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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

STUDY OF TECHNOLOGY FOR PREPARING FUNCTIONAL FOODS USING PECTIN-RICH VEGETABLES

Speciality: 3309.01- Food technology

Field of science: Technical sciences

Applicant: **Sevda Hasan Adigozalova**

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The work was conducted in the laboratories of processing, storage, quality, and functional analysis at the public legal entity "Scientific Research Institute of Vegetables" under the Ministry of Agriculture of the Republic of Azerbaijan.

Scientific supervisor: doctor of technical sciences, professor
Hasil Kamaladdin Fataliyev

Official opponents: doctor of technical sciences,
associate professor
Ahmed Gulu Malikof

doctor of philosophy in technical sciences,
associate professor
Elsa Madat Omarova

doctor of philosophy in technical sciences
Azer Tapdig Taghiyev

Dissertation council BFD 3.12 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the public legal entity Scientific Research Institute of Vegetables

Chairman of the Dissertation council:
doctor of technical sciences, professor
Mazahir Hamza Farzaliyev

Scientific secretary of the Dissertation council:
doctor of philosophy in technical sciences,
associate professor
Movlud Arastun Huseynov

Chairman of the scientific seminar:
doctor of technical sciences, professor
Mikayil Akbar Maharramov

GENERAL OVERVIEW OF THE WORK

Relevance of the topic and level of study. Ensuring food safety and public health is a top priority in national policy. The "State Program" for Ensuring Food Security in the Republic of Azerbaijan for 2019-2025 *aims to guarantee that the population has access to healthy and safe food products by 2025. The program also focuses on reducing food-related illnesses, boosting productivity and competitiveness, and expanding exports*[1].

Nutrition plays a crucial role in strengthening the body's defenses against environmental threats and reducing disease risk. As a result, contemporary food technologies emphasize incorporating high-value, health-promoting components into diets as a strategy to address health challenges within the ecosystem. Given the current global environmental crisis, offering functional food products enriched with pectin additives presents a promising and relevant approach to improving global health. Pectin is a dietary fiber with detoxifying and prebiotic properties. As a plant polysaccharide, it helps remove heavy metal ions from the body, regulates metabolism, and supports the gastrointestinal system, as well as blood sugar and cholesterol levels. Pectin is one of the most prevalent biopolymers found in nature.

Vegetables, which are rich in pectins and other biologically active compounds, provide significant protection against environmental stressors and are crucial to a healthy diet. Thus, researching the technology for creating functional plant-based beverages is essential for addressing the shortage of functional foods in people's diets. It has been shown that both the quantity and the properties of pectin in food products are important factors..

Despite the development of vegetable cultivation as a major agricultural sector in our republic, industrial production of pectin from secondary vegetable processing products has not been established. Additionally, the development of technology to preserve the natural properties of pectin has not yet been scientifically justified.

[1] Fətəliyev, H.K. Qidalanma və sağlamlıq / H.K.Fətəliyev-Bakı: "Elm", -2023. - 384 s.

This is due to the complexity of the production process and the incomplete hydrolysis-extraction stage, which requires a tailored approach for each type of raw material.

As a result, the development of pectin-based functional drinks in our country faces an urgent scientific challenge: improving the process of extracting pectin from plant materials. One key research direction is developing an advanced technology that enhances the extraction of pectin polysaccharides from raw materials while preserving their natural structure. Studies indicate that producing high-quality pectin from locally sourced vegetables and their processing by-products using advanced technologies is cost-effective for preparing functional vegetable drinks intended for therapeutic and preventive purposes.

The purpose and objectives of the study. The objective of this study is to establish the technological and operational parameters for extracting pectin from processing waste and to evaluate the use of locally sourced pectin-rich vegetables as the primary raw material for producing functional beverages.

To achieve the goal, the following tasks were defined:

- Conduct a review of scientific and technical literature, including patent data, to outline the problem and organize an analytical review.
- Examine the bioactive composition of primary raw materials and the specifics of their technological processing.
- Investigate the extraction process of pectin polysaccharides from various raw material sources and perform mathematical modeling of this process.
- Assess the factors affecting the extraction process, enhance the extractor, and improve its operational quality.
- Explore the technology for producing new varieties of functional plant-based beverages.
- Develop and practically apply the proposed technology, and calculate its economic efficiency.

Research methods. In the course of the study, a range of analytical techniques were employed, including conductometric, viscometric, spectrophotometric, complexometric analyses, high-performance liquid chromatography, as well as systematic, correlation, and

differential analysis. Mathematical modeling and multifactorial experimental design were also utilized.

The key quality indicators of vegetable raw material samples were assessed using the thermogravimetric method (AZS 937:2023) and the total acidity titration method (AZS GOST:25555.0:2023). These Azerbaijani standards were developed and approved by the State Standard, with the author preparing the standard projects.

The theoretical and methodological framework of the study is based on the research methods of contemporary and international scientists in the fields of chemistry and functional beverages.

The main provisions submitted for defense:

1. Various types of local plant raw materials were evaluated for their pectin content and other biologically active compounds, leading to recommendations for producing functional food products and pectin.

2. The principles and mechanisms of pectin extraction from plant raw materials were investigated, including the catalytic breakdown of protopectin under different conditions and the hydrolysis-extraction process aimed at maximizing product yield.

3. A design concept for a confuser-diffuser and a vacuum-effect system was developed, and the extraction process was modeled, based on the need for technological improvements.

4. Optimal parameters for the extractor, designed to enhance pectin extraction in mild conditions while preserving its natural properties, were established and recommended for implementation in production.

Scientific novelty. For the first time, various locally grown vegetables were evaluated for their pectin content and other biologically active compounds. The findings provided both theoretical and practical evidence that vegetables cultivated in local soil and climatic conditions have significant potential as therapeutic and prophylactic functional food products, making them promising candidates for pectin production.

- The hydrolysis-extraction process has been mathematically modeled, with an evaluation of the impact of external forces. During the design phase, it became possible to investigate protopectin breakdown across various types of raw materials, optimize techno-

logical conditions, and enhance the efficiency of pectin extraction while preserving its properties.

- The approach to quantitatively and qualitatively improve the technological process, aimed at maximizing output without compromising quality, has been validated. A hardware design scheme has also been developed. This improved proposal has been recognized by the Center for Expertise of Patents and Trademarks as a utility model (F 2024 0018);

- Additionally, a technological solution has been introduced that promotes energy and resource conservation through a gentler process compared to the more intensive methods of pectin extraction that rely on high pressure and temperature.

Practical and theoretical value of the work. The theoretical significance of this research is reflected in the development of a resource-efficient technology for producing functional beverages with high nutritional and preventative properties, derived from nutrient-rich plant materials cultivated within the republic.

The practical significance lies in the creation of a hardware design scheme to implement the proposed technology, along with the establishment of a comprehensive methodology for reporting operational modes and parameters of the hydrolysis-extraction process.

Approbation and application. The key findings and contributions of this research were presented at various scientific councils of the Vegetable Growing Research Institute between 2018 and 2021. A total of 19 scientific publications emerged from this work, including 6 peer-reviewed articles and 13 conference proceedings. Additionally, a patent was granted for the utility model.

These contributions were shared at several notable conferences, such as the Republican Scientific and Practical Conference "Academician J. Aliyev and Genetic Resources of Biological Diversity," dedicated to the 90th anniversary of Academician Jalal Aliyev, held at Azerbaijan State Agrarian University (ADAU) in Ganja on November 30, 2018; the Republican Scientific and Practical Conference on the "Development of Ecological Agriculture in Azerbaijan" (Ganja, October 29, 2019); and the International Scientific and Practical Conference "Application of Innovations in the Development of

Veterinary Science" at the Veterinary Research Institute (Baku, November 24-25, 2019).The 5th International Scientific and Practical Conference "Vegetables and Gardening," organized by the National Academy of Agrarian Sciences of Ukraine at the Mayak Experimental Station (Chernihiv region, March 9-10, 2019), and at the International Scientific and Practical Conference "Food. Ecology. Quality" at Altai State University (Barnaul, June 24-26, 2019). The interdisciplinary conference "Heydar Aliyev's Legacy in the Development Strategy of Azerbaijan," commemorating the 98th anniversary of Heydar Aliyev, held at West Caspian University (Baku, January 30, 2021); and the Republican Scientific Conference "New Directions in the Development of Agriculture and Environmental Protection" (Baku, May 1, 2021). The VII International Scientific and Practical Conference within the VI Scientific Forum of the National Academy of Agrarian Sciences of Ukraine (Chernihiv region, 2021); the IV International Scientific and Practical Conference "Theoretical and Practical Aspects of the Development of the Vegetable Growing Industry in Modern Conditions" (Kharkiv, May 20, 2021); and the "Agriculture - 2021" conference (Mykolaiv, April 30, 2021). The ADAU event dedicated to the 270th anniversary of the city of Shusha, titled "Application of Scientific and Educational Production in the Development of Priority Production Territories" (Ganja, March 29, 2022), and the International Conference "Biodiversity, Soil, and Water Resources of Shusha and Adjacent Territories: A Future Outlook," organized by the National Academy of Sciences of Azerbaijan (Baku-Shusha, September 22-24, 2022). The research was also featured at the "New Prospects and Approaches in the Development of Applied Sciences and the Agricultural Sector" conference, dedicated to the 100th anniversary of National Leader Heydar Aliyev's birth (Ganja, March 29, 2023).

A patent for the utility model of an extractor (F 2024 0018) was secured, and the technology, along with the experimental extractor developed in this research, was successfully tested and applied at AZGRANATA MMC (AZ0600) in the city of Agsu.

The name of the organization where the dissertation work was completed. The dissertation work was completed at the State

Legal Entity “Scientific Research Institute of Vegetable Growing” of the Ministry of Agriculture of the Republic of Azerbaijan.

The total volume of the dissertation, with a breakdown of the volume for each structural section. The dissertation consists of an introduction, four chapters, a conclusion, recommendations for production, 167 literary sources and appendices. Contains 19 figures, 41 tables and 4 appendices. According to the content of the dissertation, the introduction is 7 pages, 11,599 characters, the first chapter is 39 pages, 68,447 characters, the second chapter is 19 pages, 28,410 characters, the third chapter is 54 pages, 59,024 characters, the fourth chapter is 35 pages, 40,574 characters, general conclusions - 2 pages, 2,753 characters, recommendations - 1 page, 610 characters. The volume of the dissertation consists of 158 pages of computer writing, the total volume of which is 211,417 characters.

CONTENTS OF THE WORK

The introduction of the dissertation outlines the relevance and current state of development of the topic, along with the goals and objectives of the research. It also presents the research methods, key propositions to be defended, the scientific novelty, as well as the theoretical and practical significance of the study. Additionally, it addresses the approval and practical application of the research findings.

Chapter one provides a concise overview of the theoretical framework, drawing on both domestic and international literature. It includes an analytical review of the problem statement, examining the concept of functional nutrition and its current stage of development. The chapter discusses the technological aspects of producing functional beverages from plant materials, the structure and properties of pectin polysaccharides, the primary methods of extracting pectin from plant sources, and techniques for enhancing the extraction of key components from these materials. It highlights that the technology of functional food products represents an emerging scientific field driven by advancements in modern science and technology. According to the "healthy nutrition" concept established in the late 20th century, food should not only meet energy requirements but also play a

significant role in health prevention. During the study, the author developed the standard project AZS 938:2023, titled "Food Products. Functional Food Products. Terms and Definitions," which was approved by the Azerbaijan Institute of Standardization (AZ-STANDART) and officially registered by the state.[2]

Functionality refers to the property of a food product that indicates its suitability for its intended purpose. Functional foods should offer benefits to physical performance or mental health, in addition to meeting nutritional needs.[3] The quantity, structure, and properties of pectin polysaccharides, which contribute to the functionality of a food product, are affected by factors such as the source of the raw material, the extraction method and conditions, and the arrangement of micromolecules.[4] According to the general classification, pectins are categorized into two types: highly esterified (greater than 50%) and low esterified (less than 50%). The degree of esterification, which is determined by the presence of methoxyl groups, is a key factor affecting the physicochemical properties of pectin. Global annual pectin production exceeds 80,000 tons. The primary raw materials for industrial pectin production are apples, citrus fruits, and beet pulp[5].

Chapter Two focuses on the objects and methods of the study. The objects of the research include vegetables cultivated under local conditions, specifically apples, quinces, citrus fruits, and the pectin derived from them, which were utilized for blending. The research encompasses the extraction and production of pectin, the technological processes involved in preparing and preserving functional beverages, and the equipment employed. The study utilized various varie-

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[2] AZS 938:2023 Qida məhsulları. Funksional qida məhsulları. Termin və təriflər // -Bakı: AZSTAND, Standartlar kataloqu, - 2023, – 8 s.

[3] Донченко, Л.В. Функциональные продукты питание / Л.В.Донченко. – М.: Изд-во Юрайт, - 2019. - 176 с.

[4] Isolation and structural characterization of a pectin homo and ramnogalacturonan / Z.K.Muhidinov, D.Kh.Khalikov, F.T.Abdusamiev [et all] // Talanta.-2000.-v. 53, №1.-p.171-176.

[5] Донченко, Л.В. Технология пектина, пектинопродуктов / Л.В.Донченко, Г.Г.Фирсов; – Краснодар: КГАУ, - 2006. - 276 с.

ties of table beet (Bordo 237), carrot (Absheron winter), zucchini (Gribovskaya 37), pattypan squash (White 13), and tomatoes (Vatan 1, Leyla, Zafar, Elnur) listed in the State Register.

From 2018 to 2021, research was conducted in the laboratory of processing, storage, and quality at the "Vegetable Research Institute," a public legal entity. Additionally, analyses were performed in the institute's functional analysis laboratory.

During the research, the author developed for the first time in our country standard projects AZS 896:2021 "Fresh squash. Technical conditions" and AZS TS 794:2023 TOMATO (Solanum lycopersicum L.) and approved by the Azerbaijan Institute of Standardization (AZSTANDART) as a state standard and included in the Catalog of Standards.

The amount of dry matter in the samples was measured using the thermogravimetric method (AZS 937:2023), total acidity was assessed by titration (AZS GOST:25555.0:2023), and active acidity was determined with a pH meter (GOST 26180-84). Organoleptic properties and sensory evaluation of pectin drinks were conducted according to GOST-29186-91. Total sugars were measured with a PA-130 refractometer, and nitrate levels were analyzed using a SOEKS nitrate tester.

At the end of the chapter, methods for the hydrolysis-extraction of plant materials are detailed, following the standard experimental study methodology.

Chapter Three covers the experimental component of the research. To evaluate the potential of using pectin-rich vegetables in the production of functional drinks, local plant materials were analyzed for their pectin content (Table 1).

Table 3.1.1 demonstrates that the pectin content in locally produced vegetables is notably high. These findings indicate that these local vegetables hold significant promise for the production of functional food products, including those enriched with pectin.

The purpose and quality of functional food products are influenced by the quantity and properties of biologically active substances - functional food components - present in the raw material. Since most of the biologically active compounds in vegetables are dis-

solved in the cell juice, the vegetable samples selected for juicing were assessed for their pectin content and other biologically active substances (Table 2).

Table 1

Total amount of pectin substances in various plant raw materials (in percent per 100 g of dry matter)

Table beet	4,0 – 5,0	Pattypan squash	3,0 – 3,5
Carrot	6,0 – 8,0	Ripe tomatoes	2,0 – 2,9
Zucchini	2,5– 3,0	Cabbage	5,0 – 7,5
Melon	1,7 – 5,0	Zucchini	7,0 – 10,0

Table 2

Composition of plant materials by quantity of biologically active substances and nutritional value (per 100 g of product)

Content indicators	Quantity in various plant materials				
	Carrot	Table beet	Zucchini	Pattypan squash	tomato
Organic acids, q	0,2-0,3	0,6-0,7	0,1-0,2	0,1-0,2	0,4-0,9
Pectin substances, q	6,0-0,8	4,0 – 5,0	2,5-3,0	3,0-3,5	2,0-2,5
Proteins, %	1,8	2,3	1,2	0,8	0,6
Fats, %	0,2	1,7	0,2	0,3	0,1
Water, %	87,5	89,6	93	92	93,5
Easily digestible carbohy-drates, %	12	9,5	6,8	7,6	7,7
kkal.	35	42	18	19	18
Mineral substanses, mq%					
Sodium Na	205	225	96	98	5
Calcium Ca	34	22	400	450	10
Phosphorus P	32	34	250	260	24
Potassium K	139	155	115	118	237
Magnesium Mg	17	22	140	150	11
Iron Fe	0,6	1,1	5,0	5,2	0,27
Vitamins, mq%					
B_1 (tiamin)	0,06	0,01	0,04	0,03	0,037
B_2 (riboflavin)	0,07	0,05	0,06	0,07	0,05
C (ascorbic acid)	5,9	2,5	21	23	15-50
β – carotene, mq%	40,0	2,0	3,0	10,0	9,0

As shown in Table 2, the tebale beet contains the highest protein content at 2.3%, followed by carrots at 1.8%. In contrast, zucchini and squash have the lowest protein content, ranging between 1.2% and 1.3%

The functional and physiological value of plant materials is significantly influenced by their mineral content. As shown in the table, beetroot contains the highest amount of sodium (225 mg/kg), while zucchini (96 mg/kg) and pattypan squash (98 mg/kg) have lower levels, and carrots have an average sodium content (205 mg%). Zucchini and pattypan squash are also rich in calcium. Regarding phosphorus, carrots (32 mg/kg) and beetroot have the lowest levels, while zucchini (250 mg/kg) and pattypan squash (260 mg/kg) contain the highest amounts. Potassium levels were satisfactory across all vegetable samples (139, 115, 118, 155 mg/kg). Iron content was found to be high in zucchini and moderate in beetroot and carrots.

Zucchini and pattypan squash had the highest vitamin C levels, followed by carrots (5.9 mg) and beets (2.5 mg). Carrots (40 mg%) also had the greatest amount of β-carotene, with a smaller amount found in pattypan squash (10.1 mg%).

The influence of geographical factors on the development of functional properties in raw materials was analyzed by comparing the chemical composition of Bordeaux-237 table beets grown in regions with varying soil and climatic conditions.

As a result, it was observed that vegetables grown under local conditions in our republic contain a sufficient amount of pectin and can be considered a reliable source of raw materials for the production of functional beverages intended for preventive purposes.

To investigate the technological properties of the raw materials, the nutritional value and carbohydrate content of the study object, in the form of fresh raw materials and puree, were analyzed using samples of table beets and carrots. The study utilized vegetable purees with a pH of 2.9-3.8 and a dry matter content of 10-15%, which can be stored at a temperature of 15-20°C. A comparative analysis of the composition indicators in both raw mass and dry matter is provided in Table 3.

Table 3

Comparative analysis of composition indicators in raw mass and puree

Product name	Composition of the substance, %						
	Dry matter	Pectin		Fiber		Total Sugar	
		In raw mass	In dry matter	In raw mass	In dry matter	In raw mass	In dry matter
In fresh raw materials							
Carrot	10,52	0,58	5,51	1,27	12,07	6,77	64,35
Table beet	12,80	1,02	7,97	1,69	13,20	8,83	68,98
In puree							
Carrot	12,05	1,14	9,58	1,37	12,27	4,96	41,23

As shown in Table 3, vegetable purees are preferable to raw mass due to their higher dry matter content of 12-16% and twice the amount of soluble pectin. Therefore, using purees in the preparation of functional beverages appears to be more effective. This is attributed to their high nutritional value and safety. Additionally, by adhering to the principles of low-waste technologies, this approach allows for the processing and evaluation of non-standard raw materials.

Pectic substances are also widely distributed in fruits. Fruit pectins have a high degree of esterification and have high gelling properties.

The storage and processing characteristics of zucchini and pattypan squash, which are uncommon vegetables in Azerbaijan, along with tomato varieties with export potential, were studied, focusing on how technological factors influence protopectin levels. Optimal storage conditions were identified through experiments with three different approaches, selecting specific storage methods for each vegetable type in laboratory settings. It was demonstrated that biochemical processes are primarily influenced by the pectin content in the fruits, while the activity of polygalacturonase and pectinase enzymes is temperature-dependent.

The firmness of tomatoes is strongly linked to their pectin lev-

els. Additionally, the variation in shelf life across different varieties suggests that pectin content has a genetic component. The chemical composition losses after storage were calculated: natural losses under standard laboratory conditions ranged from 3.5% to 7.7%, in open packaging in the refrigerator from 1.9% to 2.5%, and in sealed packaging in the refrigerator from 0.9% to 0.6% (Table 4).

Table 4

Main biochemical parameters of fruits of tomato varieties before storage (TETI, 2018-2021)

Variety name	Dry matter, %	Sugar, %	Total acidity, %	Vitamin C, %
Zafar	5,5	3,0	0,49	27,2
Elnur	5,2	2,9	0,67	24,1
Vatan 1	5,2	3,2	0,48	29,5
Leyla	5,1	3,2	0,45	24,0

Pectin in tomatoes forms a calcium pectate complex with Ca+ compounds, contributing to the firmness of the tissue, with Ca+ ions acting as a "binding agent." The sensory evaluation of the stored tomato fruits was conducted in accordance with the AZS TS 794:2023 standard.

One of the main areas of research was the study of pectin extraction from plant materials:

Absence of comparable alternatives. A critical analysis of existing extractors revealed that their primary shortcomings are inefficient extraction processes, limited reliability in intensifying the extraction process, and low productivity.

Another extractor device, which closely aligns with the intended technical improvements, was also analyzed. This unit consists of a housing with loading and unloading openings, a perforated section, a confuser, cylindrical and diffuser sections, all arranged sequentially between the loading opening and the perforated zone. It includes a hopper connected to the housing’s loading opening, serving as a feeder, and an annular space surrounding the perforated section for collecting the extract. Additionally, there is a cone-plug with an axial offset.

The drawback of this extractor is the inefficient separation of the extract from the plant material, resulting in a low product yield. While productivity can be enhanced by adding a steam generator for process intensification, the increased pressure and temperature compromise the pectin's natural properties. The objective of the improvement is to achieve more efficient separation of the extract from the plant material while preserving its natural qualities.

The enhanced performance is achieved through the inclusion of a screw inside the extractor housing, with loading and unloading openings connected to it. The design also features a perforated section, confounder and diffuser sections equipped with an extractant feeder, a narrower section, and a condenser, all positioned sequentially between the loading opening and the perforated part, which is connected to both the housing's loading opening and the loading hopper. An annular space surrounds the perforated section of the housing for extract collection. Additionally, the system includes a separator, a liquid extract discharge opening on the lower side, and a gas outlet on the upper side. Furthermore, the design incorporates a constrictor, a compressor, and a vacuum pump, with the compressor linked to the confuser section and the vacuum pump connected to the diffuser section, all arranged sequentially according to the utility model. The additional components integrated into the extractor are designed to address the issue. Connecting the mixer zone to the compressor after introducing the extractant into the system enhances the extractant's penetration into the raw material. Additionally, linking the diffuser section to the vacuum pump immediately following the mixer zone increases the efficiency of extract separation from the raw material in that section. Based on the research, a design for an improved extraction unit (Figure 1) was developed, which intensifies the extraction of pectin from the raw material and ensures a high-quality yield.[6]

The novelty of the proposed improved extractor has been recognized by the Expert Center of Patents and Trademarks of the Republic of Azerbaijan as a utility model (F 2024 0018).

[6] Патент Р.Ф. №2478650. Способ получения низкомолекульяного пектина /В.В.Ковалев, М.Ю.Хотимченко, Ю.С. Хотимченко. - 2013.

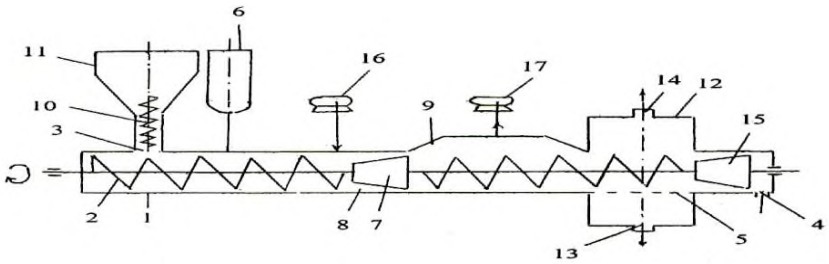

Figure 1. Scheme of the improved extraction unit: 1-barrel; 2-screw; 3-charger; 4-discharger; 5-perforated part; 6-extractant-transmitter; 7-contractor; 8-confuser; 9-diffuser; 10-feeder; 11-hopper; 12-collector space-separator; 13-exhaust outlet; 14-gas outlet; 15-contractor; 16-compressor; 17-vacuum pump.

Modeling the Extraction Process: The working hypothesis suggests that the technologically and technically enhanced extraction process operates in a dynamic mode. In this mode, the drawbacks associated with static or high-pressure and high-temperature conditions are eliminated.

Contact with a hydrolyzing agent is the timely isolation of the extracted molecules. Based on the experimental results, taking into account the accelerating factors, the maximum extraction time was determined (τ = 3 hours).

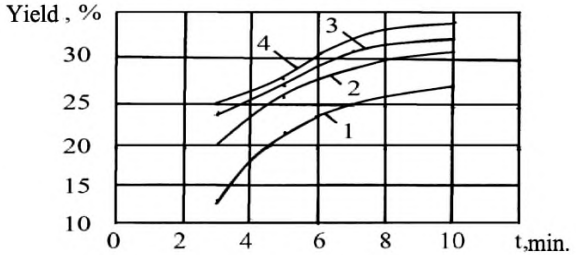

Figure 2. Curves showing the yield of pectin during rapid extraction (P=2 atm), 1-T=100^0; 2-T=120^{0}C; 3-T=130^{0}C; 4-T=140^{0}C

The "Pectin" software was developed using data from the mathematical model and relevant studies. This allows for predicting the yield and quality of pectin. Figures 2 and 3 show the relationships between pectin yield, pressure, and temperature

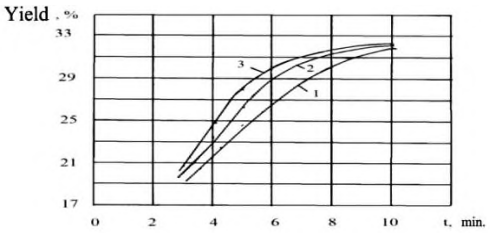

Figure 3. Curves illustrating pectin yield during rapid extraction (T=120^{0}C), 1-P = 1,5; 2-P = 2 atm ; 3-P = 3 atm .

The mathematical model and analysis of the hydrolysis-extraction process of plant raw materials are grounded in the physicochemical principles of mass transfer. The study's subject is explained through hydrodynamic, thermal, and mass transfer processes. When treating the process as a complex problem, all factors affecting the efficiency of hydrolysis-extraction must be considered in the development of a comprehensive mathematical model of pectin. Based on data from our exploratory research, a full-factor model, "Pectin", was developed.

The optimization of the main operating parameters of the extractor is presented through the use of advanced technology and research into the metal-binding properties.

The method of extreme experiment planning is employed to optimize the key parameters of the extraction process by utilizing successively varying pressures with a confuser and diffuser in an enhanced extractor operating dynamically to extract pectin from plants. As an example, a mixture of squash and beetroot was used for the experiment. The design of the multifactorial experiment and the results are presented.

Based on the values obtained from the experiment, we will derive a regression equation. This regression equation establishes the relationship between the pectin yield (y) and the identified factor indicators.

$$Y=f(X_1, X_2, X_3) \quad (1)$$

The purpose of the multifactorial experiment is to establish the following relationship:

$$y=f(x_1, x_2, ...x_3) \quad (2)$$

The maximum deviation of the experimental values is as follows:

3)

The reporting value of the Cochrane criterion is determined by the following formula:

$$G_{hes} = (S_{max}^2)/(\sum_{k=1}^{N}) = 0,45/2,88 = 0,156 \quad (4)$$

We find the tabular value of the Cochran criterion by referring to the confidence level $P_G = 0,95$ Considering this and the degrees of freedom, we determine the Cochran criterion for the critical price table as $G_{tab.}$=0,55.

As can be seen, the observed value is less than the tabular value, indicating that the experimental variances are homogeneous and the experiments are reproducible.

To determine the tabular value of the Fisher criterion, we use the probability P_F=0,95 Taking this and the degrees of freedom into account, we derive the critical value of the Fisher criterion from the table as $F_{tab.}$=5,32. It is evident that the observed value of the Fisher criterion is lower than its tabular value, confirming that the model adequately represents the experiment.

The optimization of the main operating parameters of the extractor, based on the improved technology and metal-binding research, is presented.

It was determined that three key parameters positively influence pectin yield: extraction time, screw rotation frequency, and specific power (power per unit area) generated by structural changes. The optimal values for maximizing extract yield (78.7%) are a screw rotation frequency of 16.6 cycles/min, a specific power of 50 kW/m², and a duration of 3.6 hours.

However, intensifying the process through higher pressure and temperature increases the risk of higher energy consumption and the potential loss of pectin quality and properties.

Chapter four. Research on the formulation and production technology of plant-based beverages with added pectin is underway.

A crucial aspect of determining the physical and chemical properties of pectin includes studying its moisture and ash content, degree of esterification, gelation temperature, and elemental composition. The degree of esterification of carboxyl groups and the concentration of free carboxyl groups are key quality indicators that significantly influence the physical and chemical properties of pectin.

Table 5

Physicochemical properties of pectin samples

Key indicators	Amount in different pectin samples				
	Apple	Citrus	Table beet	Zuccini	Pattypan squash
Humidity, %	9,2	10,3	9,0	8,7	8,5
Ash, %	1,25	1,50	1,71	1,20	1,10
pH 1% solution	3,3	3,0	4,0	4,1	4,1
Gel formation temperature, ^{0}C	78	82	75	52	52
The degree of etherification, %	68	71	47	56	55
Mass fraction of free carboxyl group, %	11,4	8,9	19,6	12,5	13,0
Mass fraction of ballast substances, %	16,1	17,0	27,0	16,0	16,5
Pectic acid, %	46,2	45,3	36,1	43,4	44,3
Viscosity (at 20^{0}C) Pa·san	4,4	3,4	3,6	4,2	4,5

As shown in Table 5 the physicochemical parameters of the pectin samples indicate that plant pectins are a valuable product. It has been determined that the plant pectins, which are our target products, possess a low degree of esterification and a small molecular weight. They are poorly soluble in water, only hardening under specific conditions, and are resistant to the gelling agents formed. The technology for preparing beverages containing guaranteed pectin has been studied. This approach enables the inclusion of pectin in the diet for preventive purposes and allows for the adjustment of its daily dosage. It has been established that the addition of pectin significantly affects the organoleptic properties of the beverages, particularly their consistency. The most harmonious balance of organoleptic characteristics, consistency, and chemical composition has been

achieved in vegetable and fruit-vegetable drinks prepared with plant-based pectins. The resulting beverage samples exhibit high consumer appeal and preventive health benefits.

The pectin content in the juice is aimed at preventing and reducing the risk of occupational and industrial diseases in workers by aiding in the removal of toxic substances from the body.

Preventive beverages were prepared using beetroot, carrot, squash, pattypan squash juices, and fruit and vegetable purees.

The chemical composition and energy value of the vegetables and their mixtures with fruit juices used to create these functional drinks are presented in Table 6.

Table 6 shows that vegetable juices contain a sufficient amount of beneficial elements. Water content ranges from 82.7% to 93.3%, proteins up to 1%, and sugars from 3.7% to 10.3%. The highest caloric content was found in juices made from squash-apricot pulp (62 kcal) and watermelon pulp (59 kcal).

Table 6

Chemical composition (in %) and energy value (kcal/100 g) of vegetable juices and their mixtures with fruit juices

№	The name of the juices	Water, %	Proteins %	Carbohydrates		Organic acids based On malic acid, %	Cellulose, %	Energy value of the food, kkal/100 q
				Mono and disaccharides, %	Starch, %			
1	Carrot	84,6	1,1	5,6	0,2	0,2	0,6	28
2	Table beet	83,4	1,0	9,9	0	0,2	0,9	42
3	Tomato	93,3	1,0,	3,7	0,2	0,5	0,2	19
4	Carrot-apple	88,9	0,7	8,0	0,1	0,4	0,4	21
5	Carrot- grape	87,5	0,8	10,3	0,4	0,4	0,4	35
6	Zucchini-apricot pulp	86,1	0,6	11,8	0,3	0,3	0,6	62
7	Water melon pulp	85,0	0,5	13,3	0,1	0,1	0,3	59
8	Melon pulp	82,7	0,4	15,4	0,3	0,3	0,3	53

To evaluate the nutritional value and functional properties of the prepared drinks, the vitamin and mineral content was analyzed.

The mineral and vitamin composition of the vegetable juices is presented in Table 7. The prepared drinks were assessed based on the

base juice used.

Table 7

Mineral and vitamin composition of vegetable juices (mq/100 q)

№	The name of the juices	Na	K	Ca	Mq	P	Fe	β-kar.	B_1	B_2	C
1	Carrot	26	130	19	7	26	0,6	1,60	0,01	0,02	3,0
2	Table beet	55,3	148	19	17	18	0,6	0	-	0,04	3,0
3	Tomato	3	240	7	12	32	0,7	0,50	0,03	0,03	18,0
4	Carrot-apple	11	155	21	8	20	0,7	3,5	0,02	0,04	4,0
5	Carrot- grape	16	181	26	13	22	0,5	3,5	0,02	0,04	3,7
6	Water melon pulp	14	65	13	19	67	1,1	izi	0,02	0,02	1,1
7	Melon pulp	26	115	16	13	12	1,0	izi	0,03	0,02	13,2

Table 7 shows that vegetable juices are rich in minerals such as potassium, iron, and phosphorus, as well as vitamins. The addition of pectin did not alter the taste or appearance of the drinks.

To prepare the drinks, pectin was dispersed and added to water, followed by the addition of sugar, fruit puree, and citric acid. The drinks were then heated to 80°C and subsequently cooled to 8-15°C.

The presence of 10-15% soluble dry substances and 3% acidity in beverages prepared using various recipes enhances their palatability. Each 100 g of the drink contains 0.5% pectin, with an energy value of 38-45 kcal. These beverages are an important component of a healthy lifestyle, as they are rich in vitamins, amino acids, and other essential nutrients that individuals require daily.[7]

The dosage and method of adding pectin have been established. The addition of pectin significantly influences the organoleptic properties of the beverages, particularly their consistency. The optimal balance of organoleptic qualities, consistency, and chemical composition in vegetable and fruit-vegetable drinks prepared with plant pectins has been achieved. A major advantage of incorporating pectin is that it does not alter the taste or aroma of the drinks. The degree of

[7] Адыгезалова,С.Г. Основные функциональные свойства пектиновых полисахаридов в овощном сырье//-Нижневартовск:«Бюллетен науки и практики», зарегистрированный в России научный журнал, – 2022, Vol 8, № 5, - с. - 218-223.

esterification is a key indicator of the applicability of pectin substances. Pectins with a degree of esterification below 50%, including plant-derived pectins, exhibit gelling properties only in the presence of calcium ions and other polyvalent metals. These pectins are primarily utilized in medicine and pharmacology due to their ability to eliminate heavy metals, toxins, and radionuclides from the body.

GENERAL RESULTS

1. Locally grown vegetables, which contain sufficient amounts of pectin and other functional components, can be regarded as a promising source of raw materials for producing functional food products, including pectin.
2. Using purees as a technological foundation for preparing functional drinks is more efficient due to their high nutritional value and safety. This approach enables the inclusion of non-standard raw materials in the processing, evaluated in accordance with the principles of low-waste technologies.
3. A common drawback of existing extractors for extracting plant raw materials is the lengthy extraction process and low productivity. While productivity can be enhanced by incorporating an autoclave with a steam generator to intensify the process, the application of high pressure and temperature leads to increased energy and resource costs, as well as alterations in the natural properties of plant pectin.
4. Based on the concept of improvement, the added elements to the extractor, along with the connection of the confuser zone to the compressor after the extractant is introduced into the system, enhance the penetration of the extractant into the raw material. Additionally, linking the diffuser section to the vacuum pump immediately after the confuser section increases the intensity of extract separation from the raw material. As a result, the intensification of raw material extraction and more complete extraction lead to an increase in the unit's hourly productivity.
5. The key kinetic principles of pectin extraction from plant raw materials were investigated, and a corresponding physical and math-

ematical model was developed. This modeling allows for an in-depth study of protopectin decomposition during the design phase, optimizing the technological conditions and guiding the process to enhance both the yield and quality of pectin.

6. Three parameters positively influence the pectin yield: extraction time, screw speed, and specific power (power per unit area) generated by structural changes. The optimal values for maximizing pectin yield, which is 78.7%, are as follows: screw speed – 16.6 cycles/min, specific power – 50 kW/m², and extraction time – 3.6 hours.
7. The physicochemical properties and metal-binding capabilities of pectins isolated from plant raw materials, due to their high complex-forming ability, highlight their potential use in preventive nutrition as well as in other sectors of the food and medical industries.
8. The beverages prepared using different recipes had a dissolved solids content of 10-15%, an acidity of 3%, and demonstrated good consumer properties. Each 100 g of the beverage contained 0.5% pectin, with an energy value of 19-42 kcal. The added pectin did not affect the taste or color of the drink.
9. For an enterprise with a small annual production volume (7.8 tons), the annual cost efficiency of using an experimental mixer-diffuser and vacuum extractor is 5859.06 AZN, compared to using an autoclave with a steam generator operating at high temperature and pressure.

Recommendations for production

1. Extraction of pectin from plant raw materials under mild conditions in the production line, achieved by sequentially installing confuser and diffuser elements, connecting the first to a compressor and the second to a vacuum pump, resulting in savings of energy, resources, and time.
2. Application of optimal parameters, determined through the study of the operating conditions of the hydrolysis extraction process, in organizing pectin production.
3. Utilization of plant-based pectins, obtained by acid hydrolysis in dynamic conditions, for the production of functional plant-based beverages.
4. Incorporation of the analysis and proposed scientific concepts into

the educational programs of relevant disciplines.

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