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Whey Permeate Mineral Profile at Various Stages of Membrane Filtration

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Abstract

Background and Objective: Whey permeate powder is widely used in technologies of various line groups of food products, but the major limiting factor of its use is its high ash content. The aim of this study was to establish efficiency of ash decrease and change of mineral profile at various stages of production for producing demineralized whey permeate powder appropriate for further use in technologies of lactose.

Material and Methods: Experiments were carried out based on the referee method and the common methods used in research practice. In this study, cheese whey and its concentrates and permeates achieved in the process of ultrafiltration, nanofiltration, electrodialysis, vacuum-evaporating and spray drying were used.

Results and Conclusion: Ultrafiltration made it possible to partially remove Ca^{2+}, total phosphorus and Mg^{2+} from cheese whey and nanofiltration was effective in partially remove of K^{+}, Ca^{2+}, Fe^{2+}, Mg^{2+}, Cu^{2+}, Cl^{-} and total phosphorus from ultrafiltration-permeates. Use of polymer membranes made it possible to prepare nanofiltration-concentrates with majorly lactose and increase the efficiency of electrodialysis due to their high permeability relative to water as well as their ability to eliminate proteins and partially ions of mineral salts. The mass fraction of ash in the final product decreased by 93.0%, compared to cheese whey. Furthermore, Na^{+} and K^{+} decreased by 89-94%, Ca^{2+} and Mg^{2+} decreased by 60-75%, the total phosphorus decreased by 78% and chlorides decreased by 70%. Results allow justifying the technological operation sequence to make products appropriate for further uses as raw materials for highly purified lactose.

Conflict of interest: The authors declare no conflict of interest.

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1. Introduction

In the last year, cheese world market increased by 2.0% and reached 25.3 m tons. The milk whey also increased as its unique chemical composition (50% of milk dry solids, including 95% of lactose, 80% of minerals, 20% of proteins and 10% of milk fats [1]) allows producing novel ingredients, using membrane methods of separation [microfiltration, ultrafiltration (UF), nanofiltration (NF) and reverse osmosis] due to the pressure gradient and osmotic membrane. This makes it possible to fractionate solution components by size and their molecular structures [2,3]. Membrane methods are used for milk whey or milk of high-molecular concentrates (retained by membrane) and low-molecular fractions. Thus, the moderate temperature conditions preserve components as native as possible and their functional-technological characteristics [4,5]. The world production and consumption of whey protein concentrates is constantly growing. According to the Fortune Business Insights Analytic Center, this reaches $18.12 b in 2022-2029 at an average annual rate of 7.4% [6]. However, the permeate market producing milk protein concentrates inactively develops despite unique functional-technological characteristics of the product since it was $836.5 m in 2022, showing an annual increase of 4.5% [7].

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Typical whey powder contains lactose (not more than 76-92% of dry solids), fat (not more than 0-1.5% of dry solids), protein (not more than 1.2-4.0% of dry solids) and ash (not more than 9.0% of dry solids for non-demineralized permeates, 7.0% for demineralized permeates with demineralization degrees (DD) of 25%, 4.0% for DD 50%, 2.5% for DD 70% and 1.0% for DD 90%) [8].The whey permeate powder is widely used as an independent ingredient in technologies of various products of foods (e.g. dairy, confectionary, baking, grocery, milk replacer and feed production) or a raw material for lactose production, including pharmacopeia. Production of whey permeate powder is rapidly developing in Russia, but there are no technologies for the production of highly refined lactose. One of the major limiting factors for the use of whey permeate powder for food and feed purposes is the mass fraction of minerals [7]. Food technologies exclude the use of ingredients with high ash contents. The mineral salt content in cheese whey varies 0.3-0.8%, which is up to 15.0% for dry matter. Whey and milk include similar quantitative ratios of anions (5831 $g \cdot l^{-1}$) and cations (3323 $g \cdot l^{-1}$). Sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chlorides (Cl), phosphorus (P) predominate within the minerals [9]. Sodium, potassium and chloride are electrolytes, which belong to the excessive macronutrients in diets. Their high concentrations in tissues and blood of the body disrupt water balance, osmotic pressure, acid-base balance (pH) and results in the development of diseases of kidneys, heart, gastrointestinal tract (GIT) and liver; therefore, their contents in food products should be limited.

Regarding the standard for dairy permeate powders (CXS 331-2017), the maximum ash content in whey permeate powder should not exceed 12.0%. Membrane methods allow not only fractionation of the raw materials but also refining of the finished product from minerals, preventing its use in food technologies. Permeate powder production includes the following operations of ultrafiltration, nanofiltration and electrodialysis that are widely used methods of demineralization, allowing decreases in ash content at various technological stages [10]. Ultrafiltration membranes with pore sizes of 0.01-0.1 µm preserve fats and almost all the whey proteins. In the process of ultrafiltration, ions and minerals presented in the concentrate are connected with proteins (calcium, magnesium, phosphates and citrates), while free ions and minerals (sodium, potassium, chloride) are fully transferred to the permeate. Nanofiltration membrane with pore sizes of 0.001-0,01 µm makes it possible to preserve substances with molecular weights of 100-300 Da. Therefore, minerals, organic acids, non-protein nitrogen and a small quantity of lactose (0.07%) pass into the nanofiltration permeate. Permeate production based on the known technology using ultra and nanofiltration allows preparing final whey permeate powder with partial demineralization of nearly 25% of salts removed and the mass fraction of ash in terms of dry solids is not more than 7% [11,12].

Electrodialysis may decrease the mineral content as a result of ions separation by transportation through the osmotic membranes of cation and anion exchanges under the effect of direct current, resulting in high degrees of demineralization [13]. Unlike nanofiltration, electrodialysis does not need high hydrostatic loads of the inlet solution to induce mass exchange processes. The electric field provokes ion migration, charged particles released from the soluble salts are easily removed from the solution and the uncharged ions (e.g. sugars and lactose) particularly remain in the solution. Barriers that carry out ion transportation are ion-exchange membranes of various types and selective characteristics. The aim of the current study was to establish efficiency of the ash decrease and change of mineral profile at various stages of production for producing demineralized whey permeate powder appropriate for further use in technologies of lactose. The following tasks have been set up to achieve the goals of setting up dynamics of the ash and mineral profiles of cheese whey permeate changes at various stages of production as well as assessing degrees of sample demineralization and efficiencies of sequential uses of ultrafiltration, nanofiltration (with polymer membranes) and electrodialysis methods.

2. Materials and Methods

2.1 Materials

Materials included whey permeate powders achieved after ultrafiltration, nanofiltration, electrodialysis and spray drying. The raw material for whey permeate powder production was cheese whey produced by the PJSC DP "Voronezhskii" "Kalacheevskii Cheese Factory", Voronezh, Russia.

2.2 Sample preparation and equipment

The whey was previously purified from fat and casein fume using vibratory sieve, then pasteurized at 75 ºC ±2 for 5 min and cooled down to 10-15 ºC. This was subjected to the ultrafiltration unit of UF-1 type (DMP, Stavropol, Russia) using polymer membranes of Alfa Laval GR73PE 6338/30 [polyether sulphone with molecular weight cut-off (MWCO) 10 kDa; Alfa Laval, Lund, Sweden] (P = 0.13 MPa). The permeate was subjected to the nanofiltration unit of NF-1 type of SD-Filtration (DMP Ltd supplier, Stavropol, Russia) with polymer membranes DOW FilmTecT Hypershell 245-8038 (MWCO 300 Da; DuPont de Nemours, Wilmington, USA) at 10 ºC ±2 and the process pressure up to 2.5 MPa. This was thickened up to dry solid content of 27.5%. Electrodialysis was carried out using electrodialysis unit of ED2*EWDU6*EDR-II/250 type (MEGA ProfiLine, Podolsk, Russia) at 15 ºC ±2 and ion-selective membranes (RALEX CMH-PES and RALEX AMH-PES, MEGA,

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Prague, Czech Republic) at three stages of process. Stage I was carried out with a negatively charged membrane for 4 h. Stage II included a neutralization process up to pH 6.2 for 2 h. Stage III was carried out with a positively charged membrane for 25 min until an electrical conductivity of 0.8 ms·cm^{-1} was achieved. Further, permeate was thickened up to 54-55% using vacuum-evaporating unit of TH-TVR4 (DMP, Stavropol, Russia) (P = 0.09 MPa, inlet temperature of 70-75 °C and outlet temperature of 40 °C ±5) and subjected to crystallization at 33-35°C for 3-4 h and then to 10-15 °C for 10-12 h. Then, drying was carried out using VRD-5 unit (DMP, Stavropol, Russia) at inlet temperature to the drying tower of 170-200 °C and outlet temperature of 70-100 °C. Then, whey permeate powder was cooled down to 30 °C ±5.

2.3 Methods

Experiments were carried out based on the referee method and common methods used in research scientific practice (Table 1). Physical and chemical parameters of whey permeate were assessed in laboratories of FSFEI HE "All-Russian Research Institute of Dairy Industry", the Federal Reserve "State Regional Center for Standardization, Metrology and Testing in Moscow and Moscow Region", the Federal Reserve "State Regional Center for Standardization, Metrology and Testing in Saint Petersburg and Leningrad Region", FSBEI HE "Voronezh State University of Engineering Technologies".

2.4 Research procedure

The methodological research strategy of this study is represented in Figure 1.

2.5 Statistical analysis

Experimental studies of each sample were carried out 3-5 times at a triple sequence. Calculations were carried out using methods of mathematical statistics, Microsoft Office for home and Study 2021 for Mac. Normal distribution of the continuous variables was calculated using Shapiro-Wilk test. Data were expressed as mean ±SD (standard deviation) and median (minimum and maximum values) for normally and non-normally distributed data, respectively. The *p*-values less than or equal to 0.05 were reported as significant. Limitations of the experimental studies included errors and uncertainties of the analysis methods; interfering with the represented results.

3. Results

Technology for the production of whey permeate powder (Figure 2) needs study of mineral compositions at UF-filtration, NF-filtration and electrodialysis stages. Chemical composition and mineral profile change of the samples during cheese whey processing were established in the process of experiments (Tables 2 and 3). Use of ultrafiltration made it possible to concentrate and partially remove minerals from the total protein of cheese whey. A major part of lactose and salt was transferred into the UF-permeate, predominantly in ion-molecular distribution. Nanofiltration is effective in removing part of mineral salts from UF-permeate and increasing the mass fraction of lactose in NF-concentrates samples. Optimal parameters of the process (P = 2 MPa and T = 15 °C) guaranteed a higher rate of removing chlorides without significant losses of milk sugar [14]. Proportions of lactose, calcium (30%), phosphorus (20%), potassium (25%), chlorides (50%), iron (80%), magnesium (70%) and copper (85%) were transferred into the NF-permeate, advancing its use as a raw material for the isotonic drink production. The electrodialysis treatment of NF-concentrate was carried out at 15 °C ±2 with the subsequent control of electrical conductivity and pH in the process (Figure 3).

Table 1. Research methods of composition, physical and chemical parameters and minerals of whey permeate test samples

Parameters	Method	Error (± uncertainty)	Source
Mass fraction of dry solids, %	Oven drying	(± 0.10)	GOST 29246-91
Mass fraction of total protein, %	Kjeldahl method	(± 0.22)	GOST 34454-2018
Mass fraction of lactose, %	Polarimetry	(± 12.0 % relative)	GOST 33958-2016
Mass fraction of ash, %	Dry combustion method	(± 0.04)	GOST R 56833-2015 sub-paragraph 8.22
Chlorides content, mg·(100 g)$^{-1}$	Capillary electrophoresis	(± 0.06)	GOST R 54045-2010
Calcium content, mg·(100 g)$^{-1}$	Atomic absorption spectrometry	(± 0,50)	GOST R 55331-2012
Total phosphorus content, mg·(100 g)$^{-1}$	Capillary electrophoresis	(± 0.12)	GOST 31980-2012
Sodium content, mg·(100 g)$^{-1}$	Atomic absorption spectrometry	(± 15.0 % relative)	GOST EN 15505-2013
Potassium content, mg·(100 g)$^{-1}$	Atomic absorption spectrometry	(± 12.0 % relative)	ISO 8070:2007
Iron content, mg·(100 g)$^{-1}$	Atomic absorption spectrometry	(± 0.17)	GOST EN 14084-2014
Magnesium content, mg·(100 g)$^{-1}$	Atomic absorption spectrometry	(± 0.6)	MG 4.1.3606-20
Copper content, mg·(100 g)$^{-1}$	Atomic absorption spectrometry	(± 0.17)	MG EN 14084-2014

Electrical conductivity and pH were assessed using pH-tester of HI-98130 HANNA (Hanna Instruments, Germany) at T = 20 °C ±2.

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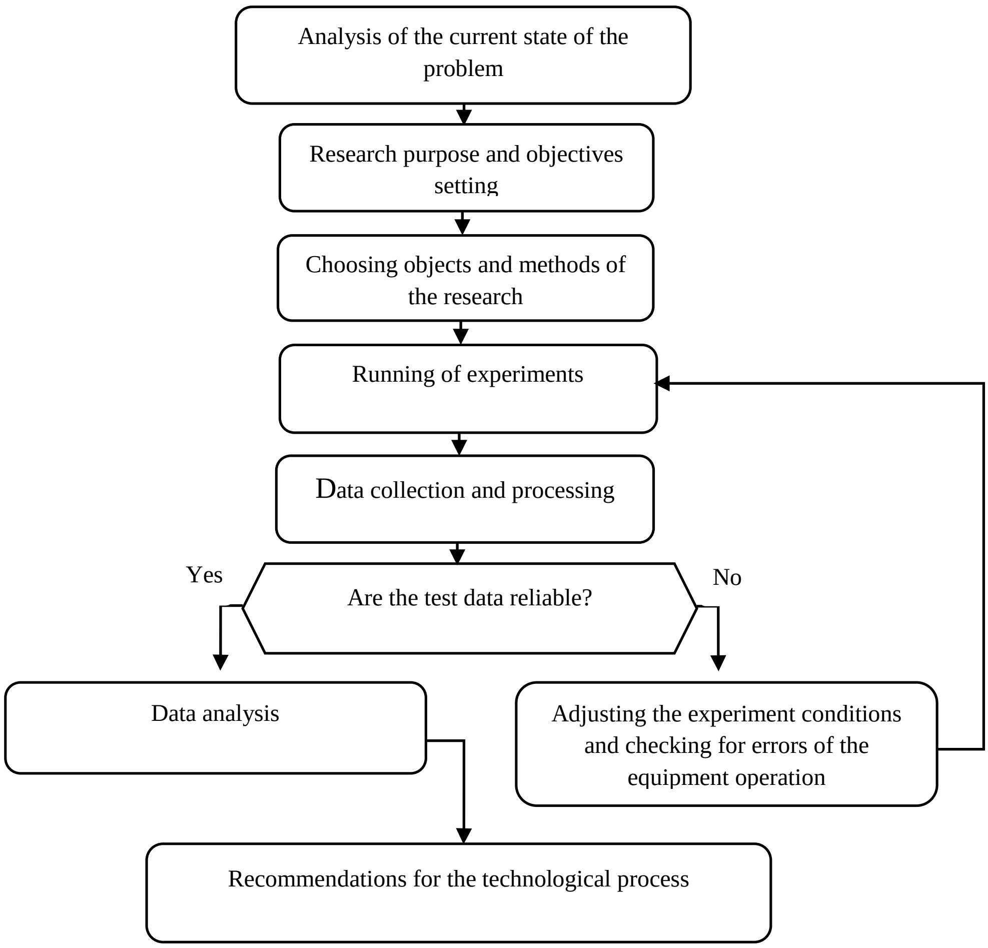

Figure 1. Methodological diagram of the current study

Table 2. Chemical compositions of the samples

Parameter description	Cheese whey	Ultrafiltration using polymer membranes		Nanofiltration using polymer membranes		Electrodialysis	Spray drying†
		UF-concentrate	UF-permeate	NF-concentrate	NF-permeate		
Mass fraction of dry solids, %	6.01±0.05	27.8±0.07	4.21±0.03	21.56±0.07	0.97±0.02	21.40±0.09	97.73±0.10
Mass fraction of lactose, %	4.43±0.36	7.54±0.40	3.48±0.33	19.21±0.53	0.35±0.13	20.93±0.51	90.60±0.47
including in dry matter, %	73.71±0.21	27.12±0.24	82.66±0.18	89.10±0.30	36.08±0.08	97.80±0.30	92.70±0.29
Mass fraction of protein, %,	0.84±0.03	19.54±0.16	0.16±0.02	0.27±0.03	-	0.26±0.02	2.31±0.05
including in dry matter, %	13.98±0.04	70.29±0.12	3.80±0.03	1.25±0.05		1.21±0.06	2.36±0.08
Mass fraction of ash, %	0.42±0.02	0.62±0.03	0.51±0.03	1.95±0.04	0.59±0.03	0.12±0.02	0.55±0.03
including in dry matter, %	6.99±0.04	2.23±0.05	12.11±0.03	9.04±0.06	60.82±0.03	0.56±0.06	0.56±0.07

†whey permeate powder with the DD 90%

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Table 3. Mineral profile changes of the tested samples during whey processing

Parameter description	Cheese whey	Ultrafiltration using polymer membranes		Nanofiltration using polymer membranes		Electrodialysis	Spray drying (whey permeate powder with the DD 90%)
		UF-concentrate	UF-permeate	NF-concentrate	NF-permeate		
Chloride content, mg·(100 g)$^{-1}$, including in dry matter, %	0.87±0.03 0.01±0.22·10^{-3}	1.32±0.05 0.01±0.20·10^{-3}	0.86±0.04 0.02±0.54·10^{-3}	1.98±0.05 0.01±0.14·10^{-3}	2.16±0.04 0.22±4.31·10^{-3}	0.58±0.02 3.00·10^{-3}±0.06·10^{-3}	3.57±0.06 4.00·10^{-3}±0.04·10^{-3}
Calcium content, mg·(100 g)$^{-1}$, including dry matter, %	21.32±0.15 0.35±2.70·10^{-3}	156.18±0.41 0.56±1.46·10^{-3}	48.61±0.19 1.15±6.33·10^{-3}	189.79±0.44 0.88±2.46·10^{-3}	86.24±0.23 8.89±0.10	17.58±0.12 0.08±0.45·10^{-3}	81.70±0.21 0.08±0.15·10^{-3}
Total phosphorus content, mg·(100 g)$^{-1}$, including in dry matter, %	64.36±0.05 1.07±4.92·10^{-3}	138.54±0.10 0.50±0.80·10^{-3}	44.39±0.03 1.05±4.10·10^{-3}	173.53±0.11 0.80±1.52·10^{-3}	76.26±0.06 7.86±0.08	49.19±0.05 0.23±0.60·10^{-3}	215.50±0.10 0.22±0.18·10^{-3}
Sodium content, mg·(100 g)$^{-1}$, including in dry matter, %	54.21±0.02 0.90±3.96·10^{-3}	141.58±0.08 0.51±0.82·10^{-3}	106.96±0.06 2.54±9.65·10^{-3}	539.63±0.76 2.50±5.75·10^{-3}	183.73±0.15 18.94±0.20	16.35±0.01 0.08±0.17·10^{-3}	88.60±0.04 0.09±0.07·10^{-3}
Potassium content, mg·(100 g)$^{-1}$, including in dry matter, %	193.40±0.10 3.22±0.01	177.10±0.09 0.64±0.96·10^{-3}	198.50±0.12 4.71±0.02	794.80±0.95 3.69±0.01	205.28±0.16 21.16±0.23	36.84±0.01 0.17±0.38·10^{-3}	159.20±0.06 0.16±0.11·10^{-3}
Iron content, mg·(100 g)$^{-1}$, including in dry matter, %	0.46±0.03 0.70·10^{-3} ±0.03·10^{-3}	2.3±0.05 0.80·10^{-3}±0.01·10^{-3}	0.42±0.02 1.00·10^{-3} ±0.03·10^{-3}	0.37±0.02 0.20·10^{-3}±0.01·10^{-3}	2.26±0.11 0.02±0.81·10^{-3}	0.13±0.01 0.60·10^{-4}±0.02·10^{-4}	less than 1.0
Magnesium content, mg·(100 g)$^{-1}$, including in dry matter, %	28.70±0.28 0.05±0.43·10^{-3}	6.30±0.05 2.00·10^{-3}±0.01·10^{-3}	3.71±0.05 9.00·10^{-3} ±0.09·10^{-3}	6.87±0.06 3.20·10^{-3}±0.02·10^{-3}	9.90±0.15 0.10±1.83·10^{-3}	3.90±0.04 0.02±0.13·10^{-3}	168.30±0.48 0.02±0.03·10^{-3}
Copper content, mg·(100 g)$^{-1}$, including in dry matter, %	0.29±0.03 0.50·10^{-3} ±0.03·10^{-3}	0.28±0.02 1.00·10^{-4}±0.04·10^{-4}	0.28±0.02 0.70·10^{-3} ±0.03·10^{-3}	0.14±0.01 1.00·10^{-4}±0.03·10^{-4}	0.23±0.01 2.40·10^{-3} ±0.08·10^{-3}	0.05±0.004 0.02·10^{-3}±0.03·10^{-3}	0.17±0.01 2.00·10^{-5}±0.05·10^{-5}

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Number of cations in the NF-concentrate decreased during stage I of electrodialysis, leading to low values of pH. Technically, protein in the NF-concentrate is not stable and may precipitate out, which negatively affects drying and physicochemical characteristics of the final product. Therefore, a mixture of solution of KOH and NaOH (1:1) was added for neutralization to pH 6.2. The process is finished when conductivity reaches 0.8 ms·cm^{-1} for the product with DD of 90%.

Increases in UF-permeate total ash were seen, compared to cheese whey (> 70%) due to the free ion transfer with no associations to other components. It decreased by 25.4% for NF-concentrate and the mineral profile changed to increases in the concentrations of Na^+, K^+ and Cl^-. The electrodialysis use for the further demineralization of NF-concentrate of cheese whey guaranteed removals of Na^+ and K^+ by 89-94%, Ca^{2+} and Mg^{2+} by 60–75%, total phosphorus by 78% and chlorides by 70%.

4. Discussion

It is well known that the efficiency of monovalent ion removal (K^+, Na^+ and Cl^-) is higher than that of multivalent ion removal (Ca^{2+}, Mg^{2+}, SO_4^{2-} and PO_4^{3-}). Studies [15-17] have established the following deionization scheme for the cations of $K^+ > Na^+ > Ca^{2+} > Mg^{2+}$ and for the anions of $Cl^- > SO_4^{2-} > PO_4^{3-} > LA^- > CA^{3-}$.

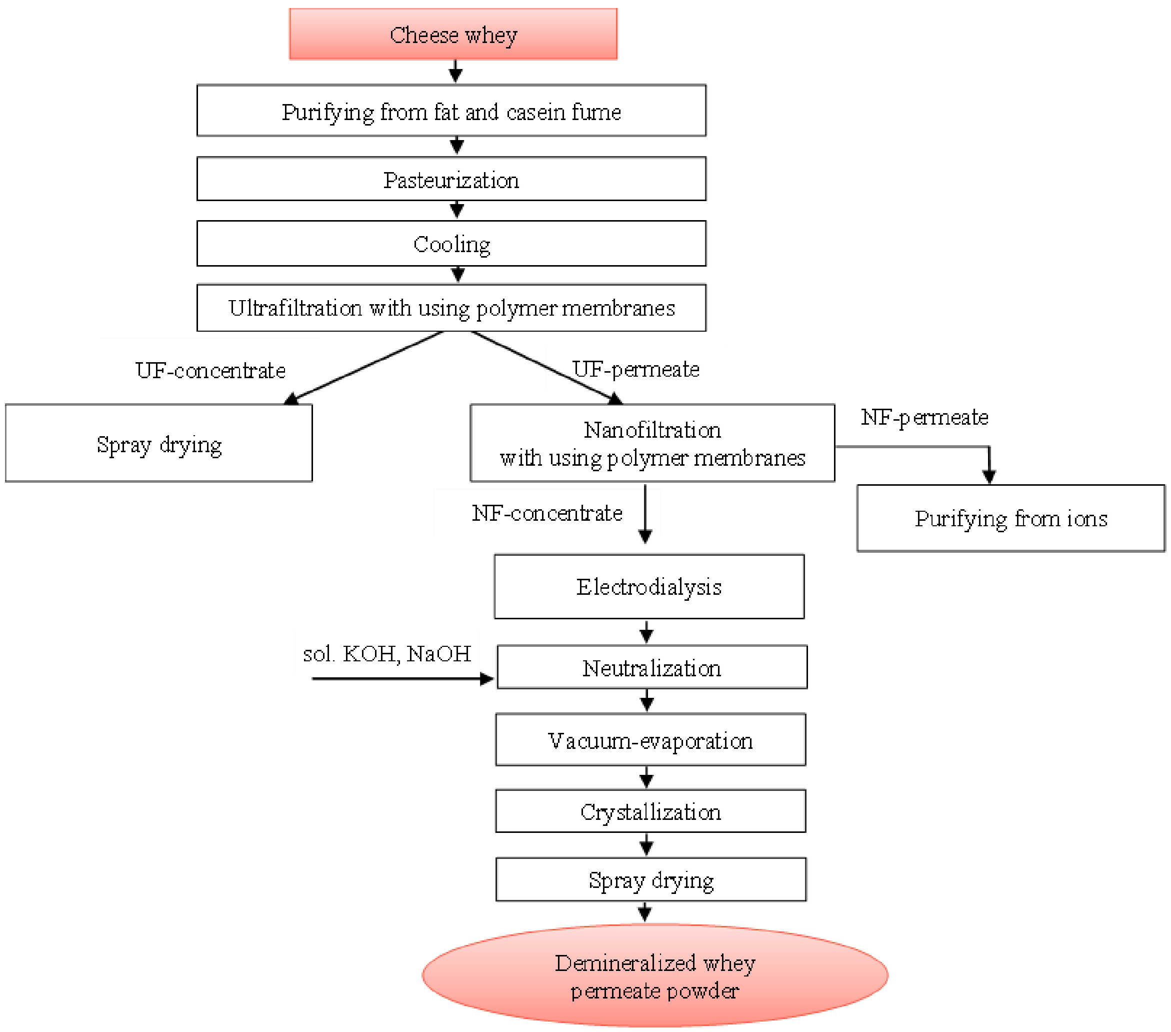

Figure 2. The cheese whey processing scheme

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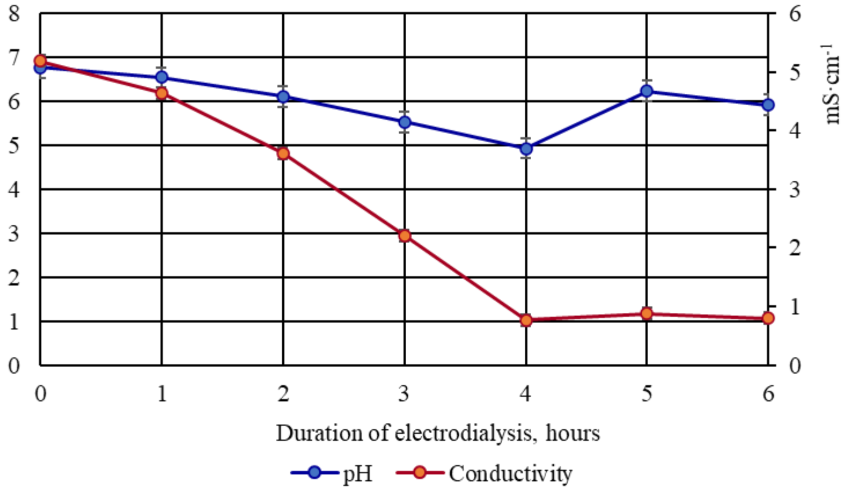

Figure 3. Changing pH and conductivity of the NF-concentrates during electrodialysis

This is because of the smaller hydrodynamic radius and the higher diffusion coefficient of monovalent ions, compared to multivalent ions. Moreover, mineral and organic profiles of the primary raw material and permeate technology affect the efficiency of demineralization [18-24]. The study has verified that monovalent ions were removed faster than multivalent ions due to their lower mobility. Regarding their ability to form complexes with proteins, the preliminary concentration of whey protein via UF or NF polymer membranes significantly affected speed and progress of demineralization by electrodialysis. The high permeability of polymer membranes relative to water as well as their ability to eliminate proteins and partially ions of mineral salts made it possible to achieve NF-concentrates containing majorly lactose and increase the efficiency of electrodialysis. Total content of the inorganic ions decreased by more than 93.0%. In the process of vacuum-evaporation, crystallization and drying, no significant changes were seen in the mineral composition.

5. Conclusion

Results have verified high DD of the samples and efficiency of the use of UF, NF (with polymer membranes) and electrodialysis methods. Additional technological operations of cheese whey processing have resulted in whey permeate powder with DD of 90% and bring the mineral profile of the final product closer to the requirements to achieve pure lactose. Advantage of this study includes that the experiment was carried out under production conditions using industrial equipment. However, limitations such as concentration polarization during membrane filtration and possible errors of the measurements could interfere with validity and interpretation of data. Furthermore, theoretical significance of this study was assessment of changes in the content of various components of cheese whey including major macro and microelements during technological processing using membrane equipment with only polymer

Membranes. Practical importance of this study included justification of the technological operation sequence to achieve demineralized products appropriate for further uses as raw materials for highly purified lactose.

6. Conflict of Interest

The authors report no conflict of interest.

7. Authors Contributions

Conceptualization, E.I.M.; methodology, E.V.B.; software, D.A.P.; validation, D.A.P.; formal analysis, E.V.B. and D.A.P.; investigation, E.V.B. and D.A.P.; resources, E.V.B. and D.A.P.; data curation, E.V.B. and E.I.M.; writing-original draft preparation, E.V.B. and D.A.P.; writing-review and editing, E.I.M. and E.V.B.; visualization, D.A.P.; supervision, E.I.M.; project administration, E.I.M.; funding acquisition, E.V.B.

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مشخصات مواد معدنی تراویده آب پنیر در مراحل گوناگون تصفیه غشایی

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چکیده

سابقه و هدف: پودر تراویده[۱] آب پنیر به طور گسترده‌ای در فرآورده‌های گوناگون غذایی مورد استفاده قرار می‌گیرد، عامل عمده محدود کننده کاربرد آن بالا بودن میزان خاکستر آن است. هدف از این مطالعه تعیین کارایی کاهش خاکستر و تغییر مشخصات مواد معدنی در مراحل گوناگون تولید برای تولید پودر تراویده آب پنیر نمک‌زدایی شده مناسب برای استفاده بیشتر در فناوری‌های لاکتوز بود.

مواد و روش ها: آزمون‌ها بر اساس روش مرجع و روش‌های متداول مورد استفاده در پژوهش‌ها انجام شد. در این تحقیق، از آب پنیر و کنسانتره و تراویده‌های حاصل از فرآیند فراپالایی[۲]، نانوصافش[۳]، الکتروتراکافت[۴]، تبخیر در خلاء و خشک‌کردن پاششی استفاده شد.

یافته‌ها و نتیجه‌گیری: فراپالایی امکان حذف Ca^{2+}، کل فسفر و Mg^{2+} از آب پنیر را ایجاد کرد و نانوصافش در حذف K^{+}، Ca^{2+}، Fe^{2+}، Mg^{2+}، Cu^{2+}، Cl^{-} و کل فسفر از تراویده‌های فراپالایی موثر بود. استفاده از غشاهای پلیمری، به‌علت نفوذپذیری بالای آن‌ها نسبت به آب و نیز توانایی در حذف پروتئین‌ها و بخشی از یون‌های نمک‌های معدنی، امکان تهیه کنسانتره نانوصافی حاوی عمدتا لاکتوز و افزایش کارایی الکتروتراکافت را ایجاد کرد. در مقایسه با آب پنیر، میزان خاکستر محصول نهایی به‌میزان ۹۳/۰ درصد کاهش یافت، همچنین، Na^{+} و K^{+} تا ۹۴-۸۹ درصد، همچنین Ca^{2+} و Mg^{2+} تا ۶۰-۷۵ درصد، فسفر تا ۷درصد و کلریدها تا ۷۰درصد کاهش داده شدند. نتایج تداوم عملیات تکنولوژیکی برای ساخت محصولات مناسب برای کاربردهای بعدی به‌عنوان مواد خام برای لاکتوز بسیار خالص را توجیه می‌کند.

تعارض منافع: نویسندگان اعلام می‌کنند که هیچ نوع تعارض منافعی مرتبط با انتشار این مقاله ندارند.

تاریخچه مقاله

دریافت ۱۰ جولای ۲۰۲۳
داوری ۷ آگوست ۲۰۲۳
پذیرش ۱۵ آگوست ۲۰۲۳

واژگان کلیدی

- میزان خاکستر
- الکتروتراکافت
- نانوصافش
- فراپالایی
- آب پنیر

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[۱] Permeate شاره‌ای که در فرایند صافش غشایی، از غشا خارج می‌شود
[۲] Ultrafiltration جداسازی مواد خیلی ریز یا کلوئیدی از شاره به‌وسیلهٔ غشاهایی با منافذ بسیار ریز یا نیمه‌تراوا
[۳] Nanofiltration نوعی فرایند صافش که در آن ذراتی با اندازهٔ نانو را می‌توان صاف کرد
[۴] Electrodialysis فرایند یون‌زدایی آب که در آن یون‌ها تحت تأثیر میدان الکتریکی و به واسطهٔ غشای تبادل یون از یک پیکرهٔ آب جدا و به پیکرهٔ دیگر منتقل می‌شوند

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