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Contents

Nutritional and bioactive composition of different carrot pomace varieties

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Abstract

Introduction. Carrot pomace is a by-product with functional value that is usually discarded. This work aimed to evaluate the properties of carrot pomace from four varieties: Baltimore, Belgrado, Niagara and Sirkana.

Materials and methods. The proximate composition was determined according to international standards; fiber was determined by acid and alkaline digestion; total polyphenols, β-carotene and antioxidant activity were measured spectrophotometrically; color was analyzed by reflectance and molecular properties were evaluated by FT-IR spectrometry.

Results and discussion. Carrot pomace nutritional value differed significantly ($p < 0.05$) in function of variety. The highest protein, lipids, ash and fiber content and the lowest carbohydrates amount was observed in Sirkana carrot pomace. Sirkana variety also presented the greatest total polyphenols and β-carotene content, while the highest antioxidant activity was observed for Baltimore carrot pomace. Sikrana pomace was also distinguished by its highest hue angle and yellow index, while Baltimore exhibited the greatest white index. FT-IR spectra confirmed the presence of polyphenols, fibers and β-carotene as main bioactive compounds. The lowest transmittance for almost all the main peaks identified were for Niagara, followed by Sirkana, Baltimore and Belgrado. Niagara carrot pomace powder presented different vibrations at 2929, 2853 and 2375 cm^{-1} compared to the other samples. The relationships between variables indicated that Baltimore carrot pomace can be differentiated from the other varieties by its dry matter content, white index, carbohydrates content and antioxidant activity, while Sirkana can be distinguished through its total polyphenols, ash and fiber content. Strong positive correlations ($p < 0.05$, $r > 0.95$) were observed among some of the chemical components (proteins and fibers, ash and β-carotene) and between lipids content and color parameters (yellow index and hue angle).

Conclusion. These results suggest that carrot pomace characteristics depend on variety. This by-product can be successfully used as a functional ingredient to enhance staple food nutritional value.

Introduction

The carrot (*Daucus carota* L.) is a widely cultivated root vegetable that can be effectively processed into such products as juices, nectars, and soft drinks. The most important carrot cultivator in the European Union is Polonia, followed by France and Germany. Romania ranks 6th in the European Union with a carrot cultivation area of 7570 ha in 2021 and a total production of 203.3 thousand tons (National Institute of Statistics: Bucharest, Romania, 2022).

Carrot pomace (CP), the main by-product of carrot juice processing, with a yield of 30–50% concerning the total raw material (Rezvani and Goli, 2024), is usually disposed of in the environment or treated as a substance of low economic value, being often used as animal feed or fertilizer (Virtanen et al., 2017). This by-product of carrot juicing is a valuable source of carotenoids, polyphenols, dietary fiber, vitamins, minerals, and other nutrients that can be used to enhance the quality of food products by improving their nutritional content (Bajraktari et al., 2024; Garg et al., 2024; Halim et al., 2024) or functional properties (Richards et al., 2024).

The high fiber content (20.09–33.34%), carbohydrates (46.55–58.95%), proteins (6.87–9.14%), and ash (5.29–5.89%) found in carrot pomace derived from different carrot varieties (Luca et al., 2022; Rezvani and Goli, 2024) revealed a sustainable opportunity to improve the nutritional and functional properties of food products by its addition, and in the same time, the reduction of food waste with positive impact on the environment. Regarding the fiber content, it was reported that carrot pomace contains approximately 55% total dietary fiber on a dry weight basis (Sharma et al., 2012). Moreover, both insoluble and soluble fibers, with the ideal levels of pectic polysaccharides, hemicellulose, and cellulose are found in carrot pomace (Richards et al., 2024; Yadav et al., 2017). These components play an essential role in food manufacturing, affecting the water-holding capacity, gel-forming ability, and fat-binding capacity of dietary fiber. The consumption of fiber helps reduce blood pressure and the risks of chronic diseases, including heart disease and diabetes, and improves cholesterol levels, along with the feeling of satiety (Anderson et al., 2009).

As a rich source of bioactive compounds, particularly carotenoids, such as β-carotene (Elik et al., 2020; Richards et al., 2024), carrot pomace can be used as a functional ingredient or as natural food coloring and flavor enhancer (Arscott and Tanumihardjo, 2010; Oncică et al., 2024). The total carotene content in pomace may be up to 2 g/kg dry matter depending on processing conditions (Singh et al., 2006). In a study on the composition of bound polyphenols from carrot dietary fibers and its antioxidant capacity, forty-two bound polyphenols compounds were identified, promoting their potential to develop functional food (Dong et al., 2021). The bioactive substances like polyphenols presents in carrot pomace are related to the antioxidant activities and prebiotics properties of carrot dietary fiber (Liu et al., 2019) and could potentially play a role in gastrointestinal and colonic health (Mall and Patel, 2024).

Carrot pomace can therefore be used as a functional ingredient for the development of pasta production with enhanced nutritional, functional, and sensorial properties, affecting also the color of pasta which has a very strong influence on the final choice of consumers.

The aim of this paper was to evaluate the nutritional profile in terms of dry matter, protein, fat, ash, lipids and carbohydrates, bioactive compounds such as β-carotene and total polyphenols content, molecular characteristics and color properties of four carrot pomace varieties.

Materials and methods

Materials

Carrots from four varieties (Baltimore – Ba, Belgrado – Be, Niagara – Ni and Sirkana – Si) were purchased in 2024 from a local producer from Romania and the juice was extracted by using a domestic blender. The resulting pomace was dried at 60 °C until less than 6% moisture content was achieved, then it was ground and sieved to obtain carrot pomace powder with particle size < 200 μm.

Nutritional profile determination

The nutritional profile in terms of dry matter, protein, fat, ash of carrot pomace powders was analyzed using international methods (ICC): moisture (101/1), fat (104/1), protein (105/2), and ash (105/1). The total crude fiber content was evaluated by acid and alkaline digestion using an automatic analyzer (Fibertec 2010, Tecator, Hillerod, Sweden). The carbohydrate content was calculated by difference.

Total polyphenols content determination

The extract preparation was carried out according to the method described by Ziobro et al. (2022). A total of 6 g of sample powder was dissolved in 30 mL of 80% ethanol, and the mixture was stirred for 120 min using a shaker. After centrifugation for 15 min at 4500 rpm, the supernatant was collected and subsequently used for the analysis of phenolic compounds (Ziobro et al., 2022).

In a test tube, 0.2 mL of the sample extract was mixed with 2 mL of Folin-Ciocalteu reagent and 1.8 mL of 7.5% Na_2CO_3. The mixture was kept in the dark at 20°C for 30 min before measuring the absorbance at 750 nm. A Shimadzu 3600 UV-VIS-NIR spectrophotometer (Tokyo, Japan) was used, and the calibration curve was prepared using gallic acid (R^2 = 0.99). The results were expressed as mg GAE/100 g of sample weight.

β-carotene content evaluation

For the extraction of β-carotene, 0.1 g of the sample was weighed and quantitatively transferred into a 10 mL volumetric flask, and the volume was adjusted with $CHCl_3$. The mixture was sonicated for 15 min at 20°C and then centrifuged at 1500 × g for 10 min. The extraction was repeated twice, and the combined supernatant was filtered through a sterile 0.45 μm syringe filter and diluted 3:10 mL. The absorbance of the extracts was measured at 450 nm using a UV-Vis spectrophotometer (Jasco V630). A calibration curve was prepared with β-carotene standard (R^2 = 0.99), and the results were expressed as mg β-carotene/100 g of product.

Optical properties analysis

The optical properties were measured by reflectance, using the CIE Lab system, with a Konica Minolta CR-400 device (Konica Minolta, Tokyo, Japan). The hue angle (H), yellow index (YI) and white index (WI) were calculated based on a* – red-green intensity, b* – yellow-blue intensity and L* – luminosity parameters by using Equations 1–3.

$$H = arctg\frac{b^*}{a^*}. \quad (1)$$

$$YI = 142.86\left(\frac{b^*}{L^*}\right). \quad (2)$$

$$WI = 100 - \sqrt{\left(100 - L^*\right)^2 + a^2 + b^2} \quad (3)$$

Molecular properties determination

The FT-IR spectra used for the molecular characterization of carrot pomace powders were collected in the range of 650 – 4000 cm^{-1}, using a Thermo Scientific Nicolet iS20 instrument (Waltham, MA, USA), at a resolution of 4 cm^{-1} and 32 scans. The spectra were processed with the Omnic software.

Statistical analysis of data

All the experimental results were expressed as mean ± SD (n = 3). The software used was XL STAT 23 version and the means were compared by ANOVA with the Tukey test ($p \leq 0.05$). To highlight the relationships between variables, a Principal Component Analysis (PCA) was performed.

Results and discussion

Nutritional profile

The content of protein, ash, lipids, dry matter, fiber and carbohydrates in carrot pomaces is displayed in Figure 1. Belgrado and Baltimore varieties exhibited the highest dry matter content, while Niagara and Sirkana showed significantly lower values. The highest content of protein was observed for Sirkana carrot pomace, followed by Niagara, Belgrado and Baltimore with the lowest content. Niagara carrot pomace showed the smallest lipids content, while Sirkana was the richest in lipids (Figure 1). The ash content also showed significant differences ($p < 0.05$) among carrot pomace varieties, with the highest value registered for the Sirkana variety and the lowest for Niagara. Significant differences were obtained for fiber content ($p < 0.05$) and it varied in the following order: Sirkana > Niagara > Belgrado > Baltimore. The greatest value for carbohydrates was exhibited by Baltimore carrot pomace, while the lowest content was observed for the Sirkana variety. The values obtained for protein, fiber, ash and lipid content are in line with those reported previously in the literature: 4–5% protein, 8–9% reducing sugar, 5–6% minerals and 20–48% total dietary fiber ≈ 1.3 % ash and ≈ 70% carbohydrates (Surbhi et al., 2018). Another study reported values of 6.54% for moisture, 6.50% for protein, 2.12% lipids, and 5.12% ash for carrot pomace used to enhance cookies nutritional value (Bellur Nagarajaiah and Prakash, 2015). Haq et al. (2016) stated that the content of fibers and minerals depends on carrot size since a bigger root size led to an increased formation of fibers and accumulation of minerals. Genetic factors have a great importance for a species' adaptation to different environmental conditions. Carrot chemical composition depends on both biotic and abiotic factors during the entire production stage and the genotypes dictate the quantity of bioactive compounds, with key gene being implied in differentiation especially regarding sugars and vitamins (Paudel and Subedi, 2023).

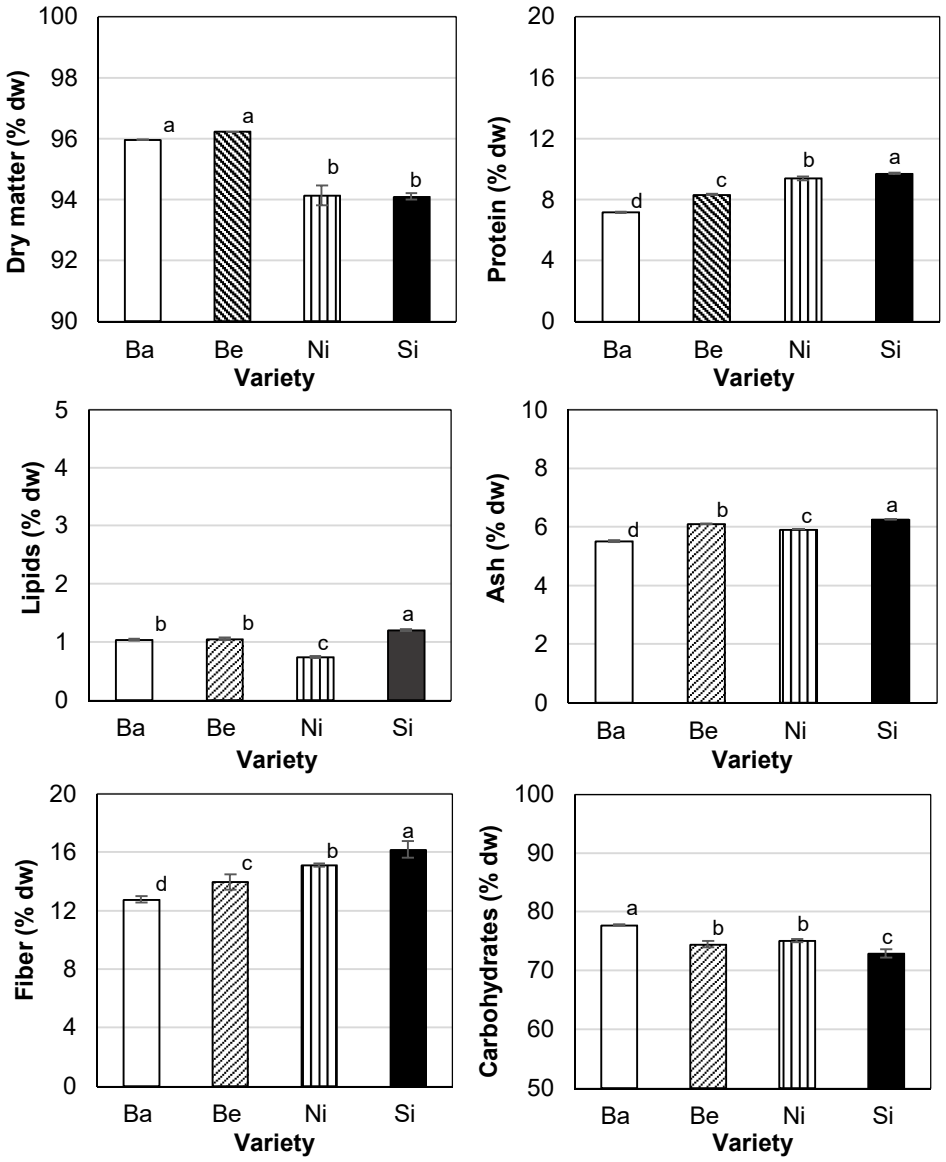

Figure 1. Proximate composition of carrot pomace varieties: Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana

The total polyphenol content of carrot pomace powders is presented in Table 1. Significant differences were observed between the carrot varieties ($p<0.05$), with the highest polyphenol content found in the carrot pomace from the Sirkana variety. The results are similar to those reported by Hernández-Ortega et al. (2013) for carrot pomace (14.12-18.41 mg GAE/g, depending on the drying method applied). The polyphenol content depends on

both the variety and the methods used for juice extraction and processing of the resulting pomace (Purkiewicz et al., 2020).

Among the carrot varieties, pomace from the Sirkana and Belgrado varieties had the highest β-carotene content (Table 1). The results were consistent with those reported in the literature by Begum et al. (2023) for carrot pomace (11.83 mg/100 g). The β-carotene content varies depending on the carrot variety, as demonstrated by Alasalvar et al. (2001). Significant differences ($p < 0.05$) were found between samples regarding antioxidant activity. The highest value was observed in the carrot pomace from the Baltimore variety. Antioxidant activity was attributed to the presence of bioactive compounds, such as proanthocyanidins, flavonoids, and anthocyanins, and is influenced by the carrot variety (Ma et al., 2013).

Table 1

Bioactive compound content and antioxidant activity of carrot pomace from different varieties

Sample	TPC (mg GAE/g)	β-carotene (mg/100 g)	AA (%)
Ba	21.45 ± 0.05 [b]	5.14 ± 0.01 [c]	19.66 ± 0.28 [a]
Be	19.55 ± 0.05 [d]	7.34 ± 0.00 [a]	11.10 ± 0.29 [d]
Ni	20.70 ± 0.00 [c]	6.74 ± 0.00 [b]	12.56 ± 0.36 [c]
Si	24.05 ± 0.05 [a]	7.34 ± 0.01 [a]	16.22 ± 0.21 [b]

Different letters in the same column indicate statistic difference between means at $p \leq 0.05$,
Ba – Baltimore, Be – Belgrado, Ni – Niagara,
Si – Sirkana, AA – antioxidant activity, TPC – total polyphenols content

The optical properties of carrot pomaces differed significantly ($p < 0.05$) among the studied varieties (Table 2). Whiteness index refers to the extent to which a surface resembles the characteristics of a perfect reflecting diffuser—an ideal surface that reflects light with equal intensity in all directions, without absorbing or transmitting any light. Yellow index indicates the degree to which the nuance of a surface shifts from a desired white (or colorless) state towards yellow.

Table 2

Optical properties of carrot pomace from different varieties

Sample	H	YI	WI
Ba	62.99 ± 0.24 [b]	280.28 ± 2.90 [b]	65.93 ± 0.20 [a]
Be	62.32 ± 0.30 [c]	272.32 ± 3.42 [c]	63.85 ± 0.09 [b]
Ni	56.36 ± 0.11 [d]	214.69 ± 0.86 [d]	58.66 ± 0.05 [d]
Si	64.69 ± 0.14 [a]	302.05 ± 1.90 [a]	62.56 ± 0.03 [c]

Different letters in the same column indicate statistic difference between means at $p \leq 0.05$, Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana, WI – white index, H – hue angle, YI – yellow index, AA – antioxidant activity, TPC – total polyphenols content.

Niagara variety exhibited the lowest H, YI and WI values, while Sirkana showed the greatest H and YI (Table 2). WI varied among carrot pomace varieties in the following order: Niagara < Sirkana < Belgrado < Baltimore. The hue angle values located between 0 (red) and 90° (yellow) suggest the orange color of the samples. Sirkana exhibited a more yellow nuance (greater H value), while Niagara variety was more reddish (smaller H value). It was demonstrated that the content of pigments in carrots is affected by factors like genotype, growth temperatures, and storage conditions (Ahmad et al., 2019), which may explain the color variations in the four carrot pomaces studied. It was demonstrated that carotene content is correlated with yellow color (Rakcejeva et al., 2012). This fact is supported by our results since Sirkana carrot pomace is the richest in β-carotene and presents the highest Yi value.

FT-IR spectra of carrot pomace powders for the four varieties investigated are presented in Figure 2. The lowest transmittance values for almost all the peaks were obtained for the Niagara sample, followed by Sirkana, Baltimore and Belgrado. Sirkana showed the highest peak at 2929 cm^{-1} which may be explained by its highest β-carotene content (Table 2). The peak at 1556 cm^{-1} given by the C=C groups linked with CH_3, the peak at 1421 cm^{-1} and 1368 cm^{-1} assigned to the asymmetrical and symmetrical CH_3 bending (Joda et al., 2022) suggested the presence of β-carotene in the samples studied. Niagara and Sirkana carrot pomaces exhibited the highest peak at 1610 cm^{-1} which can suggest the content of pectin because in this region the peaks are given by C=C stretching vibrations (Jayesree et al., 2021). The presence of polyphenols can be indicated by the peaks at 3320 cm^{-1} generated by the –OH stretching vibrations (Sucheta et al., 2019). All the samples studied exhibited peaks at 1421, 1368, and 1107 cm^{-1} which may be given by the presence of cellulose (Szymanska-Chargot and Zdunek, 2013). Sikrana and Niagara carrot pomaces exhibited the highest protein content (Table 1), a fact confirmed by the highest peaks at 1556 cm-1 given by the N–H, C–N (Amide II) vibrations (Thummajitsakul et al., 2020).

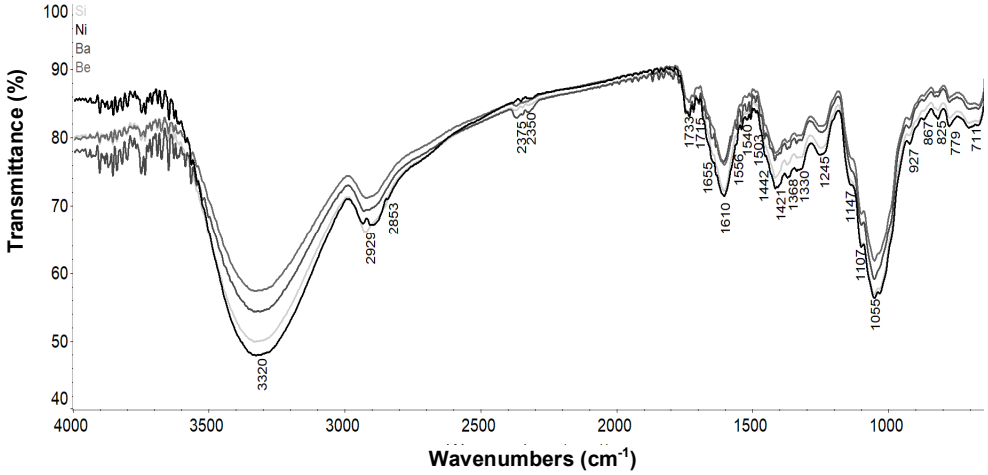

Figure 2. FT-IR molecular characteristics of carrot pomace from different varieties

The correlations between variables are listed in Table 3. Fiber content was strongly positively correlated with proteins ($p < 0.05$, $r = 0.98$). Lipids content was positively correlated with H and YI ($p < 0.05$, $r = 0.99$). Strong positive correlation ($p < 0.05$, $r = 0.97$) was obtained between ash and β-carotene. The antioxidant activity (AA) was strongly

positively correlated with YI ($p < 0.05$, $r = 0.99$). Ash and carbohydrates were negatively correlated ($p < 0.05$, $r = -0.99$). Similar to our results, Riaz et al. (2022) reported significant positive correlation ($p < 0.05$) between carrot protein content and fiber. Lipids may influence the stability of carotenoids during processing and storage, potentially affecting the color intensity of carrot products (Mutsokoti et al., 2017). This could explain the correlation between lipids content and color parameters.

Table 3

Correlations between variables

Variables	DM	Proteins	Lipids	Ash	Fiber	CH	TPC	β-carotene	AA	H	YI	WI
Dry matter	1											
Proteins	-0.86	1										
Lipids	0.21	-0.07	1									
Ash	-0.42	0.80	0.34	1								
Fiber	-0.86	0.98*	0.10	0.82	1							
Carbohyd.	0.55	-0.87	-0.32	-0.99*	-0.89	1						
TPC	-0.61	0.43	0.56	0.29	0.59	-0.39	1					
β-carotene	-0.37	0.78	0.16	0.97*	0.76	-0.95	0.07	1				
AA	0.06	-0.46	0.39	-0.59	-0.32	0.52	0.56	-0.76	1			
H	0.32	-0.23	0.99*	0.19	-0.05	-0.16	0.51	0.00	0.48	1		
YI	0.26	-0.18	0.99*	0.22	0.01	-0.20	0.56	0.03	0.49	0.99*	1	
WI	0.77	-0.78	0.68	-0.37	-0.66	0.44	0.03	-0.48	0.58	0.78	0.75	1

Values marked with * are significant at $p < 0.05$,
DM – Dry matter; CH - Carbo hydrates; WI – white index, YI – yellow index, H – hue angle, AA – antioxidant activity, TPC – total polyphenols content

The relationships between variables are highlighted by the PCA (Figure 3).

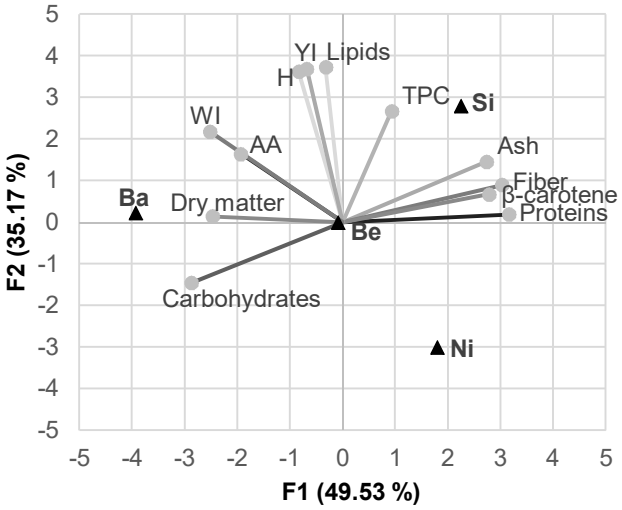

Figure 3. Principal Component Analysis bi-plot:
Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana, WI – white index, H – hue angle, YI – yellow index, AA – antioxidant activity, TPC – total polyphenols content

A percent of 49.53% of data variability was explained by the first component (PC1) and 35.17% by the second one (PC2). Proteins, β-carotene, fiber, ash, dry matter, carbohydrates AA and WI were associated with PC1, while H, Yi, lipids and TPC were associated with PC2.

Baltimore variety is differentiated by the other samples by the content of dry matter, WI, AA and carbohydrates, white TPC, ash, fiber, β-carotene and proteins contribute to the differentiation of Sirkana variety from the other carrot pomaces. Baltimore sample was positioned in the left upper quadrant, Sirkana was positioned in the right upper one, while Niagara was positioned in the right lower quadrant. The position of the Belgrado sample in the middle of the graphic highlights its small contribution to data variability.

Conclusions

Carrot pomaces from different varieties were investigated. The results highlighted that the nutritional composition, color and the bioactive compound content of carrot pomace depend on the variety. The richest in protein, fiber, lipids, β-carotene and total polyphenols was the carrot pomace from Sirkana variety. These data confirm the opportunity to create new functional foods with enhanced antioxidant potential and fiber content by using carrot pomace. Further research will be directed towards the evaluation of carrot pomace impact on wheat flour dough and pasta quality.

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Improvement of fermented dairy-plant concentrate technology

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Abstract

Introduction. The global trend toward developing functional food products has spurred interest in creating fermented dairy-plant concentrates. These products balance nutritional and biological value by combining animal and plant proteins, offering enhanced functionality and meeting consumer demands for healthy, plant-based alternatives.

Materials and methods. The research involved experimental and analytical methods to determine optimal technological parameters. Sensory evaluation, physicochemical analysis, and statistical processing were applied to evaluate the quality of dairy-plant concentrates. The methods used include soaking, homogenization, pasteurization, fermentation, and analysis of whey-plant suspensions with varying ratios of dairy and plant components.

Results and discussion. The study established that the procedure of preparation of whey-plant suspensions involves soaking peanut (*Arachis hypogaea*) kernels for 480 minutes in a 5:1 ratio and homogenizing them for 4–5 minutes. Model samples of dairy-plant concentrates were prepared with whey-plant suspensions at ratios of 9:1, 4:1, 7:3, and 3:2. Results showed a decreasing trend in concentrate yield and increasing moisture content with higher proportions of whey-plant suspension. At a 9:1 ratio, the yield was 26.28%, decreasing to 21.8% at a 3:2 ratio. Simultaneously, the moisture content increased from 62.9% to 82.8%. The 4:1 and 7:3 ratios were identified as optimal, providing good functional and sensory properties. The water-holding capacity ranged from 59.1% at a 9:1 ratio to 76.2% at 3:2. Sensory analysis confirmed that concentrates with a 4:1 or 7:3 ratio had the most balanced texture, flavor, and appearance, closely resembling traditional milk-protein concentrates. The improved technology ensures consistent quality of fermented dairy-plant concentrates, allows for the use of plant components to enhance functional properties and enrich the amino acid profile, and provides the potential for their application as a base for other dairy products, including curd-based items.

Conclusions. The feasibility of using peanut kernels in dairy-plant mixtures has been demonstrated, addressing the issue of milk raw material shortages while enhancing the biological value of concentrates due to a more balanced amino acid composition.

Introduction

Current trends in expanding the range of dairy and protein products focus on creating nutritionally and biologically balanced products. Products with an optimized composition of essential nutrients are widely developed and introduced, which is ensured by selecting and combining proteins of animal and vegetable origin. The need to improve consumer properties, increase competitiveness, and ensure stable product quality requires rationalizing the composition and adjusting traditional dairy product technologies. The active use of plant-based milk is associated with both individual intolerances to lactose and/or milk casein in a large number of consumers and the popularization of vegetarianism and the physiological benefits of vegetable protein consumption, especially in geriatric nutrition (Rasane et al., 2013). The production of multicomponent milk and protein products is carried out using non-traditional raw materials of plant origin and various food additives (Slyvka et al., 2019). At the same time, there is a growing consumer interest in plant-based milk substitutes, which affects the market structure and encourages manufacturers to expand the range of dairy-plant products (Antoshchenkova and Kravchenko, 2022). These trends highlight the relevance of developing new technologies, particularly fermented dairy-plant concentrates, which combine the benefits of both components and meet modern consumer demands.

Each type of plant-based milk has its own characteristics in terms of compatibility with raw milk at the level of sensory properties. Today, there are many types of plant materials from which milk analogs are made. Some scientific papers attempt a general classification of these products, according to which five categories of beverages are distinguished, namely: (a) cereals: oat, rice, corn, and spelt milk; (b) legumes: soy milk, peanut-based milk, lupine, cowpea (Chinese asparagus beans); (c) nuts: almond, coconut, pistachio, hazelnut, and walnut milk; (d) seeds: sesame, sunflower, flax, hemp; (e) pseudo-cereals: milk from quinoa, amaranth, and tofu (Sethi et al., 2019).

Numerous studies have focused on soy milk (Kumari et al., 2022; Letizia et al., 2024; Zhang et al., 2023), as soybeans contain 35 to 52% high-value protein, 17 to 27% high-quality vegetable oils with a fatty acid composition, 18 to 25% various hydrocarbons, essential vitamins, and are a substitute for cow's milk (Al-Saedi et al., 2020; Osthoff et al., 2010). Cereals, oilseeds, nuts, tubers, and fruits are also used to produce plant milk, taking into account the properties of the plant ingredients (Lopes et al., 2020; Seong et al., 2022; Souza et al., 2020). The functional and technological properties of plant ingredients require additional research to produce plant milk with stable quality indicators during storage. However, it is necessary to investigate several technological problems to prepare plant milk as an alternative to cow's milk with stable sensory and physicochemical characteristics.

By using various extraction and processing methods, plant-based raw materials can be treated as dairy analogs and further fermented and/or prepared into fermented dairy analogs such as yogurt and cheese. In addition to selecting raw materials with appropriate flavor and nutritional properties, the extraction of such plant materials to create suitable ingredients is also critical to the development of a satisfactory plant milk analog. Extraction processes have a profound effect on the composition of the raw material, which then determines its behavior in the following stages of product development.

Overview of the latest research and publications

The development of dairy-plant products is a significant direction in the food industry, as they combine high nutritional value and meet the modern consumer's demand for healthy nutrition. Today, there is a need to create new food products that would not only expand the

range but also have resource-saving technologies. One of the most promising ways to solve this problem is the rational use of by-products of dairy production with the combination of plant raw materials (Onopriichuk et al., 2022; Skuibida et al., 2022; Stabnikova et al., 2021). Researchers evaluated the characteristics of soybean grinding using different wet grinding systems and found that particle size had a significant impact on protein recovery in extracted milk, regardless of the type of grinder used (Vishwanathan et al., 2011). A study was conducted that showed that an acceptable vegan cheese analog can be made from mixtures of soy milk and cashew nut milk. This cheese analog can be a source of plant-based protein and potentially reduce the incidence of protein-energy malnutrition. It can also be a rich source of essential fatty acids (Oyeyinka et al., 2019).

It has been shown that the properties of tofu cheese depend on pretreatment, soaking and heating conditions of soybean seeds, and the type and concentration of coagulant. These factors affect the technological parameters of soybean processing and, accordingly, the quality of the resulting tofu cheese (Zhang et al., 2017). Some physicochemical, rheological, and sensory properties of plant-based and milk-based yogurts were studied. The quality indicators of plant-based yogurt had similar values to those of milk-based yogurt (Grasso et al., 2020).

Fermented beverages with cashew pulp were prepared with different whey concentrations of 10, 20, and 30%. Probiotic beverages with cashew fruit had physicochemical and microbiological stability when stored at 4 ± 2 °C for 28 days (Souza et al., 2020).

The kernels of *Arachis hypogaea* have a high nutritional value due to the presence of a significant level of proteins and fats that are easily digested. It should be noted that the fat (about 50%) of the peanut contains about 20% saturated and 80% unsaturated fatty acids, among which oleic and linoleic acids account for the largest share (Olajuyigbe et al., 2013). The protein composition of the kernels of *Arachis hypogaea* is represented by such proteins as albumin, globulins, and glutelins. The high biological value of the kernels of *Arachis hypogaea* proteins is associated with the content of 8 essential amino acids, which are necessary for human life but cannot be synthesized by the body, and 10 nonessential amino acids, which brings it closer to animal composition. Literature data indicate that the composition of the kernels of *Arachis hypogaea* protein is mainly represented by such amino acids as arginine, glycine, leucine, alanine, and methionine, while others are present in small amounts (Abdualrahm et al., 2013).

The vitamin composition of the kernels of *Arachis hypogaea* is characterized by a high content of vitamin E and B vitamins, the quantitative content of which is (mg/100 g): E - 6.93, B1 - 0.438, B2 - 0.098, B3 - 13.5, B5 - 1.4, B6 - 0.256, and B9 - 145. One of the functional components of the kernels of *Arachis hypogaea* is resveratrol, which has antioxidant, anticarcinogenic, and anti-inflammatory properties (Sales et al., 2013).

A rather significant group of substances in the chemical composition of the kernels of *Arachis hypogaea* is polyphenols, which are mainly represented by n-coumaric acid, ferulic acid, esterified derivatives of n-coumaric acid, hydroxybenzoic acid, and resveratrol (Lehnert et al., 2019). The above polyphenolic compounds have antioxidant properties that inhibit lipid oxidation. The analysis of the general chemical composition of the kernels of *Arachis hypogaea* shows a high content of biologically active substances, which makes it possible to recommend it for use in the technology of multicomponent milk and plant concentrates. The implementation of these measures is achieved through the improvement and scientific substantiation of the main technological processes.

However, oilseeds of the legume family, which includes the kernels of *Arachis hypogaea*, contain a high content of trypsin and chymotrypsin inhibitors. In general, enzyme

inhibitors account for about 6% of the total protein content. The kernels of *Arachis hypogaea* contain both high and low molecular weight inhibitors. The inactivation or reduction of trypsin and chymotrypsin inhibitors has been described, and their effectiveness has been compared (Degon et al., 2021; de Jongh et al., 2020; Dubinina et al., 2017). It was found that all types of heat treatment can reduce the content of phytic acid by 3.8-24.7%, trypsin inhibitors by 15.6-61.2%, tannins by 6.7-68.5%, lectins by 75-100%, and improve protein digestibility by 21%. Autoclaving, boiling, roasting with salting, and deep-frying proved to be the most effective. These methods not only reduce the content of phytic acid, tannins, and lectins but also significantly inactivate trypsin and chymotrypsin inhibitors, thereby improving the nutritional value and digestibility of proteins.

It has also been confirmed that the kernels of *Arachis hypogaea* contain a fairly high amount of oxalic acid and copper salts. To create high-quality products based on the kernels of *Arachis hypogaea*, it is necessary to minimize the content of these toxic and antinutrient substances. To solve this problem, we used a physical method – hydrothermal treatment, namely cooking followed by roasting. Hydrothermal treatment simultaneously reduces oxalic acid and its salts, and salts of heavy metals, due to diffusion into the solution. In addition, heat treatment leads to the inactivation of trypsin and chymotrypsin inhibitors, which makes the kernel protein of *Arachis hypogaea* easier to digest. At the same time, roasting improves the sensory quality of the kernels (Dubinina et al., 2017).

Modern technologies for the production of dairy-plant concentrates involve the use of fruit and berry coagulants for protein precipitation. The application of organic acids derived from fruit and berry raw materials promotes the formation of protein-micellar complexes with improved functional and technological properties. This approach not only enhances the quality of the final product but also increases its biological value due to the natural content of vitamins and antioxidants present in the coagulant (Grek et al., 2020).

One of the promising directions in the food industry is the development of high-protein fermented beverages based on plant ingredients. Using protein sources such as chickpeas and flaxseed protein, combined with fermentation processes, allows for the creation of products with high biological value. These beverages exhibit improved sensory properties, reduced antinutritional factors, and enhanced protein digestibility. This technology facilitates the production of alternative products for consumers with lactose intolerance and those adhering to a plant-based diet (Novik et al., 2022).

The development of peanut-based milk alternatives has gained significant attention in recent years due to the growing demand for plant-based functional food products. Research shows that peanut milk possesses high nutritional value and functional characteristics, making it a promising alternative to traditional dairy products (Sakthi et al., 2020) studied the physicochemical, nutritional, and sensory properties of peanut milk. The results indicated that peanut milk has a balanced composition of proteins, fats, and carbohydrates, with high levels of unsaturated fatty acids, particularly oleic and linoleic acids. These properties enhance its nutritional profile and ensure good sensory acceptability.

The impact of processing methods such as autoclaving, roasting, and fermentation has been examined in numerous studies. These methods not only improved the physicochemical stability of peanut milk but also contributed to better emulsification properties and protein solubility. For example, it was demonstrated that pressure blanching preserved the sensory qualities of peanut milk and reduced undesirable bitterness, making it more appealing to consumers (de Albuquerque et al., 2015). Some studies explored the possibility of enriching peanut milk with bioactive compounds from other plant sources, such as guava and umbu. These enriched products exhibited enhanced sensory and functional properties, making them attractive to health-conscious consumers.

A review of the studies highlights the promising potential of peanut milk as a functional food product. Its high nutritional value, combined with technological advancements in processing and enrichment, positions peanut milk as a sustainable and health-promoting alternative to traditional dairy products. Further research is needed to optimize production methods and expand its applications in the food industry.

The fermentation of cowpea-peanut milk with *Lacticaseibacillus rhamnosus* enhances its nutritional and functional properties, producing a probiotic-rich beverage with significant antioxidant activity and essential amino acids (Chawafambira et al., 2022). The study suggests that such fermented plant-based milk alternatives could serve as viable options for health-conscious consumers, particularly in regions where dairy consumption is limited. This research contributes to the growing body of knowledge on plant-based fermented beverages, highlighting the potential of legumes such as cowpeas and peanuts in developing nutritious and functional dairy alternatives.

Considering the aforementioned characteristics, the kernels of *Arachis hypogaea* represent a promising plant-based raw material for the production of dairy-plant concentrates. It is crucial to account for the preliminary processing of *Arachis hypogaea* kernels to inactivate undesirable components and to determine the optimal inclusion level for achieving the best sensory and physicochemical properties of the product.

The aim of the present study is to improve the technology of fermented dairy-plant concentrates. To achieve this aim, the following tasks were defined: determination of the optimal conditions for obtaining whey-plant suspension from milk whey and kernels of *Arachis hypogaea*; determination of the physicochemical and sensory characteristics of fermented dairy-plant concentrates; establishing the optimal ratio for replacing cow's milk with whey-plant suspension in the production of fermented dairy-plant concentrates; improving the technology of fermented dairy-plant concentrates.

Materials and methods

Materials

The dairy-plant mixture was prepared from skimmed milk and whey-plant suspension in component ratios of 9:1, 4:1, 7:3, and 3:2, corresponding to suspension levels of 10%, 20, 30, and 40%. The active acidity of the suspension was 6.7±0.1 pH units, and the dispersed phase size ranged from 50 to 200 μm. Particles of this size are optimal for forming a uniform suspension, facilitating better fat emulsification and even protein distribution in the dairy-plant concentrate.

To obtain the whey-plant suspension, the peanut kernels were soaked in water at a temperature of 20±2 °C and left to swell for 360 to 660 minutes prior to mechanical processing. The kernels were then washed 2–3 times to remove insoluble residues through filtration. Next, the swollen kernels were mixed with curd whey in a ratio of 5:1, and the resulting mixture was homogenized using a disperser operating at 1000 rpm for 4 to 8 minutes. The obtained whey-plant suspension was filtered and then added to the prepared skimmed milk.

Methods

The yield (weight) was determined by the weight method: the sample was weighed after self-pressing the concentrate obtained from 1 l of the dairy-plant mixture.

The active acidity was determined potentiometrically using the universal ionomer EV-74.

The moisture content was determined by an accelerated method (using a «Quartz» device).

To determine the moisture content of the product, 150x150 mm newsprint bags (single or double layers) were rolled diagonally, the corners and edges were bent. The package was placed in a sheet of parchment slightly larger than the package, without wrapping the edges. The finished bags were dried on a «Quartz» apparatus for 3 min at a temperature of 150–152 °C.

The prepared bag was weighed with 5 g of the test product to the nearest 0.01 g. The product was distributed evenly over the entire surface of the bag. The bag with the sample was closed and placed in the device between the plates heated to 150–152 °C for 5 min.

The bags with dried samples were cooled in a desiccator for 3–5 min and weighed.

The moisture content of the product was determined by the formula:

$$W = \frac{(M - M_1)}{5} \cdot 100,$$

where W is the mass fraction of moisture, %; M is the mass of the bag with the sample before drying, g; M_1 is the mass of the bag with the sample after drying, g; 5 is the mass of the product, g.

The difference between the parallel determinations did not exceed 0.5%.The final result was the arithmetic mean of three parallel determinations.

The water-holding capacity was determined by the Grau-Hamm gravimetric method in the modification of A.A. Alekseev, based on determining the amount of water released from the product during light pressing, which is absorbed by filter paper. The water-holding capacity of the product was determined by the formula:

$$HWC = \frac{a - b}{a} \cdot 100,$$

where HWC is moisture holding capacity, %; a is the amount of moisture in the product by weight, mg; b is the amount of moisture released from the product sample, mg, is determined by the difference in weight before and after pressing.

$$a = \frac{0.3 - W_W}{100} \cdot 100,$$

where 0.3 is product weight, mg; W_w is the mass fraction of moisture in the product, %.

Results and discussion

Selection of technological parameters of pre-processing of peanut kernels

At the first stage of the research, thermal treatment of peanut kernels was carried out. This is a crucial step in the technological process, ensuring the inactivation of enzyme inhibitors such as trypsin and chymotrypsin. These antinutritional substances negatively affect protein digestion, reducing their bioavailability and assimilation by the body. It is

hypothesized that thermal treatment at a temperature of 120 ºC for 30–35 minutes effectively reduces the content of enzyme inhibitors to a safe level while maintaining the high functional and technological properties of the proteins. This temperature regime also promotes the breakdown of antinutritional substances such as phytic acid and tannins, further enhancing the sensory and physicochemical properties of the product. Thus, the conditions for preliminary thermal treatment not only improve the nutritional value of peanut kernels but also ensure their safety for use in the production of dairy-plant concentrates.

The main objective in processing plant raw materials for subsequent combination with cow's milk is to obtain a homogeneous and stable whey-plant suspension with dispersed phase particles ranging from 50 to 200 μm. To determine the optimal parameters for the preliminary preparation of *Arachis hypogaea* kernels, the influence of technological parameters, namely soaking and grinding durations, on their sensory characteristics was evaluated using a 5-point scale, as shown in Table 1.

Table 1

Influence of technological parameters of preliminary processing of peanut kernels on their sensory characteristics

Duration, min		Score	Duration, min		Score
Soaking	Grinding		Soaking	Grinding	
360	4	3	480	8	4
360	5	3	540	3	4
360	6	4	540	5	4
360	7	4	540	6	5
360	8	3	540	7	5
420	4	3	540	8	4
420	5	3	600	4	3
420	6	4	600	5	4
420	7	4	600	6	5
420	8	3	600	7	5
480	4	3	600	8	4
480	5	4	660	4	3
480	6	5	660	5	4
480	7	5	660	6	3
480	8	4	660	7	3

The analysis of the results showed that the duration of soaking and grinding of peanut kernels significantly affects their sensory properties. The highest average scores were obtained with a soaking duration of 480 minutes, where the ratings ranged from 6 to 8 points. Soaking for 360 and 420 minutes yielded slightly lower results, particularly for sensory characteristics. Regarding the grinding duration, optimal results were achieved with a duration of 4–5 minutes, where the scores consistently ranged from 4 to 5 points. Increasing the grinding time beyond 6 minutes did not lead to a significant improvement in the scores. The obtained results correlate with the studies of (Siva Sakthi et al., 2021), which examined the comparative effects of different processing methods, such as soaking and roasting, on the properties of the resulting plant mixture. Thus, the best results for the preliminary preparation of *Arachis hypogaea* kernels are achieved with soaking for 480 minutes and grinding for 4–

5 minutes, ensuring optimal sensory properties for further processing and use in the technology of dairy-plant concentrates.

Determination of the optimal ratio of skimmed milk and dairy-plant suspension in mixtures for precipitation

The next stage of the research involved determining the optimal replacement level of skimmed milk with whey-plant suspension in fermentation mixtures. To achieve this, the yield, physicochemical, and sensory properties of the resulting dairy-plant concentrates were evaluated. Model samples were prepared using skimmed milk and whey-plant suspension in component ratios of 9:1, 4:1, 7:3, and 3:2, corresponding to suspension levels of 10%, 20%, 30%, and 40%, respectively. The active acidity of the suspension was 6.7±0.1 pH units. The selection of the optimal replacement level was based on maintaining the standard physicochemical parameters characteristic of milk-protein concentrates, which can serve as a base for producing various types of curd products. Acid-rennet technological regimes were applied for the production of both traditional fermented milk-protein concentrates (control) and dairy-plant concentrates.

The research results (Figure 1) revealed a trend of decreasing yield and increasing moisture content in the obtained dairy-plant coagulates as the proportion of whey-plant suspension with *Arachis hypogaea* kernels increased.

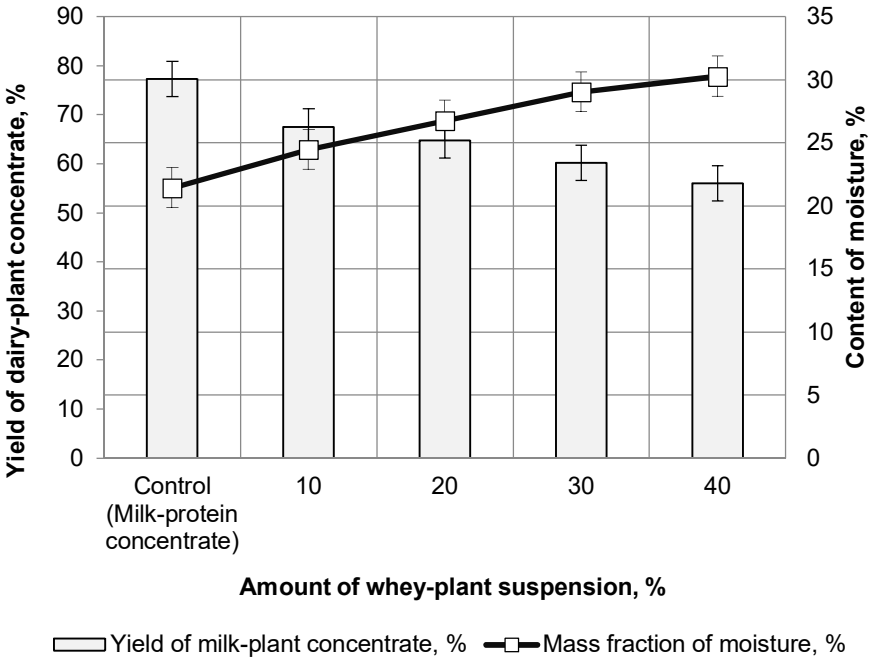

Figure 1. Yield and content of moisture in dairy-plant concentrates

The research results indicate that as the proportion of whey-plant suspension in mixtures with milk increases from 9:1 to 3:2, there is a trend of decreasing yield of dairy-plant concentrates by 5.37–11.17% compared to the control sample (milk-protein coagulate), which uses only dairy raw materials. This reduction is attributed to the decrease in the total protein mass fraction in the mixtures due to the replacement of a portion of the milk with whey-plant suspension containing peanut kernels. At a 9:1 ratio, the concentrate yield is 26.275%, which is 12.5% lower than the control sample (30.05%). With a further increase in the suspension proportion, the yield decreases to 21.8% at a 3:2 ratio, reflecting a 27.5% reduction.

Regarding the mass fraction of moisture, an increase is observed from 62.9% to 82.8% with a higher proportion of whey-plant suspension. For instance, at a 9:1 ratio, the moisture content is 67.9%, which is 12.9% higher than the control sample (60.1%). At a 3:2 ratio, this indicator reaches a maximum of 82.8%, demonstrating the ability of plant components to retain more moisture. This also affects the product's consistency: at a 9:1 ratio, the concentrate has a more cohesive texture, while at a 3:2 ratio, the samples exhibit a smooth, paste-like consistency, with the self-pressing process taking longer.

Analyzing the graph depicting the water-holding capacity of dairy-plant concentrates (Figure 2), a clear dependence of this parameter on the ratio of milk to whey-plant suspension can be observed. The control sample, made from dairy raw materials, demonstrates a water-holding capacity of 72.5%, serving as a benchmark.

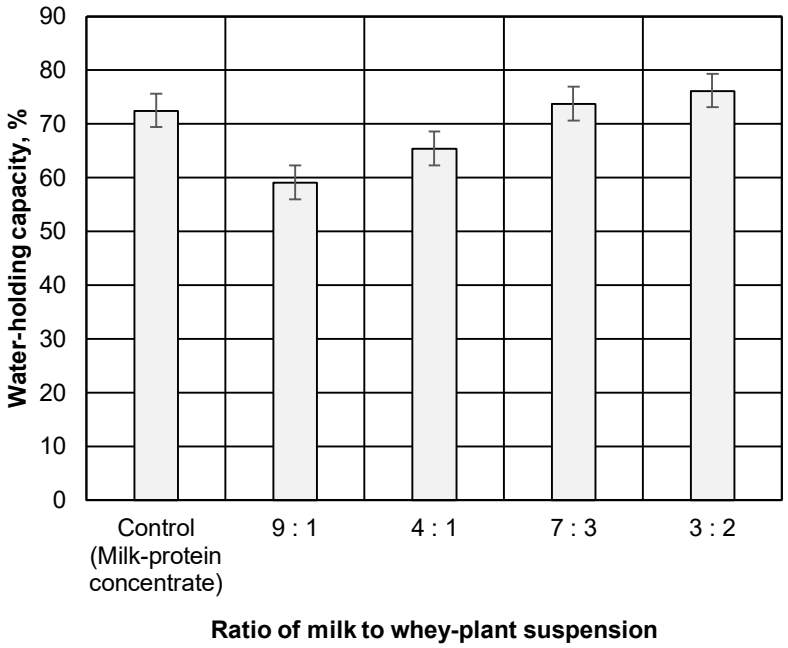

Figure 2. Water-holding capacity of dairy-plant concentrates

With an increasing proportion of whey-plant suspension, the water-holding capacity shows a rising trend. At a 9:1 ratio, this indicator decreases to 59.1%, which is 13.4% lower than the control. For samples with a 4:1 ratio, the water-holding capacity increases to 65.4%,

only 7.1% less than the control. At a 7:3 ratio, the value reaches 73.8%, exceeding the control by 1.3%. The maximum water-holding capacity is observed at a 3:2 ratio, reaching 76.2%, which is 3.7% higher than the control sample.

The optimal ratios for producing dairy-plant concentrates are 4:1 and 7:3. At a 4:1 ratio, the water-holding capacity is close to the control sample, ensuring good functional and sensory properties of the product. The 7:3 ratio provides an even higher water retention level (73.8%) without significantly compromising the product's texture. Although the 3:2 ratio demonstrates the highest water-holding capacity (76.2%), it may result in an excessively paste-like consistency, which could be undesirable under certain consumption conditions.

Thus, the ratios of 4:1 and 7:3 are optimal for producing dairy-plant concentrates with high technological and consumer qualities.

To determine the optimal dosage of whey-plant suspension for the production of dairy-plant concentrate, a sensory evaluation was conducted, as presented in Table 2.

Table 2

Sensory characteristics of dairy-plant concentrates

<table>
<tr><th rowspan="2">Ratio of skimmed milk to whey-plant suspension</th><th colspan="3">Sensory Characteristics of the Concentrate</th></tr>
<tr><th>Consistency and appearance</th><th>Taste and aroma</th><th>Color</th></tr>
<tr><td>9 : 1</td><td rowspan="3">Uniform, soft, spreadable</td><td rowspan="2">Clean, fermented milk-like, with a mild peanut taste and aroma</td><td rowspan="2">Slightly noticeable light cream color, uniform throughout the mass</td></tr>
<tr><td>4 : 1</td></tr>
<tr><td>7 : 3</td><td>Clean, fermented milk-like, with a slight peanut aroma</td><td>Cream-colored, uniform throughout the mass</td></tr>
<tr><td>3 : 2</td><td>Uniform, slightly liquid, floury</td><td>Clean, fermented milk-like, with a pronounced peanut taste and aroma</td><td>Overly pronounced, rich yellowish-cream color, uniform throughout the mass</td></tr>
</table>

The analysis of the sensory characteristics of dairy-plant concentrates, presented in the table, confirms the optimality of the 4:1 and 7:3 ratios. At a 4:1 ratio, the concentrate is characterized by a uniform, soft, and spreadable consistency. Its taste and aroma are clean, fermented milk-like, with a slight peanut aroma. The color is cream and uniform throughout the mass, indicating a balanced combination of dairy and plant components that ensures high consumer qualities of the product. The 7:3 ratio also demonstrates similar positive characteristics. The consistency is uniform and spreadable, while the taste is clean, fermented milk-like, with a slight peanut aroma. The color is uniformly cream. This option provides a high water-holding capacity (73.8%) and a good balance between texture and flavor. In contrast, the 9:1 ratio shows a less pronounced peanut aroma and a weak cream color, indicating an insufficient contribution of the plant component. The 3:2 ratio, while having the highest water-holding capacity (76.2%), is characterized by a slightly liquid, floury consistency and an overly saturated yellowish-cream color, which may affect the perception of the final product. Thus, the sensory evaluations support the previous conclusions regarding the optimality of the 4:1 and 7:3 ratios, as they provide the best balance between texture, taste, aroma, and appearance of the concentrates.

Improvement of the technology for the production of fermented dairy concentrates

Based on the conducted research, the technology for producing fermented dairy-plant concentrates was improved. Initially, a dairy-plant mixture is prepared using skimmed milk and whey-plant suspension at the optimal ratio of 4:1 or 7:3. Pasteurization of the prepared dairy-plant mixture is carried out at an optimal temperature of 74–76 °C with a holding time of 20–30 seconds. This regime ensures the coagulation of thermolabile whey proteins, thereby increasing the yield of the dairy-plant protein concentrate. The pasteurized dairy-plant mixture is then cooled to 28–30 °C during the warm season and 30–32 °C during the cold season before being sent for fermentation. The aforementioned temperature regimes are optimal for the development of key starter microorganisms, ensuring active acid production from the beginning of the fermentation process, primarily mesophilic lactic streptococci. The fermentation of the dairy-plant mixture lasts 6–8 hours. To accelerate the fermentation process, a symbiotic starter culture, made from mesophilic and thermophilic streptococci in a 1:1 ratio, is used. The temperature of the dairy-plant mixture is set at 38 °C during the cold season and 35 °C during the warm season, reducing the fermentation time to 4–4.5 hours. For the production of the milk-protein base using the acid-rennet method, calcium chloride and milk-clotting enzymes are added to the milk along with the starter culture. Calcium chloride is added at a rate of 400 g of anhydrous salt per 1000 kg of the mixture in the form of a solution with a mass fraction of calcium chloride of 30–40%. During the production of the milk-protein base using the acidic method, the dairy-plant mixture is fermented until the curd reaches an acidity of 75–85 °T, and for the acid-rennet method, 61–65 °T. After fermentation, steps are taken to expedite whey removal: the curd is cut into cubes approximately 2 cm on each side using special wire knives. The cut curd is left undisturbed for 40–60 minutes to increase acidity and facilitate more intensive whey separation. Whey is then partially removed. For protein coagulation using the acidic method, the curd is heated to 36–40 °C with a holding time of 15–20 minutes to enhance and expedite whey removal.

For final whey removal and obtaining a milk-protein base with a standard moisture content, the curd undergoes self-pressing, followed by forced pressing. The pressed concentrate is cooled to 3–8 °C to stop lactic fermentation and prevent further acidity increase. The dairy-plant protein concentrate is then cooled in a refrigeration chamber to 2–4 °C.

Conclusions

The feasibility of using peanut (*Arachis hypogaea*) kernels in dairy-plant mixtures has been demonstrated, addressing the issue of milk raw material shortages while enhancing the biological value of concentrates due to a more balanced amino acid composition. Based on the assessment of the influence of technological parameters on the sensory properties of the kernels, the optimal preparation involves soaking *Arachis hypogaea* kernels for 480 minutes in a 5:1 ratio and homogenizing them for 4–5 min.

It has been established that the partial replacement of skimmed milk with whey-plant suspension in ratios of 4:1 and 7:3 allows the production of dairy-plant concentrates with high physicochemical and sensory properties, comparable to milk-protein concentrates (control).

The improved technology ensures consistent quality of fermented dairy-plant concentrates, allows for the use of plant components to enhance functional properties and enrich the amino acid profile, and provides the potential for their application as a base for other dairy products, including curd-based items.

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Effect of spray drying temperature on physical properties and quality characteristics of dry mare's and sheep's milk

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Abstract

Introduction. The aim of the research was to determine the influence of spray drying temperature of sheep and mare's milk, intended for use in the technology of products for infants, on its physical properties and quality indicators.

Materials and methods. Native cow, mare and sheep milk were used for the research. Milk was dried using a Niro-Atomiser spray dryer at a temperature range of 130–190 °C. The peroxide value, particle size, insolubility index, and wettability were studied. The relative dissolution rate, viscosity, insolubility index and moisture content were determined in the prepared infant formulas.

Results and discussion. In mare's milk, the peroxide index increased by 12% with increasing temperature from 140 to 150 °C. At lower drying temperatures (130–140 °C), the peroxide index also increased. Slow migration of fat in the particles during spray drying due to differences in density, non-polar nature and particle size resulted in excess fat on the surface of the powders. In sheep's milk, the peroxide index increased by 12% when dried in the temperature range from 160 to 170 °C and by 36% in the temperature range from 170 to 180 °C. The particle size of the dry milk depended on the chemical composition of the milk and the drying temperature. With an increase in the spray drying temperature in the range of 130–190 °C, the particle size of mare's milk decreased by 67%, and that of cow's milk by 29%. For sheep's milk, the particle size decreased by 21% with an increase in temperature to 180 °C, and a further increase in temperature contributed to the solidification of the dry milk particle and a partial increase in size. Mare's milk dried at low temperatures (130 °C) had a high insolubility index (0.4 cm^3), which was unacceptable for infant formulas. When it was dried at a temperature of 140 °C, the insolubility index decreased 4 times, and at a temperature of 150 °C – the insolubility index was 2 times higher compared to the drying temperature of 140 °C. The increasing of the insolubility index was related to the increase in the amount of denatured whey protein during drying at high temperatures. Sheep milk dried at high temperature 180 °C was characterised by a high insolubility index of 0.4 cm^3. At a drying temperature of 170 °C, the insolubility index was the lowest 0.1 cm^3. A wettability time shorter than 1 minute was achieved when mare's milk was dried at a temperature of 130–160 °C and sheep's milk at 170–180 °C. The rational temperature of the drying agent for spray drying of milk for the purpose of using in the infant formula technology was 140 °C for mare's milk, and 170 °C for sheep and cow's milk.

Conclusions. Infant formulas based on mare's and sheep's milk produced at rational drying temperatures had similar viscosity curves to the control, and were characterised by high quality indicators and relative dissolution rate.

Introduction

A large number of infants in the world are bottle-fed. Despite the fact that human breast milk is considered the best product for supporting the growth and development of infants in early childhood, only 38% of infants are exclusively breastfed during the first 6 months of life (Kondrashina et al., 2024). Dry milk mixtures for infants are mainly produced on the basis of cow's milk (Martin et al., 2016). There are also mixtures based on goat's milk (Hageman et al., 2019; Nayik et al., 2022). Meanwhile, it is known that cow's milk proteins can cause food allergy (Paschke and Besler, 2002; Wal, 2002). Therefore, it is necessary to expand the range of raw materials for infant food mixtures and to research other types of milk, such as mare's and sheep's, for their use in the technology of these products.

Dry milk is the main component in mixtures for artificial feeding of infants, so its quality will significantly affect the quality of the product. Studies of the chemical composition and nutritional value of vegetable and mare milk have been the focus of many recent studies (Blanco-Doval et al., 2024; Li et al., 2022), but the drying technology of mare and sheep milk and its effect on the physical properties of milk wasn't investigated enough. The quality of dry milk is determined by its physical properties (Dec et al., 2023), which are extremely important for infant formula (Masum et al., 2019). Usually, the physical properties of dry milk are determined by its composition and surface properties of powder particles, which change during technological processes (Sharma et al., 2012). The factors that are most important in the spray drying process are the inlet temperature between 120-180 ºC, the inlet air flow and the feed flow rate, these variables affect the physical properties of the powders, such as: yield, moisture, hygroscopicity, water activity, solubility and bulk mass (Samsu et al., 2020).

There are data on the spray drying of sheep's milk at a temperature of 160 °C with the addition of 2% soy lecithin. The product was evaluated according to the content of moisture, fat, protein, pH, water solubility, microbiological and sensory indicators (Endres et al., 2024). The results obtained during drying at this temperature did not fully justified the feasibility of the selected temperature regime for drying sheep's milk.

High-quality dry mare's milk was obtained by spray drying at an inlet air temperature of 273-280 °C after concentration of mare's milk by vacuum evaporation. Physical characteristics of dry milk were: solubility index >99.5%; dispersion index >97.0%; wettability index < 5 s (Schuck et al., 1995). Such a high drying temperature negatively affected the preservation of the nutritional value of milk, which was a significant disadvantage, considering its potential use for infant food products.

The process of freeze-drying had a positive effect on the indicators of preservation of components of mare's milk, which practically did not change in terms of dry matter (Cais-Sokolińska et al., 2023). But it was also necessary to take into account the economic component of the methods of drying mare's milk, since freeze-drying was eight times more expensive than spray drying of milk, and vacuum drying was four times more expensive than spray drying (Lee et al., 2018).

Therefore, the aim of the work was to investigate the influence of the spray drying temperature of sheep and mare milk on its physical properties and quality indicators for use in the technology of products for infants based on dry milk.

Materials and methods

Materials

Native cow's milk, mare's milk and sheep's milk were used for the study. Milk was collected on farms in eastern, central and southwestern Ukraine.

Methods

Milk drying was carried out on a semi-industrial spray dryer "Nyro-Atomizer" with a working volume of the chamber of 0.9 m^3 and productivity in terms of evaporated moisture up to 5.0 kg/h. The dryer made it possible to ensure the temperature of the drying agent in the range of 120 – 250 °C at the entrance to the dryer and 60 – 100 °C at the exit from it.

Drying took place according to the following parameters: the speed of movement of the drying agent was 0.5 m/s, the relative humidity of the drying agent was 25%, the size of the droplets of the sprayed product was 40-50 μm, the mass fraction of dry substances in the product was 40 – 43%.

Milk powder was tested 2 hours after drying.

Determination of the peroxide value

Milk powder sample (5.0 g) was mixed with chloroform-glacial acetic acid solution (40:60, v/v, 5 ml), and saturated potassium iodide solution (1 ml) was added. The mixture was reacted in the dark for 3 min. Then, it was diluted with distilled water (50 ml) and added to starch solution (1%, w/v, 1 ml). The clear liquor was separated by filtration, and the POV was determined at 585 nm (Wang et al., 2020).

Size of milk powder particles

Particle size distribution of the milk powder samples was measured by a mechanical tapping sieve shaker. 100 g sample was weighed using the weighing balance and poured into the top sieve. After being vibrated with the same strength and time, a different aggregate of particle sizes was collected on each sieve and weighed. The particle size distribution was measured twice for each trial to increase accuracy. Particle size distributions were calculated based on results from sieve analysis (Zhang et al., 2023).

Insolubility index

Studies on the determination of the insolubility index were carried out according to ISO 8156:2005 (Majadi et al., 2024; Pugliese et al., 2017). Dry milk was dissolved in water at a temperature of 25 °C and centrifuged. The supernatant was removed and replaced with water, centrifuged again and the volume of insoluble sediment was measured. The insolubility index indicated the amount of substances that did not dissolve in the reducing agent (water), but precipitate.

Wettability of dry milk

The wettability of dry milk was determined by the GEA NIRO method (Koca et al., 2015; Salunke et al., 2023). 13 g of dry whole milk was poured into a special funnel made of antistatic plastic (funnel height 100 mm, diameter 40 mm), and the bottom of the funnel was covered with a 130 mm long glass pestle. 100 cm^3 of distilled water with a temperature of 40±2 °C was poured into a chemical beaker with a volume of 400 cm^3, a diameter of 70 mm

and a height of 135 mm. A glass of water was placed under the watering can, the pestle was raised and the stopwatch was turned on at the same time. The stopwatch was turned off when all the powder was wet. Wettability was estimated by the time required for complete wetting of the powder.

Speed of dissolution

The speed of dissolution was determined by the modified method described in (King, 1966). 5 g of dry milk was placed in a mixing glass, 35.2 cm^3 of water was poured through the inclined channel in the eccentric of the stirrer along the wall of the glass. The water temperature was 20±2 °C. The electric drive was turned on and stirred for 5 seconds, then the resulting mixture was filtered under vacuum through a Schott glass filter No. 1. The content of dry substances was determined in the resulting filtrate using a refractometer. The amount of dry substances of the product that went into solution, related to the weight of the product, represent the speed of dissolution, which was expressed as a percentage.

Moisture content

Moisture content was determined by oven drying method (GEA, 2024).

Rheological indicators

The rheological parameters of the mixtures were studied on a rotary viscometer "Rheotest-2" with a system of coaxial cylinders S/S1 in the strain rate range 3 – 1312 c^{-1} (Kambulova et al., 2020).

Statistical analysis

The statistical processing of the results was performed by sequential regression analysis using the Microsoft Excel XP and Origin Pro8 software calculating correlation coefficients (Hinkle et al., 2003).

Results and discussion

The chemical composition of milk is important for the formation of the nutritional value of products based on it. The chemical composition of mare's and sheep's milk is significantly different from cow's milk (Table 1).

Table 1

Chemical composition of native milk

Type of milk	Content, % on dry matter		
	Protein	Fat	Lactose
Cow	24.2±0.3	27.3±0.2	41.0±0.4
Mare	16.7±0.1	12.4±0.3	69.1±0.2
Sheep	26.6±0.2	33.6±0.2	22.4±0.4

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

Mare's milk contains less protein by 31% and fat by 54.5% than cow's milk, but more amount of lactose. Sheep's milk is high in protein, but fatter than cow's milk.

Different fat content, namely the amount of free fat on the surface of milk particles, the amount of hydrolyzed triglycerides affected the change in the peroxide value during milk drying. The surface free fat content of spray-dried powders depends on many factors, including total fat content, fat type, product composition and drying conditions (Pisecky, 2012). The peroxide value was determined 2 hours after drying.

The peroxide index was differrent in all types of milk (Table 2). In sheep's milk, it was 2.1-2.4 times higher than in mare's milk, and 1.3-1.5 times higher than in cow's milk. This difference is explained by the fact that milk contains a different mass fraction of fat (Pietrzak-Fiećko and Kamelska-Sadowska, 2020), and therefore a different amount of free fat, which is primarily oxidized.

Table 2

Peroxide index of fat in dry milk at different drying temperatures

Temperature, °C	Peroxide index of fat, mmol/kg		
	Cow milk	Mare milk	Sheep milk
130	1.38±0.01	0.88±0.03	1.89±0.02
140	1.41±0.02	0.95±0.02	1.92±0.03
150	1.55±0.02	1.06±0.01	2.05±0.02
160	1.76±0.02	1.09±0.01	2.20±0.02
170	2.30±0.01	1.23±0.02	2.46±0.03
180	2.33±0.01	1.32±0.01	3.35±0.01
190	2.33±0.01	1.38±0.02	3.37±0.01

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

When the air temperature increased, there was a rapid increase in the peroxide index of milk. In mare's milk, with an increase in temperature from 140 °C to 150 °C, the peroxide value increased by 12%. However, even at lower drying temperatures (130 – 140 °C), the peroxide value also increased. This is explained by the fact that during spray drying, water molecules diffused from the inside to the surface of the droplets and evaporated. Components such as fat, protein, lactose, and minerals counter-diffused or migrated into the middle of the drop. The slow migration of fat due to differences in density, nonpolar nature, and particle size led to an excessive amount of fat on the surface of powders (Kim et al., 2003). According to the data (Deshwal et al., 2020; Foerster et al., 2016), the coating of the surface of the powder with fat for dry whole and skim milk, dried by the spray method, was 90% and 18%, respectively. Higher surface fat content is known to increase susceptibility to lipid oxidation (Hardas et al., 2000).

In cow's milk, when the temperature changed from 140 °C to 150 °C, the peroxide value increased by 10%, and when the temperature changed from 160 °C to 170 °C, the peroxide value increased by 31%. In sheep's milk, the peroxide number increased by 12% in the temperature range of 160-170 °C and by 36% in the temperature range of 170-180 °C. The total increase in peroxide value when the drying temperature changed from 130°C to 190°C in cow's milk was 69%, mare's milk – 57%, sheep's milk – 78%.

Cow's milk accumulated 4-5% more peroxides than mare's milk and 15-16% less than sheep's milk. This difference is explained by the fact that triglycerides of milk fat during thickening and drying were partially hydrolyzed with a decrease in their composition of

unsaturated fatty acids. However, the amount of free fat increased during drying with increasing temperature, and since sheep's milk contained the most amount of fat (Li et al., 2022), and a larger amount of free fat was formed in it during the drying process. Cow's milk contained less fat than sheep's milk, but the amount of unsaturated fatty acids in it was more than in sheep's milk. Mare's milk was the least capable of oxidation, since the mass fraction of fat in it was the smallest.

Thus, it was found that with an increase in the drying temperature, the amount of peroxide compounds in milk increased, which negatively affected its storage. It was found that the intensity of the accumulation of peroxides in milk, in addition to the drying temperature, was influenced by the mass fraction of fat. Therefore, it must be taken into account when choosing rational parameters for drying milk.

When setting the rational temperature of the drying agent during spray drying of milk, the size of the formed particles was of great importance (Panthi et al., 2021). The size of the particles of dry milk made it possible to predict the quality of the recovery of the product. The smaller the milk powder particles, the greater the specific surface area for the reducing agent, and the faster the reduction process wase. Drying milk at different temperature ranges allowed obtaining particles of different sizes (Figures 1–3).

When drying milk with an increase in temperature, a decrease in dry milk particles was observed. When the drying temperature increased from 150 to 160 °C and from 160 to 170 °C, the size of cow's milk powder particles decreased by 9% and 5%, respectively. With the next increase in temperature by 10 °C, the size of the particles decreased by another 10%. The decrease in the size of the powder particles with increasing temperature was caused by more intense evaporation of moisture from the inner layers. Also, when the air temperature increased, the fat balls were crushed. And since fat molecules had a significant influence on the formation of particle size, as the diameter of fat globules decreased, the size of the particles on which it was located decreased.

When drying mare's milk at low temperatures of 130 °C, larger particles were obtained than at higher drying temperatures. This is explained by the incomplete removal of free moisture, which kept proteins in a colloidal state. With an increase in temperature to 140 °C, due to greater removal of moisture from a drop of the sprayed product, the size of the particles decreased by 40%. The subsequent increase in temperature contributed to the further reduction of the particle size.

When drying sheep's milk in three temperature ranges, a decrease in the size of the particles was observed, and at a temperature of 190 °C, the size of the particles increased. The smallest particle size of sheep's milk were found at a temperature regime of 180 °C. When the temperature droped to 160 °C, the particle size already increased by 28%. It was obvious that the reason for this phenomenon was a decrease in the diffusion rate. The temperature of the drying agent 190 °C caused obtaining powder with large particles. Their size was increased by 14% compared to the particles obtained at a temperature of 180 °C. The explanation for this was the instant hardening of the surface of a particle of dry milk. In spray-dried milk samples, the presence of vacuoles on the particle surface was observed, which were caused by the removal of water (López Fialho et al., 2019; Nuzzo et al., 2017). Drying milk at elevated temperatures removed surface water from particles and increased surface viscosity, resulting in a dry, hard surface (Kim et al., 2009; Westergaard, 2004). This solid barrier prevented the diffusion of water vapor and air, which, in turn, led to an increase in particle size. In the process of storage, such a powder loosened.

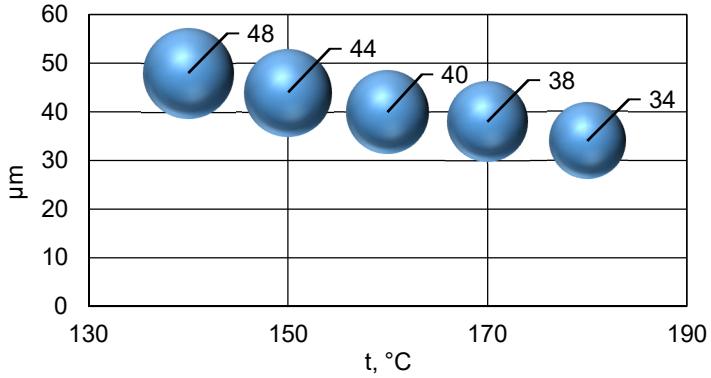

Figure 1. Particle size of cow milk powder depending on the drying temperature

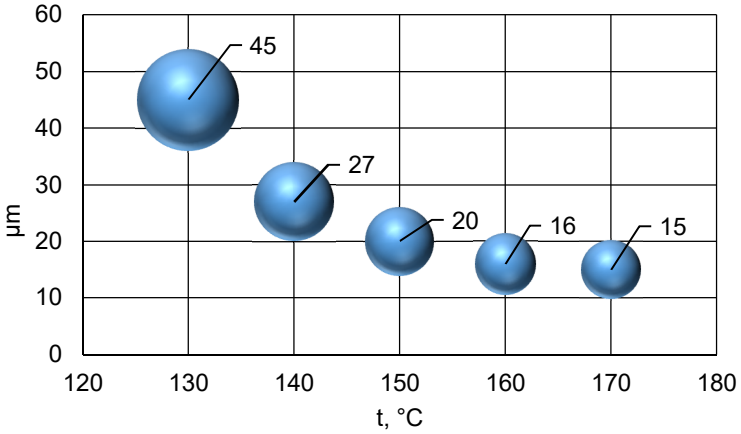

Figure 2. Particle size of mare milk powder depending on the drying temperature

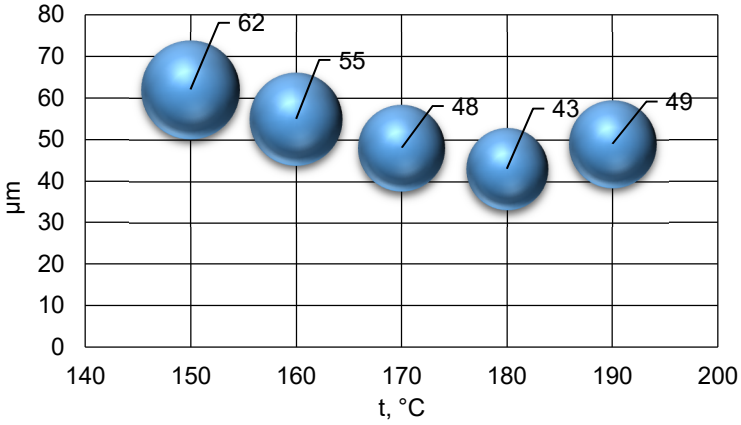

Figure 3. Particle size of sheep milk powder depending on the drying temperature

There were also significant differences between the particle sizes of different types of milk. It was likely that such a difference was due to the chemical composition of milk, namely the size of casein micelles. Because both whey proteins and casein proteins had larger molecules, they almost always turned into amorphous powders during spray drying. The slower migration of protein due to the large size and surface-active nature of the droplets, compared to lactose and minerals, led to an overrepresentation of protein on the surface of the powders (Kim et al., 2003; Masum et al., 2019). Therefore, the size of the particles of milk powder depended on the chemical composition of whole milk and the drying temperature. With an increase in the temperature of spray drying in the range of 130 – 190 °C, the particle size of mare's milk decreased by 67%, cow's milk – by 29%. For sheep's milk, the particle size decreased up to a temperature of 180 °C (by 21%), a further increase in temperature contributed to solidification of the dry milk particles and a partial increase in size.

When recovering dry milk, one of the main indicators of its quality was the insolubility index. The insolubility index indicates the amount of substances that do not dissolve in the reducing agent (water), but precipitate. The rate of dissolution was also important (Sharma et al., 2012). Since milk powder was being studied for use in instant infant products, its dissolution in water should also be quick. The solubility of milk powder was mainly influenced by the amount of insoluble denatured protein and the amount of free fat in the milk powder (Deshwal et al., 2020), as well as the particle diameter and temperature of the drying agent (Straatsma et al., 1999). The insolubility index of dry milk was determined 2 hours after drying milk.

Mare's milk, dried at a low temperature of 130 °C, had a high insolubility index (0.4 cm^3), which was unacceptable for infant food products (Figure 4). This temperature of the drying agent did not ensure complete removal of free moisture. As a result, lactose crystallized, thereby causing fat destabilization. The poor solubility of dry milk can be caused by the high moisture of the product.

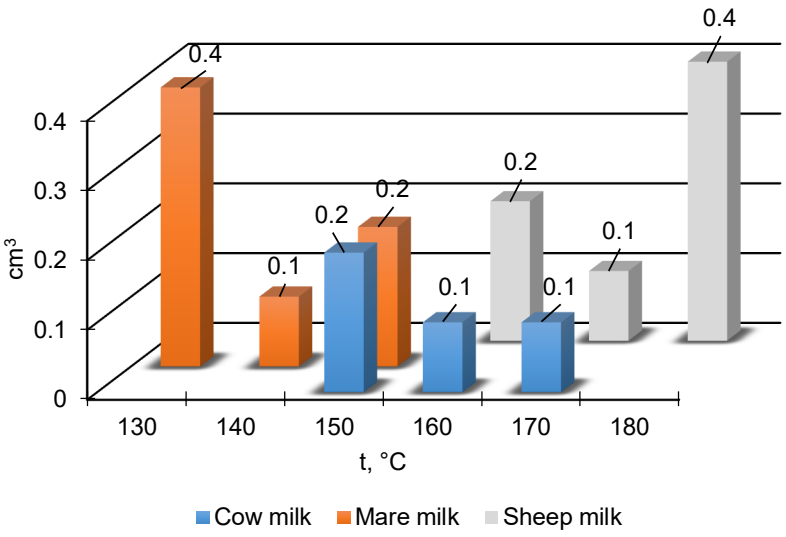

Figure 4. Insolubility index of milk powder

Drying mare's milk at a temperature of 140 °C allowed to reduce the insolubility index 4 times. When the temperature increased to 150 °C, the insolubility index of dry mare's milk was 2 times higher compared to the drying temperature of 140 °C. During spray drying, the main factor controlling the insolubility index was the temperature of the particles when their moisture content was between 10 and 30%. The insolubility of milk powder was explained by the unfolding of β-lactoglobulin and its aggregation with casein (Thomas et al., 2004). Mare's milk contained a significant part of whey proteins, which are heat-labile proteins. The zone in which casein proteins were most sensitive to heat was in the moisture range that occurred during spray drying (Baldwin, 2010).

Therefore, increasing the drying temperature led to an increase in the amount of denatured whey protein, which in turn reduced the solubility of dry milk. Sheep's milk dried at high temperature (180 °C) had a high insolubility index, which was unacceptable for infant food products. A loose product with a large number of cracks was formed. This created favorable conditions for the concentration of free fat on the surface of a particle of dry milk. As a result, the wetting of particles and, as a result, the solubility of dry milk deteriorated. The high temperature of the drying agent led to intensive denaturation of proteins, increasing the amount of insoluble sediment during recovery of dry milk.

At a drying temperature of 170 °C, the insolubility index was characterized by the best indicators. When drying cow's milk in the temperature range of 160 – 170 °C, a product with a low solubility index was formed, which also met the requirements for fast-dissolving products. When the drying temperature was reduced to 150 °C, the insolubility index was 2 times higher. The reason for this can also be the lower dispersion of fat, which reduced the specific surface for the action of water.

The main physicochemical indicator of the quality of dry dairy products, on which their speed of recovery depended, was wettability. The different wettability of dry products obtained with different drying modes was explained primarily by the unequal intensity of thermal effects on milk proteins and salts, as well as the difference in the shape and size of their particles (Pugliese et al., 2017; Schuck, 2011).

Quick-dissolving dry products for infant food were characterized by a short duration of wettability, so this indicator should be taken into account when choosing rational parameters for drying milk powder.

For this purpose, the influence of the drying temperature on the wettability of dry milk was analyzed (Figure 5).

In samples of mare and cow milk powder, with an increase in the drying temperature, a decrease in the duration of wetting was observed. This phenomenon was probably related to the size of the milk powder particles. It is known that the smaller the particle size, the greater the surface area for contact with water. As previous studies showed, with an increase in the drying temperature, the size of the particles of milk powder decreased. This explains why the wettability of milk dried at higher temperatures was better than that of milk dried at lower temperatures.

In sheep's milk, as the drying temperature increased, the duration of wetting decreased, but at a drying temperature of 180 °C longer wetting was observed than at lower temperatures. This was probably also due to the size of the particles and the large amount of free fat on their surface. Because when drying sheep's milk at a temperature of 180 °C, large particles were formed, which was established by previous studies. It is known that with an increase in the content of surface fat, the wettability of powders decreases (Fäldt and Bergenståhl, 1996).

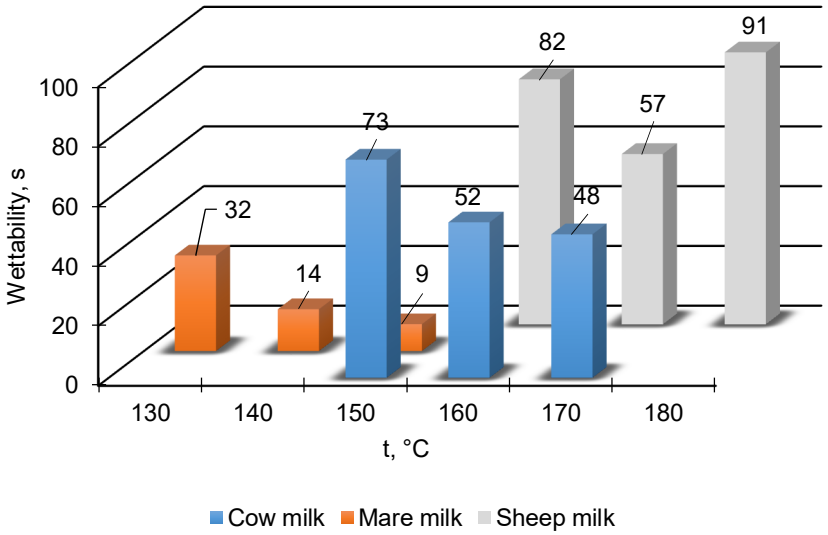

Figure 5. Wettability of milk powder

Dry mare's milk wetted the fastest among all samples. The explanation for this phenomenon can be the low fat content, the smallest particle size, a large amount of lactose, which did not prevent the penetration of water into the pores of the product, while in other types of milk, the mass fraction of fat was larger and the particle sizes were larger, compared to mare's milk.

The shortest duration of wettability, which was desirable for fast-dissolving products, was achieved when drying cow's milk at a temperature of 170 °C, mare's milk – 130 – 150 °C, sheep's milk – 170 °C.

The lowest value of the insolubility index, which allowed obtaining high-quality fast-dissolving products and powdered milk for infant food, was achieved at the drying temperature of cow's milk 160–170 °C, mare's milk – 140 °C and sheep's milk – 170 °C.

Based on the results of the research, rational temperatures for drying milk were found, which are presented in Table 3.

Table 3

Characteristics of milk drying

Indicator	Cow's milk	Mare's milk	Sheep's milk
Temperature of the drying agent at the entrance, °C	170±2	140±2	170±2
Dry milk amount, %	11.9±3	9.8±2	15.5±2
Moisture, %	2.9±0.2	2.3±0.1	2.6±0.1

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

Indicators of ready-made mixtures for infant food mainly depend on the quality of dried milk. Dry milk mixture «Malyutka hypoallergenic» (Khorolsky milk-canned plant for children's products, Ukraine) was chosen as a control.

Formulations of dry milk infant formulas based on sheep's and mare's milk were developed (Table 4).

Table 4

Formulations of sheep and mare milk based infant formulas

Components	Content in the mixture, %	
	Ligans (with dry mare's milk)	Agnus (with dry sheep's milk)
Dry sheep's milk	–	56.00
Dry mare's milk	84.65	–
Soybean oil	–	4.00
Sunflower oil	7.00	2.00
Olive oil	8.00	–
Lactose	–	36.30
Lactulose	–	1.00
Fat-soluble vitamins	0.0003110	0.0002800
Water-soluble vitamins	0.0022854	0.0031056
Mineral substances	0.207	0.556
Taurine	0.03	0.03
Inositol	0.11	0.11

Physico-chemical characteristics of mixtures are given in Table 5.

Table 5

Physico-chemical characteristics of infant formulas

Mixture	Moisture, %	Insolubility index, cm^3
Control	4.0±0.1	0.2±0.02
With dry sheep's milk	3.0±0.1	0.1±0.01
With dry mare's milk	3.0±0.1	0.1±0.02

* Results given as: M±SD (mean±standard deviation) of triplicate trials.

The moisture in the developed mixtures was 1% lower than in the control. This difference was due to the different moisture content in the raw materials from which the mixture was prepared. In the mixtures with sheep's and mare's milk the insolubility index was 2 times lower than in the control. The explanation for this can be the different composition of the mixtures, the quality of the raw materials, and the difference in the main nutrients in the raw materials – proteins, fats, carbohydrates.

Dry infant formulas are quick-cooking products. The use of milk powder as an ingredient in formulations or as a finished product consumed by consumers may be limited by the poor rehydration characteristics of the powder when reconstituted in a liquid medium (Xu et al., 2024). When in contact with water, they must quickly restore the structure and

ensure the transition of dry substances into the solution. Therefore, studies were conducted to determine the relative rate of dissolution of mixtures. Water for infant food, heated to a temperature of 37–40 °C, was used to restore the mixtures.

The results of the study (Figure 6) indicated that in one minute of preparation of the mixture, there was almost a complete transition of dry substances into the solution. However, in the mixture with dry mare's milk, dissolution occurred more intensively than in other mixtures. The rate of dissolution of the product depends on the size of the particles and on the depth of protein denaturation (Singh and Creamer, 1991). This is the explanation of the different rate of dissolution of mixtures. Thus, the composition of the mixture with dry sheep's milk, which, according to previous studies, had the largest particle size. Therefore, the intensity of dissolution of the mixture with dry sheep's milk was the lowest.

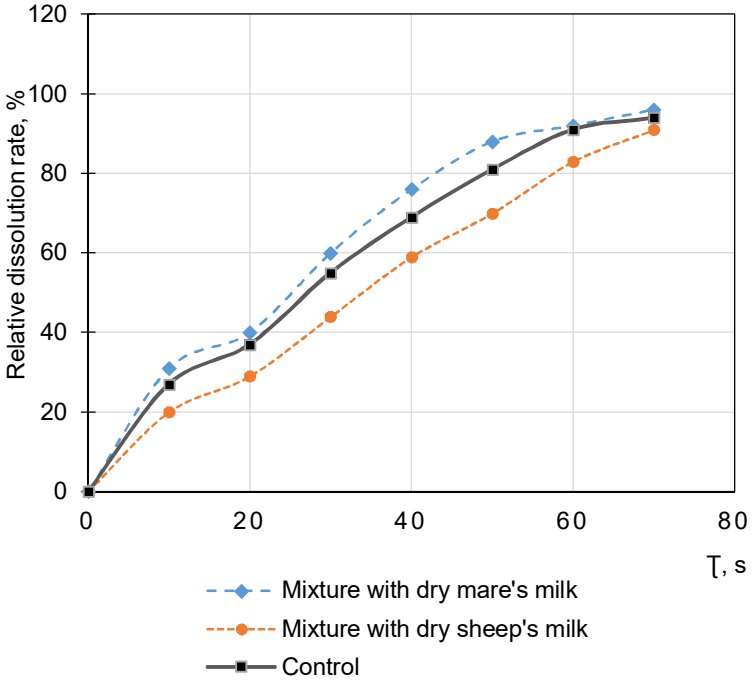

Figure 6. Relative dissolution rate of infant formulas

Despite the differences in the intensity of dissolution of the mixtures, in a minute of cooking, all the mixtures almost completely restored their structure, which was evidenced by the amount of substances that transferred into the solution: for the mixture with dry mare's milk – 97.5%, for the mixture with dry sheep's milk – 96.0 %, for the control – 97.0%.

The results of the change in the viscosity of the samples are shown in Figure 7.

Analyzing the nature of the obtained dependencies, the viscosity of the samples decreased as the shear stress increased. Probably, as a result of the destruction of the structure of these systems, their macromolecules were more oriented in the direction of the flow, which contributed to a decrease in viscosity (Kambulova et al., 2020).

At a shear stress (300–360 s^{-1}) intensive destruction of the structure occurred in the experimental and control samples. With a further increase in shear stress, the viscosity acquired a stable minimum value, characteristic of an almost completely destroyed structure.

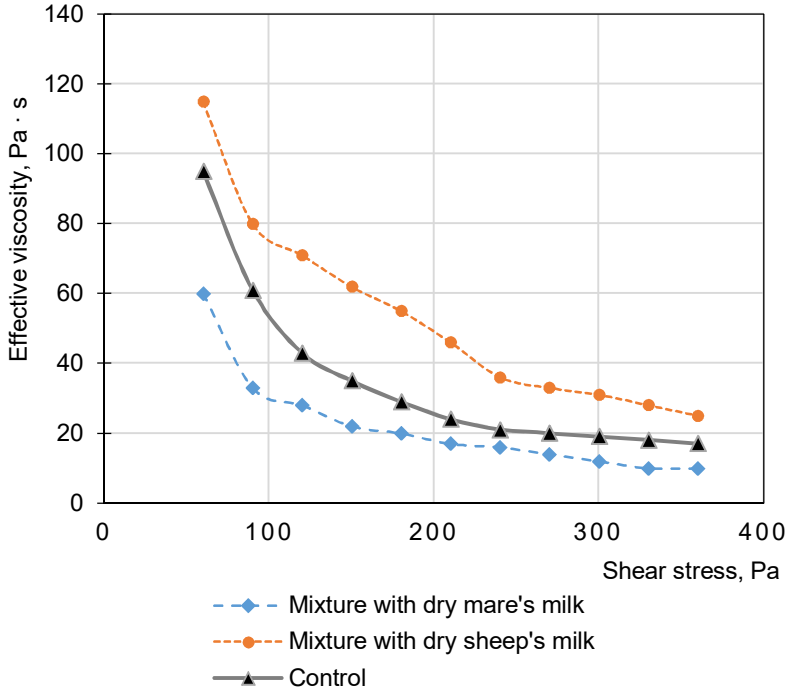

Figure 7. Dependence of viscosity of the reconstituted solutions of infant formulas on shear stress

A similar character of the viscosity curves was observed for all samples. The value of the effective viscosity of the experimental systems differred little from the viscosity of the control sample, that is, they had a similar structure, which confirmed the introduction of a rational amount of reducing agent into the dry mixtures. The viscosity values for the mixture with dry sheep's milk and the mixture with dry mare's milk were respectively 116.2 and 58.1 Pa·s., for control – 96.8 Pa·s. It was found that with an increase in voltage shear viscosity of systems decreased.

Conclusions

Studies of mare's, sheep's and cow's milk powder showed that with an increase in the temperature of the drying agent in the range of 130 – 190 °C, there was a rapid increase in the peroxide value (up to 78% depending on the type of milk), a decrease in the particle size (up to 67% depending on type of milk), the insolubility index (2-4 times depending on the type of milk) and for most samples the duration of wetting was reduced.

Based on a complex of studies, it was found that the rational temperature of the drying agent for spray drying of milk for the purpose of its use in the technology of mixtures for infant food was: 140°C for mare milk and 170°C for sheep and cow milk. The study of the developed dry mixtures for infant food showed that the relative rate of dissolution of these products was similar to the value of the same indicator in the control, which indicated the high quality of the product. In 1 minute of cooking, all mixtures almost completely restored their structure, as evidenced by the amount of dissolved substances: mixture with dry mare's milk – 97.5%, mixture with dry sheep's milk – 96.0%, control – 97.0%.

The values of the effective viscosity of the reconstituted mixtures of mixture with dry sheep's milk and the mixture with dry mare's milk were 116.2 and 58.1 Pa·s, respectively. Viscosity curves had a similar character to the control sample. It was found that the selected rational temperatures for spray drying mare's milk (140 °C) and sheep's milk (170 °C) provided quality indicators of the finished mixtures that corresponded to the control samples.

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Modeling of alternating impulses of pressure for hydrodynamic conditions in mixing technology

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Abstract

Introduction. The aim of this study is to investigate the influence of the application of alternating impulses of pressure throughout treatment of liquid solutions by the numerical modelling.

Materials and methods. The volume parametric imitation and visualization, modeling methods, math modeling methods were used for the description of the conditions at the working parts of the rotary-pulsed apparatus during the liquid treatment.

Results and discussion. By the modelling processes, mathematical and numerical modelling was found that the value of the linear speeds of a stream should be from 21.98 m/s to 22.13 m/s for the first rotor and from 23.58 m/s to 23.70 m/s for the second rotor. The value of angular velocity was 314 s^{-1} and the frequency of hydrodynamic oscillations was $3 \cdot 10^3$ Hz. The coaxial clearance between first rotors, stator and second rotor was from 100 to 500 μm. The value of shear rate was for the first rotor from $2.2 \cdot 10^5$ s^{-1} to $0.44 \cdot 10^5$ s^{-1} and for the second rotor from $2.4 \cdot 10^5$ s^{-1} to $0.47 \cdot 10^5 s^{-1}$. The value of shear stress for the first rotor was from 219.8 Pa to 44.26 Pa and for the second rotor from 235.5 Pa to 47.4 Pa. The pressure difference between the input and the output liquid solutions at the working volume before and after treatment is $\Delta P = 50 \cdot 10^3$ Pa. According to the results of the research, it was found that the alternating pressure pulses in the system are $\Delta P = 370 \cdot 10^3$ Pa near the outer surface of the inner rotor; $\Delta P = 240 \cdot 10^3$ Pa near the outer surface of the stator; $\Delta P = 155 \cdot 10^3$ Pa near the inner surface of the stator; $\Delta P = 190 \cdot 10^3$ Pa near the inner surface of the outer rotor. The local pressure values in the zone of water and alcohol inlet and water-alcohol mixture outlet from the clearance change: near the outer surface of the inner rotor from $-50 \cdot 10^3$ Pa to $+300 \cdot 10^3$ Pa; near the outer surface of the stator from -150 to $100 \cdot 10^3$ Pa; near the inner surface of the stator from $+40 \cdot 10^3$ Pa to $-120 \cdot 10^3$ Pa; near the inner surface of the outer rotor from $+ 100 \cdot 10^3$ Pa to $-100 \cdot 10^3$ Pa.

Conclusions. A numerical calculation was accomplished to determine the hydrodynamic parameters of equipment that implements the basic mechanisms and concept of the alternating impulses of pressure, that realize in rotary-pulsed apparatus for the processing of water and ethanol-containing products.

Introduction

Today alternative foodstuff technologies, methods and equipment as innovative food production technologies provide increased productivity with limited resources and an improved carbon footprint. Food security has become a major challenge for the future owing to the scarcity of land, rising global population, urbanization, and polluted soil and water resources (Erekath et al., 2024). There are intensively developing novel food processing technologies that are environmentally-friendly and energy-saving ones (Ivanov et al., 2021).

Understanding how liquid interact with each other is key to conseption how structures arise and how their properties arise from these (Welton, 2018). These interactions arise from a combination of Coulomb forces, hydrogen bonds, pi-pi interactions, and dispersion forces (Fumino et al., 2014).

Hydrodynamic cavitation includes many structures, such as a Venturi tube, orifice, and pulsed jet Selfexcited oscillation cavitation is a kind of pulsed jet (Nie et al., 2022). Consequently, electrical plasma discharge can be used alone as well as in combination with other advanced oxidation processes techniques, such as UV photocatalysis and ozonation (Fang et al., 2019).

Cavitation is another advanced oxidation processes that generates cavities through ultrasound or changes in device geometry, and the processes of cavity generation, growth and collapse increase mass transfer rates and generate highly reactive free radicals to intensify certain chemical reactions (Wang et al., 2022). As regards industrial processes, assessing the heat exchanges occurring as two fluid constituents are mixed together is a most common requirement, whatever the quantities to be considered (Mhammedi et al., 2019).

However, various chemical and physical processes can be strengthened by utilizing the high temperature and pressure liquid environment generated by cavitation bubble collapse, which makes it possible to apply hydrodynamic cavitation to water treatment(Song et al., 2022). Using an effective and economic hydrodynamic cavitation reactor can increase the quality of water treatment and the commonly used hydrodynamic cavitation reactor include the venturi tube cavitation reactor, orifice plate hydrodynamic cavitation reactor and rotor hydrodynamic cavitation reactor (Wang et al., 2021).

The method of alternating impulses of pressure is one of the methods of controlled energy impact with many hydrodynamic effects, such as power of pressure of shift, cavitations, the effect of explosive boiling, collective effects in assembly of vials, crossness of an interphase surface in gas-liquid bubbly medium, action of hydrodynamic oscillations, alternating impulses of pressure, effects which associated with acceleration of movement of a continuous phase. During the last values cavitation and adiabatic boiling can be present (Li et al., 2018).

The most important effects of the alternating impulses of pressure are allied with increase of velocity of association of a continuous phase of medium. Three-dimensional and period concentration of energy gives the possibility to receive the big capacity of pulsation power accomplishment, to release internal energy of substance, to create active energetic processes which take place at microlevel and also at nanolevel (Shurchkova et al., 2015).

To intensify mixing of water and another component such as ethanol or fertilizers it is necessary to use rotary-pulsed apparatus. High energy transitional hydro-mechanical influence on liquid media and solutions in rotary pulsed apparatus conducts to transformation of structural formation and in the same time there is no intensive destruction of macromolecules and associates.

To optimize the process of hydrodynamic treatment it is necessary to define the level of power influence on the liquid media and solutions for indispensable transformations which

can provide predictable physical and chemical parameters. Thus, the numerical and mathematical modeling of the hydrodynamic conditions in the rotary-pulsed apparatus is relevant and needs further study.

The aim of this study is to investigate the influence of the application of alternating impulses of pressure throughout treatment of liquid solutions by the numerical modelling.

Materials and methods

Materials

Liquid solutions and systems: water, alcohol, water-alcoholic solutions and mixtures in a wide range of concentration, percentage of alcohol in mixtures was varied from 5 to 90%, double distilled water, hydroponic, hydroponic with fertilizers were used for experiments.

Methods

The volume parametric imitation and visualization, modelling methods OF numerical simulation of the flow dynamics based on the Navier-Stokes equations, math modeling methods on RNG k-ε model of turbulence were used for the description of the conditions at the working parts of the rotary-pulsed apparatus during the liquid treatment.

Experimental installation

The experimental investigation was carrying out on the investigational unit on Figure 1.

The main device of this unit is rotary-pulsed apparatus. That's why the object of this scientific investigation study was rotary-pulsed apparatus in which liquid solutions of different types were processed by alternating impulses of pressure and were powered by hydrodynamic effects such as the speeds of shift of a stream, pressures of shift of a stream.

The work of the experimental unit is carried out as follows. At first liquids: associated liquid aqueous systems, water solutions, media are inflowing at the tank for liquid 1. After that through the flowmeter 3 liquid aqueous systems and solutions follows into the chamber of rotary-pulsed apparatus 8 for the processing by alternating impulses of pressure. From the tank 2 for another liquids such as alcohol or nutrients, or fertilizers are inflowing through the flowmeter 3 and follows into the chamber of rotary-pulsed apparatus 8. In the chamber of rotary-pulsed apparatus 8 instant mixing occurs by the alternating impulses of pressure in the hydrodynamic conditions.

There are two ways of the processing. The first way is in continuous uninterrupted mode at once and the second way is in recirculation mode after instant mixing by alternating impulses of pressure in the chamber of rotary-pulsed apparatus 8 in the hydrodynamic conditions with specific variable duration period of processing.

After mixing liquid solutions and mixtures follows into tank of treatment liquids 10 through the valve 9.

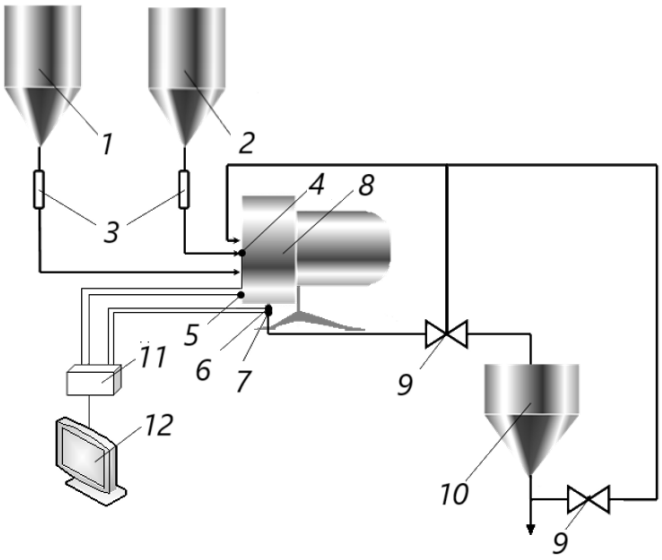

Figure 1. Scheme of experimental unit:
1 – tank for alcohol; 2 – tank for water; 3 – flow meters; 4 – thermocouple;
5 – pressure transducer; 6 – thermocouple; 7 – pressure transducer;
8 – rotary-pulsed apparatus; 9 – valve; 10 – tank for water-alcohol mixture;
11 – analog-to-digital converter; 12 – personal computer.

During the experimental investigation a number of parameters are controlled: temperature by the thermocouple 4 and 6, pressure by pressure transducer 5 and 7. Other parameters are controlled by analogue-digital transmitter 11 and results transmitted on personal computer 12. The construction of rotary-pulsed apparatus was the cylindrical type with the working chamber. The subsequently positions in working volume between coaxial cylinders of the «rotor-stator-rotor» system were selected (Fig. 2) (Dubovkina, 2017).

Figure 2. Working chamber of rotary pulsed apparatus
1 – external rotor; 2 – stator; 3 – internal rotor

Important technical parameter such as speed of shift of a stream was recognized for treatment of liquid solutions with the appliance of the alternating impulses of pressure (Dubovkina et al., 2019).

By the consequences of the computation was established that the principal values of speeds of shift of a stream emerge in RPA with coaxial clearances between first rotors, stator and second rotor 100×10^{-6} m. For circulation out of processes of treatment liquid solutions and mixing provided in to processing in uninterrupted mode during special time and exceptional hydrodynamic conditions which can realize during the alternating impulses of pressure.

The duration of treatment varied from 0.5 s to 300 s. This time was found by the mathematical calculating and volume parametric imitation modeling and was applied in nature experimental investigations.

Throughout the treatment in uninterrupted mode was used instantaneous depressurization in a working volume. The recovering of the parameters to the atmosphere pressure was spent by two ways. The first way was recovering to primary pressure during 30 s. The second way was recovering to primary pressure instantly.

Results and discussion

Numerical simulation model

The lowest energy costs in the implementation of energy impact are characterized by the pulsating form of implementation and implementation – the principle of discreteness. Today, a significant number of impacts are implemented only in the pulsating form.

The rotary pulsation apparatus is designed for structural transformations of liquids at the micro- and nano- levels in order to change their physicochemical parameters intensify mass exchange and hydromechanical processes. In RPA, the conversion of low-concentration energy into high-local-concentration energy at unstable points of the substance structure is carried out. Its well-known that the cavitation reactor consists of rotor, stator and casing. There are a number of blind holes on the stator and rotor (Song et al., 2022).

The numerical simulation and visualization was employed for hydrodynamic computation of the treatment and mixing processes in working volume (chamber) of the rotary pulsed apparatus (RPA). For the choice of numerical model of fluid flow in the «rotor-stator-rotor» system of the RPA, it was suggested that the current in the prevailing case is two-dimensional. The heterogeneous stream was considered to be a homogeneous medium with the effective thermophysical properties.

To consider the dynamics difficulty, the horizontal section of the working parts of the RPA, perpendicular to the axis of the «rotor-stator-rotor» system, was selected. This section has slits on the surfaces of the first rotor, stator and second rotor. Also this section consists of the left and right parts of the rotors.

$$\frac{1}{R}\frac{\partial(RV)}{\partial R}+\frac{\partial \Omega}{\partial \theta}=0 \tag{1}$$

$$\frac{\partial V}{\partial H}+\frac{1}{R}\frac{\partial (RV^2)}{\partial R}+\frac{\partial (V\Omega)}{\partial \theta}-\Omega^2 R=-\frac{\partial P}{\partial R}+\frac{2}{\mathrm{Re}R}\frac{\partial}{\partial R}\left(R\beta\frac{\partial V}{\partial R}\right)-$$
$$-\frac{2}{\mathrm{Re}R}\beta\left(\frac{\partial \Omega}{\partial \theta}+\frac{V}{R}\right)+\frac{1}{\mathrm{Re}R^2}\frac{\partial}{\partial \theta}\left(\beta\frac{\partial V}{\partial \theta}\right)+\frac{1}{\mathrm{Re}}\frac{\partial}{\partial \theta}\left(\beta\frac{\partial \Omega}{\partial R}\right) \quad (2)$$

$$\frac{\partial \Omega}{\partial H}+\frac{1}{R^2}\frac{\partial (R^2\Omega V)}{\partial R}+\frac{\partial \Omega^2}{\partial \theta}+\frac{\Omega V}{R}=$$
$$\frac{1}{R^2}\frac{\partial}{\partial \theta}\left[-P+\frac{2}{\mathrm{Re}}\beta\left(\frac{\partial \Omega}{\partial \theta}+\frac{V}{R}\right)\right]+ \quad (3)$$
$$\frac{1}{\mathrm{Re}R^3}\frac{\partial}{\partial R}\left[R\beta\left(R^2\frac{\partial \Omega}{\partial R}+\frac{\partial V}{\partial \theta}\right)\right]$$

$$\frac{\partial \vartheta}{\partial H}+\frac{1}{R}\frac{\partial (R\vartheta V)}{\partial R}+\frac{\partial \vartheta \Omega}{\partial \theta}=$$
$$\frac{1}{\mathrm{RePr}}\left[\frac{1}{R}\frac{\partial}{\partial R}\left(\Lambda R\frac{\partial \vartheta}{\partial R}\right)+\frac{1}{R^2}\frac{\partial}{\partial \theta}\left(\Lambda\frac{\partial \vartheta}{\partial \theta}\right)\right]+\beta S^2 \quad (4)$$

$$\overline{S}=\left[2\left(\frac{\partial V}{\partial R}\right)^2+2\left(\frac{\partial \Omega}{\partial \theta}+\frac{V}{R}\right)^2+\left(\frac{1}{R}\frac{\partial V}{\partial \theta}+R\frac{\partial \Omega}{\partial R}\right)^2\right]^{0.5} \quad (5)$$

The adduction to the dimensionless form of the equation system made by the changing. Where standard values were calculating:

$$V=\frac{v_r}{\omega_0 r_0};\quad \Omega=\frac{\omega}{\omega_0};\ R=\frac{r}{r_0};\ H=\tau\omega_0;$$

$$P=\frac{(p-p_0)}{(\rho\omega_0 2r_0^2)};\qquad \vartheta=\frac{(T-T_0)\rho Cp}{(\omega_0\mu_0)};\qquad \mathrm{Re}=\frac{\rho\omega_0\times r_0^2}{\mu_0};\quad \mathrm{Pr}=\frac{c_p\mu_0}{\lambda_0};$$

p_o – the pressure of the medium behind the working chamber of the rotary-pulsed apparatus;

T_o – the temperature of the medium behind the working chamber of the rotary pulsed apparatus;

$\omega=\frac{\vartheta}{r}$ – angular velocity;

ω_0 – angular velocity of the rotor spinning;

r_0 – radius of the internal surface of the internal stator;

$\beta=\frac{\mu_{ef}}{\mu_0}$; $\Lambda=\frac{\lambda_{ef}}{\lambda_0}$; μ_{ef} – effective values of the viscosity coefficient;

λ_{ef} – effective values of the coefficient of thermal conductivity;

μ_0 – conditional scale of the viscosity coefficient;

λ_0 – conditional scale of the coefficient of thermal conductivity.

Since rotary-pulsating apparatuses belong to periodic devices, it is necessary to recompense attention to the fact that there is a geometrical periodicity of the design of the «rotor-stator-rotor» system of working volume. The periodic relative motion of rotor and stator leads to a periodic close and leave process between grooves, which results in periodic cavitation (Sun et al., 2021).

In this connection, the frequency of changes in the dynamic characteristics of the fluid flow through the working area of the RPA is observed.

When the RPA mode is set, the movement of the fluid is repeated after rotating the rotors at a periodic angle $\Delta\theta$.

To solve this assigned problem, a certain segment was selected that periodically repeats the angle $\Delta\theta$.

The segment contained a fragment of the «rotor-stator-rotor» system with a slits on the surfaces of the rotors and stator also clearance between these working elements of the system.

The pressure difference between the input and the output liquid solutions at the working volume before and after treatment is $\Delta P = 50 \cdot 10^3$ Pa.

Geometric sizes of working elements were set according to constructional and design dimensions of RPA.

The frequency of rotation of the rotor was given $n = 60$ sec^{-1}. In the calculation it was considered that the flow regime of the liquid in the RPA is turbulent, so for this case RNG k-ε model of turbulence was chosen.

The system of equations was reduced to dimensionless form:

$$\frac{\partial K}{\partial H}+\frac{1}{R}\frac{\partial(RVK)}{\partial R}+\frac{\partial(\Omega K)}{\partial\theta}=\frac{1}{\mathrm{Re}}\left[\frac{1}{R}\frac{\partial}{\partial R}\left(\frac{R\varsigma}{\sigma_K}\frac{\partial K}{\partial R}\right)+\frac{1}{R^2}\frac{\partial}{\partial\theta}\left(\frac{\varsigma}{\sigma_K}\frac{\partial K}{\partial\theta}\right)\right]+\frac{\bar{S}^2}{\mathrm{Re}}\varsigma-E$$

$$\frac{\partial E}{\partial H}+\frac{1}{R}\frac{\partial(RVE)}{\partial R}+\frac{\partial(\Omega E)}{\partial\theta}=\frac{1}{\mathrm{Re}}\left[\frac{1}{R}\frac{\partial}{\partial R}\left(\frac{R\varsigma}{\sigma_K}\frac{\partial E}{\partial R}\right)+\frac{1}{R^2}\frac{\partial}{\partial\theta}\left(\frac{\varsigma}{\sigma_K}\frac{\partial E}{\partial\theta}\right)\right]+$$

$$\left[C_1-\frac{\eta_\varepsilon}{1+\beta_\varepsilon\eta_\varepsilon}\left(1-\frac{\eta_\varepsilon}{\eta_{\varepsilon_0}}\right)\right]\frac{\bar{S}^2}{\mathrm{Re}}\varsigma\frac{E}{K}-C_2\frac{E^2}{K}$$

Where were used for calculating:

$$\xi=\frac{\nu_1}{\nu}=C_\mu\,\mathrm{Re}\frac{K^2}{E};\quad \varsigma=\frac{\mu_{ef}}{\mu};\quad K=\frac{k}{(\omega_0 r_0)^2};$$

$$E=\frac{\varepsilon}{(\omega_0^3 r_0^2)^2};\quad \eta_\varepsilon=\frac{K\bar{S}}{E}$$

The constants for this model were taken in accordance with (Basok et al., 2002) and were:

$$C_\mu = 0.0847;\ C_1 = 1.42;\ \beta_\varepsilon = 0.012;\ \eta_\varepsilon = 4.38$$

Number σ_k was determined from the equation:

$$\left|\frac{\sigma_k^{-1}-1.3929}{0.3929}\right|^{0.632}\left|\frac{\sigma_k^{-1}+2.3929}{3.3929}\right|^{0.3679}=\frac{\nu}{\nu_1}$$

Number σ_1 was taken equal to σ_k. The turbulent Prandtl number for the energy equation was also calculated from the equation:

$$\left|\frac{\sigma_0^{-1}-1.3929}{\sigma^{-1}-1.3929}\right|^{0.632}\left|\frac{\sigma_0^{-1}+2.3929}{\sigma^{-1}+2.3929}\right|^{0.3679}=\frac{\nu}{\nu_1}$$

and was solved in conjunction with (1)–(5) using numerical methods.

The investigation of the structure of the stream, and the vortical nature of the fluid movement, was performed by numerical simulation of the flow dynamics based on the Navier-Stokes equations. The main factors of the flow structure is determined by the fields of pressures, speeds, accelerations (Nakorchevskii et al., 2002) .

The changes of the pressure in different points of the working volume have complicated pulsating character. For the numerical simulation were selected different positions of the «rotor-stator-rotor» system of working chamber.

It was selected for calculations the next points: on the external surface of the internal rotor, on the external stator surface, on the inner stator surface, on the inner surface of the external rotor.

The subsequently positions in working volume between coaxial cylinders of the «rotor-stator-rotor» system were selected: open slit; half closed slit; half open slit; closed slit.

Investigation of velocity

By the volume three-dimensional parametric imitation visualization modelling processes, mathematical and numerical modelling was found that the value of the linear speeds of a stream should be from 21.98 m/s to 22.13 m/s for the first rotor and from 23.58 m/s to 23.70 m/s for the second rotor in Table 1.

According to the calculation results, it was found that the largest shear stresses occur in the RPA with annular coaxial clearances of 100 μm. The flow shear rate acquires the greatest value at annular coaxial clearances of 100 μm too.

Investigation of alternating impulses of pressure

For the processing of liquid media, namely for the processing of water and the process of mixing water and alcohol (ethanol) in the hydrodynamic conditions by influence of alternating impulses of pressure, an important geometrical parameters. When conducting a numerical experiment, the design and geometric parameters of the rotary-pulsed apparatus, which are given in Table 1, were occupied into account.

The pressure fields that arise when the components are separately passed into the working zone of the RPA for mixing were calculated.

The pressure change in different areas of the working volume shown on Figures 3 and 4.

It has a complex pulsating character. By the numerical calculation were visualizated pressure fields in the rotary-pulsed apparatus during the passing components (water and ethanol) into the working area of the chamber.

The study of the flow structure and the vortex nature of fluid motion was performed using numerical modelling of flow dynamics based on the Navier-Stokes equations.

Table 1

Technical parameters of rotary-pulsed apparatus

Technical parameter, dimension	Frequency of hydrodynamic oscillations, kHz	Angular velocity, s^{-1}	Linear velocity, m/s		Shear rate, 10^5 s^{-1}		Shear stress, Pa		Coaxial clearance , μm
No			Rotor 1	Rotor 2	Rotor 1	Rotor 2	Rotor 1	Rotor 2	
1	3	314	21.98	23.58	2.2	2.4	219.8	235.5	100
2	3	314	22.02	23.60	1.5	1.6	146.8	157.3	150
3	3	314	22.04	23.61	1.1	1.2	110.2	118.5	200
4	3	314	22.05	23.62	0.88	0.94	88.20	94.48	250
5	3	314	22.07	23.64	0.73	0.79	73.57	78.80	300
6	3	314	22.09	23.66	0.63	0.68	63.11	67.60	350
7	3	314	22.10	23.68	0.55	0.59	55.25	59.2	400
8	3	314	22.12	23.69	0.49	0.53	49.15	52.64	450
9	3	314	22.13	23.70	0.44	0.47	44.26	47.4	500

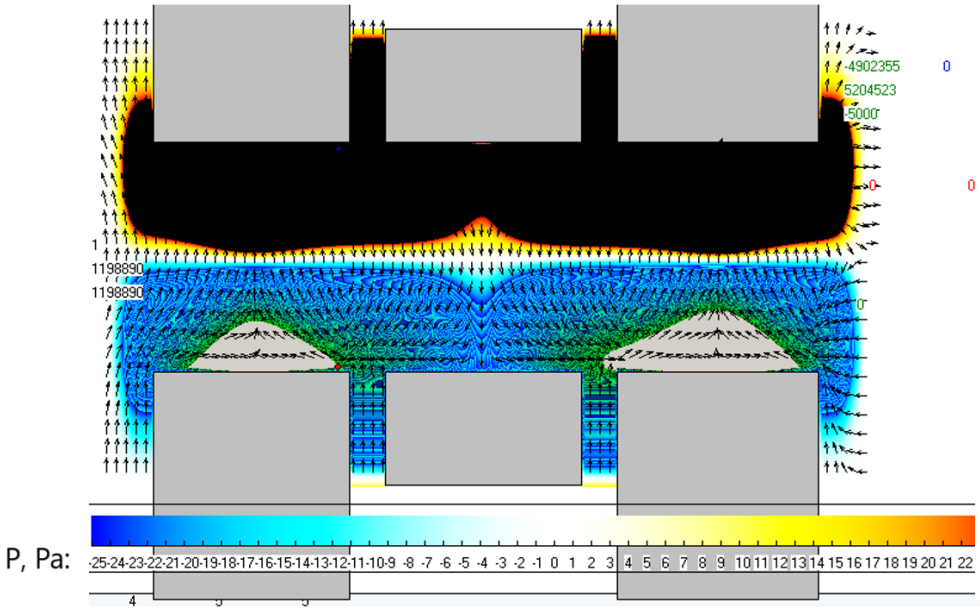

Figure 3. Pressure fields with an open channel in the system rotor-stator-rotor

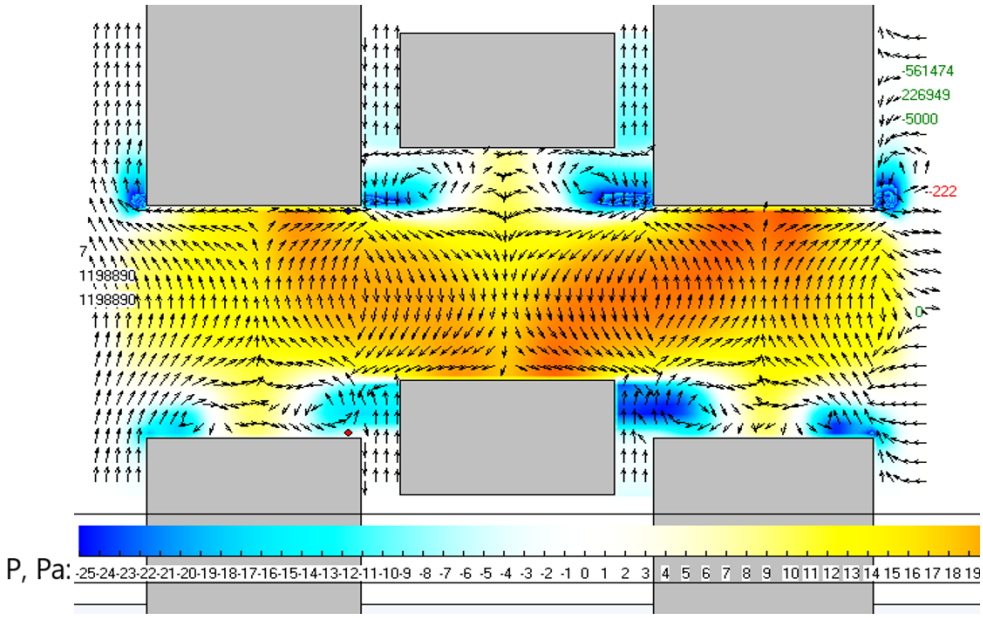

Figure 4. Pressure fields at half-closed channel in the rotor-stator-rotor system

During the research, the nature of the movement of water-alcohol mixtures was studied, so water and ethanol enter the working zone of the RPA with a pressure of P_0. Then a complex rotational-reciprocal motion is carried out under the action of a pressure drop $\Delta P = 50$ kPa, while water and ethanol instantly mix Figure 5 and 6.

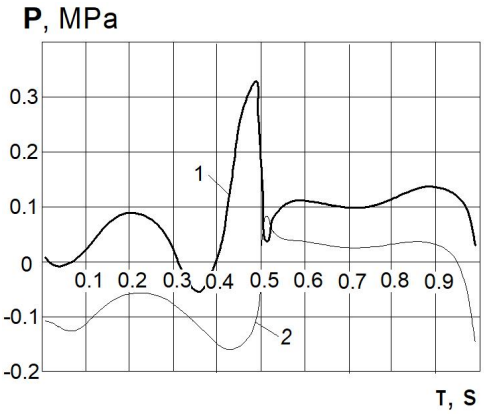

Figure 5. Pressure change at points:
1 – near outer surface of the inner rotor;
2 – near outer surface of the stator;

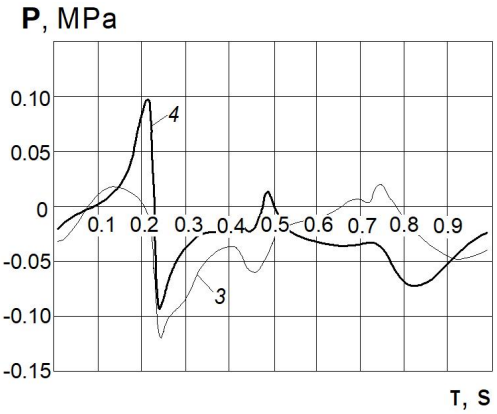

Figure 6. Pressure change at points:
3 – near inner surface of the stator;
4 – near inner surface of the outer rotor.

The local pressure values in the zone of water and alcohol inlet and water-alcohol mixture outlet from the clearance change:

– near the outer surface of the inner rotor from -50·10^3 Pa to +300 ·10^3 Pa;
– near the outer surface of the stator from -150·10^3 Pa to 100·10^3 Pa;
– near the inner surface of the stator from +40·10^3 Pa to -120·10^3 Pa;
– near the inner surface of the outer rotor from + 100·10^3 Pa to -100·10^3 Pa.

The latter values determine the zone in which cavitation and adiabatic boiling can occur under certain conditions.

According to the results of the analysis of the obtained calculations, it was established that the reduction of the clearances between the outer and inner rotors and the stator leads to an increase in the depth of the negative pressure impulse, which contributes to the intensification of the instant mixing process, excluding the contact of the components before they enter the working zone of the RPA, intensification of masstransfer, which in turn affects the speed of the hydration process, structure formation and association.

In addition, the value of the average mass radial velocity of the liquid in the inlet section in front of the inner rotor Figure 7 and its change depending on time were determined.

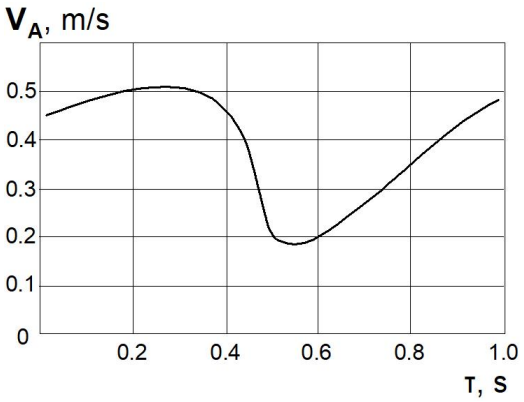

Figure 7. Change in the average velocity of fluid movement over time in entrance intersection

The radial motion of the fluid is provided by the external pressure drop ΔP = 50 ·10^3 Pa and the centrifugal force caused by the rotating motion of the fluid. As a result, a radial velocity is established that is periodic in time and averaged over the inlet cross section. It should be noted that the fluid flow in the RPA has a pulsating nature of movement; within one period the speed reaches 0.52 m/s and sharply decreases to the minimum value of 0.18 m/s.

At a molecular scale, molecular dynamic simulation is an appropriate tool for analyzing these static and dynamic properties (Obeidat et al., 2018).

At the moment when the speed decreases, there is a sharp braking of the liquid flow, thus pressure impulses appear in the zones before and after the stator intersection, which are caused by the inertia forces of the masses of the water-alcohol mixture.

According to the results of the research, it was found that the alternating pressure pulses in the system are ΔP = 370· 10^{3}Pa near the outer surface of the inner rotor; ΔP = 240·10^3 Pa near the outer surface of the stator; ΔP = 155·10^3 Pa near the inner surface of the stator; ΔP = 190·10^3 Pa near the inner surface of the outer rotor.

Conclusions

A numerical calculation was accomplished to determine the hydrodynamic parameters of equipment that implements the basic mechanisms and concept of the alternating impulses of pressure, that realize in rotary-pulsed apparatus for the processing of water and ethanol-containing products. It was established that the flow shear rates, flow shear stresses, high-frequency oscillations, and alternating impulses of pressure reach their greatest values at technological clearance between of coaxial working elements (cylinders) "rotor-stator-rotor" of 100 μm.

It was established that reducing the technological clearance leads to an intensification of hydrodynamic parameters, in turn; the design of clearance less than 100 microns is technologically complicated and requires special equipment, which is economically inexpedient due to the increased cost of manufacturing the equipment.

Based on a numerical experiment, the feasibility of using equipment that implements the basic principles and mechanisms of discrete-pulse input of energy, namely processing using alternating impulses of pressure, flow shear stresses, and flow shear velocities, has been substantiated and proven. It is gives the possibility to intensification of mixing processes.

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Dependence of flour yield on moisture content of chickpea seeds

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Abstract

Introduction. The aim of the study was to determine the effect of chickpea seed moisture on the yield of flour (sieve mesh size 132 μm) obtained in hammer and roller mills.

Materials and methods. Primary crushing of chickpea seeds was performed in a hammer mill with a sieve hole diameter of 4 mm and a hammer rotation speed of 80 m/s. Chickpea seeds were crushed in a roller mill using corrugated and smooth rollers with three crushing and grinding systems. After each system, the flour was separated and the flour yield was determined in relation to the initial weight of the seeds.

Results and discussion. Grinding dry chickpea seeds with 8.9% moisture content in a hammer mill yielded 10.5% flour. Increasing the chickpea moisture content to 11.6% increased the flour yield to 11.9%. Further increasing the chickpea moisture content decreased the flour yield (132 μm sieve pass). The optimum moisture content was 11.5%. The highest flour yield was 12.0% with a moisture content of 11.5%. The total flour yield from chickpea seeds crushed in a roller mill was only 50.6% (sieve pass 132 μm).

The flour yield on 2- and 3- crushing systems was only 1.0% and 1.2%, respectively. This means that these break systems with corrugated rollers are not practical to use due to the low flour yield.

To obtain a higher yield of chickpea flour, it is necessary to increase the number of milling systems. It was not possible to completely grind the chickpea kernel and achieve the maximum possible flour yield from the kernel due to the insufficient length of the roller installation line (3- crushing systems).

Analysis of the cumulative flour whiteness curve shows that with increasing flour yield, its whiteness decreases from 39.8 to 27.0 units. It indicates that the flour quality decreases with increasing flour yield.

Conclusion. For intermediate crushing of chickpea seeds with subsequent crushing on smooth rollers, one crushing system is sufficient. For more complete crushing of chickpea seeds, it is necessary to increase the number of crushing systems.

Introduction

Chickpeas (*Cicer arietinum* L.) are the second most popular legume in the world after beans. Chemical composition of chickpea includes, % of dry matter (DM): crude protein, 22.76-24.63; crude fiber, 6.49-9.94; nonfibrous carbohydrate, 46.81-49.13; starch, 38.48-39.12; soluble sugars, 7.53-8.43; total phenolic compounds, 0.26-0.27 (Maheri-Sis et al., 2008; Rachwa-Rosiak et al., 2015). Content of lipids in chickpeas varies from 3.10 to 5.67% DM containing mostly unsaturated fatty acids linoleic and oleic acids (Grasso et al., 2022). Chickpeas also contain minerals (potassium, phosphorus, calcium, magnesium, iron, and zinc) (Jukanti et al., 2012) and water- soluble vitamins such as vitamin C, riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), and folic acid (B9). Fat-soluble vitamin A and vitamin E (α-and γ tocopherols) as well as vitamin K are reported to be present in chickpeas (Noordraven et al., 2021; Wang et al., 2021). Chickpeas have been found to have a variety of beneficial properties including antidiabetic, anticancer, antihypertensive and antioxidant activities (Li et al., 2024; Begum et al., 2023). Flour produced from chickpeas is a valuable product being used in preparation of different functional food (Augustin et al., 2024; Buresova et al., 2017; Goranova et al., 2020; Noordraven et al., 2021; Stabnikova et al., 2021).

The technology of grinding chickpea seeds is of great importance when processing them into flour (Figure 1).

Figure 1. Chickpea seeds and flour

One of the indicators of the efficiency of the grinding process is the total yield of flour, and it is important for assessing the use of the potential of the processed grain (Martin et al., 2022). In the production of flour, the initial task is to separate the chickpea seeds from the husk. It has been shown that the husk can be easily separated from the kernel after soaking the chickpea seeds (Martin et al., 2022). The separated chickpea seeds can be easily processed into fine flour. However, it is not known what length of roller mill is required to completely grind the chickpea kernels into fine flour and obtain a particle size of less than 132 μm (Martin et al., 2022). The sieve size of 132 μm is taken by analogy with the production of premium wheat flour, which is also obtained by passing through sieves with openings of this size (Finnie and Atwell, 2016).

Shutenko et al. (2014) studied the process structures of chickpea seed grinding into the roller mills with corrugated rollers. They proposed to grind whole chickpea seeds and cracked chickpea into grist (particle size range from 1000 μm to 219 μm) with the aim the next grinding this grist into flour. It was noted that it is possible to obtain 83-84 % of grist and only 15-16 % flour (sieve passage with 219 μm openings). This research does not answer the question of what maximum flour yield from chickpea seeds can be reach in general. The proposed methods of chickpea grinding are only part of the initial stage of grinding.

Martin et al. (2022) conducted a study on milling whole and cracked chickpea seeds into flour using a pilot scale facility that consisted of roller mills, cleaners, and plansifters. Two types of chickpea flour were obtained. The first type was the coarse flour with the particle size between 315 μm and 150 μm. The second type was a fine flour with the particle size below 150 μm. The yield of coarse flour ranged from 54.07 to 63.8%. The yield of fine flour ranged from 16.03 to 23.9%. The total flour yield ranged from 70.1 to 87.7% depending on the chickpea variety.

A specific feature of these studies was the use of purifiers in the chickpea seed grinding process, which made it possible to significantly influence the efficiency of chickpea seed grinding. Martin et al. (2022) noted that chickpea seed moisture of 11.0 % was optimal for separation of the hull. In their studies, chickpea seeds had a moisture content of 10.9 %, for this reason they did not moisten the seeds. The researchers did not study the effect of moisture on grinding efficiency. However, humidification of chickpea seeds can have a very different effect on milling efficiency. When moisture penetrates the grain, the water creates stresses that weaken the bonds between protein compounds and starch (Pasha et al., 2010). Martin et al. (2022) also emphasized that the hulls are obtained after milling and did not consider the possibility of separating the hulls before milling.

Tikle and Mishra (2018) investigated the characteristics of different chickpea varieties and showed that the *dal* yield ranged from 66 to 71%. The biggest limitation of their study is the lack of sieve characteristics that would give an indication of the particle size of the milled product.

Thus, the effect of chickpea seed moisture on the fine grinding yield remains unexplored. An important issue is the effect of pre-grinding of chickpea seeds on the fine milling process. The aim of the present study was to determine the effect of moisture content on the flour yield from chickpea seeds and the efficiency of grinding chickpea seeds into flour using pre-grinding in a hammer mill and roller milling.

Materials and methods

Materials

Chickpea seeds were used with the following quality characteristics: bulk density, 789±2.5 g/l; original seed moisture content, 8.9±0.19 %; mass of 1000 seeds, 402±1.6 g.

Methods

Chickpea seeds were ground in two stages. Chickpea flour yield after grinding in the hammer mill was explored on the first stage at seed moisture content was changing. In the second stage the pre-ground products were ground in the roller facility. The need to grind chickpea seeds in a hammer mill is due to the fact that large seeds are not captured by the rollers. The whole seeds require destruction into smaller particles for further grinding by the rollers.

Grinding chickpeas in hammer mill

The study of the effect of chickpea seed moisture on the yield of flour during grinding in a hammer mill was carried out using the following method. Dry chickpea seeds of weight 400 g were poured into four containers and the calculated amount of water was added to the seeds. Seeds were tempered for 24 hours at room temperature.

The required chickpea moisture content was taken at 11.0, 13.0, 15.0 and 16.0%. 300 g chickpea seeds were taken from each containers after the tempering in order to grind in the hammer mill. The remaining seeds were used to determine their moisture content. The actual moisture content was determined according to ISO 712:2009 (E). "Cereals and cereal products. Determination of moisture content" (ISO, 2009). The moistening was performed with water at room temperature.

Water amount, which was added to chickpea seeds calculated by following equation (Kharchenko et al., 2022):

$$G_w = G_g \left(\frac{W_1 - W_0}{100 - W_1} \right), \quad (1)$$

where G_w, G_g –water weight and dry chickpea seed weight respectively, g; W_0, W_1 –initial and required moisture content of chickpea seeds respectively, %.

Grinding was performed by the hammer mill with the screen that had the diameter of openings of 4.0 mm. The hammer mill had a vertical situated motor. The cross-shaped hammers were fixed to the shaft of the motor. Rotate speed of hammer edges was ≈ 80 m/s (Figure 2).

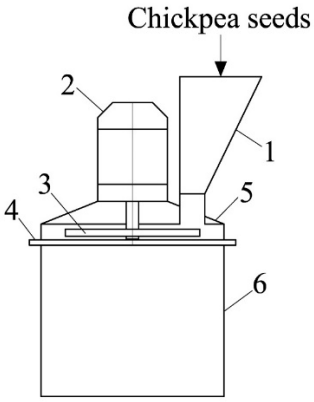

Figure 2. **Laboratory hammer mill**:
1 – grain hopper; 2 – motor; 3 – hammer; 4 – screen;
5 – hammer body; 6 – hopper for grinded products

After optimal moisture content was defined, chickpea seeds were moistened and ground by the hammermill. The ground products were directed to roller facility LM-2.

The ground product was sifted by the lab sieve kit according to the method, which described by the paper (Kharchenko et al., 2021). Particles of ground product, which passed through the 132 μm sieve were attributed to fine flour.

Chickpea seeds milling by roller facility

Chickpea seeds milling by the roller facility LM-2 (Elelmiszeripari Gepgyar, Budapest, Hungry) (Ulmer, 2014) was performed using the next method. Chickpea seeds with weight of 2.1 kg were moistened to moisture content of 11.5 % with next tempering for 24 hours. Water amount was calculated using equation 1. Moistened chickpea seeds were ground by the hammer mill with the screen, which had a diameter of openings of 4.0 mm. Fine flour was obtained through a sieve passage of 132 μm. The products remaining on the sieve were directed to the receiving hopper of the roller facility LM-2. The research flow sheet shown in Figure 3.

All ground products were collected to the individual containers during milling. All collected products were weighed and calculated into percentages. A distance between I break rollers was 0.4 mm, II break rollers – 0.25 mm, and III break rollers – 0.1 mm. The distance between reduced system rollers was established as the smallest of 0.05 mm. The distances were established by the manual tare probe.

After flow yield was established in the individual flows the flour whiteness was conducted by the VBB-1MK device (Motom, Lviv, Ukraine). The cumulative flour whiteness curve was calculated based on the output values of the obtained streams and their whiteness using the formula (Sakhare and Inamdar, 2014):

$$\bar{W} = \frac{\sum_{i=1}^{N}\left(Y_i \times W_i\right)}{\sum_{i=1}^{N} Y_i} \tag{2}$$

where Y_i, W_i are flour yield value (in %) and whiteness of each flour flow (units), respectively.

Statistical analysis

The weighted average particle size of the ground seeds is a characteristic of the grinding efficiency. The weighted average particle size d_k of all ground product was calculated by follow equation (Brandt, 2014):

$$d_k = \frac{m_1 d_1 + m_2 d_2 + \ldots + m_i d_i}{m_1 + m_2 + \ldots + m_i} \tag{3}$$

where m_1, m_2, m_i are productamount of each fraction, %; d_1, d_2, d_i are average particle size of each fraction, which was defined as half the sum of the sizes of the sieve openings, μm, respectively.

Scattering measure of ground product particle size is standard deviation S, which was calculated by follow equation (Chornyi et al., 2021):

$$S = \pm \sqrt{\frac{\sum_{i=1}^{n} m_i x_i^2}{\sum_{i=1}^{n} m_i} - \left| -\frac{\sum_{i=1}^{n} \bar{m}_i \bar{x}_i}{\sum_{i=1}^{n} m_i} \right|} \tag{4}$$

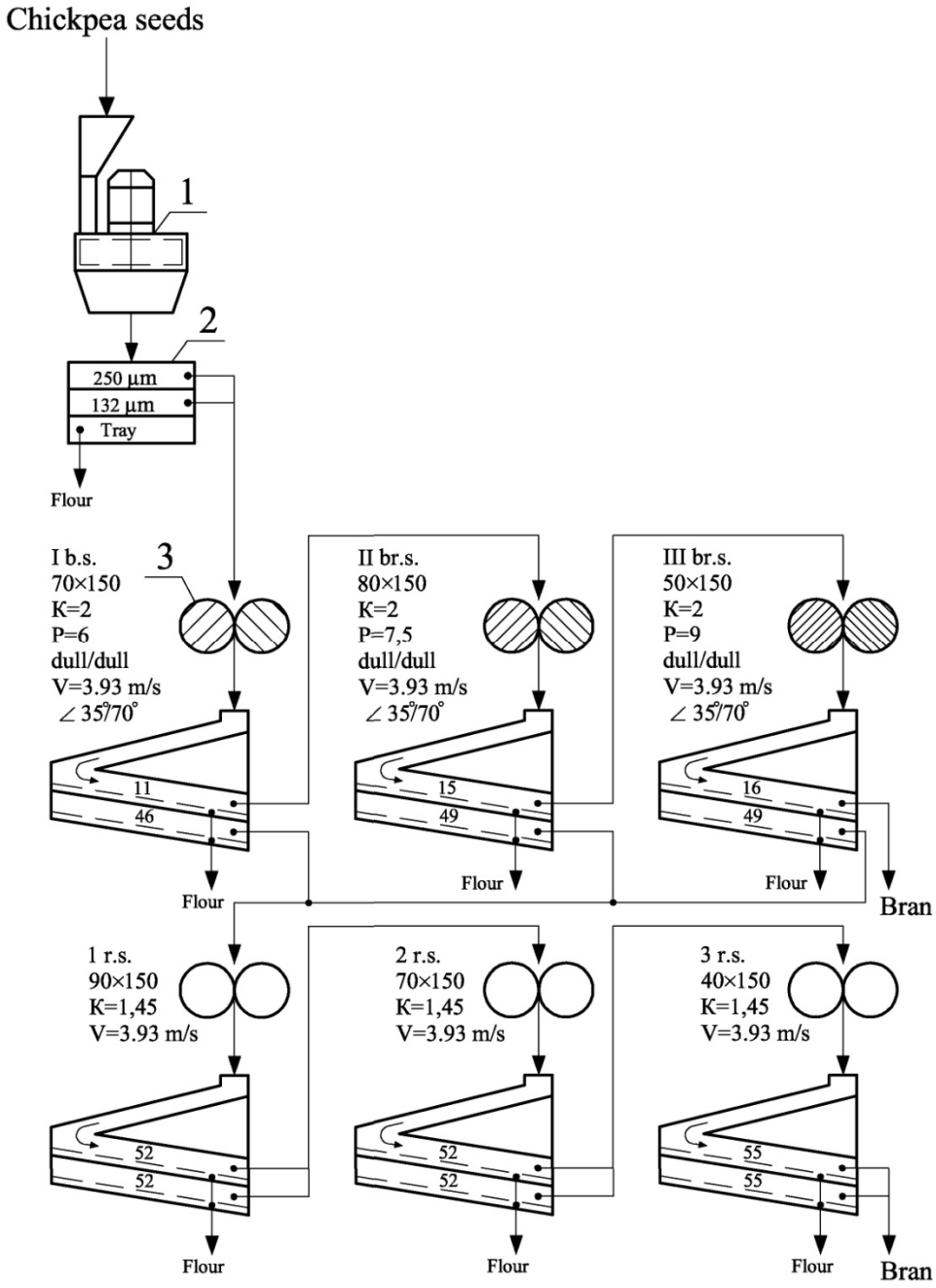

Figure 3. Flow sheet of chickpea seed milling
1 – hammermill with screen of diameter 4.0 mm; 2 – laboratory sieve kit; 3 – laboratory mill

Results and discussion

Chickpea seed milling of hammer mill

Research has shown that dry chickpea seeds are ground by the hammer mill with a low flour yield. Most ground products with particle size up to 1000 μm have a yield of less than 10 %.

Analysis of flour yield during grinding in the hammer mill (Figure 4) showed that with an increase in chickpea seed moisture content from 8.9 % to 11.0 %, flour yield increases. An increase in chickpea seed moisture content to 15.8 % leads to a decrease in flour yield. This indicates that there is an extremum point at which flour yield is the highest.

Research of flour yield (sieve passage 132 μm) confirmed the hypothesis of the presence of an extremum point at different moisture content (Figure 4).

The parabola shown in Figure 4 is approximated by a second-order equation:

$$B = -0.213W^2 + 4.907W - 16.183 \quad (5)$$

where B is flour yield (sieve passage 132 μm), %; W is chickpea seed moisture content, %.

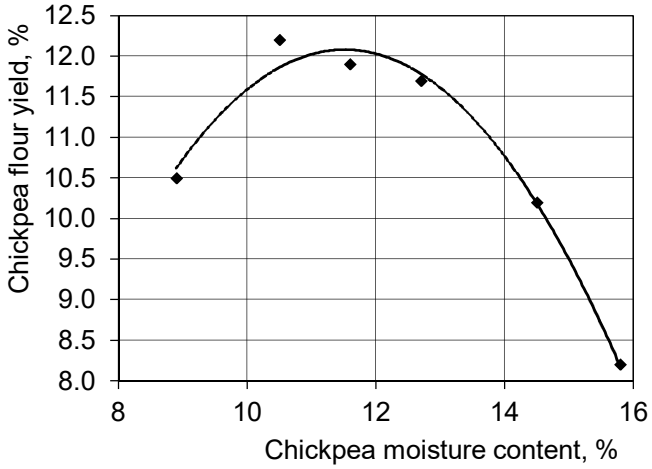

Figure 4. Effect of chickpea moisture content on flour yield

The correlation coefficient was R = 0.991, that indicates a special high relation between the studied values.

It is of practical interest to determine the chickpea moisture content when the flour yield is the highest. To find the extremum point, differentiate equation 5 and set it equal to zero:

$$\frac{dB}{dW} = -2 \cdot 0,213W + 4.907 = -0.426W + 4.907$$

$$-0.426W + 4.907 = 0$$

$$-0.426W = -4.907$$

$$W = \frac{4.907}{0.426} = 11.5 \ \%$$

where B is flour yield (sieve passage 132 μm), %; W is chickpea seed moisture content, %.

Mathematical analysis showed that the optimal moisture content at which the highest yield of flour from chickpea seeds is W = 11.5 % at a screen opening size in the hammer mill of 4.0 mm (Ravi and Harte, 2009).

Substituting the obtained value into equation 5, the flour yield is calculated:

$$B = -0.213 \cdot 11.5^2 + 4.907 \cdot 11.5 - 16.18 = -28.169 + 56.43 - 16.18 = 12.0 \ \%$$

The highest flour yield at a moisture content of 11.5 % will be 12.0 %. This value was also confirmed experimentally. It is likely that at that moisture content the highest flour yield will be observed, when chickpea seeds will grind by a roller mill. This phenomena is due to the fact that chickpea moisture content directly affects the elastic-plastic properties of chickpea seeds (Dobraszczyk et al., 2002), and not the grinding method.

Since the average particle size of the ground mixture characterizes the grinding efficiency, studies were conducted on the weighted average particle sizes of the ground chickpea seed mixture. The results also confirmed that with an increase in moisture content from 12.7 % to 15.8 %, the efficiency of the chickpea seed grinding process in a hammer mill decreases. The results of the studies shown in Table 1.

Table 1

Chickpea grinding efficiency in the hammer mill at the different moisture content

Moisture content in chickpea seeds, %	Average particle seize of the mixture, μm	Flour yield, %
8.9±0.19	1623.0±1032.8	10.5
10.4±0.68	1586.7±1042.7	12.2
11.6±0.09	1623.4±1032.8	11.9
12.7±0.05	1625.4±1039.3	11.7
14.5±0.16	1728.6±1012.3	10.2
15.8±0.11	1754.4±998.5	8.2

Based on the above analysis, it can be concluded that the optimal moisture content for chickpea seeds is W = 11.5 %. At this moisture content, a flour yield of 12.0 % was obtained. Studies also confirm the fact that the best moisture content for chickpea seeds is in the moisture range of 11.0 % (Martin et al.,2022).

During the screening of the grinding products obtained in the hammer mill, it was noticed that a significant part of the hulls remained on the sieve with holes Ø2.0 mm. It is advisable to direct the outlet of the sieve Ø2.0 mm into the air separator in order to separate the hulls from the kernel particles.

The hammer mill is not able to grind chickpea seeds into flour, which has a particle size of less than 132 μm. Whole chickpea seeds grinding by the hammer mill is an important step in chickpea seed grinding technology. This stage allows to break the relations between the anatomical parts of seeds and promotes better separation of the hulls before the fine grinding by the roller mill.

In order to more completely extract the chickpea seed kernel, products remaining on the sieve were ground in a LM-2 roller mill. Pre-grinding of chickpea seeds by a hammer mill is also necessary so that the rollers of the roller mill better capture the chickpea kernel when these products enter between the rollers. Whole chickpea seeds are not captured by the rollers when the seeds enter the inter-roller space and the grinding process stops. Whole seeds cannot be destroyed.

Chickpea flour milling by the roller mill LM-2

Research of the chickpea seed flour yield by the LM-2 roller mill showed that chickpea seeds cannot be ground into flour with particle sizes less than 132 μm (sieve passage 132 μm) with maximum yield unless the length of the roller line is increased. Research results showed in Table2.

Table 2

Milled product yield of chickpea seeds in the roller mill LM-2

Products	Chickpea flour yield, %	Flour whiteness
Hammer mill	12.0	34.4±0.4
I break system	2.42	29.5±1.2
II break system	1.0	27.0±1.7
III break system	1.2	28.2±1.2
1 reduce system	7.51	32.4±1.6
2 reduce system	3.75	33.4±0.3
3 reduce system	3.81	39.8±1.3
Sorting system	18.9	29.3±1.8
Σ	50.6	
Bran	6.5	–
Meal	41.16	–
Aspiration waste	1.74	–
Σ	100	

The moisture content was 13.0 ± 0.05 % during the grinding of chickpea seeds. Chickpea seed moisture content was 1.5 % higher than optimum (Martin et al., 2022) established above.

The calculated amount of water was added to chickpea seeds to increase their moisture content from 8.9 % to 11.5 % during the moistening. The actual moisture content turned out higher than the calculated one. It can be explained by the significant hydrophilicity of the chickpea seeds. Accordingly, the flour yield in the hammer mill was obtained somewhat less than the maximum possible. However, the actual flour yield in the hammer mill was 11.1 %, and the calculated flour yield according to formula 5 is 11.6 %. Close values indicate the adequacy of the obtained dependence for large chickpea seeds.The total flour yield (sieve passage 132 μm) was 50.6 %, which is only half of the total amount of seeds directed to grinding. It should be noted that 38.6 % of flour was obtained by the roller mill LM-2, and 12.0 % of flour was obtained in the hammer mill. This indicates that seven grinding systems are not sufficient for complete grinding of chickpea seeds into flour. The products of third break system have not increased the chickpea flour yield.

However, the obtained results provide valuable information for organizing the technological process of chickpea seed milling into fine flour. Among the grinding roller systems, the highest flour yield was obtained by the reducing systems. However, three reducing systems are not enough for complete grinding of chickpea seeds into flour.

Based on the conducted research, the following conclusions can be drawn on the organization of the technological process of chickpea seeds grinding into flour. It is necessary to install the plansifter to separate the flour from other products After chickpea seeds were grinding into flour by the hammer mill with a screen which has the holes Ø4.0 mm. In addition, the receiving sieve should be the screen with holes Ø2.0 mm. Installing such a screen will allow separating large products from small ones, and the seed hulls are also separated together with the coarse product.

It is advisable to direct the coarse product from the screen with holes Ø2.0 mm to the air separator. This will separate the light hulls from the large particles and reduce the turnover of products in the technological process. Whole particles should be directed to the roller mill of the I break system.

It is clear from the data in Table 2 that the II and III break systems were extracted the flour with the yield of 1.0 % and 1.2 %, respectively. Such insignificant flour yields may indicate that these systems are unnecessary in the technological process of chickpea seed milling and all obtained those products should direct to 1 reduce system.

Product remaining on the sieve of 3 reducing system was sieved by control sieve (132 μm) for the target of additional flour extraction. This is due to the fact that the screening surface of the LM-2 plansifter is not sufficient for complete screening of milling products. Therefore, it can be recommended to additionally re-screen those products in an additional sorting system. When organizing the technological process of an industrial plant, a sorting system is also necessary for screening aspiration waste. It is important to allocate a sifting surface for flour control.

Based on the data in Table 2, it can be seen that the flour is 41.16 %. This product is chickpea seed kernel and hulls, which is obtained as a residue on the sieve from the three reduce system. The obtained amount is large. It indicates that it is advisable to allocate three more grinding systems with micro-rough rollers to grind this amount of products. At the same time, the main amount of coarse bran remains in the break process.

The flour whiteness was determined for each flour stream, the whiteness values are given in Table 2. A cumulative weighted average whiteness curve was constructed based on the flour yields and their whiteness, which is given in Figure 4.

The results shown in Table 2 indicate that chickpea seeds can be ground into fine flour without the use of the purifiers. The total yield of fine flour can be obtained more than 23.9 % (Martin et al., 2022).

Chickpea whiteness

The flour whiteness was determined for each flour stream, the whiteness values are given in Table 2. A cumulative weighted average whiteness curve was constructed based on the flour yields and their whiteness, which is given in Figure 5.

Analysis of the chickpea flour whiteness showed that with increasing flour yield, the whiteness decreases. This phenomena can be explained by the fact that the whiteness of flour is a quantity inversely proportional to the ash content, therefore, with a decrease in the whiteness of flour, the ash content of its flows increases (Kalitsis et al., 2021). In turn, this indicates an increase in the flour of hull and high-ash products.

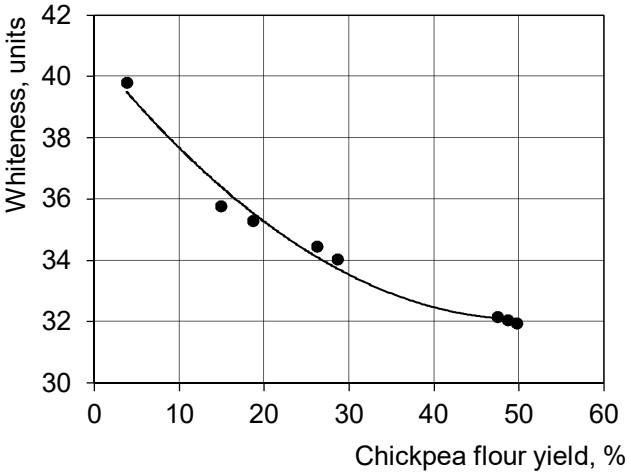

Figure 5. Cumulative curve of chickpea flour whiteness

Flow sheet of chickpea seed milling

A flow sheet for grinding chickpeas into flour is proposed. The flow sheet is shown in Figure 6.

The proposed flow sheet uses the stage of pre-grinding chickpea seeds. Since some of the hulls are separated before fine milling, this circumstance allows not to use purifiers when milling chickpea seeds into fine flour as is done by Martin et al. (2022).

The technological process involves the use of the hammer mill, air separator, roller mills, centrifugal impactor, and plansifters. The use of centrifugal impactors helps to increase the extraction of flour from intermediate products. However, the presented flow sheet of the chickpea seed grinding process requires further experimental confirmation on an industrial scale. The use of centrifugal impactors allows the increasing of flour extraction from intermediate milling products.

The proposed flow sheet has a shortened break process and an expanded fine reducing process into fine flour.

Conclusions

The optimum moisture content of chickpea seeds for hammer milling is 11.5%. At this moisture content, the flour yield was 12.0%. Increasing the moisture content of chickpea seeds reduces the flour yield from 12.0% to 8.2%.

Grinding of chickpea seeds in a hammer and roller mill gives a flour yield of 50.6% (sieve pass 132 μm). Complete grinding of chickpea seeds into fine flour was not possible due to the short length of the roller mill line LM-2.

Using a hammer and roller mill, it is possible to obtain flour of 50.6% (sieve pass 132 μm). Complete grinding of chickpea seeds into fine flour could not be achieved due to the short length of the roller line of the laboratory roller mill.

Analysis of flour yield and whiteness showed that increasing the flour yield reduces flour whiteness from 39.8 to 27.0 units. This indicates a deterioration in the quality of the flour.

Pre-grinding of wet chickpea seeds in a hammer mill allows the separation of large particles of husk, which can be useful for improving the quality of flour.

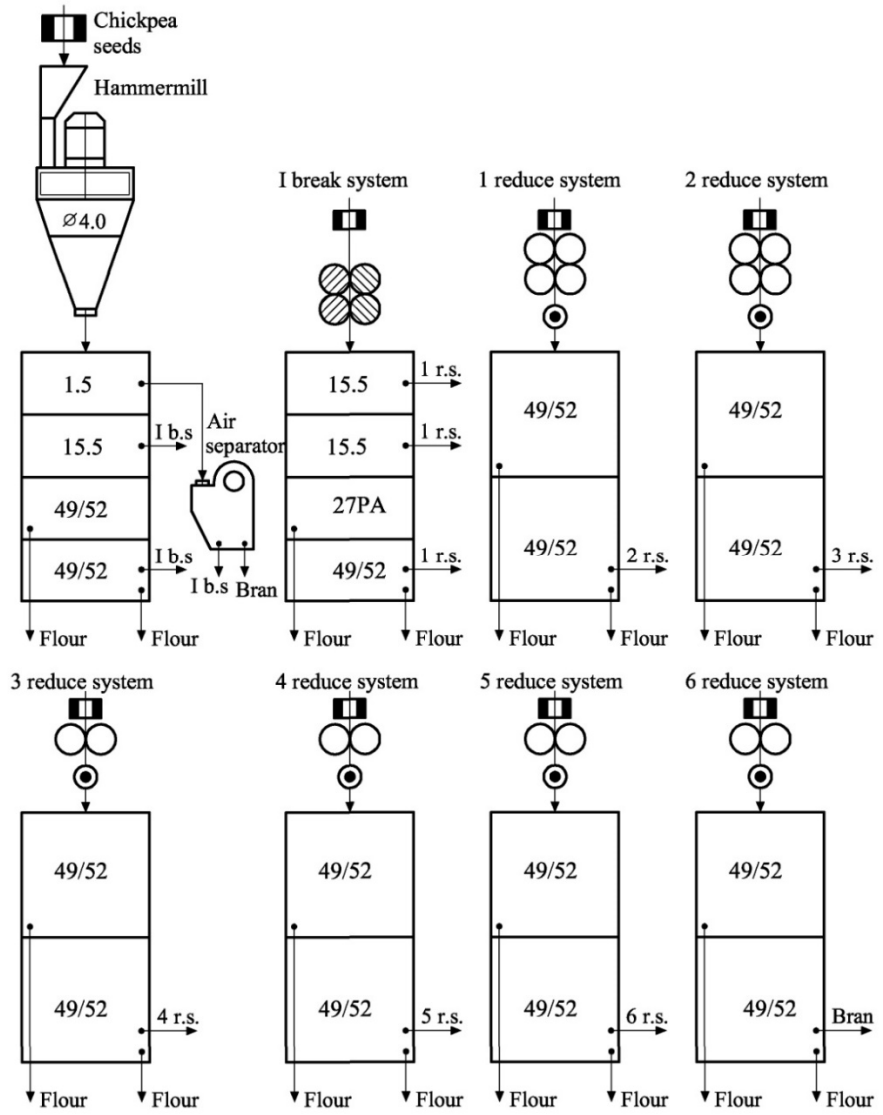

Figure 6. Referential flow sheet of chickpea seeds milling to fine flour

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Andaliman spice coffee as functional drink

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Abstract

Introduction. To increase the health benefits of traditional foods, it is advisable to add spices to them. The aim of this study was to fortify coffee with Andaliman powder, evaluate the changes in antioxidant activity, total dissolved solids, and total acid content of fortified coffee, and evaluate its sensory properties.

Materials and methods. Ground Robusta coffee and Andaliman powder were the main materials in the study. DPPH method was used to determine antioxidant activity; content of total dissolved solid was measured using a refractometer; content of total acid by the titration method; sensory properties by a scoring method by testing quality attributes such as color, aroma, taste, and overall.

Results and discussion. The treatment given was 10 g of robusta coffee powder and 15 g of palm sugar with the addition of 0% (P0), 5% (P1), 10% (P2), and 15% (P3) of andaliman spice powder. The data from the antioxidant activity test were analyzed descriptively, the total dissolved solids and total acid test data were analyzed using Analysis of Variance (ANOVA) with a significant level of 5%, and the data from the sensory test was analysed by the Kruskal Wallis nonparametric test with a significant level of 5%.

Along with the increased of added of Andaliman powder to ground Robusta coffee from 0 to 15%, antioxidant activity of Andaliman spice coffee has increased 66.66 to 75.03 %, content of the total dissolved solids increased from 12.12%Brix to 12.41%Brix, content of total acids from 0.13% to 0.25%, showing a real difference ($p \leq 0.05$).

The addition of andaliman powder does not change the color of the coffee brew, but the aroma produced in the coffee brew is the typical aroma of Andaliman. The level of acceptance of the panelists to the product as a whole is influenced by the color, aroma, and taste. The overall test showed that P2 was preferred by the panellists, this is because P2 has a strong coffee color, a strong andaliman aroma, and a bitter taste that is not too dominant.

Conclusion. The addition of andaliman powder to coffee increased its antioxidant activity, content of total dissolved solids and total acids. The best option for Andaliman spice coffee as a functional drink is coffee with 10% andaliman powder added.

Introduction

Indonesia is a country with abundant and diverse natural resources. Among the agricultural crops grown in Indonesia, coffee production is an extremely important and plays a significant role in agrobusiness. Indonesia was the fifth largest coffee producer in 2023 after Brazil, Vietnam, Colombia, and Ethiopia, producing 8.15 million of 60 kg bags that consisted 5% % of Global Production (USDA, 2023).

Coffee is one of the beverage products that is very popular with the public because it can have the effect of relieving drowsiness, giving a delicious sensation, soothing, relieving stress and improving focus. There are two types of coffee currently cultivated in Indonesia, namely Robusta coffee and Arabica coffee. The production of Robusta coffee reached 80.4% or more than 601,000 tons and the production of Arabica coffee reached 19.6% or more than 147,000 tons (Yuhendra and Pebrian, 2023). Coffee beans contain chemical compounds such as caffeine, chlorogenic acid, carbohydrates, fats, organic acids, amino acids, and volatile compounds (Mahriani et al., 2020; Stabnikova and Paredes-Lopez, 2024). Chlorogenic acid ($C_{16}H_{18}O_9$), the main phenolic component in coffee, and caffeine ($C_8H_{10}N_4O_2$) are considered to be the major components, giving coffee of its beneficial effects.

Generally, coffee beans are processed into powder and brewed with hot water and added sugar as a sweetener. However, processed coffee products are still not fully usable by the community, so it is necessary to innovate or develop processed products. Spiced coffee is one of the innovation opportunities, because spiced coffee has many benefits and can be used as a functional drink.

Addition of spices in form of powder or extracts in preparation of different traditional food products is well known trend having the aim to improve their health value (Aminzare et al., 2015; Khareba et al., 2021; Kochubei-Lytvynenko et al., 2022; Stabnikova et al., 2021).

Functional beverages are beverages that contain nutrients and have physiological properties that are beneficial to the human health (Batubara and Pratiwi, 2018). Spiced coffee, a mixture of coffee powder and spice powder, can be one such functional beverages. Spices added to coffee are natural ingredients that contain bioactive compounds that are essential for well-being (Hanif et al., 2020). Innovation in the preparation of spiced coffee aims to produce new flavours and aromas, enrich the properties of coffee, and impart health benefits to it (Junianda et al., 2023). Andaliman is one of the spices that can give a unique flavor and aroma to coffee and may provide health benefits when consuming this fortified beverage.

Andaliman (*Zanthoxylum acanthopodium* DC), also known as Batak peppercorn, is one of the typical spices of North Sumatra that is often used as a spice for Batak cuisine in food processing. Andaliman contains antioxidant compounds, such as phytosterols, carotene, tannins, alkaloids, and flavonoids that can act as free radical scavengers (Adrian et al., 2023). Andaliman spice is useful for nourishing the body, has a warming effect, can be used in traditional medicine for fever and stomach pain, and can relieve mild illnesses such as stomach colic, coughs, flu, and fever (Silalahi et al., 2018; Turnip et al., 2024).

In addition, andaliman is also useful as a medicinal plant, antibacterial and has an attrition oil content. Product development is needed in order to improve product quality, so that the products produced have a selling value and there is an improvement in product quality. Robusta coffee with the addition of andaliman spice powder can be one of the alternative products that can maintain the distinctive taste and aroma of coffee and provide functional benefits for the body. The purpose of the research conducted is to produce spice coffee innovations and determine the antioxidant activity, total dissolved solids, total acid, and sensory activity in coffee with the addition of andaliman spice as a functional drink. The

benefit of this study is to provide information about the addition of spices to coffee and increase the functional value of spice coffee products that can have health effects.

Materials and methods

Materials

The material used in this study is ground robusta coffee with the brand Pure Coffee Powder from Humbang Hasundutan Regency, North Sumatra. Andaliman powder with a healthy palm brand and palm sugar with the Dari Bumi brand were obtained from Shopee.

Methods

Making Andaliman spice coffee

Coffee with spices "Andaliman" was prepared as follows: 150 ml of mineral water was boiled, cooled to 90 °C, and 10 g of coffee powder "Robusta" was added, to which "Andaliman" powder was previously added in the amount of 0% (P0), 5% (P1), 10% (P2) and 15% (P3), as well as 15 g of palm sugar.

Antioxidant activity test

The antioxidant activity of spice coffee was determined according to (Rabani and Fitriani, 2022). Antioxidant activity testing was carried out by the 2,2-diphenyl-2-picrylhydrazyl (DPPH) method. 0.05 mM DPPH solution was prepared by dissolving 15.8 mg of DPPH with 100 ml of methanol as a raw solution. 1 ml of the solution is mixed with a sample of 2 ml. Blanks were made by adding 1 ml of DPPH 0.05 mM with 4 ml of methanol p.a. The solution was homogenized and left for 30 minutes in a dark room or place. The test was carried out using a UV-Vis spectrophotometer with a wavelength of 520 nm.

Total dissolved solids test

The total dissolved solids (TDS) test refers to (Bayu et al., 2017). TDS was measured using refractometer. The sample was taken as much as one drop and dripped onto a prism refractometer that has been calibrated using sterile aquades and wiped with a soft cloth. Then the refractometer was directed at the light source. The value indicated on the refractometer indicated the amount of TDS in the sample in degrees Brix.

Total acid test

The total acid test by the titration method is an analysis of the large amount of acid contained in a solution. Total acid testing refers to (Kasim et al., 2020). The total acid test begins with filtering using filter paper, then continues the dilution process, especially so that the color of the tested sample is not too dark. Dilution is carried out by dissolving 10 ml of sample solution on a 100 ml measuring flask and adding with aquades until it reaches the miniscus line. Then the solution is taken in the amount of 10 ml and put into the erlenmeyer. 1% PP (*Phenolphtelain*) solution is added as many as 2 drops to the sample solution and titrated by slowly opening the valve on the burette so that the 0.1 N NaOH alkaline solution is mixed with the sample, then waited until it changes color to reddish. The required NaOH

volume is recorded. The percentage of total acid content is calculated using the following formula:

$$Total\ acid\ (\%) = \frac{\text{Volume titran} \times \text{N} \times \text{P} \times \text{Mr Acid}}{\text{Volume sampel} \times 1000} \times 100\%$$

where N is normality of titran,
P is a dilution multiplier factor,
Mr. Acid is a molecular weight of acid (g/mol) (chlorogenic acid = 354)

Sensory test

Sensory testing refers to modified research (Nurhayati, 2017), which is carried out using a scoring method by testing quality attributes such as color, aroma, taste, and overall. The test was carried out by 25 semi-trained panelists with samples brewed using hot water and placed in containers that have been given codes. Then the panelists will fill out the test format sheet by providing an assessment in the form of checklist marks on the available table columns. The color test was carried out on an assessment scale consisting of 4 levels, namely: (1) light, (2) slightly dark, (3) dark, (4) very dark. The testing of aroma parameters was carried out on an assessment scale consisting of 4 levels, namely (1) not typical of andaliman, (2) somewhat typical of andaliman, (3) typical of andaliman, (4) very typical of andaliman. The taste parameter test was carried out with an assessment scale consisting of 4 levels, namely (1) not bitter, (2) slightly bitter, (3) bitter, (4) very bitter. The overall parameter testing was carried out on an assessment scale consisting of 4 levels, namely (1) very disliked, (2) disliked, (3) liked, (4) strongly liked.

Data analysis

The data from the antioxidant activity test results were analyzed descriptively. The total dissolved solids and total acid content test data were analyzed using Analysis of Variance (ANOVA) with a significant level of 5% and will be continued with the Duncan Multiple Range Test (DMRT) if there is a real effect between treatments ($p \leq 0.05$). The data from the sensory test results were analyzed by the Kruskal Wallis nonparametric test with a significant level of 5% followed by Mann-Whitney if there was a real influence between treatments ($p \leq 0.05$). All data was analysed using the SPSS for Windows 26.0 application.

Results and discussions

Antioxidant activity

The data displayed is a test of 4 treatments, namely P0 (0%) without the addition of andaliman, P1 with the addition of 5% (0.5 g) of andaliman powder, P2 with the addition of 10% (1 g) of andaliman powder), and P3 with the addition of 15% (1.5 g) of andaliman powder (Table 1).

Table 1

Andaliman spice coffee antioxidant activity

Sample	Andaliman powder (%)	Inhibition (%)
P0	0	69.66±0.35[a]
P1	5	71.04±0.35[a]
P2	10	71.85±0.27[b]
P3	15	75.03±1.77[c]

Note:
Data displayed in average form ± standard deviation;
Different lowercase superscripts show real differences ($p \leq 0.05$)

Antioxidant activity of Andaliman spice coffee has increased along with the increased addition of andaliman. The highest antioxidant activity was observed for P3 with the addition of andaliman by 15% (1.5 g), which was 75.03%, while the lowest antioxidant activity was produced at P0 without the addition of andaliman, which was 69.66%. This happens because the Andalim spice (*Zanthoxylum acanthopodium*) contains active compounds such as alkalis, tannins, flavonoids, terpenoids, saponins, and phenols that can act as antioxidants. Andaliman fruit contains active compounds of anticocidiants with an IC50 value of 66.91 bpj/ppm (Winarti et al., 2018). Coffee has antioxidants obtained from polyphenol compounds (chlorogenic acid and caffeine) as well as melanoidin (Liczbinski and Bukowska, 2022). In addition, the addition of palm sugar to coffee can also increase antioxidant levels in spice coffee derived from melanoidin compounds (South et al., 2020).

Total dissolved solids

Content of total dissolved solids in Andaliman spice coffee samples is shown in Table 2.

Table 2

Total dissolved solids content in Andaliman spice coffee

Sample	Andaliman powder (%)	Total dissolved solids (%Brix)
P0	0	12.12 ± 0.08[a]
P1	5	12.24 ± 0.05[b]
P2	10	12.38 ± 0.08[c]
P3	15	12.42 ± 0.08[c]

Note:
Data displayed in average form ± standard deviation;
Different lowercase superscripts show real differences ($p \leq 0.05$)

Based on Table 2, the total dissolved solids in P0 have an average of 12.12 %Brix, in P1 have an average of 12.24 %Brix, in P2 have an average of 12.38 %Brix, and in P3 have an average of 12.42 %Brix. The highest total dissolved solids of spice coffee were found in P3, which was 12.42 %Brix, while the lowest was found in P0, which was 12.12 %Brix. The total dissolved solids test in each treatment has increased not too high. However, the more

andaliman powder is added to coffee, the more the total value of dissolved solids tends to increase. Total dissolved solids is a measure of substances that can be dissolved in water (organic and inorganic substances) (Nurhayati, 2017). Coffee contains sucrose, chlorogenic acid, caffeine, and organic acids such as lactic acid, citric acid, and malic acid, which can increase the total dissolved solids. Andaliman contains several compounds that can be dissolved in water, namely flavonoids, tannins and saponins (Salim, 2024). In addition, the addition of palm sugar to spice coffee brewing affects the total dissolved solids produced because sugar contains sucrose and reduced sugars such as glucose and fructose (Purba et al., 2021).

Total acid content

Total acid content in Andaliman spice coffee is shown in Table 3.

Table 3

Total acid content in Andaliman spice coffee

Sample	Andaliman powder (%)	Total acid (%)
P0	0	0.49 ± 0.19^{a}
P1	5	0.57 ± 0.19^{ab}
P2	10	0.84 ± 0.19^{bc}
P3	15	1.00 ± 0.30^{c}

Note:
Data displayed in average form ± standard deviation;
Different lowercase superscripts show real differences ($p \leq 0.05$)

Based on Table 3, it was obtained that the total acid yield in P0 had an average of 0.49%, in P1 it had an average of 0.57%, in P2 it had an average of 0.84%, and in P3 it had an average of 1.00%. The highest total dissolved solids of spice coffee are found in P3, which is 1.00% while the lowest is found in P0, which is 0.49%. The data on the results of the total acid test in each treatment experienced a not too high increase. However, the more andaliman powder is added to coffee, the more the total acid value tends to increase. According to Kasim et al. (2024) Total titrated acid is the number of acid components contained in a solution. Andaliman has an acid content that can affect the total acid of spice coffee products, namely ascorbic acid or vitamin C (Wira et al., 2024). Andaliman also contains phenolic acids (polyphenols, phenols) and carboxylic acids which have acidic properties and are also aromatic acid compounds. Coffee contains chlorogenic acid, oxalic acid, lactic acid, acetic acid, citric acid, and formic acid. In addition, palm sugar also contains organic acids such as acetic acid, lactic acid, malic acid, and ascorbic acid (Suharto et al., 2021).

Sensory evaluation

Based on the results of sensory testing with the Kruskal Wallis test, it was shown that the addition of andaliman powder to coffee for color parameters had no real effect ($p \geq 0.05$), while for aroma, taste and overall parameters had a real effect ($p \leq 0.05$) (Table 4).

Table 4

Andaliman spice coffee sensory test

Sample	Andaliman powder (%)	Color	Aroma	Taste	Overall
P0	0	3.00±0.87	1.44±0.71^{a}	212±0.88^{a}	2.96±1.01^{a}
P1	5	2.76±0.88	2.20±0.82^{b}	2.56±0.82^{ab}	2.40±0.76^{b}
P2	10	2.9±0.81	2.68±0.85^{c}	2.64±0.91^{b}	3.00±0.71^{a}
P3	15	3.00±0.82	3.08±1.08^{cd}	2.96 ± 0.89^{b}	2.52±1.00^{ab}

Note: Data displayed in average form ± standard deviation

The color in the Andaliman coffee brew is dominated by the dark (black) color of the coffee and the addition of andaliman powder does not change the color of the coffee brew. The aroma produced in the coffee brew is the typical aroma of Andaliman. This happens because andaliman is a plant that contains aromatic compounds. The aroma of Andaliman comes from essential oils as well as linalool and limonene compounds (Meutia et al., 2015). The brewing coffee has a bitter taste. Coffee has a distinctive bitter taste that comes from chlorogenic acid and caffeine while andaliman has a bitter and spicy taste similar to orange and can stimulate the secretion of saliva (saliva) derived from the content of essential oils (Permana et al., 2021). The level of acceptance of the panelists to the product as a whole is influenced by the color, aroma, and taste. The overall test showed that P2 was preferred by the panellists, this is because P2 has a strong coffee color, a strong andaliman aroma, and a bitter taste that is not too dominant.

Conclusions

Based on the results of the study, it can be concluded that the addition of andaliman powder has an effect on antioxidant activity, total dissolved solids, and total acid content. The best option for andaliman spice coffee as a functional drink is coffee with 10% andaliman powder added.

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Effect of temperature of baking chamber and process duration on rusk loaf crust color

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Abstract

Introduction. The aim of research is to determine the effect of temperature of the baking chamber and duration of the baking process on the color of rusk loaf crust.

Materials and methods. Rusk loafs were produced from wheat pastry dough, baked in an oven with radiation-convection heating in the temperature range of 120–200 °C. The baking and drying processes of rusk loafs were combined in one baking chamber. The color of the crust was determined on a universal photometer. The temperature along the thickness of the rusk was determined using a set of thermocouples.

Results and discussion. With an increase in the duration of the baking process from 20 to 140 min and an increase in the temperature of the baking chamber from 120 to 190 °C, the reflective capacity of rusks crust surface decreases from 43–53 to 12–30% according to a logarithmic dependence.

The permissible value of reflective capacity is 20–30%. With a decrease in this value, the crust surface will be excessively dark. The maximum duration of heat treatment, during which the required surface quality is ensured, decreases according to an exponential dependence from 8 h at a temperature of 120 °C to 33 minutes at 200 °C.

It is proposed to determine the defining size of a rusk loaf as the ratio of the loaf volume to its surface area, taking into account the coefficient of the ratio of product sizes. It allows to take into account the shape and dimensions of the product to determine rational modes of combined baking and drying processes.

When the air temperature increases from 120 to 190 °C and the value of the defining size decreases from 0.02 to 0.01 m, the duration of the drying process is reduced from 180 to 33 minutes.

With an increase in the defining size of the product from 0.005 to 0.03, the rational operating temperature of the baking chamber decreases from 240 to 140 °C. Exceeding the temperature leads to low crust quality.

Conclusions. The use of the obtained results will ensure high intensity of drying and proper reflectivity of the crust surface of the rusk loaf. The rational temperature of the baking chamber is 160–200 °C.

Introduction

The use of new technologies for drying food products is noted as one of the main trends of the food industry development in 2021-2030 (Ivanov et al., 2021). The present study examines the surface quality of small-sized bread rusk loafs (Figure 1) manufactured using an innovative method, namely, the baking and drying processes of rusks take place in the same baking chamber.

a b

Figure 1. Baked rusk loafs (a) and cut rusks (b)

One of the main indicators of the quality of finished rusks is the color of the crust and the absence of cracks. The main color criteria include:

(1) Uniformity of the color. The crust should have a uniform color without dark or light spots (Mior Zakuan Azmi at al., 2019; Telychkun et al., 2012).

(2) Acceptable colour. Usually it is golden-brown or dark-brown colour, depending on the formulation and type of product (Ahrner et al., 2002; Lohinova et al, 2023).

(3) Absence of the burnt areas. Burnt or overdried areas are not allowed (Therdthai et al., 2007).

(4) Matte or glossy surface. This indicator depends on the type of rusks (for example, some rusks may have a slight glossiness due to glazing).

(5) Foreign inclusions. The uneven color, carbon deposits, or traces of flour are not allowed (Telychkun et al., 2013).

The color and thickness of the crust depend on the temperature (Ahrner et al., 2002), the duration of the heat treatment process (Purlis et al., 2009), and the recipe composition (Purlis et al., 2009). From the point of view of the drying process of the rusk slices, which occurs after the rusk loaves are cut, it is desirable that the crust be less intensely coloured and have a thickness of more than 3 mm (Telychkun et al., 2013). Therefore, when baking rusk loaves with a high sugar content, the temperature of the baking chamber in the second drying period should not exceed 180–200 °C (Mior Zakuan Azmi et al., 2019).

When small-sized crackers produce, it is advisable to combine the baking and drying processes in one baking chamber (Telychkun et al., 2013).

However, in this case, the heat treatment process is longer, so at the end of the process the crust temperature approaches the coolant temperature. In addition, the significant duration of the process contributes to the thickening of the crust and its burning (Dessev et al., 2020).

The aim of the research was to determine the effect of the temperature of the baking chamber and the duration of the baking process on the color of rusk loaf crust.

Materials and methods

Recipe for rusk loaves

The rusks loaves for baking and drying were prepared according to the following recipe, kg: Premium grade wheat flour, 100; pressed yeast, 3; salt, 1; margarine with fat content 82%, 7; sugar, 15; water, 42 l.

Description of experimental installation

Baking was conducted in the baking chamber of the experimental installation (Figure 2). The baking chamber has upper and lower heating surfaces, which corresponds to the principle of operation of most industrial tunnel ovens.

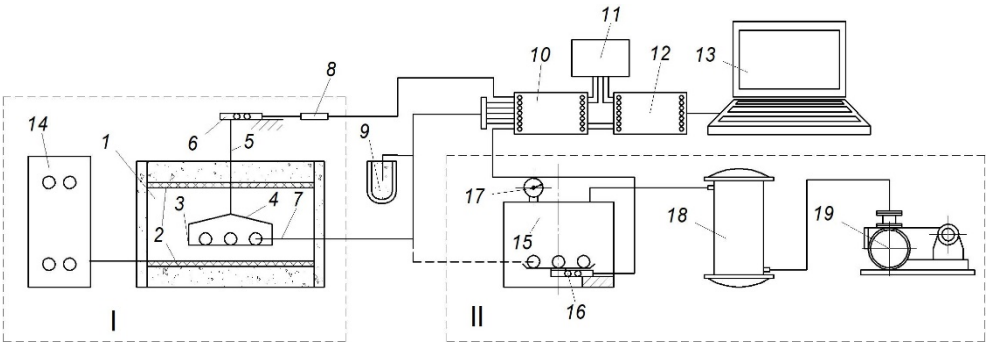

Figure 2. Experimental installation for baking and drying of rusk loaves:
I – installation for baking-drying rusk loaves;
II – installation for cooling of rusk loaves under vacuum conditions
1 – baking chamber, 2 – upper and lower heating surfaces, 3 – sheet, 4 – pendant, 5 – rod, 6 – weight strain gauge sensor, 7 – thermocouple block, 8 – signal amplifier, 9 – Dewar vessel, 10 – analog module, 11 – power supply, 12 – conversion module, 13 – computer, 14 – control panel, 15 – vacuum chamber, 16 – weight strain gauge sensor, 17 – pressure gauge, 18 – condenser, 19 – vacuum pump.

The installation consists of a baking chamber 1 with upper and lower 2 heating surfaces. On the sheet 3, which is held on the pendant 4, there are dough loaves. The pendant is attached to the rod 5, which is connected to the weight strain gauge sensor 6. The dough weight values are recorded via the analog module 10 and the conversion module 11.

The oven has an autonomous automatic temperature control of the upper and lower heating surfaces, which is carried out from the control panel 14. The panel also displays the temperature of the baking chamber.

The temperature in the layers of dough loaves is measured by thermocouples, the potential of which is supplied to the analog module ICP CON I-7018 10, which is powered by the power supply 11. Using the conversion module ICP CON I-7520 12, the signal is converted and transmitted to the computer 13. Appropriate software is used to record data in the computer.

After baking and drying, the rusk loaves are loaded into a vacuum chamber and cooled under vacuum conditions.

Determining of color of rusk crust

To determine the intensity of crust glossiness, a universal photometer FM-56 was used. The principle of operation of the device is based on comparing two light fluxes by changing the area of one of them using a diaphragm with a hole (CIE, 2023).

Due to the fact that the surface of the bread and rusk is not white, but has a certain color, measurements are complicated by the multi-color comparison fields. Therefore, the whiteness of the sample is determined as the average value of the reflectance coefficients measured through red, blue and green light filters.

Reflection coefficient R_0 of the rusks crust:

$$R_0 = r \cdot R,$$

where r is a ratio of the average brightness coefficient of the sample to the brightness coefficient of the barite plate;

R is a reflection coefficient of the barite plate.

Almost all light-scattering surfaces exhibit a sheen at the illuminated directional light, which is manifested in the fact that the brightness of the surface in the direction of specular reflection is greater than in other directions.

Using a universal photometer, the sheen (glossiness) of the crust can be examined at a constant angle between the beam of light incident on it and the beam of light in which the observation is made.

The value $\gamma_{(\delta)}$, which characterizes the glossiness of the surface at an angle δ, is determined by the formula (Telychkun et al., 2012):

$$\gamma_{(\delta)} = \frac{100P}{m(\delta)},$$

where P is the refinement coefficient of the device, P=1.305;

m is the value on photometer scale, which corresponds to the average position of photometric equilibrium;

δ is the angle at which the glossiness of the surface has the greatest value.

Results and discussion

Effect of temperature of baking chamber and duration of heat treatment on reflection coefficient of rusk crust

It was found that with an increase in the baking chamber temperature *t*, the reflectivity of the surface of the rusks R_0 decreases (Figure 3).

Increasing the duration of the drying process leads to a decrease in the reflectivity of the crust surface R_0 (Figure 4) at all temperatures in the baking chamber t.

The decrease in the reflection coefficient R_0 (Figure 4) with increasing baking chamber temperature t and the duration of heat treatment process τ occurs due to the accumulation of coloring products – Maillard reaction (Lohinova et al., 2023; Mandiuk et al., 2024).

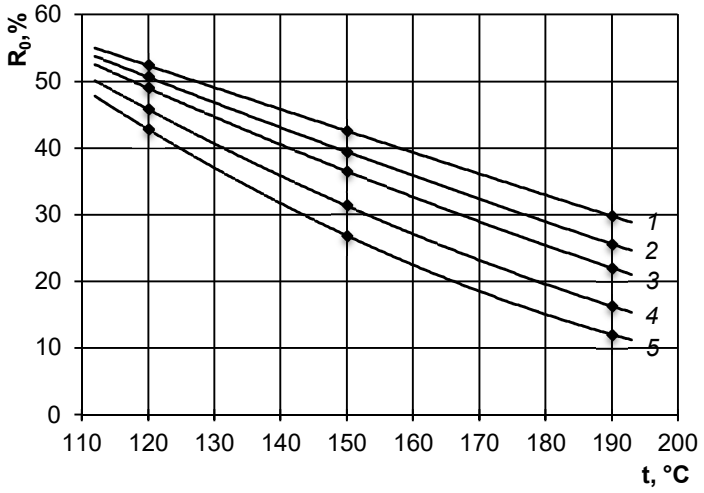

Figure 3. Effect of temperature in baking chamber on reflection coefficient of surface of rusk loaves
Process duration, min: 1 – 20; 2 – 40; 3 – 60; 4 – 100; 5 – 140.

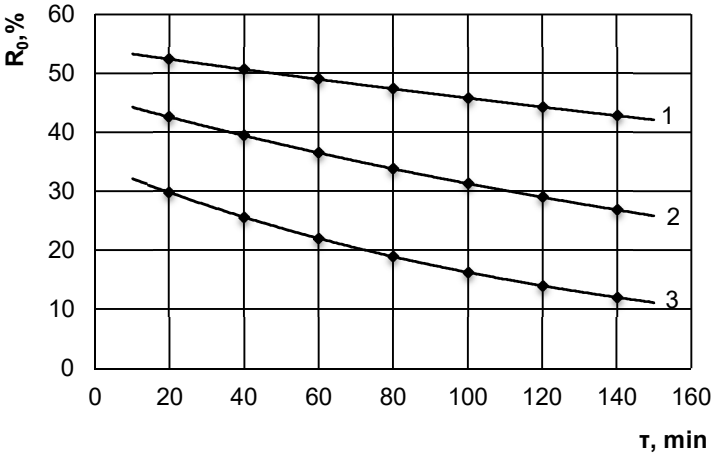

Figure 4. Effect of duration of heat treatment process on reflectance coefficient of rusk loaves surface.
Baking chamber temperature t, °C: 1 – 120, 2 – 150, 3 – 190.

The dependence of the reflectivity coefficient of rusk loaves surface on the temperature of baking chamber and the duration of heat treatment was obtained:

$$R_0 = (-9.33 \cdot \ln(\tau) - 20.74) \cdot \ln(t) + 39,58 \cdot \ln(\tau) + 168.3 .$$

The rational value of the reflection coefficient R_0 of rusk loaves surface is 20–30%, which corresponds to 3–4 units of the reference color scale.

Influence of product shape and size on duration of heat treatment

According to the results obtained, it was determined the geometric dimensions of the loaves for which it is advisable to combine the baking and drying processes.

Figure 5 shows the duration of the process at which high-quality coloring of the surface of the products is ensured depending on the temperature of the baking chamber.

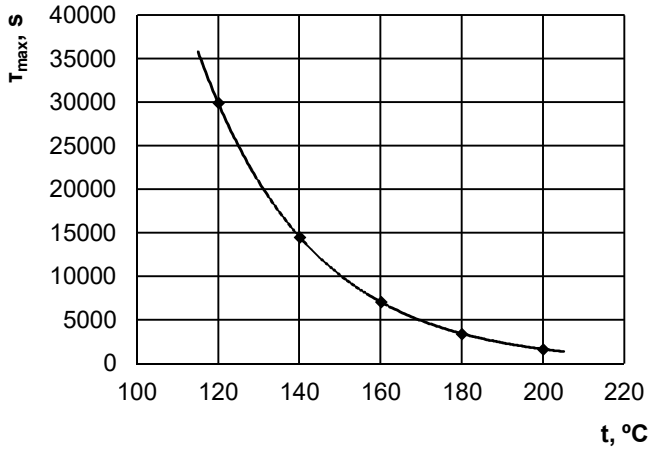

Figure 5. Effect of temperature in baking chamber on duration of heat treatment, which ensures a high-quality rusk surface

As can be seen from Figure 5, the temperature of the baking chamber significantly affects the intensity of the surface color and the duration of the process. The dependence can be described by the equation:

$$\tau_{\max} = 2.25 \cdot 10^6 \cdot e^{-0.036t} .$$

At a rational temperature of the heating chamber, maximum intensity of moisture release is ensured and high quality of the products is maintained, namely, the crusts do not burn. The color of the crust depends on its temperature, the duration of heat treatment, and, accordingly, on the defining size.

The defining size of rusk is proposed to be calculated by the formula:

$$R = i\frac{V}{F},$$

where: V is a volume of loaf, m^3;

F is a heat exchange surface area, m^2;

i is the coefficient of the product dimensions ratio, which takes into account the ratio of the 3 final dimensions of the loaf. This coefficient is defined as the sum of the ratios of the dimensions along which heating passes to all dimensions of the loaf:

$$i = \frac{x}{x} + \frac{x}{y} + \frac{x}{z},$$

where x is the size of the loaf along which the heat flow is directed, m;
y, z is two another sizes, m.

When the air temperature increases from 120 to 190 °C, the duration of the drying process is reduced by more than half (Figure 6).

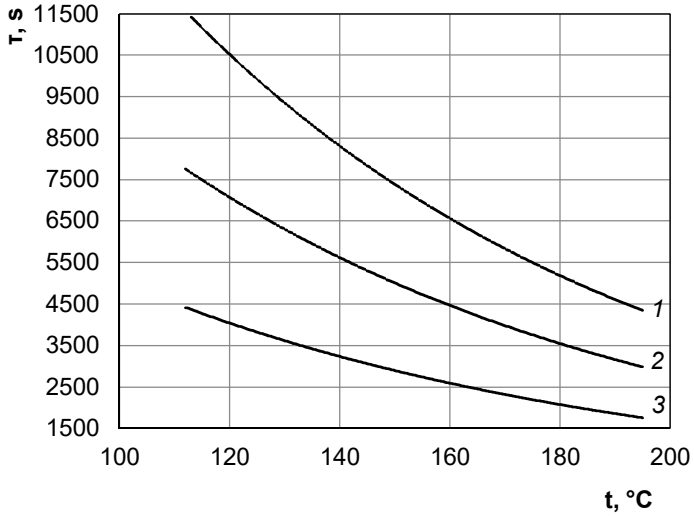

Figure 6. Effect of baking chamber temperature on duration of baking-drying of rusk loaf. Defining size of loaf: R, m: 1 – 0.02, 2 – 0.015, 3 – 0.01.

To prevent overheating of the crust, consider the dependence of the surface temperature of the rusk loaves on the temperature of the baking chamber (Figure 7).

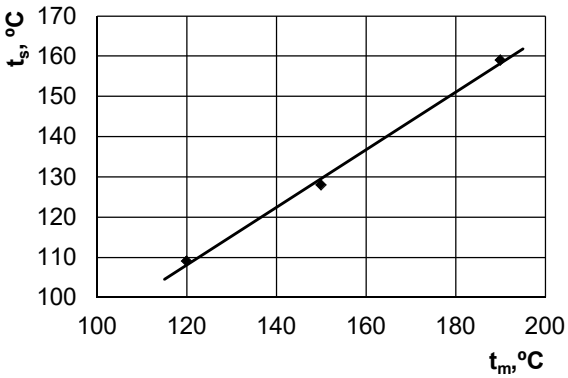

Figure 7. Effect of temperature of the baking chamber (t_m) on the surface temperature of rusk loaves (t_s) at end of drying process

If the crust temperature exceeds 150 °C, it burns and the rusks taste deteriorates. Therefore, when producing butter rusks by combining baking and drying, a baking chamber temperature of 150 to 170 °C is recommended to obtain a high-quality surface. Lowering the baking chamber temperature below 150 °C leads to an increase in the duration of the process.

Therefore, the following data: (1) dependence of the duration of the baking-drying process on the defining size (Figure 6), and (2) dependence of the final surface temperature of the rusk loaves and the duration of heat treatment, which ensures a high-quality surface, on the temperature of the baking chamber (Figure 4, Figure 5) allow to determine the rational temperature of the baking chamber depending on the defining size of the dough loaves (Figure 8).

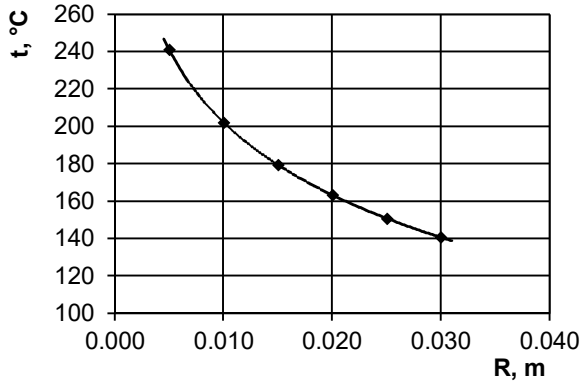

Figure 8. Effect of defining size of rusk loaves on rational temperature of baking chamber

The dependence of the rational temperature of the baking chamber on the determining size is logarithmic:

$$t_r = -56\ln(R) - 55.67\ ^\circ\mathrm{C}$$

Since the defining size of the products R is within 0.01–0.02 m, from the point of view of ensuring high-quality crust coloring at high intensity of the drying process, it is necessary to ensure a baking chamber temperature of 160–200 °C. Lowering the temperature significantly slows down the process duration. Increasing the baking chamber temperature is limited by the thickness and coloring of the crust (Helou et al., 2016; Telychkun et al., 2012).

Conclusions

1. The feasibility of combining the baking-drying processes of rusk loaves in one baking chamber has been confirmed. The process should be divided into 2 periods - baking and drying. The duration of the drying process is significantly longer than baking.
2. The drying period can be reduced by increasing the temperature of the baking chamber, but the maximum temperature value is limited by the color of the crust. The duration of the drying period is determined by an empirical equation depending on the temperature of the baking chamber.

3. With an increase in the baking time of rusk loaves from 20 to 140 min and an increase in the temperature of the baking chamber from 120 to 190 °C, the reflectivity of the surface of rusk loaf crust decreases from 43–53 to 12–30% according to a logarithmic dependence.
4. The permissible value of the reflectivity is 20–30%. With a decrease in the permissible value, the surface of the crust will be excessively dark. The maximum duration of heat treatment, which ensures the required surface quality, decreases exponentially from 8 hours at a temperature of 120 °C to 33 minutes at 200 °C.
5. It is proposed to calculate the defining size of a rusk loaf as the ratio of the volume of the loaf to its surface area, taking into account the coefficient of the ratio of product proportions. This allows you to take into account the shape and dimensions of the product to determine rational modes of combined baking and drying processes.
6. When the air temperature increases from 120 to 190 °C and the value of the defining size decreases from 0.02 to 0.01 m, the duration of the drying process is reduced from 180 to 33 minutes.
7. With an increase in the defining size of the rusk loaves from 0.005 to 0.03, the rational temperature of the baking chamber medium decreases from 240 to 140 °C. Excess temperature leads to a deterioration in the quality of the crust.
8. The using of results allows to ensure high drying intensity and proper reflectivity of the surface of rusk loaf crust. The rational temperature of the baking chamber is 160–200 °C.

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Author contributions

Abstract. The **abstract** should contain the following mandatory parts:

Introduction provides an aim for the study (2-3 lines).

Materials and methods briefly describe the materials and methods used in the study (3-5 lines).

Results and discussion describe the main findings (23-26 lines).

Conclusion provides the main conclusions (2-3 lines).

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Нанотехнології
Процеси та обладнання
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1 автор	(Arych, 2019)
2 і більше авторів	(Bazopol et al., 2021)

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Cheung T. (2011), *World's 50 most delicious drinks*, Available at: http://travel.cnn.com/explorations/drink/worlds–50-most-delicious-drinks–883542

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