Due to environmental concerns, increasing attention is given to whey as a valuable secondary raw material. Modern research confirms its high nutritional and biological value due to its content of lactose, proteins, and minerals. The object of this study is the production of functional beverages based on whey enriched with natural juices from apples, sea buckthorn, and pears grown in the northern regions of Azerbaijan. The problem to be solved is the creation of a zero-waste processing technology that transforms whey into a functional product with enhanced organoleptic and nutritional properties. The development of such technologies contributes to the rational use of resources and the reduction of negative environmental impacts.

In the course of the study, the organoleptic and physicochemical properties of both the control whey sample and the experimental samples with added juices were examined. It was found that the addition of plant-based components enhances the taste, aroma, and appearance of the beverage, while also increasing its nutritional value. The article presents the formulation and technological scheme for producing beverages with improved organoleptic properties and storage stability. Physicochemical analysis confirms that the developed beverages meet GOST R 56543-2015and monitoring changes in acidity, dry matter, and sugars over a 5-day storage period in fridge (0…+6°C) demonstrates satisfactory product stability. Thus, the proposed technology for processing whey into functional beverages not only contributes to the expansion of the range of high value-added products but also addresses environmental issues related to the disposal of dairy waste. All of the above makes it possible to assert the necessity of implementing this technology in industrial production

Keywords: milk whey, dairy waste, functional beverages, waste disposal, environmental problems

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DEVELOPMENT OF A PRODUCTION TECHNOLOGY FOR FUNCTIONAL BEVERAGES BASED ON WHEY ENRICHED WITH NATURAL JUICES FROM PLANT-BASED RAW MATERIALS

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1. Introduction

Although the dairy industry is a vital sector in food production, it leads to the generation of large amounts of waste. One of the most widespread forms of this waste is whey. Whey is the liquid byproduct separated during milk curdling or fermentation processes and contains high levels of protein, lactose, and minerals. However, whey is often treated as waste, and if not properly managed, it can cause serious environmental damage. The failure to reuse whey in an environmentally friendly manner results in the waste of water and energy resources, as well as pollution of the environment [1]. Improper management of industrial and agricultural wastewater-particularly its release into water sources without proper treatment-undeniably results in dangerously contaminated drinking water for hundreds of millions of people [2, 3]. In the absence of sustainable practices, whey is considered the most significant environmental pollutant in the dairy industry, as large volumes of it are disposed of as wastewater, posing a serious ecological threat [4]. Nevertheless, modern approaches in sustainable production and biotechnology view whey not as waste, but as a valuable raw material for the creation of high value-added products. Whey proteins are widely used in the production of sports and infant nutrition, lactose is utilized in the pharmaceutical and food industries, and technologies are being developed to produce biofuels, animal feed, and biodegradable packaging from whey components [5].

The rational use of whey not only reduces the environmental burden but also increases the profitability of the dairy industry through the additional processing of by-products. Initially, whey waste was disposed of through soil, discharged directly into water bodies without treatment, stored in separate containers, or drained into the sewage system [6]. Over time, established waste management regulations restricted such disposal methods, which naturally led to increased wastewater treatment costs and marked the beginning of a growing market for whey-based products. Thus, growing consumer attention to the environmental aspects of dairy industry operations has become a driving force for the active adoption of more resource-efficient and environmentally friendly whey processing methods prior to disposal [7, 8].

Rethinking whey not as waste, but as a secondary raw material opens up broad prospects for the development of zero-waste and environmentally sustainable technologies in the food industry. The integration of innovative whey processing methods contributes not only to reducing environmental impact but also to increasing the economic efficiency of dairy enterprises by creating high value-added products. The rational use of whey is a crucial step toward the sustainable development of the agro-industrial sector [9, 10]. Numerous species of various plants grow in Azerbaijan, which are used as food products, applied in medicine, and serve as raw materials for the vitamin and pharmaceutical industries [11, 12].

The nutritional and biological value of plant raw materials is determined by their chemical composition, which depends on the variety, growing location, harvest time, climatic conditions, processing technology, and other factors [13, 14]. Therefore, using local plant raw materials as enrichers is both relevant and practical, as these plants are rich sources of biologically active compounds, especially flavonoids, carotenoids, phytosterols, and others [15, 16].

Global environmental concerns have stimulated increased research focused on studying whey's properties, chemical composition, nutritional value, and potential technological applications [17, 18]. It is important to emphasize that whey retains significant nutritional value because of its residual protein content, which has led many scientific studies to concentrate on its efficient processing and valorization [19, 20].

Therefore, research aimed at developing a zero-waste production technology for whey-based products is highly relevant and holds both scientific and practical significance. At the same time, it offers the opportunity to utilize plant juices from the northern regions of Azerbaijan – which account for up to 50% of the country's fruit production – for the creation of a new generation of functional products [21].

2. Literature review and problem statement

The study [22] presents the results of research on the development of a fermented dairy product, "Gatyg", based on buckwheat varieties grown in Azerbaijan. It has been shown that the use of local raw materials not only enriches the product with functional components but also increases its biological value. However, unresolved issues remain related to the scaling of the technology and ensuring the stability of organoleptic properties during industrial production. Overcoming these challenges may involve the development of standards for the selection and preparation of plant-based raw materials. A similar approach was used in study [23], which presented research findings on the development of a cooked sausage technology with the inclusion of natural plant extracts. These extracts helped slow the growth of spoilage microorganisms, positively affecting the shelf life and microbiological stability of the final product. However, unresolved questions remain regarding the antibacterial and antioxidant effects of the extracts, as well as their interactions with each other and with the meat matrix. These challenges may be due to the chemical composition of plant raw materials, making research in this area impractical. This approach was also applied in study [24], which investigated the development of cooked sausages using buckwheat extracts and assessed their impact on product quality and shelf life. It was shown that the inclusion of buckwheat extracts enhances antioxidant activity, improves organoleptic characteristics, and extends the shelf life of the product without the use of synthetic additives. Nonetheless, unresolved issues remain regarding the optimal dosage of plant components, their interactions with the meat base, and their effect on product structure during long-term storage. These difficulties may stem from the complexity of standardizing the composition of plant-based extracts, as well as the high cost of their production, making research in this direction challenging. A potential solution to these challenges could be the development of a comprehensive approach to extract standardization.

The paper [25] presents research results on obtaining biologically active peptides from whey protein hydrolysates and their application in the production of functional food products. It has been shown that enzymatic hydrolysis effectively isolates peptides with pronounced antioxidant and antimicrobial properties, opening broad prospects for developing high-value-added products. However, unresolved issues remain regarding the technology for producing biopeptides and ensuring the stability of their biological activity. Due to their cost, conducting research in this area is challenging. Overcoming these difficulties may lead to the implementation of biotechnological solutions aligned with the economic realities of the food industry. A similar approach was used in study [26], which summarizes the latest advances in whey processing and utilization. It demonstrates that modern methods such as membrane filtration, enzymatic hydrolysis, and "green" processing technologies effectively extract valuable whey components while minimizing environmental impact. Nonetheless, unresolved issues persist related to integrating advanced technologies into existing production chains. These challenges are partly due to the fundamental impossibility of fully utilizing all components without additional energy costs, making research in this direction impractical. Article [27] presents research results focused on developing an integrated approach to whey processing. It shows that combining various methods, including anaerobic digestion, fermentation, chemical, and thermochemical treatments allows for effective utilization of by-products and extraction of valuable products such as biogas, organic acids, and nutrients. However, unresolved issues remain related to selecting optimal processes depending on raw material composition and energy costs. These challenges stem from the need to adapt processes to changing conditions and the high costs involved, making research in this area difficult.

The paper [28] presents research results on the bioengineering of whey proteins and their impact on human health. It demonstrates that whey proteins possess biologically active properties, including antioxidant and metabolic effects, making them valuable components for functional food products. However, unresolved issues remain concerning the optimization of protein modification methods to enhance functional properties. These challenges are due to the complex structural organization of proteins and the limited availability of analytical techniques, which hinder the development of universal approaches for their application.

The paper [29] presents research results focused on the development of technology for extracting juices from pumpkin, persimmon, and rosehip fruits using various extraction methods. It was shown that the choice of extraction method significantly affects the yield of the final product, the content of biologically active substances, and the organoleptic properties of the juices. However, unresolved issues remain related to selecting optimal technological parameters for each type of raw material, ensuring the stability of vitamins and antioxidants, and minimizing losses during processing. These challenges arise from the differences in the physicochemical characteristics of the fruits used, their seasonality, and the high sensitivity of biologically active components to thermal and mechanical processing, making research in this area difficult or impractical.

Thus, whey represents a valuable secondary resource, the rational use of which helps reduce environmental impact and increase the efficiency of the dairy industry. Enriching whey with juices from local plants such as apple, pear, and sea buckthorn allows the creation of functional products with high nutritional value. The use of local plant raw materials not only expands the product range but also meets modern demands for environmental sustainability and healthy nutrition.

However, despite the well-known nutritional value of whey and the potential of local plant-based additives, an optimized, practical, and resource-efficient technology for producing functional whey-based beverages with high nutritional value, stable organoleptic properties, and suitability for small and medium-sized enterprises has not yet been developed.

3. The aim and objectives of the study

The aim of this study is to develop a technology for producing whey-based beverages enriched with natural apple, pear, and sea buckthorn juices. This will allow expanding the range of sustainable functional products and improving the efficiency of whey utilization.

To achieve this aim, the following objectives are accomplished:

– to investigate the organoleptic and physicochemical quality indicators of whey;

– to develop the formulation and technological scheme for producing beverages based on whey;

– to study the nutritional value and quality indicators of experimental samples during storage.

4. Materials and methods

4. 1. The object and hypothesis of the study

The object of the study is the production of beverages based on whey with the addition of natural juices from apple, sea buckthorn, and pear. The research hypothesis is that it is possible to create next-generation functional beverages with enhanced nutritional value, pronounced preventive and therapeutic properties, as well as improved organoleptic characteristics. The study assumes that the selected juice concentrations and processing conditions ensure the preservation of nutrients and flavor qualities. At the same time, the research is limited to the use of three types of juices, standard heat treatment methods, and laboratory storage conditions.

The whey used in the production of functional beverages was provided by an enterprise located in the territory of the Azerbaijan.

To address the objectives, modern organoleptic – sensory profiling, physicochemical, and technological methods were used to study both the raw materials and the finished products.

The methodology for determining the organoleptic and physicochemical indicators of whey was conducted according to GOST 53438-2009.

Sensory profiling, this method involves a trained tasting panel that evaluates the beverage based on multiple sensory attributes (taste, aroma, color, texture) using intensity scales. Each attribute (descriptor) is evaluated using a scoring system from 0 to 10 (for example, 0 – not present at all, 10 – very strongly expressed).

The results are presented as a sensory profile (often in the form of a spider or radar chart), allowing for comparison of products based on their sensory perception.

4. 2. Determination of acidity

A 50 cm^3 beaker was filled with 20 cm^3 of distilled water and 10 cm^3 of whey. The mixture was thoroughly stirred, then 3 drops of phenolphthalein were added. It was titrated with a 0.1 N alkali solution until a faint pink color appeared that persisted for 1 minute.

Acidity (X, °T) was calculated using the formula

$$X = V \times 10. \tag{1}$$

where V – volume of alkali used (ml).

4. 3. Determination of mass fraction of dry matter (accelerated method)

A 3 cm^3 sample was placed into a prepared crucible containing sand and a glass rod, evenly distributed over gauze, covered with a lid, and weighed. Then, the crucible with the lid removed was placed in a drying oven at 105°C for 60 minutes, after which it was cooled and weighed again. Drying continued until a constant weight was obtained (difference not exceeding 0.001 g).

The mass fraction of dry matter (C, %) was calculated using the formula

$$C = (m - m_0)/(m - m_1) \times 100, \tag{2}$$

where m_1 – mass of the crucible with sand and glass rod, g;

m – mass of the crucible before drying, g;

m_0 – mass of the crucible after drying, g.

4. 4. Determination of mass fraction of fat

The analysis was conducted using two fat testers. Into clean fat testers, 10 cm^3 of sulfuric acid (density 1810–1820 kg/m^3) was poured, followed carefully by 10.77 cm^3 of whey. The pipette was positioned at an angle to prevent mixing of the liquids. The liquid level was set at the bottom of the meniscus.

4. 5. Determination of mass fraction of protein (Kjeldahl method)

Protein content was determined according to GOST 23327-98. The method is based on measuring total nitrogen after acid digestion of the sample, followed by ammonia distillation and titration. Protein content was calculated using the formula

$$\text{Protein (\%)} = N \times 6.38. \tag{3}$$

This conversion factor reflects the average nitrogen content of milk proteins and allows for an estimation of total protein in the sample.

4. 6. Determination of mass fraction of lactose

Lactose was determined according to GOST 36251-2016 using the Bertrand method or the enzymatic method. The method is based on the reducing properties of lactose.

4. 7. Determination of ash content

Ash content was determined using the gravimetric method in accordance with GOST 3626–73. A 3–5 g sample was placed into a pre-calcined crucible and ashed in a muffle furnace at a temperature of 525–550°C until constant weight was achieved. After cooling in a desiccator, the crucible was weighed. Ash content (%) was calculated using the formula

$$\text{Ash content (\%)} = (m_2 - m_1)/m \times 100, \quad (4)$$

where m – mass of the crucible with ash, g;
m_1 – mass of the empty crucible, g;
m_2 – mass of the sample, g.

5. Results of the technology for producing functional beverages based on whey

5. 1. Comparison results the organoleptic and physicochemical quality indicators of whey of control whey and samples with natural juice additives

Three recipe variants were developed, from which one optimal formulation was selected. The following parameters were evaluated: appearance, consistency, color, taste, and odor. At the initial stages of the analysis, the composition and properties of whey without any additives were examined. The organoleptic indicators of the whey and examples of finished whey-based products with added fruit juices are presented in Table 3.

The organoleptic quality indicators of the drink are listed below (Fig. 1).

To produce whey-based beverages, necessary studies were conducted to determine the physicochemical composition of the whey. The analysis data are presented in Table 2.

The analysis data show that the whey meets the requirements of GOST 34352-2017 (ISO 5534:2004; ISO 8968-1:2014; ISO 22662:2024) and is suitable for further use and combination with apple, sea buckthorn, and pear juices.

Table 2

Physicochemical properties of whey

Parameter name	Values	Standard
Active acidity	4.26	4.2–6.4
Titratable acidity, °T	56	50–85
pH	5.3	3–8
Protein mass fraction, %	1.76	Not less than 0.4
Dry matter mass fraction, %	5.6	Not less than 5.0
Lactose mass fraction, %	4.9	Not less than 3.5
Ash content, %	0.45	0.4–0.8

5. 2. Development of the formulation and technological scheme for producing beverages based on whey

A formulation and technological process were developed for functional beverages based on whey enriched with fruit juices from plants growing in the northern part of Azerbaijan (Fig. 2, Table 3).

Table 3

Formulation of functional beverages based on whey (per 100 liters of finished product)

Component	Quantity (l/kg)
Whey (pasteurized)	80 l
Apple juice (clarified)	6 l
Pear juice (clarified)	6 l
Sea buckthorn juice	3 l
Sugar	4 kg (to taste, up to 50 kg allowed)
Citric acid	0.04–0.06 kg
Drinking water	Up to 100 l

Table 1

Organoleptic characteristics of whey with added apple, sea buckthorn, and pear juices ($n = 10$)

Indicator name	Characteristics of whey without additives	Sample 1 (apple, $n = 10$)	Sample 2 (sea buckthorn, $n = 10$)	Sample 3 (pear, $n = 10$)
Appearance and consistency	Homogeneous liquid, no foreign impurities	Opaque homogeneous liquid	Homogeneous liquid without foreign inclusions	Homogeneous liquid without foreign inclusions
Taste and smell	Clean, typical of whey, slightly sour, without foreign notes	Pleasant sweet and sour taste, specific whey flavor not noticeable, apple juice blends harmoniously	The beverage is dominated by the slightly sour taste of sea buckthorn juice	The beverage is dominated by a mild sweet taste with characteristic notes of pear juice
Color	Greenish	Light green	Light orange	Light green

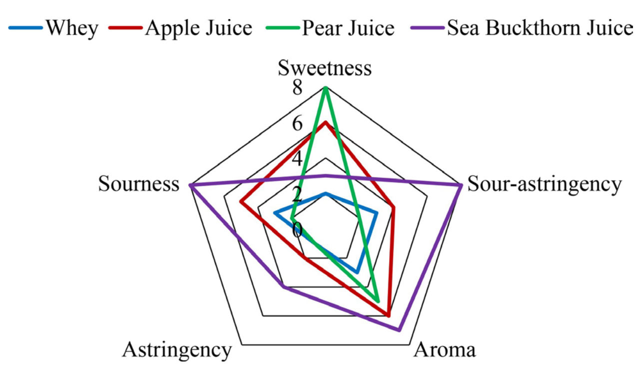

Fig. 1. Organoleptic flavor profiles of whey with added apple, sea buckthorn, and pear juices

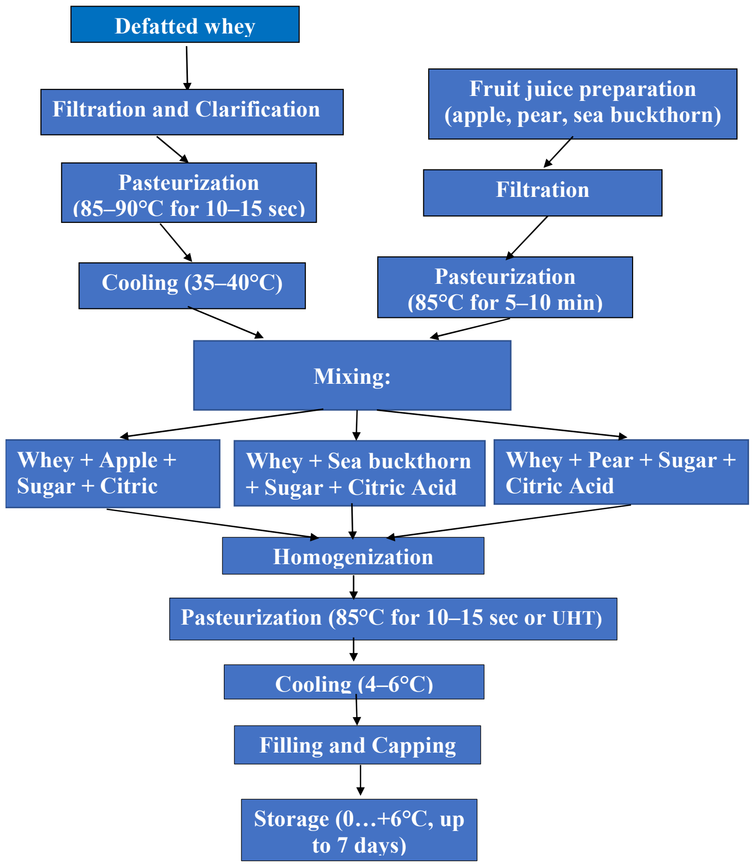

Fig. 2. Technological scheme for producing functional beverages based on whey with added fruit juices

The addition of natural juices to the product formulation not only improves the organoleptic properties but also increases the biological value of the beverage by enriching it with vitamins, thus giving the product a functional purpose.

5. 3. Results of the study on nutritional value and quality indicators of experimental samples during storage

Pasteurization of apple, sea buckthorn, and pear juices was carried out at 85°C for 10 minutes. The titratable and active acidity values of the samples studied are presented in Table 4.

The production of beverages from whey with the addition of sugar and fruit juices represents a promising direction in the rational utilization of dairy waste.

Table 4

Titratable (°T) and active acidity (pH) in apple, sea buckthorn, and pear juices

Type of juice	Before pasteurization		After pasteurization	
	°T	pH	°T	pH
Apple	8.2	4.0	7.7	4.0
Sea buckthorn	26	3.0	25.8	3.2
Pear	14	3.5	14.7	3.5
GOST 34127-2017	0.1–35.0	3–7	0.1–35.0	3–7

The mass fraction of dry matter and the mass concentration of sugars were determined in the presented samples. The data are shown in Fig. 3.

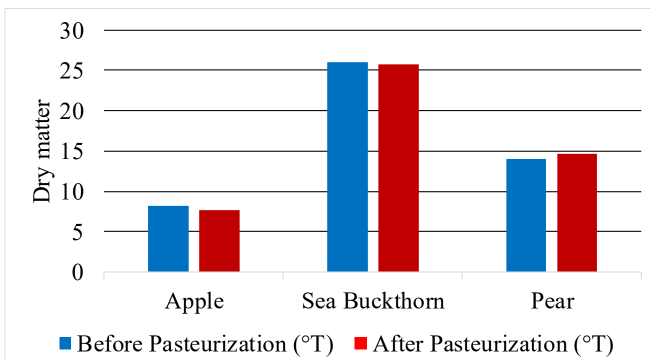

Fig. 3. Content of mass fraction of dry matter concentration

Therefore, a study was conducted to examine changes in titratable and active acidity of the beverages over a 5-day storage period. The results are presented in Table 5.

The three experimental beverage samples were stored in glass containers in a refrigerator at a temperature of 0...+6°C during the shelf-life study.

To ensure the reliability of the obtained data, all experimental determinations were carried out in triplicate. The results are presented as mean values ± standard deviation (SD). Statistical analysis was performed using one-way ANOVA, followed by Tukey's test for multiple comparisons at a significance level of $p < 0.05$.

As a result of the research, formulation No. 2 was selected as the most suitable whey-based beverage, meeting the requirements of GOST 53438-2009 standards.

Table 5

Storage stability study of beverages made from apple, sea buckthorn, and pear juices (mean ± SD, $n = 3$)

Sample	Indicators	Day 1	Day 2	Day 3	Day 4	Day 5
Whey + apple juice	Acidity, °T	60.0 ± 0.6^a	61.0 ± 0.5^a	63.0 ± 0.8^b	65.0 ± 0.7^c	68.0 ± 0.9^d
	pH	4.50 ± 0.02^a	4.50 ± 0.03^a	4.40 ± 0.02^b	4.50 ± 0.02^a	4.30 ± 0.03^c
	Dry matter, %	8.00 ± 0.05^a	8.20 ± 0.04^b	8.60 ± 0.06^c	8.40 ± 0.05^b	8.40 ± 0.06^b
	Sugar, g/100 cm^3	6.30 ± 0.04^a	6.40 ± 0.03^a	6.60 ± 0.05^b	6.50 ± 0.04^b	6.70 ± 0.05^c
Whey + sea buckthorn	Acidity, °T	62.0 ± 0.6^a	62.0 ± 0.7^a	65.0 ± 0.8^b	67.0 ± 0.7^c	69.0 ± 0.9^d
	pH	4.50 ± 0.02^a	4.30 ± 0.03^b	4.50 ± 0.02^a	4.20 ± 0.02^c	4.30 ± 0.02^b
	Dry matter, %	7.00 ± 0.05^a	7.00 ± 0.04^a	7.20 ± 0.05^b	7.20 ± 0.04^b	7.20 ± 0.05^b
	Sugar, g/100 cm^3	5.90 ± 0.04^a	5.90 ± 0.04^a	5.90 ± 0.05^a	6.00 ± 0.03^b	6.00 ± 0.04^b
Whey + pear juice	Acidity, °T	58.0 ± 0.5^a	59.0 ± 0.6^b	61.0 ± 0.7^c	63.0 ± 0.6^d	66.0 ± 0.8^e
	pH	4.70 ± 0.02^a	4.60 ± 0.03^b	4.50 ± 0.02^c	4.40 ± 0.02^d	4.20 ± 0.03^e
	Dry matter, %	7.50 ± 0.05^a	7.60 ± 0.04^b	7.80 ± 0.05^c	7.70 ± 0.04^b	7.60 ± 0.05^b
	Sugar, g/100 cm^3	6.00 ± 0.03^a	6.10 ± 0.04^b	6.20 ± 0.04^c	6.30 ± 0.03^d	6.30 ± 0.04^d

Note: different superscript letters within a row indicate statistically significant differences ($p < 0.05$).

6. Discussion of the results of producing functional beverages based on whey

The approach presented in this study for developing functional beverages based on whey enriched with natural apple, pear, and sea buckthorn juices introduces several technological and conceptual innovations compared to previously described methods.

Unlike the method in [26], which emphasizes energy-intensive membrane and enzymatic treatments that require sophisticated equipment, the current research utilizes an energy-efficient technique involving mild pasteurization and moderate homogenization. This strategy effectively preserves bioactive compounds without the need for advanced processing technologies, making it particularly suitable for small- and medium-scale food enterprises.

The evaluation of the organoleptic and physicochemical properties of the whey confirmed its compliance with established standards. Key parameters include an active acidity of 4.26, titratable acidity of 56°T, pH of 5.3, protein content of 1.76%, and lactose concentration of 4.9% (Table 2), all indicating the suitability of this raw material for functional beverage production.

In contrast to the work in [25], where bioactivity is achieved through enzymatic hydrolysis of whey proteins into peptides, this study relies on the synergistic interaction between whey components and natural juices. This method enhances the bioavailability of essential nutrients, such as vitamins, organic acids, and antioxidants, without the need for prior protein fractionation.

While study [29] focused on optimizing juice extraction methods, the present work prioritizes formulation development that ensures stable organoleptic and physicochemical properties throughout the product's shelf life. This led to the creation of a beverage with enhanced sensory characteristics and elevated nutritional value (Table 1, Fig. 2).

A moderate increase in dry matter and sugar content contributed to improved flavor, while sensory evaluations confirmed the consistency of taste, aroma, and appearance (Table 1, Fig. 1). The results suggest that natural preservatives found in the juices – especially in sea buckthorn – play a key role in maintaining product stability. As shown in Fig. 1 and Table 4, sea buckthorn juice demonstrated the most pronounced stabilizing effect due to its high content of natural acids and antioxidants.

The study of nutritional and quality indicators during refrigerated storage (at +2 to +6°C) revealed that the beverage retained physicochemical stability for up to five days (Table 5, Fig. 3). A slight increase in acidity was observed (e.g., from 60 to 68°T in the apple juice sample), while the pH remained within acceptable limits (around 4.3–4.5).

Despite these promising results, several limitations must be acknowledged. Firstly, the range of tested formulations and component ratios was limited, restricting the exploration of a broader spectrum of sensory and functional properties. In addition, no analysis of raw plant material was conducted to assess potential contaminants such as heavy metals, pesticide residues, or other xenobiotics. Secondly, the stability assessment was limited to refrigeration conditions (+2 to +6°C), which constrains the beverage's potential for transport and storage outside of the cold chain. Thirdly, the shelf life assessment was confined to five days, and longer-term changes in quality were not studied. Another limitation is that the proposed technology has not yet been tested under industrial production conditions, introducing uncertainty in terms of scalability and reproducibility of the beverage's quality characteristics in real-world settings.

To address these limitations, future research should include a broader formulation matrix by varying juice proportions and determining optimal component ratios. Additionally, microbiological monitoring during storage is recommended.

In conclusion, the implemented strategies enabled the development of a functional whey-based drink with improved sensory and nutritional qualities through a streamlined and resource-conscious technological process. The outcomes expand existing scientific knowledge by incorporating regional fruit juices, optimizing processing parameters, and demonstrating storage stability. This approach contributes to a sustainable and health-oriented product, offering a meaningful solution for dairy waste reduction while aligning with modern consumer preferences.

7. Conclusions

1. The analysis of the physicochemical and organoleptic properties of the whey used in the study confirmed its full compliance with GOST 34352-2017 standards. The high levels of protein (1.76%) and lactose (4.9%) indicate its suitability for the production of functional beverages and

explain the nutritional value and stability of the product during storage.

2. A formulation and technological scheme were developed for beverages based on whole pasteurized whey with the addition of apple juice (6 l/100 l), sea buckthorn juice (3 l/100 l), and pear juice (6 l/100 l). The technological scheme involves mild pasteurization at 85°C for 10 minutes and moderate homogenization, which allows the preservation of all bioactive components without the use of complex equipment or enzymatic treatment. The resulting beverage is characterized by a balanced taste, high bioactivity, and good stability (dry matter 7.0–8.6%, sugar 5.9–6.7 g/100 ml, active acidity 4.26–4.70, titratable acidity 56–62°T).

3. Storage tests showed that the organoleptic and nutritional properties were preserved for 5 days at a temperature of +2...+6°C. The fruit juices contributed to stabilizing acidity and dry matter content due to their natural antioxidants and organic acids. For example, the acidity changed only slightly (apple juice: 60 → 68°T), while the pH remained within 4.3–4.5. These results demonstrate the potential of natural juices as preservatives that enhance microbial stability without the use of synthetic additives.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intel-ligence technologies when creating the current work.

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