.024	0.04	6.12	0.42	5	2

The experiments were randomized using tables of random numbers to reduce the influence of uncontrolled parameters on the results. Based on the studies' results, regression equations were obtained that adequately (according to the Fisher criterion) describe the dependences of the above indicators of the quality of granulated mixed fodder on the factors w and τ that affect them. Data processing and all necessary calculations were done using the PLAN sequential regression analysis program developed at the Odessa National Academy of Food

Technologies. The essence of sequential regression analysis is that the least squares method, implemented in matrix form, calculates the regression coefficients, checks for significance, removes the coefficient from the insignificant ones with a minimum ratio of its magnitude to the critical value, and then recalculates the regression coefficients. This cyclic procedure ends when only significant regression coefficients remain in the equation. Then, according to the Fisher criterion, the adequacy of the obtained regression equation to the experimental data is checked. Three parallel experiments were carried out in the center of the experiment to determine the error variance (reproducibility) of the experiments. The regression coefficients were calculated using matrices in natural dimensions, and the equations themselves were also obtained in natural dimensions.

The general form of regression equations for three factors is as follows:

$y_i = b_0 + b1K + b2t + b3\tau + b12\ Kt + b13K\tau + b23t\tau$,

where yi– i- indicators of pectin yield and quality of melon extract;

K – acidity, degrees;

t – temperature, °C;

τ – processing time, hour.

The compiled regression equations are mathematical models that allow predicting changes in the pectin yield and quality indicators depending on the values of the technological modes of processing the melon extract, i.e., factors K, t, and τ - acidity, temperature, and duration of treatment. Table 6 provides summary data on the obtained regression equations in natural variables. The same table shows the root-mean-square errors of the experiments Sэ and inadequacy Sн.ad., as well as settlement Fp and critical Fкр values of the Fisher criterion, indicating that both obtained equations adequately describe the experimental data at a confidence level $p < 0.05$. The listings of their calculations (Appendix A) provide more detailed data on the statistical characteristics of the obtained regression equation.

Table 6. Regression equations in natural variables and statistical characteristics of the dependencies of the quality indicators of the Torpedo variety melon extract on various technological modes

Regression Equations in natural variables	**Standard deviation**		**Criterion Fisher**	
	experimental	**inadequacy**	**estimated**	**critical**
$y_1 = 0.0854 + 0.01083\,K + 0.1425\,\tau$	0.0064	0.0106	2.75	19.30
$y_2 = 8.4425$	0.083	0.0523	2.52	4.74
$y_3 = -1.2628 + 0.2878\,K + 0.03722\,t - 0.00722\,Kt$	0.0081	0.0197	5.91	19.25
$y_4 = 24.5000$	0.240	0.316	1.74	19.35
$y_5 = 13.07500 + 1.5641\,\tau - 0.04023\,t\tau$	0.130	0.122	1.13	5.79
$y_6 = -0.1296\,K + 0.3113\,t$	0.120	0.309	6.63	19.33
$y_7 = 0.2701 - 0.00650\,t + 0.00283\,\tau$	0.0012	0.00491	16.74	19.30
$y_8 = 0.03979 - 0.1178K + 0.1018\tau + +0.003057\,Kt\ -0.002651\,t\tau$	0.00210	0.00516	6.05	19.16
$y_9 = -18.7656+0.6394t+3.8794\tau-0.1006t\tau$	0.140	0.547	15.26	19.25
$y_{10} = -6.4599 + 1.5694\,K + 0.1806t - 0.03417\,\tau - -0.04056\,Kt$	0.028	0.118	17.79	19.16
$y_{11} = -58.1667 + 1.6667t + 12.3333\tau - 0.3333\,t\tau$	0.280	1.225	19.13	19.25
$y_{12} = 11.7500 - 0.2500\,t$	0.130	0.540	17.26	19.33

where K is acidity (degrees);

t is temperature(°C);

τ is duration (h)

A brief analysis of the obtained regression equations shows that such quality indicators of melon extract as vitamin content C (y_1) and total sugars (y_4) generally do not depend on the processing modes (of course, in the investigated range of their change), and the fluctuations in their values in the experiments are insignificant and lie within the experimental errors. From just one factor, temperature t, depends on the presence of mold after processing the extract. The output of pectin depends on two regime factors: acidity K and processing time τ. (y_1). The carotene content depends on the acidity K and temperature t (y_3) and sucrose (y_6). Also, two factors, but already the temperature t and the duration of treatment τ, depend on the content of glucose with fructose (y_5), vitamin A (y_7), potassium (y_9), and content of microorganisms (y_{11}). All three considered regime factors K, t, and τ affect only vitamin E (y_8) and iron (y_{10}) content. If we analyze the direction of the influence of technological regime factors on the studied 12 indicators, then the correct conclusions can be obtained only for some of them—y_1, y_6, y_7, and y_{12}, which is due to the linearity of these indicators from some factors. So, from the equation for y_1, it can be seen that pectin yield linearly depends on the factors K and τ, and with their increase, pectin yield will also increase. But the duration of treatment has a more significant effect on the yield of pectin - its increase from 2 to 5 hours almost doubles the yield of pectin in the entire range of acidity, which increases the yield of pectin by only 48% (i.e., the pectin content when changing temperature can be considered almost unchanged). Sucrose content y_6 will increase with increasing decrease in acidity K and increasing temperature t. Vitamin A content y_7 will increase with decreasing temperature t and increasing treatment time τ. Finally, the mold content has the simplest linear dependence, y_{12}, which depends only on temperature t—with its increase, the mold will decrease. The corresponding response surfaces shown in Fig. 3 clearly confirm the described regularities of the influence of technological factors on the indicators analyzed above.

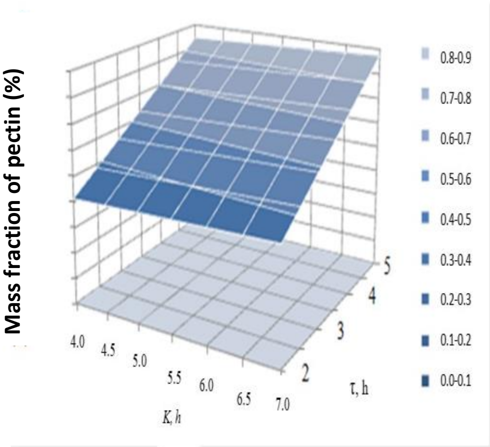

Fig. 3a) Dependence of pectin mass fraction on factors K and τ

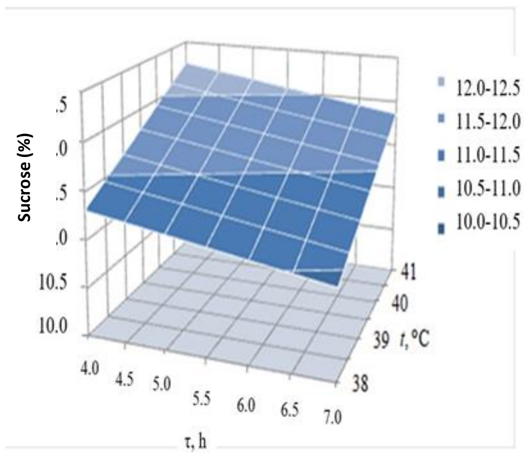

Fig. 3b) Dependence of the mass fraction of sucrose on the factors τ and t

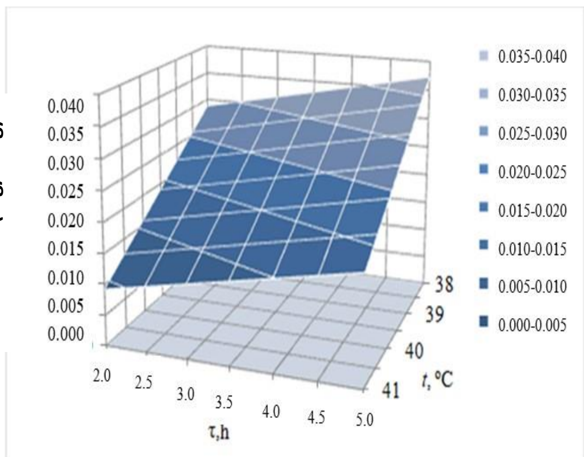

Fig. 3c) Dependence of vitamin A content on factors τ and t

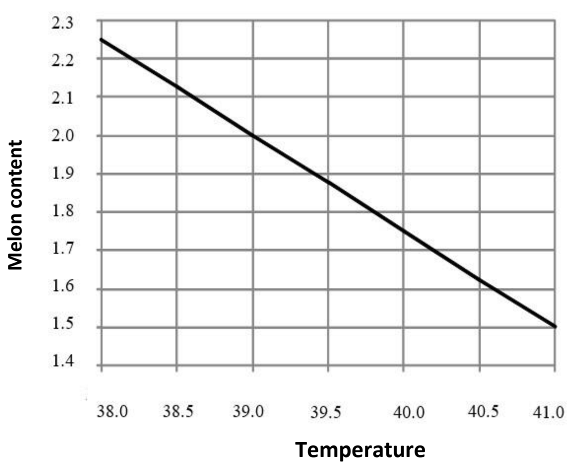

Fig. 3d) Dependence of melon content on temperature (t)

Fig 3. Linear dependencies of pectin output and some indicators of quality of melon extract from several regime factors (a, b, c, d).

As shown in Fig. 3, the linear nature of the influence of the considered factors on the pectin yield and some indicators of the quality of the melon extract is explained by the absence of statistically significant coefficients of pairwise mutual influences of some pairs of factors in the regression equations. These coefficients are present in the rest of the regression equations. Therefore, it is very difficult to analyze the influence of technological regime factors on the nature of the change in the quality indicators of melon extract according to nonlinear regression equations. However, this can be done clearly by graphical interpretation of the regression equations - by response surfaces constructed according to the regression equations of interest to the researcher. Fig. 4 shows the response surface for the mass fraction of carotene y_3 and a number of indicators of the quality of the melon extract (the content of glucose with fructose y_5, vitamin E y_8, potassium y_9, iron y_{10}, and microorganisms y_{11}), giving a visual representation of the nature of their dependence on the technological modes of processing. From the above response surfaces, it can be seen that the most complex and contradictory nature of the mutual influence of factors is manifested in the mass fraction of carotene (Fig. 4-a). Thus, the mass fraction of carotene increases with a decrease in the processing temperature from 41 °C to 38 °C, but this trend is observed only when the treatment lasts from 5.5 to 7 hours. With a shorter processing period, a decrease in temperature exposure leads to a decrease in the mass fraction of carotene. In the same way, thermal treatment duration also manifests itself as ambiguous. An increase in the duration of heat treatment at 38 °C contributes to an increase in the mass fraction of carotene, but the same treatment at a temperature of 41 ° C only leads to a decrease in the mass fraction of carotene.

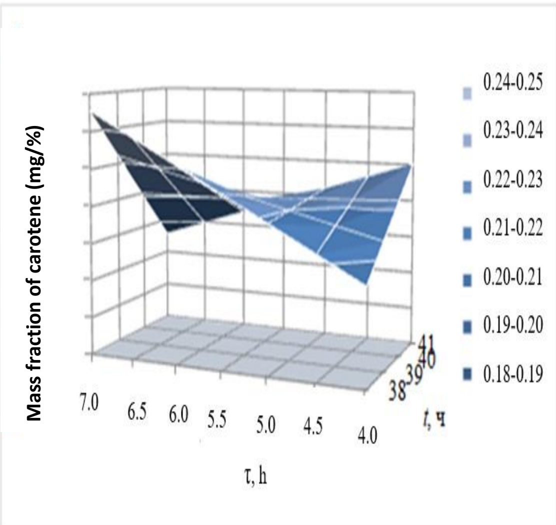

Fig. 4a) Dependence of the mass fraction of carotene on the factors τ and t

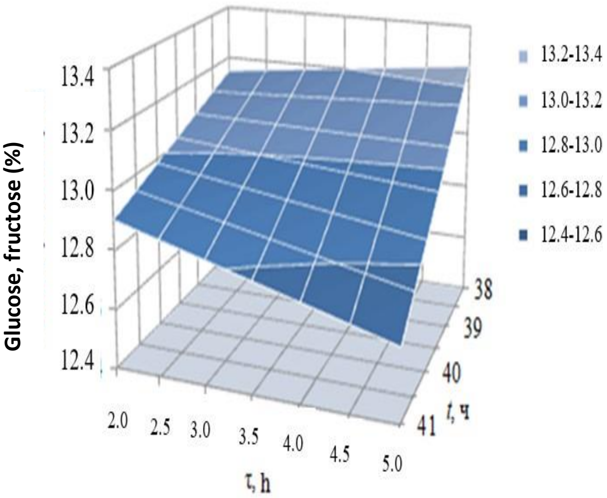

Fig. 4b) Dependence of the mass fraction of glucose and fructose on the factors τ and t

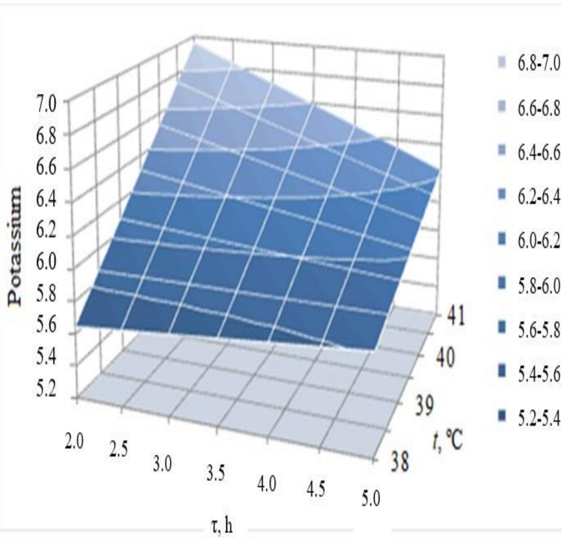

Fig. 4c) Dependence of potassium content on factors τ and t

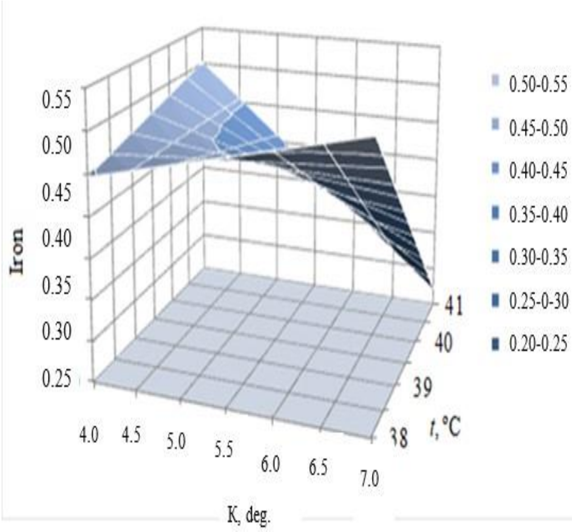

Fig. 4d) Dependence of iron content on factors K and t.

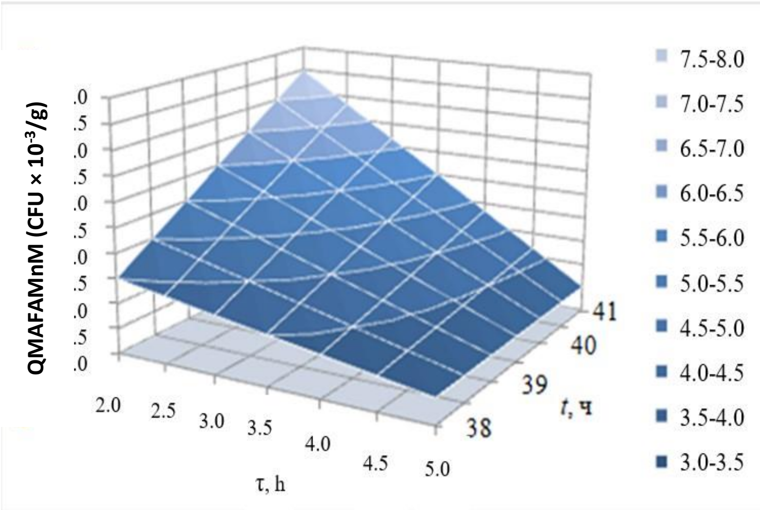

Fig. 4e) Dependence of QMAFAMnM on factors τ and t.

Fig. 4. Response surfaces of non-linear dependences of pectin yield and some indicators of extract quality on several regime factors (taking into account the effects of paired mutual influences of factors; a, b, c, d, e).

The content of glucose and fructose (Fig. 4b) unequivocally decreases with an increase in temperature from 38 to 41 °C, only at τ = 2 h this decrease is slower than at τ = 5 h; in the first case, it is 0.24%, and in the second 0.60%. Otherwise, the duration of processing is affected. At a temperature of 38 °C, with an increase in τ from 2 to 5 hours, the content of glucose and fructose increases slightly from 13.15% to 13.25%, and at a temperature of 41 °C, the same increase in the duration of treatment τ leads to a slight decrease in it — from 12.90% to 12.65%. The nature of the influence of the factors τ and t on the potassium content in the melon extract is as follows (Fig. 4-c). An increase in temperature from 38 to 41 °C leads to an increase in the potassium content at τ = 2 h from 5.64 to 6.96 mg/100 g, and at τ = 5 h from 5.81 to 6.22 mg/100 g. Changing the duration of treatment from 2 to 5 hours at a temperature of 38 ° C increases the potassium content from 5.64 to 5.61 mg/100 g, and at a temperature of 41 °C reduces it from 6.96 to 6.22 mg / 100 g. The influence of acidity K and temperature t on the iron content is very contradictory (Fig. 4-d). It is increasing K from 4 to 7 deg. At t=38 °C it increases the iron content (from 0.45 to 0.53 mg/100 g), and at t=41 °C, on the contrary, it decreases (from 0.52 to 0.22 mg/100 g). The temperature behaves similarly - its growth from 38 to 41 °C at K = 4 degrees. Increases the iron content (from 0.45 to 0.50 mg/100 g) at K = 7 deg. It reduces (from 0.53 to 0.22 mg/100 g). Considering the effect of treatment duration and temperature on QMAFAMnM (y_{10}), clearly shown in Fig. 4-e, it can be seen that an increase in temperature from 38 to 41 ° C with a short treatment time (τ = 2 h) leads to an increase in the microbiological contamination of the melon extract (from 4.5×10^3 to 7.5×10^3 CFU/g). However, during processing for 5 hours, the contamination is already reduced to level 3,5·103 CFU/g over the entire range of investigated temperatures (38-41 °C). It can also be seen that an increase in temperature to 41°C with a minimum duration of treatment (2 hours) contributes to a significant increase in QMAFAMnM - from 4.5×10^3 to 7.5×10^3 CFU/g. Thus, it becomes obvious that from the point of view of achieving minimum contamination, the treatment should be carried out within 5 hours. At the same time, the temperature can be kept at 38 ° C, which will save energy. However, to make a final decision, conducting a joint analysis of all the studied quality indicators is necessary. As mentioned above, all three regime factors, K, t, and τ, affect only the content of vitamin E (y_8) and iron (y_{10}), as shown in Figs. 5 and 6. From the equation y_8, there is no unambiguous linear dependence of vitamin E content on each factor K t and τ, since the equation contains statistically significant coefficients of pair interactions b_{12} and b_{23}. This means that the influence of acidity K will manifest itself differently depending on the temperature t.

In turn, the influence of treatment temperature t. This is clearly shown in Fig. 5-a, b temperature (t) will depend on the duration of treatment τ., and the effect of treatment time τ will depend on the treatment temperature t. This is clearly shown in Figs. 5-a, b. A deeper analysis shows that with a treatment duration of 5 hours, an increase in the acidity of K from 4 to 7 deg. at a temperature of t = 38 °C, it will reduce the content of vitamin E by 1.15 times, and at t=41 °C, on the contrary, it will increase by 1.64 times. The temperature also affects differently - at K = 4 degrees. An increase in temperature from 38 to 41 ° C reduces the yield of vitamin E by 1.09 times, and at K = 7 deg. increases it by 1.73 times.

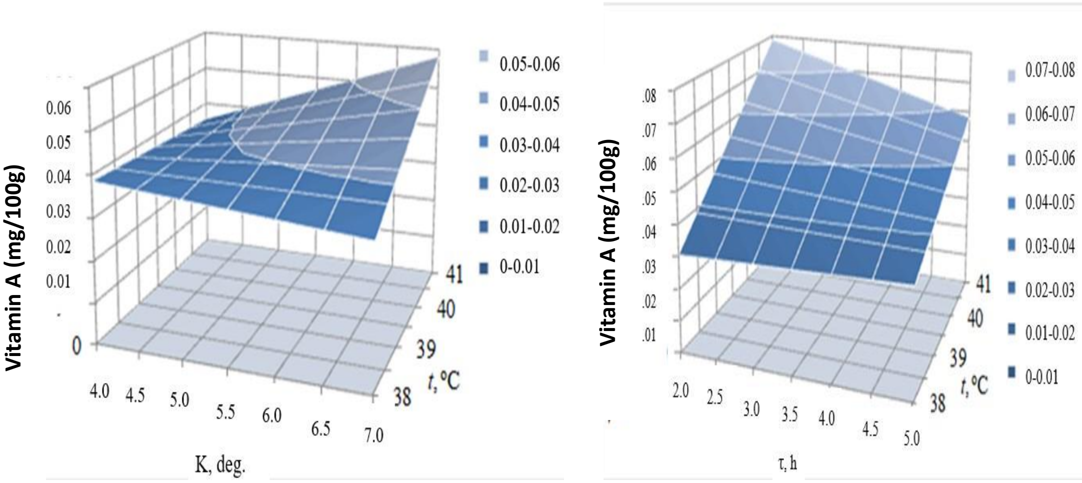

Fig 5. a) the influence of factors K and t on the content of vitamin E (at τ=5 hours) **Fig. 5 b)** influence of factors t and τ on the content of vitamin E (at K=7 deg.)

Fig 5. Response surfaces of non-linear content dependencies vitamin E in melon extract from regime factors taking into account the effects of pair interactions t–τ (a) and K–t (b).

The same applies to the mutual influence of factors t and τ at an acidity of 7 degrees. At a temperature of t = 38 °C, an increase in the duration of τ from 2 to 5 hours leads to a slight increase in the content of vitamin E, by 1.10 times, and at t = 41 °C, on the contrary, to a decrease in vitamin E by 1.36 times. At τ = 2 hours, an increase in temperature from 38 to 41 °C increases the content of vitamin E by 2.58 times, and at τ=5 hours, only 1.73 times. Thus, the pair interaction of factors changes not only the rate of change in the content of vitamin E, but also the direction of this change, which is very clearly seen in Fig. 5. Simple Equation Analysis y_{10}, shows that only the factor τ linearly changes the content of iron; as τ increases, the content of iron decreases (which is confirmed by the minus sign of the coefficient b_3 factor τ). The factors K and t have a joint (pair) mutually opposite effect on the iron content, which is clearly seen in Fig. 6.

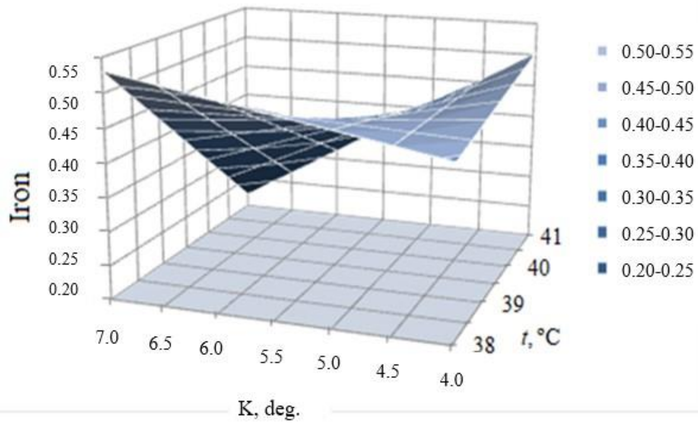

Fig. 6. The response surface of the mutual influence of factors K and t on the content iron in melon extract (at τ = 2 h).

If at *K* = 4 deg. increase the temperature or at *t* = 38 °C increase the acidity, this will increase the iron content by 12-13%. And if at *K* = 7 deg. increase the temperature or increase the acidity at *t* = 41 °C, this will lead to a decrease in the iron content by 27…40%. The highest iron content, equal to 0.53 mg/100 g, can be obtained at *K* = 7 deg. and *t* = 38 °C. At the final stage of the research, the technological modes of processing the melon extract were optimized. In this case, two optimization options were considered. In the first - to ensure the maximum yield of pectin while maintaining the quality indicators within the specified limits, and in the second - to ensure the minimum seeding of the melon extract, while maintaining the yield of pectin and other quality indicators within the specified limits.

The equation:

$Y_1 = 0.0854 + 0.01083K + 0.1425\,\tau \rightarrow max.$

Limitations for other quality indicators, both dependent on the studied factors and not dependent on them, were as follows:

0.40	$\leq$	$y_1 = 0.0854 + 0.01083K + 0.1425\ \tau$	$\leq$	0.90
0.082	$\leq$	$y_2 = 8.4425$	$\leq$	0.086
0.017	$\leq$	$y_3 = –1.2628 + 0.2878\ K + 0.03722\ t – 0.00722\ Kt$	$\leq$	0.27
23.0	$\leq$	$y_4 = 24.5000$	$\leq$	27.0
12.0	$\leq$	$y_5 = 13.07500 + 1.5641\ \tau – 0.04023\ t\tau$	$\leq$	14.0
10.5	$\leq$	$y_6 = –0.1296K + 0.3113\ t$	$\leq$	13.5
0.006	$\leq$	$y_7 = 0.2701 – 0.00650\ t + 0.00283\ \tau$	$\leq$	0.052
0.01	$\leq$	$y_8 = 0.03979 – 0.1178\ K + 0.1018\ \tau + 0.003057\ Kt – 0.002651\ t\tau$	$\leq$	0.10
5.0	$\leq$	$y_9 = –18.7656 + 0.6394t + 3.8794\ \tau – 0.1006\ t\tau$	$\leq$	8.2
0.08	$\leq$	$y_{10} = –6.4599 + 1.5694\ K + 0.1806\ t – 0.03417\ \tau – 0.04056\ Kt$	$\leq$	0.75
$1 \cdot 10^3$	$\leq$	$y_{11} = –58.1667 + 1.6667t + 12.3333\ \tau – 0.3333\ t\tau$	$\leq$	9×10^3
0	$\leq$	$y_{12} = 11.7500 – 0.2500\ t$	$\leq$	5

Limitations on the range of changing conditions (modes) of processing were taken equal to the ranges of changing experimental conditions:

4 deg. $\leq K \leq$ 7 deg.; 38 °C $\leq t \leq$ 41 °C; 2 h. $\leq \tau \leq$ 5 h.

Using the obtained system of equations, the optimal technological modes of processing the extract of melon variety "Torpedo" were determined by the method of nonlinear programming.

K = 5 deg., t = 41 °C, τ = 5 h.,

which, subject to all the requirements (restrictions) on the quality of the melon extract, provide a maximum pectin yield equal to y_1= 0.87 %.

To determine the technological modes of processing melon extract, in which maximum safety (minimum content of microorganisms) will be ensured, the equation was used as the objective function

$Y_{11} = –58.1667 + 1.6667t + 12.3333\tau – 0.3333\ t\tau \rightarrow min.$

Restrictions on other quality indicators, as well as on the ranges of changes in processing conditions (modes), were the same as when optimizing pectin yield.
Using the obtained system of equations, the optimal technological processing modes were determined by the method of nonlinear programming

K = 5 deg., t = 41 °C, τ = 5 h,

which, subject to all requirements (restrictions) on the yield of pectin and all indicators of the quality of melon extract, provide a minimum content of microorganisms equal to y_{11} = 3. 5 × 10^3 CFU/g. As can be seen, the obtained values of the optimal technological regimes, providing both the maximum yield of pectin and the minimum content of microorganisms, coincided. The calculated optimal values of the remaining quality indicators of the Torpedo variety melon extract are given in Table 7. Thus, the processing of the Torpedo variety melon extract under optimal technological conditions will allow obtaining the maximum amount of pectin with guaranteed food safety.

Table 7. Quality indicators of melon extract under optimal conditions technological processing of melon extract, providing maximum output of pectin.

Quality indicators	min		opt		max
y_1 – mass fraction of pectin (%);	0.40	≤	0.87	≤	0.90
y_2 – mass fraction of vitamin C (mg /%);	0.082	≤	0.44	≤	0.086
y_3 – mass fraction of carotene (mg /%);	0.017	≤	0.21	≤	0.27
y_4 – total sugar (%);	23.0	≤	24.5	≤	27.0
y_5 – glucose, fructose (%);	12.0	≤	12.65	≤	14.0
y_6 – sucrose (%);	10.5	≤	11.86	≤	13.5
y_7 – vitamin A (mg/100 g);	0.006	≤	0.02	≤	0.052
y_8 – vitamin E (mg/100 g);	0.01	≤	0.058	≤	0.10
y_9 – potassium (mg/100 g);	5.0	≤	6.24	≤	8.2
y_{10} – iron (mg/100 g);	0.08	≤	0.12	≤	0.75
y_{11} – QMAFAnM (CFU•10^3/g);	1×10^3	≤	3.5×10^3	≤	9×10^3
y_{12} – mold (CFU/g)	0	≤	1.5	≤	5

DISCUSSION

Melon is considered one of the sweet gourds, and it is common in many countries, especially in Central Asia and Kazakhstan. In the southern region of Kazakhstan, different varieties of melons are grown annually on large irrigated fields. The most consumed by the population is the excellent variety of melon "Torpedo", which gives a good harvest and increased quality indicators for consumer properties (Donchenko 2000; Iztayev *et al.* 2021). Under unfavorable conditions, great losses occur, and producers often remain at a loss. The efficiency of melon production can be facilitated by the development of efficient methods for processing melon into extracts for pectin's, separating them into their constituent components: peel, pulp, and seed, drying them and grinding them into fine dry powders for use in food production (Kulazhanov *et al.* 2021). This article considers the first problem of extracting pectin from pomace using the Torpedo melon variety as an example. The article presents the results obtained but narrows issues related to substantiating the optimal conditions for forming a hydro module with a ratio of 1:10, ensuring the maximum yield of pectin extract. For the rational management of the technological process of pectin extract extraction, mathematical modeling and optimization of technological modes (K-acidity, deg, temperature t ℃, and extraction time τ h) were compiled, which makes it possible to automate and computerize the work of technological food for the production of pectin. Based on the conducted research, the following conclusions were drawn:

1. The analysis of existing technologies for producing pectin substances led to the conclusion that hydrolysis-extraction under the influence of acid solutions is the primary (traditional) method for obtaining pectin from plant materials. The most suitable hydrolyzing agent is hydrochloric acid. Existing methods for conducting acid hydrolysis lead to the degradation of pectin macromolecules and the loss of the main properties of the target products (Kulazhanov *et al*. 2021; Jyotsana & DelGiorno 2022).
2. The results of the study of the optimal technological regimes (hydraulic modulus and temperature) when obtaining a pectin-containing extract from pomace of melon variety "Torpedo" showed the best hydromodulus 1:10, amounted to 0.72 and 0.71, respectively. How high are values compared to other experiences experiments?
3. During the enzymatic extraction of pectin from the pomace of the melon variety "Torpedo," it was found that at the recommended temperature of 40-41^{0}C, pH=6.0, and hydromodulus 1:10, the optimal dose of the enzyme is 2.0% and exposure time 4-5 hours (pectin content—0.85 - 1.05%).
4. A detailed study of the physicochemical and biochemical parameters of pomace and pectin products from melon showed that the content of carotene, vitamins A, B_{12}, B_6, C, E, RR, and metals Na, K, Mg, Ca, P, Fe, Cu, Zn, in all analyses, data from melon pomace is much higher than pectin extract.

5. An assessment of the quality indicators of pectin-containing extracts from pomace of the melon variety "Torpedo" was given. The biochemical composition, sugar content in raw materials, and pectin products, which are ballast substances about pectin, have been determined, necessitating the preparation of these raw materials for hydrolysis-extraction of pectin substances.
6. Analytical characteristics (the content of free carboxyl groups, methoxyl, acetyl, and polyuronide components) characterizing the obtained pectin extracts were determined.
7. For the operational management of the production of pectin from melon varieties "Torpedo", plans were drawn up for a complete multivariate study of Type PFE-2^3, allowing to establish the mathematical dependence of the pectin yield and its quality indicators on technological modes (acidity K, deg), temperature (t, C^0) and duration of melon processing (τ, h).
8. The quality of the melon was assessed by many indicators in the studies carried out; the main physicochemical, biochemical, and microbiological ones were determined:
y_1 - mass fraction for pectin, %
y_2 – mass fraction of vitamin C, mg/%;
y_3 – mass fraction of carotene, mg/%;
y_4 - total sugar, %
y_5 - glucose, fructose, %,
y_6 – sucrose, %;
y_7 - vitamin A, mg / 100 g,
y_8 - vitamin, mg / 100 g,
y_9 - potassium, mg / 100 g,
y_{10} - iron, mg / 100 g,
y_{11} - QMAFAnM, CFU•10^3/g,
y_{12} – molds, CFU/g.
All this allows you to control pectin-containing melon products' quality and safety indicators simultaneously.
9. Based on the use of the PLAN sequential regression analysis program, using the least squares method implemented in matrix form, the regression coefficients were calculated, their significance was checked, the insignificant ones were removed, the Fisher criterion checked the adequacy and 12 regression models were obtained that describe changes in the quality and safety of melon pectin from technological modes (K-acidity, hail, t-temperature, ^{0}C and duration, hour).
10. The influence of each regime factor and the mutual influence of two factors on the indicators of the quality and safety of melon pectin are analyzed in detail: mass fraction of sucrose on factors τ and t ℃; vitamin A content on factors τ and t ℃; mold content on temperature t ℃; mass fraction of carotene on factors τ and t ℃; mass fraction of glucose and fructose on factors τ and t ℃; potassium content on factors τ and t ℃; iron content on factors K and τ; and dependence of QMAFAM on factors τ and t ℃; vitamin E content from factors K and t ℃; and t ℃ and τ as non-linear dependencies. At the same time, it was found that the factors K and t ℃ have a joint (paired) mutually opposite effect on the iron content.
11. At the final stage of the research, the technological modes of processing the melon extract were optimized. At the same time, two optimization options were chosen. In the first one, the maximum pectin yield was ensured while maintaining the quality indicators within the specified limits, and in the second, the minimum seeding of the extract was ensured while maintaining the pectin yield and quality indicators within the specified limits.
12. To determine the technological modes of processing the melon extract, in which the maximum yield of pectin is ensured, the equation $y_1 \leq$ max, and to ensure maximum safety (minimum content of microorganisms), the equation is used as the objective function $y_{11} \leq$ min.
13. Using the obtained system of equations, the optimal technological modes of processing the extract of the melon variety "Torpedo" were determined by the method of nonlinear programming; for both options the same optimal technological modes of processing were obtained: K = 5 degrees, t = 41 ℃, τ = 5 hours which, subject to all the requirements (restrictions) on the quality of the melon extract, provide the maximum pectin yield and the minimum content of microorganisms, i.e. modes matched.

CONCLUSION

From the given values of pectin substances from melon and carried out on analyses by a technological factor of 12 quality and safety indicators from y_1 to y_{12} of pectin extract, regression models have been developed that describe their changes and can be used in the development of many functional products. Mathematical modeling and optimization of technological modes of the pectin obtained from extracts of the melon variety "Torpedo" were built.

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Not applicable.

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