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Contents

Food Technology………………………………………………………….. 125

Artur Mykhalevych, Galyna Polishchuk, Magdalena Buniowska-Olejnik, Marta Tomczyńska-Mleko, Stanisław Mleko
Functional and technological properties of protein ingredients in whey ice cream………………………………………………………………….. 125

Olena Bilyk, Liudmila Burchenko, Yuliia Bondarenko, Oksana Vasheka, Valentyna Rak
Application of a multi-component bakery improver in the technology of wheat bread enriched with the mixture of sprouted grains........................... 136

Vladyslav Shpak, Andrii Marynin
Influence of electrochemically activated water on the rheological indicators of starch suspensions.. 149

Anastasiia Shevchenko, Svitlana Litvynchuk
Protein substances of oat bran and their influence on conformational transformations in dough and bread from wheat flour.................................. 161

Yuliia Kambulova, Nataliya Overchuk, Olena Kohan
Effects of mono- and disaccharides on fruit gel formation………………... 171

Processes, equipment and control systems……………………………… 184

Serhii Baliuta, Petro Zinkevych
System analysis of automated power supply control system for a food industry enterprise using a photovoltaic plant and energy storage................ 184

Abstracts………………………………………….…………………….. 200

Instructions for authors…………………………………………………... 207

Functional and technological properties of protein ingredients in whey ice cream

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Abstract

Introduction. This study explores rheological characteristics of mixes of whey ice cream with protein ingredients.

Materials and methods. The viscosity characteristics of the mixes were studied by the method of rotational viscometry. Foam overrun and foam resistance of ice cream mixes were determined using modified methods.

Results and discussion. The expediency of using protein ingredients in whey ice cream mixes to increase their nutritional value was shown. Addition of whey protein isolate in the amount of 3–5%, micellar casein, 3%, or whey protein concentrate, 3%, increased the foam overrun of whey ice cream mixes, while addition of soy protein isolate decreased it. The highest rate of foam resistance, 57.6–58.4%, was recorded for the mix with 3–5% of whey protein isolate.

Based on the results of the analysis of flow rheograms of ice cream mixes with various protein ingredients, they were classified as food systems with a coagulation structure, characterized by pronounced thixotropic properties. In the case of micellar casein, whey protein concentrate or whey protein isolate, the thixotropic ability of the mixes increases from 58.2% to 62.2–72.2%. Soy protein isolate does not show the specified technological activity.

The highest thixotropy of the mixes was observed for mixes with 3% micellar casein and 3–5% whey protein isolate due to their specific ability to form a spatial coagulation structure, which spontaneously restores the structure after destruction due to the presence of numerous low-energy bonds. Whey protein concentrate has a moderate effect on the rheological characteristics of the mixes, while the presence of soy protein isolate leads to a partial loss of the ability of the mixes to spontaneously restore the destroyed structure.

The possibility to increase the total protein content in ice cream from 3.45% to 6.02–7.81% due to the use of technologically effective milk-protein ingredients has been proven.

Conclusions. Micellar casein and whey protein isolate in the composition of whey ice cream mixes show high technological activity and significantly improve the quality indicators of the finished product.

Introduction

Whey ice cream is a frozen dessert, made on the basis of secondary dairy resources such as fresh or powdered whey (sweet or acid) (Goff, 2008; Kamińska-Dwórznicka et al., 2022). However, in case of using whey as a milk base, the level of total solids, in particular high-value whey proteins, is quite low (Barros et al., 2021; Jeličić et al., 2008). The high content of free water in whey ice cream mixes prolongs the ripening process and reduces its effectiveness due to the low viscosity of the mixes, which subsequently affects the freezing process and the quality indicators of the ice cream. To increase the content of solids in whey ice cream, it was proposed to use of hydrolyzed concentrates of demineralized whey (total solids, 40%; protein, not less than 4.6%; lactose, not more than 6.6%) as a basis (Osmak et al., 2021). Their use will increase the level of solids in ice cream to 39.61–49.61%, of which the mass fraction of protein is about 3.3%. However, further enrichment of ice cream with proteins to a content of 6–8% is appropriate both for improving the texture and significantly reducing the size of ice crystals, and for increasing the nutritional value of this product (Arslaner and Salik, 2020; Polishchuk et al., 2020).

In the process of ice cream production there is an additional mechanical impact on the mixes during such technological stages as dosing, packaging, transportation through pipelines and devices with moving working organs (Kasapoglu et al., 2023). The structural and mechanical properties of ice cream mixes with a low protein and fat content during processing can be significantly changed depending on various technological factors such as temperature (Goff et al., 2013), moisture content and its connection with the food material (Soukoulis et al., 2014), and pressure (Innocente et al., 2009). Therefore, to avoid a negative mechanical effect on the rheological characteristics of mixes with a low protein and fat content, it is necessary to improve their composition using ingredients with clearly expressed moisture-binding, stabilizing and foam-forming properties, namely polysaccharides and proteins (Cheng et al., 2015; Himashree et al., 2022).

Protein concentrates with protein content < 90% and isolates with protein content > 90%, such as whey, casein, and soy are natural techno-functional and enriching ingredients of animal or plant origin, which are widely used in the food industry (Day et al., 2022; Mykhalevych et al., 2022). The use of such protein additives during the preparation of whey mixes can contribute to an increase in their viscosity, foaming properties, which will affect the quality of ice cream during further production, and is also appropriate from the point of view of the popularity of protein-enriched products (Hossain et al., 2021; Sipple et al., 2022).

Soy protein isolates and whey protein concentrates are the most studied representatives of protein ingredients in food systems (Chen et al., 2019; Himashree et al., 2022). Saentaweesuk and Aukkanit (2019) reported that whey protein isolate added in the amounts 2.5% and 5% makes the taste of ice cream closer to the control sample and also it increases overrun and resistance to melting. Whey and soy protein additives are widely studied in traditional types of milk-based ice cream, but their additional use in classic whey ice cream with a low protein content of 1.28-1.41% is limited, in particular because whey ice cream is not a product of mass consumption, but belongs to the amateur type (Shevchenko et al., 2022; Young, 2007). Micellar casein due to a special production technology has high solubility, emulsifying and foaming abilities, so it is also a promising ingredient, but not widely used (Goff, 2022; Polishchuk et al., 2020).

Mixes for ice cream, in particular whey, belong to multicomponent systems (Schiraldi et al., 2019) with a complex structure, the nature of which changes under the influence of time-varying external mechanical stresses could only be investigated using rotational viscometry.

That is why the study of the main rheological characteristics of whey ice cream mixes with increased protein content is of great practical importance for obtaining an objective assessment of the process of forming quality indicators of whey ice cream at various stages of the technological process, in particular during low-temperature processing.

The aim of the present research was to study the functional and technological properties of protein concentrates and isolates of various origins in the composition of whey ice cream mixes.

Materials and Methods

Materials

Hydrolyzed demineralized whey concentrate, stabilization system Cremodan SE 406 (DuPont™, Danisco®), white crystalline sugar, vanilla and water were used to make whey ice cream mixes. Soy protein isolate 90% (ISOPRO 900EM-UPI, China), whey protein concentrate 70% (Hadyachsyr, Ukraine), micellar casein 85% (Ingredia Promilk, France), whey protein isolate (Spomlek, Poland) were chosen as protein ingredients.

Preparation of samples

The hydrolyzed concentrate of demineralized whey was mixed in drinking water and heated to a temperature of 40±5 °C, after which pre-weighed and mixed dry components were added. The mixes were stirred for 1–2 min, filtered and pasteurized at a temperature of 85±2 °C for 5 min. Homogenization was carried out under a pressure of 12.0±2.5 MPa using a laboratory homogenizer-disperser model 15M-8TA "Lab Homogenizer & Sub-Micron Disperser" (Gaulin Corporation, Massachusetts, USA). The homogenized mixes were cooled to a temperature of 4±2 °C and left for ripening for at least 12 hours.

Whey ice cream based on hydrolyzed concentrate of demineralized whey served as a control. The content of the stabilization system was chosen at the level of 0.6% in accordance with the manufacturer's recommendations. Protein ingredients were used in amounts from 3 to 11% in 2% increments. The applied ranges of the protein content in ice cream mixes provided the level of protein supply from 14.71 to 27.55%, which gives the right to consider this product as enriched with protein (more than 12%) or a source of protein (more than 20%) (Regulation (EC) No 1924/2006).

Methods

Determination of the chemical composition of mixes

Protein content in ice cream mixes was determined by the Kjeldahl method. Total solids content in samples was carried out by the arbitration method, the principle of which is to dry the sample, diluted with distilled water and mixed with sand, at a temperature of 102°C to a constant mass, followed by weighing to determine the mass of the residue.

Definition of foam overrun

After cooling to a temperature of 2–6 °C, the ice cream mixes were whipped for 5, 10, and 15 min with 5-min breaks according to the method of Lim et al. (2008). Foam overrun was determined as the ratio of the volume of the whipped mix to its initial volume, expressed as a percentage.

Determination of foam stability

The foam stability of experimental samples of ice cream mixtures was determined by the modified method of Philips L., according to which a container with a hole at the bottom was used for foam to drain after churning (Lim et al., 2008). The foam stability indicator was taken as the time during which 50% of the initial volume of the mix, which was used for whipping, is formed as a result of foam destruction.

Definition of rheological behavior

Viscosity-speed characteristics of ice cream mixes were determined on a rotary viscometer with a measuring system "cylinder-cylinder" by recording deformation of kinetic curves. Measurements were made at a temperature of 20°C. Shear stress τ (Pa) was measured at twelve values of the shear rate gradient D in the range 3–1312.2 s^{-1} during forward and reverse course (Bass et al., 2017).

The maximum effective viscosity of the almost undamaged structure (γ=3 s^{-1}), the minimum effective viscosity of the marginally destroyed structure (γ=1312.2 s^{-1}) and the effective viscosity of the restored structure (γ=3 s^{-1}) were recorded. The degree of restoration of the structure of ice cream mixes (thixotropic ability) was determined in percent by the difference in the values of the effective viscosity of the practically intact structure at the beginning and at the end of the measurement at a shear rate gradient (γ=3 s^{-1}) (Sapiga et al., 2021).

Statistical processing

Data were expressed as the mean with standard deviation of triplicate measurements. Statistical analysis was performed using the program Statistika 10.

Results and discussion

The control sample of the whey ice cream mix based on the hydrolyzed concentrate of demineralized whey had the following composition: total solids, 39.6%, of which fat was 0.74%, protein was 3.45%, stabilization system was 0.6%, and sugar was 9%.

The chemical composition of the experimental mixes of whey ice cream with protein additives was as follows: total solids, 42.6–50.6%; fat, 0.74–0.85%; protein, 6.02–13.57%; stabilization system, 0.6%; sugar, 9%.

The use of protein technological ingredients in the composition of ice cream is appropriate for increasing the foaming properties of ice cream mixes and improving the efficiency of the freezing process due to uniform and finely dispersed air saturation and the corresponding formation of a homogeneous and creamy structure of the product (Bahramparvar and Tehrani, 2011).

To study the effect of protein additives on the rheological properties of ice cream mixes, their foam overrun and foam resistance were determined (Table 1).

Table 1

Foaming properties of whey ice cream mixes

Ice cream mix with protein additive, %		Foam overrun, %			Foam stability, min		
		Time of whipping, min					
		5	10	15	5	10	15
Control	0	150.0±1.5	201.4±4.2	187.5±1.6	44.8±0.6	49.5±0.5	48.1±1.3
Whey protein isolate	3	142.5±5.2	160.0±5.8	162.5±1.4	41.0±0.8	42.2±0.1	42.8±0.8
	5	135.8±1.4	148.2±3.8	139.7±2.3	34.4±0.4	36.7±1.2	38.5±0.6
	7	129.4±0.9	133.5±1.9	130.6±1.7	32.4±1.1	34.6±0.5	35.0±0.8
	9	126.8±3.3	125.7±2.4	120.7±3.4	29.1±0.4	30.8±1.2	32.8±1.0
	11	115.1±1.8	114.3±3.8	110.7±2.5	28.2±0.2	29.4±1.2	31.6±0.9
Micellar casein	3	216.2±0.4	229.7±1.9	221.6±1.8	46.9±0.5	55.8±0.3	54.9±0.5
	5	197.4±4.1	210.5±1.4	207.0±3.0	44.1±1.2	45.7±0.8	48.5±0.6
	7	168.0±5.2	179.6±2.5	170.8±2.2	39.8±0.7	40.6±0.8	38.3±1.2
	9	144.3±4.4	150.4±1.0	145.8±1.4	37.0±0.7	38.8±0.3	40.2±1.1
	11	138.9±0.7	142.7±2.5	139.1±2.8	32.8±1.0	34.5±0.9	35.9±0.3
Whey protein concentrate	3	185.0±1.6	205.0±1.5	200.0±3.6	44.8±1.1	46.3±0.6	46.2±0.9
	5	169.5±2.3	184.8±3.4	178.2±0.9	37.8±0.8	39.5±0.2	38.7±0.8
	7	153.8±1.9	162.7±1.1	159.5±0.7	35.1±0.5	36.4±0.3	35.8±1.1
	9	139.5±1.7	145.7±3.0	141.2±1.8	32.5±0.9	33.6±1.0	31.4±0.5
	11	122.4±2.6	124.8±1.8	119.3±2.8	29.5±0.1	30.2±0.6	30.0±0.6
Whey protein isolate	3	203.3±1.7	236.7±2.5	246.7±4.7	48.4±0.7	58.4±0.2	61.9±0.4
	5	192.1±2.0	220.4±3.2	221.5±1.2	45.9±0.8	57.6±0.9	59.3±1.0
	7	178.5±1.4	206.4±0.5	192.0±2.4	44.8±0.1	55.7±0.4	53.8±0.8
	9	148.6±5.4	166.0±1.1	156.2±3.9	41.3±1.9	44.2±1.2	42.0±1.4
	11	139.4±0.3	144.5±1.0	140.7±1.9	38.4±1.0	39.6±1.2	38.0±0.3

The use of whey protein isolate, 3%, led to a decrease in the foaming properties of the mixes, compared to the control. Micellar casein in the first five minutes of whipping provided the highest foaming of all protein ingredients, however, after further whipping for 10 min, this value was less than for 3% whey protein isolate, and after 15 min it decreased, while for the whey proteins isolate, on the contrary, increased.

It is known that micellar casein has a foaming ability (Zhao et al., 2022), however, due to the instability of the formed bubbles due to the weaker interfacial elasticity of casein, this did not ensure the formation of strong bonds that form a dense protein matrix (Sato et al., 2021), similar for systems with whey protein isolate, which also confirm the obtained foam resistance values. Xinqi Zhao et al. (2022) in the study of aqueous solutions with whey protein isolate, which were treated with ultrasound, showed an increase in their foam ability from 60.06 to 143%. In our case, the obtained values were significantly higher, because studied ice cream mixes are multicomponent food systems. However, homogenization under pressure can also partially increase the foaming properties of mixes (Jambrak et al., 2008). The effect of whey protein concentrate, 3%, is more moderate compared to micellar casein and whey protein isolate, but it significantly increases foaming and foam resistance compared to the control.

The appearance of whipped whey mixes with the highest foam overrun and foam resistance is shown in Figure 1.

a b c

Figure 1. Whipped whey ice cream mixes:
a, control, b, with 3% of micellar casein, c, with 3% of whey protein isolate

Viscosity-speed characteristics were studied in mixes that had the highest foaming abilities (Table 2).

Table 2

Viscosity-speed characteristics of whey ice cream mixtures

Ice cream mixture	Effective viscosity (mPa·s) under variable shear rate gradient			The time of ultimate destruction of the structure (γ=1312.2 s^{-1}), min	The degree of structure recovery, %
	$\gamma = 3\ s^{-1}$ (forward course)	$\gamma = 1312.2\ s^{-1}$	$\gamma = 3\ s^{-1}$ (reverse course)		
Control	601.0±11.8	20.0±1.0	350.3±10.5	5.5±0.2	58.2
3% SPI*	569.1±10.5	41.8±1.1	323.8±7.4	5.3±0.1	56.9
3% MC	650.1±15.7	46.1±2.2	430.0±13.0	6.7±0.3	66.1
5% MC	636.9±14.5	45.6±1.4	407.2±11.1	6.4±0.1	63.9
3% WPC	571.7±9.2	38.4±1.7	394.5±4.8	5.9±0.2	62.2
3% WPI	676.1±12.6	49.7±2.1	488.4±17.2	7.5±0.2	72.2
5% WPI	623.4±17.4	47.4±1.1	421.4±12.6	7.2±0.3	67.6

Note: *SPI is whey protein isolate; MC is micellar casein; WPC is whey protein concentrate; WPI is whey protein isolate.

The high content of solids in the ice cream mixes ensured a high degree of thixotropy, 58.2%, even for the control sample. In the case of using protein ingredients (micellar casein, whey protein concentrate, whey protein isolate), the thixotropy of the mixes increased from 58.2% to 62.2–72.2%, except for the sample with soy protein isolate.

Thus, whey protein isolate showed the greatest ability to restore whey mixes of ice cream, which is associated with its high solubility (Tavares et al., 2019), as well as the formation of elastic bonds that increase the strength of the gel network, stimulating the formation of more intense intermolecular interactions. Micellar casein is also capable of forming a gel network (Zhao et al., 2022), but it is not as strong as in case of whey protein isolate use (de Castro et al., 2017). Although whey protein concentrate exhibits thixotropic ability, it is less than in the case of micellar casein and whey protein isolate, which is due to lower degree of its purification. Other scientists also reported about ability of soy protein isolate to deteriorate the rheological properties of mixtures (Zhang et al., 2021). Soy protein isolate, compared to other selected protein ingredients, is unable to form energy bonds that, after the destruction of the structure, reveal active restoration of the structure.

The dynamics of changes in the effective viscosity of samples that show the highest thixotropy during rheometric measurement are shown in Figure 2.

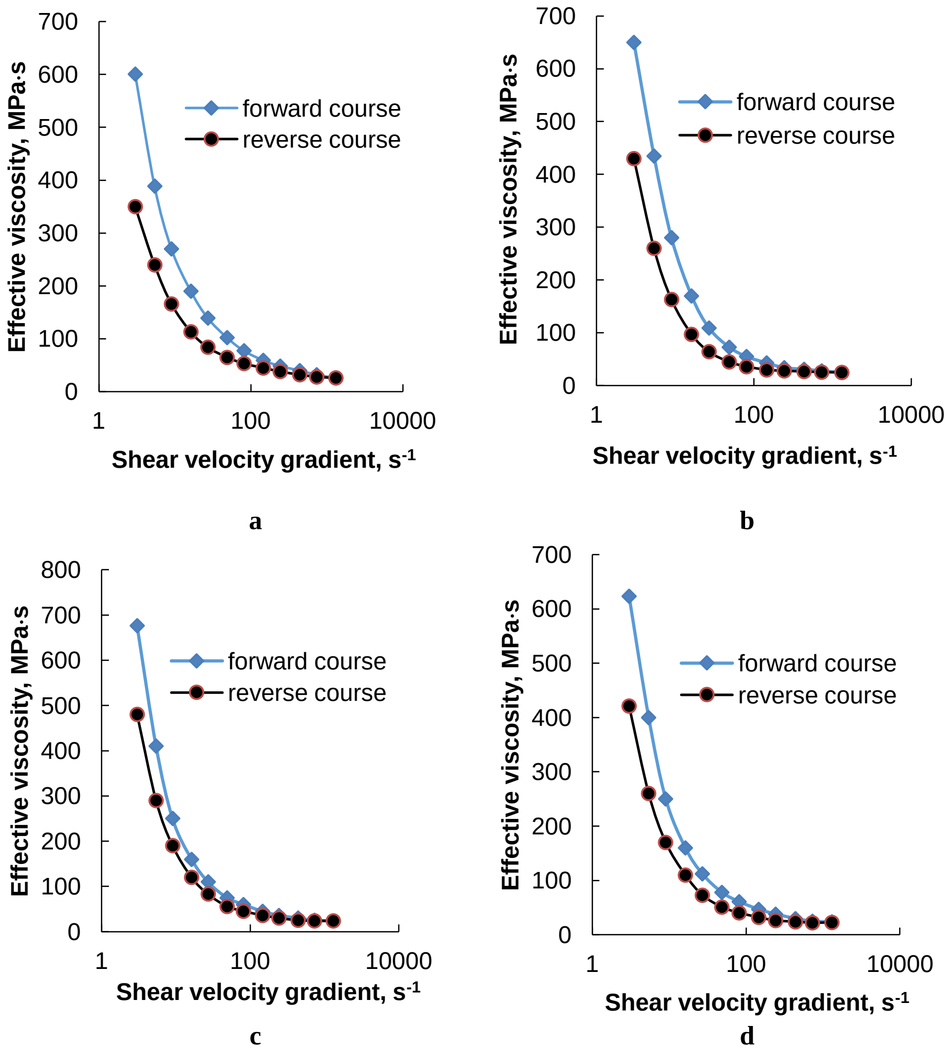

Figure 2. Flow rheograms of whey ice cream mixes:
a, control; b, ice cream mix added with micellar casein, 3%;
c, ice cream mix added with whey protein isolate, 3%;
d, ice cream mix added with whey protein isolate, 5%

The analysis of flow rheograms of the studied samples indicates the ability of micellar casein added in amount of 3% to more effectively restore the structure of food systems than for the control sample. Ice cream mixes (Fig. 1) belong to systems with a pronounced coagulation structure, but samples with whey protein isolate, 3–5%), show the highest thixotropic properties. This effect could be explained by the specific functional properties of whey proteins, in particular, their ability to form a spatial coagulation structure capable of spontaneous restoration of the structure after destruction in the presence of numerous low-energy bonds.

Conclusions

Micellar casein and whey protein isolate in the composition of whey ice cream mixes show technological activity and increase the foam overrun and foam resistance of the finished product. Thus, the foam overrun of the mix with micellar casein, 3%, was 229.7%, and with whey protein isolate, 3-5%, was 221.5–246.7%. The highest rate of foam resistance, 57.6–58.4%, was recorded with the use of 3–5% whey protein isolate.

The highest thixotropic ability was observed for mixes containing 3% micellar casein, 66.1%, and 3–5% whey protein isolate, 67.6–72.6%. The use of whey protein concentrate has a moderate effect on the rheological characteristics of mixes. The presence of soy protein isolate leads to a partial loss of the mixture's ability to self-restore the destroyed structure.

The perspective of further research is to determine the quality indicators of samples of whey ice cream with protein additives at various stages of low-temperature processing.

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Application of a multi-component bakery improver in the technology of wheat bread enriched with the mixture of sprouted grains

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Abstract

Introduction. The aim of the study was to develop the composition of a multi-component baking improver to preserve the sensory properties and prolong the freshness of bread made from wheat flour with the addition of a mixture of germinated grains.

Materials and methods. The development of the composition of the multi-component baking improver (MBI) was carried out using the influence of individual food additives on the quality of bread. The effect of MBI on bread staling was assessed by changing the deformation of the crumb, the formation of an under crust layer, and the accumulation of aromatic substances and dextrins in the bread.

Results and discussion. The composition of MBI includes whey powder enriched with Mn and Mg, wheat gluten powder, chicory inulin, carboxymethyl cellulose, lactic acid, phosphatide concentrate, and enzyme preparation Deltamalt FN-A50. For the production of wheat bread containing a mixture of sprouted grains, 15% by weight of flour, it is advisable to add the multi-component baking improver in the amount of 1.8% by weight of flour. Addition of MBI ensured the sensory characteristics and specific volume of bread enriched with the mixture of sprouted grains, which did not differ from control. Incorporation of the multi-component baking improver increased the overall, plastic and elastic deformations of the crumb of the bread, reduced the crumb's crumbliness and the thickness of the under crust layer. The deformation of the crumb of bread enriched with a mixture of sprouted grains and developed multi-component baking improver was after 72 hours of storage by two times greater than of the control (wheat bread). In bread containing the mixture of sprouted grains, 15% to the weight of flour, the addition of the multi-component baking improver increased the accumulation of low molecular weight dextrins by 77.6% compared to control.

Conclusions. The use of the developed multi-component baking improver has a positive effect on the quality of wheat bread enriched with the mixture of sprouted grains and prolongs bread freshness up to 72 hours without packaging.

Introduction

According to the American Association of Cereal Chemists with the endorsement of the United States Department of Agriculture "Sprouted grains are malted or sprouted grains containing all of the original bran, germ, and endosperm shall be considered whole grains as long as sprout growth does not exceed kernel length and nutrient values have not diminished" (Benincasa et al., 2019). Sprouting activates grain metabolism resulting in the synthesis of secondary metabolites such as various enzymes, vitamins, and phytochemicals, degradation of macronutrients compounds such as proteins and carbohydrates to increase their digestibility, and has often used as a method to improve the nutritive value of grains (Benincasa et al., 2019; Park et al., 2021; Peñaranda et al., 2021). This is a reason to use germinated grain seeds as a source of biologically valuable components in preparation of functional foods, production of which is one of the modern trends in food technology (Ivanov et al., 2021; Peñas and Martínez-Villaluenga, 2020).

The mixture of sprouted grains (MSG) containing equal amounts of sprouted wheat, oats, barley, and corn grains produced by the company Choice, Ukraine was used as non-traditional raw material in the present study. This mixture of sprouted grains is rich in vitamins (A, E, B1, B2, B3, B5, B6, B9, H, choline, PP), trace elements (boron, molybdenum, selenium, chromium, iron, vanadium, manganese, zinc, iodine, copper, fluorine), minerals (potassium, calcium, silicon, magnesium, phosphorus), essential amino acids (valine, isoleucine, leucine, lysine, methionine, threonine, tryptophan, phenylalanine), and enzymes (lipase, cytase, proteases, phosphatases, α- and β-amylases) (Choice Sprouted Grains, https://uakrasa.net/en/choice-proroshcheni-zerna-paket-150g/).

In our previous study based on the results of trial baking, the dosage of the mixture of sprouted grains 15% to the weight of the high-grade flour was recommended to improve the nutritional and biological values of bread (Burchenko, 2018). It was found that addition of the mixture of sprouted grains to wheat flour reduces the volume of bread and its porosity (Burchenko, 2018). The application of bakery improvers allows to eliminate the negative impact of non-traditional raw materials on the quality of dough and bread, as well as intensify the technological process and extend the freshness period of bakery products (Bilyk et al., 2020; 2022).

To increase the quality ad prolong freshness of products made with the addition of a mixture of sprouted grains, it is advisable to use multi-component baker improvers containing fillers (wheat flour, soybean flour, starch), oxidizers, reducing agents, enzymes, emulsifiers, malt flour, malt extract, modified starches, calcium sulfate, calcium carbonate, calcium propionate, calcium phosphate, ammonium chloride, carbohydrates (sucrose, glucose), lecithin, soy flour, acids (citric, lactic), protein supplements (dry gluten, dry milk, vegetable protein), and hydrogenated vegetable oils (Codina et al., 2007; Courtin and Delcour, 2002; Liang et al., 2021; Zhygunov et al., 2019).

The aim of the present study was the development of a multi-component baking improver that will increase the quality of products and extend their freshness period when using an addition to wheat flour the mixture of sprouted grains of wheat, oats, corn, and barley. To create multi-component baking improver the components, which belong to food additives, which are Generally Recognized as Safe (GRAS), were used.

Materials and methods

Materials

The mixture of wheat, oats, barley, and corn sprouted grains produced by the company Choice, Ukraine, was used in the study. Dough was prepared using high grade wheat flour.

Preparation of dough samples

Dough samples were prepared according to the recipe, g: high grade wheat flour, 100.0; pressed baker's yeast, 3.0; salt, 1.5; the mixture of wheat, oats, barley, and corn sprouted grains, 15.0. The dough was kneaded in a two-speed Escher kneading machine (Italy) straight with a moisture content of 44.0%. The fermentation period was replaced by a 20-minute proofing period. Dough processing was carried out manually, the proofing was carried out at a temperature of 38±2°C and a relative humidity of 78±2 % until ready. Bread was baked in a Sveba-Dahlen cabinet oven (Italy) at a temperature of 200–220 °C in a humidified baking chamber for 30 minutes. All experiments were performed at least in triplicate.

Methods

Specific volume of bread

The specific volume of bread was determined by dividing the volume of bread by its weight and expressed in cm^3/g (Zhu et al., 2016).

Porosity of bread

The porosity of bread reflects the volume of the pores in a certain volume of the crumb, expressed as a percentage to the total volume (Verheyen et al., 2015).

Complex quality indicator

Quality evaluation of finished products was carried out based on sensory, physical, and chemical properties of bread, and expressed as a calculated complex quality indicator. The complex quality indicator is the total number of points that the experimental sample receives during its analysis. For its calculation, each product was evaluated by the following properties: correct form, specific volume, shape stability, crust color, crust surface condition, crumb color, porosity structure, crumb rheological properties, staling after 72 hours, bread aroma, bread taste, crumb chewiness. The obtained values were evaluated on a five-point scale, taking into account the weighting factor, which was established for each indicator through expert evaluation. That is, the number of points assigned to the indicator was multiplied by the weighting factor. Next, the sum of the obtained values was found. The greater the number of points the sample receives as a result of the calculation, the better its quality indicators (Bilyk et al., 2022). The expert commission included seven candidates of technical sciences, three post-graduate students for a doctor of philosophy degree and 15 students of higher education in the specialty "Food Technologies".

Crumb deformation

The duration of freshness preservation of the products was studied by the changes in the structural and mechanical properties of the crumb. Its total deformation after 48 hours of storage was determined using an AP 4/1 penetrometer "Finemass" (Germany) (Bilyk et al., 2022).

Content of aromatic substances

The content of aromatic substances in finished products was estimated by the amount of bisulfite-binding compounds (Bilyk et al., 2022).

Condition of the under crust layer

The degree of staleness was assessed by hand through the area and hardness of the under crust layer. Using scanning and graphic editors, the average thickness of the under crust layer was determined (Petrusha et al., 2018).

Microscopy of bakery products

Microscopy of bakery products was carried out after 72 hours of storage. The samples were stored without packaging at a temperature of 20±0 °C. Preparation of samples was carried out by freezing, freeze-drying, and spraying carbon on a dried sample in a vacuum chamber. The samples were examined using an electron scanning microscope IEOLJSMM–200 (Japan) at 1000 magnification, and the most visible areas were photographed.

Dextrin content

Dextrin content was determined by their mass fraction, based on the ability of dextrins to precipitate at different concentrations of ethyl alcohol in the solution (Bilyk et al., 2022).

Results and discussions

Development of a multi-component baking improver

A multi-component baking improver for bread from high-grade medium strength wheat flour containing 15% of a mixture of sprouted wheat, oats, barley, and corn grains to the weight of flour was proposed. Such food additives with GRAS status were chosen for the multi-component mixture: (1) apple pectin (Zhang et al., 2019), dry wheat gluten, carboxymethyl cellulose (Ammarab et al., 2020), chicory inulin, dry whey enriched with Mg and Mn (Kochubei-Lytvynenko et al., 2023) as moisture-retaining additives; (2): phosphatide concentrate (Gómez et al., 2004) as surface-active substances (3) amylolytic enzyme preparation Deltamalt FN-A50, and (4) lactic acid as a natural oxidizer.

Based on the results of trial baking, complex quality indicators of high-grade wheat bread with different multi-component baking improvers were calculated (Table 1).

According to the complex quality indicator, the best amounts of the components in wheat bread, % to the weight of flour, were: 0.5% for dry whey enriched with Mn and Mg; 0.004% for enzyme preparation Deltamalt FN-A50; 0.4% for carboxymethyl cellulose; 0.5% for dry wheat gluten; 0.6% for apple pectin; 1.0% for chicory inulin; 0.3% for phosphatide concentrate, and 0.2% for lactic acid (Table 1). During the preparation of multi-component baking improver, it is recommended to halve the found dosage of the component due to the synergistic effect in case of simultaneous their application (Bilyk et al., 2020). As a result, a recipe included 15% mixture of sprouted grains to the mass of flour, for a multi-component baking improver was developed. This improver intended to intensify the technological process, improve consumer properties, and extend the freshness of wheat bread (Table 2).

Table 1

Determination of the best dosage of ingredients in multi-component baking improver

The complex quality indicator		Dosage of component, %, to the mass of flour				
Control	15% mixture of sprouted grains					
		Dry whey enriched with Mn and Mg				
		0.25	0.5	0.75	1.0	1.25
84.6	76.2	80.6	82.1	82.2	82.6	82.8
		Enzyme preparation Deltamalt FN-A50				
		0.001	0.002	0.004	0.006	0.008
84.6	76.2	78.2	81.6	86.4	86.4	86.4
		Carboxymethyl cellulose				
		0.1	0.2	0.3	0.4	0.5
84.6	76.2	80.6	82.9	84.3	86.7	86.2
		Dry wheat gluten				
		0.2	0.3	0.4	0.5	0.6
84.6	76.2	79.2	80.6	81.4	82.3	82.3
		Apple pectin				
		0.2	0.4	0.6	0.8	1.0
84.6	78.4	80.8	82.2	84.9	84.8	84.5
		Chicory inulin				
		0.2	0.4	0.6	0.8	1.0
84.6	76.2	82.2	83.1	84.3	86.6	86.8
		Phosphatide concentrate				
		0.10	0.20	0.30	0.40	0.50
84.6	76.2	80.5	81.9	82.6	82.6	82.5
		Lactic acid				
		0.1	0.15	0.2	0.25	0.3
84.6	76.2	80.8	81.6	81.6	81.5	81.4

Table 2

Composition of multi-component baking improver

Component	Amount, kg per 100 kg
Chicory inulin	28.5
Dry whey enriched with Mn and Mg	14.3
Dry wheat gluten	14.3
Apple pectin	17.1
Carboxymethyl cellulose	11.4
Phosphatide concentrate	8.6
Deltamalt FN-A 50 enzyme preparation	0.1
Lactic acid	5.7
Total	100.0

To further study the effect of the developed polycomponent mixture on the structural and mechanical properties of dough and biochemical processes in it, the recipe with 15 % mixture of sprouted grains (MSG) and 1.8% multi-component baking improver (MBI) to the mass of flour was chosen (Table 3, Figure 1).

Table 3

Effect of a multi-component baking improver on the technological process and quality of wheat bread

Indicator	**Control (without additives)**	**15% MSG to the mass of flour**	**15% MSG and 1.8% MBI to the mass of flour**
Dough			
Moisture, %	44.0		
Titrated acidity, degrees: initial	1.6	2.0	2,2
final	2.0	2.4	2.6
Proofing time, min	60	50	50
Gas formation in the dough during fermentation and proofing, cm^3/100 g of dough	812	992	1058
Bread			
Specific volume, cm^3/100 g	298	263	312
Shape stability, H/D	0.47	0.25	0.48
Acidity, degrees	1.8	2.4	2,2
Porosity, %	78.0	64.0	82.0
Total crumb deformation, penetrometer units: 4 hours	84	98	106
72 hours	42	74	88
Crumb condition and color	Smooth without cracks and tears, light yellow color	Smooth without cracks and tears, golden color	
Correct form	Bread with a noticeably convex upper crust	Bread with a dome-shaped upper crust	
Crumb color	Light white	Gray	Light gray
Porosity structure	Small, thin- and medium-walled pores, distributed fairly evenly	Pores of different sizes, medium thick, unevenly distributed	Small, thin- and medium-walled pores, distributed fairly evenly
Taste and aroma	Typical for this type of product without extraneous taste and smell	Typical for this type of product with a pleasant taste and aroma, the aftertaste of sprouted grains can be felt	

Figure 1. Breads:
1, control (without additives); 2, with 15% mixture of sprouted grains to the mass of flour; 3, with 15% mixture of sprouted grains and 1.8% multi-component baking improver to the mass of flour.

It was found that the mixture of sprouted grains added in amount of 15% to the mass of flour leads to a deterioration of the sensory, structural, and mechanical properties of the finished product that can be explained by the excessive activity of amylolytic and proteolytic enzymes in the germinated cereals. The developed multi-component baking improver increased the quality of wheat bread prepared with the addition of the mixture of sprouted grain. Multi-component baking improver has a positive effect on the rheological properties of the dough. The duration of dough proofing with the mixture of sprouted grains and with mixture of sprouted grains and multi-component baking improver was 50 minutes, which was 10 minutes less than for the control sample. The initial and final acidity of dough increases in comparison with the control sample by 0.6 degrees. Gas formation in the dough with multi-component baking improver increases by 23.3%, which is a base for the increasing of the specific volume in the breads. Due to using the developed multi-component baking improver, the specific volume of breads increases by 15.7% and by 4.5% compared to the control sample. The dimensional stability of floor products approaches the results of the control sample. The acidity of the breads increased compared to the control sample by 0.6 degrees and 0.8 degrees, respectively, but did not exceed the permissible values. When adding multi-component baking improver, the porosity of the breads improves. Thus, the bread with the mixture of sprouted grains and multi-component baking improver had a porosity of 82%, which is by 22% more than for the bread with mixture of sprouted grains and by 4.9% more than of the control sample. When adding the mixture of sprouted grains and multi-component baking improver to the dough, the total, plastic, and elastic deformations of the crumb have been improved.

Application of the developed multi-component baking improver helps to preserve of freshness of bread. Thus, the deformation of the crumb of bread enriched with a mixture of sprouted grains and developed multi-component baking improver was after 72 hours of storage by two times greater than of the control (wheat bread). The application of multi-component baking improver enhanced the sensory properties of bread: the crumb color of the bread lightens; the porosity structure becomes uniform, the pores are thin-walled and medium in size; the crumb becomes elastic, the lumpiness and stickiness disappear. Bread has a pleasant taste and aroma, and the taste of sprouted grains can be felt.

Effect of a multi-component baking improver on the quality and prolongation of the shelf life of wheat bread with the mixture of sprouted grains

The taste and aroma of bread are important consumer properties (Meziani, 2012). Therefore, the effect of the mixture of sprouted grains and a developed multi-component baking improver on the flavor of bakery products was studied. The formation of taste and aroma depends on the recipe composition and the fermentation process. Incorporation of the mixture of sprouted grains and multi-component baking improver in the dough changes the content of proteins, carbohydrates, and fats, which leads to the changes in aroma formation, namely, due to increase in the amount of carbonyl compounds.

The improved aroma of bread, namely, the increased content of bisulfite-binding compounds, is explained by the fact that the mixture of sprouted grains increases the content of sugars and amino acids. Ingredients of multi-component baking improver, namely dry milk whey, dry wheat gluten, and apple pectin additionally increase the content of protein that increases the number of carbonyl compounds and slow down their release during the storage of bread. The composition of the developed multi-component baking improver includes apple pectin, phosphatide concentrate, dry whey enriched with Mg and Mn, and chicory inulin, which accelerate the fermentation process and contribute to the accumulation of aromatic substances. So, the content of carbonyl compounds in finished product increases by 2.1 times caused the improvement of crust color and bread aroma.

During cooling and storage, the internal process of moisture migration takes place in bread due to the driving force, which is the gradient of relative moisture content between structurally different parts of the product, namely, the crumb and the crust. The gradient of relative moisture content is formed due to the baking process where the crust, which is exposed to high temperatures, is crispy, and the crumb, which is formed at lower temperatures, is soft. This causes parts of the same product to have different moisture content, therefore, its equalization takes place during the storage period. This leads to the crust softening, the crumb staling, and a thicker under crust layer forming.

Table 4

Content of bisulfite-binding substances, mg-eq/100 g of bread

Part of bread	Control (without additives)	15% MSG* to the mass of flour	15% MSG and 1.8% MBI** to the mass of flour
After 4 hours			
Crumb	6.2	11.8	13.6
Crust	18.9	26.1	29.2
After 24 hours			
Crumb	5.2	10.1	12.3
Crust	16.2	26.1	27.2
After 48 hours			
Crumb	4.4	9.1	11.4
Crust	14.1	20.2	25.3
After 72 hours			
Crumb	3.1	7.2	9.1
Crust	12.8	15.1	20.8

*MSG, mixture of sprouted grains; **MBI, multi-component baking improver.

Addition of the mixture of sprouted grains and combined use of mixture of sprouted grains and developed polycomponent mixture reduce the formation of the under crust layer, and therefore have a positive effect on slowing down the staling process of bakery products (Figure 2).

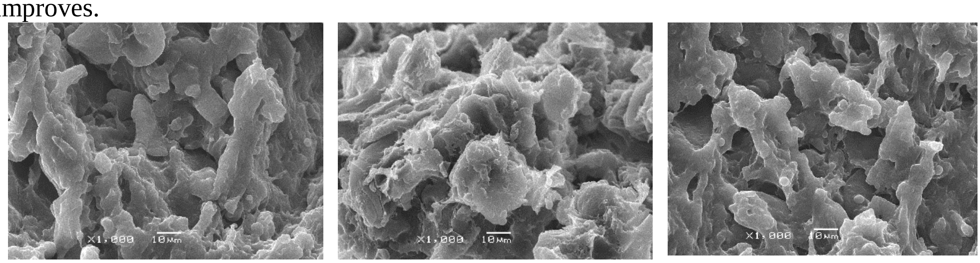
1 2 3

Figure 2. Formation of under crust layer during the storage of bakery products after 72 hours: 1, control (without additives); 2, with 15% mixture of sprouted grains to the mass of flour; 3, with 15% mixture of sprouted grains and 1.8% multi-component baking improver to the mass of flour.

It was shown that the under crust layer in the bread with mixture of sprouted grains or mixture of sprouted grains and multi-component baking improver after 72 hours of storage was thinner compared to the under crust layer of the control. To confirm it, a section of breads was scanned and the thickness of the under crust layer was measured. It was found that the under crust layer was 10.4 mm in the control bread, 8.5 mm in the bread with 15% mixture of sprouted grains, and 3.24 mm in the bread with 15% mixture of sprouted grains and multi-component baking improver (Figure 2).

To confirm the positive effect of addition of the mixture of sprouted grains and the combined use of the mixture of sprouted grains and multi-component baking improver on the crumb, microscopy of bakery products was carried out after 72 hours of unpacked storage at a temperature of 20 °C. Prepared samples were examined using an electron scanning microscope IEOLJSMM-200 with a magnification of 1000 and the most revealing, characteristic areas were photographed. The analysis of microphotographs showed that when using the mixture of sprouted grains or the mixture of sprouted grains combined with developed multi-component baking improver, the crumb consists of swollen and partially pasteurized starch grains, which are interspersed in a solid mass of coagulated proteins, with few visible layers of air (Figure 3).

The microphotograph analysis of the control sample showed that the crumb is characterized by the presence of voids formed due to the transition of starch from an amorphous to crystalline state and protein compaction. Thus, addition of the developed multi-component baking improver showed positive effect on the sensory properties of wheat bread with the mixture of sprouted grains, the formation of the under crust layer decreases when storing the products in unpackaged form for 72 hours, and the structure of their crumb improves.



1 2 3

Figure 3. Microstructure of wheat bread after 72 hours of storage:
1, control (without additives);
2, with 15% mixture of sprouted grains to the mass of flour;
3, with 15% mixture of sprouted grains and 1.8% multi-component baking improver to the mass of flour.

An increase in sugar content leads to improved porosity of bakery products: it becomes more thin-walled and uniform, the taste of the products improves, and the shelf life is extended (Müller et al., 2021). It is also known that increased autolytic activity contributes to the accumulation of dextrins during baking, which in turn extends the shelf life. Due to the fact that mixture of sprouted grains has high autolytic activity and high content of its own sugars (Lazaridou, 2027), and multi-component baking improver includes the enzyme preparation Deltamalt FN-A50, which reduces the autolytic activity of the dough system, it was expedient to study the change in the amount of dextrins in wheat bread. Determination of dextrin content was carried out 4 hours after cooling (Table 5).

Table 5

Dextrin content in breads

Bread samples	Dextrin content of by fractions, % to dry matter			Total dextrin content
	Amylo-dextrins	Erythro-dextrins	Malto- and macro-dextrins	
Control (without additives)	0.786	0.274	0.634	1.694
15% SGM to the mass of flour	1.426	0.542	1.246	3.214
15% SGM and 1.8% MCM to the mass of flour	1.236	0.421	1.126	2.783

The results confirmed an increase in the amount of dextrins compared to the control when using the mixture of sprouted grains or the mixture of sprouted grains combined with multi-component baking improver. It is known that low molecular weight dextrins, namely malto-dextrins and acro-dextrins, extend the shelf life of bakery products due to the formation of a three-dimensional network that prevents starch from giving off moisture and thus slows down its retrogradation. Thus, in bread with 15% mixture of sprouted grains to the weight of flour, the use of multi-component baking improver increases the accumulation of low molecular weight dextrins by 77.6% compared to the control. Therefore, the developed multi-component baking improver contributes to the accumulation of low molecular weight dextrins, which slow down the process of wheat bread going stale.

Conclusions

1. To produce wheat bread with increased nutritional and biological values, a mixture of sprouted wheat, oats, barley, and corn grains was included in the recipe. With the dosage of mixture of sprouted grains being 15% to the mass of flour, there is some deterioration of the sensory, structural, and mechanical properties of the finished product, which can be explained by the excessive activity of amylolytic and proteolytic enzymes of mixture of sprouted grains. In order to increase the quality of wheat bread, it is recommended to use multi-component bakery improvers.
2. A composition of multi-component baking improver has been developed, which is intended for intensifying the technological process and improving the quality of finished products. The composition of the multi-component baking improver includes food additives that are Generally Recognized as Safe. The developed multi-component baking improver has a positive effect on the quality of wheat bread enriched with the mixture of sprouted grains.
3. In the production of wheat bread which contains 15% of the mixture of sprouted grains to the mass of flour, it is advisable to use the developed multi-component baking improver in the amount of 1.8 % to the mass of flour.
4. Application of the developed multi-component baking improver extends the freshness of bakery products. The mixture of sprouted grain and the developed multi-component baking improver contribute to the accumulation of low molecular weight dextrins, which slow down the staling process due to the formation of a three-dimensional network that prevents the loss of water by starch. It has been confirmed that in the bread with a multi-component baking improver, the crumb of products stored for 72 hours without packaging consists of a solid mass of proteins coagulated during baking, in the middle of which swollen, partially gelatinized starch grains are interspersed with few layers with visible air, which confirms the slower starch retrogradation.

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Influence of electrochemically activated water on the rheological indicators of starch suspensions

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Abstract

Introduction. The purpose of the work is to determine the influence of electrochemically activated water (catholith and anolyte) on the rheological indicators of corn starch suspensions under different temperature regimes.

Materials and methods. The functional and technological properties of corn starch were investigated in terms of water-absorbing, moisture-retaining, fat-absorbing and fat-retaining ability. The influence of electrochemically activated water on these parameters were determined in comparison with tap water. Rheological characteristics of starch suspensions prepared on electrochemically activated water were determined at different temperatures on a Kinexus Pro+ rheometer.

Results and discussion. Electrochemically activated water causes change in the functional and technological properties of corn starch: the water absorption and moisture retention ability of starch prepared on catholyte decreased by 26% and 10%, and when anolyte is added, it increased by 18% and 36%, compared to the sample on tap water. Starch is able to absorb more amount of water in an acidic medium (anolyte) than in an alkaline one (catholite). Electrochemically activated water also has a significant effect on the rheological parameters of starch suspensions: when the shear rate changed in the range of 0.1–100 s^{-1}, the shear stress increased linearly. At the temperature of gelatinization shear stress was 0–10.6 Pa, 0–13.6 Pa and 0–23.8 Pa for control sample, sample on anolyte and catholyte, respectively. At a temperature of 25 ºC, the change was greater – 0–19.5 Pa, 0–28.4 Pa, and 0–30.8 Pa, respectively. At zero shear rate, the initial shear viscosity of suspensions at 25 ºC and at 68 ºC on the catholyte and anolyte was higher than the control sample. When the shear stress changed at 25 ºC, the values of the shear viscosity increased, having the highest values at the final stage on the catholyte and anolyte – 1.7 and 13 Pa·s compared to the control sample – 0.6 Pa·s. At 68 ºC, the trend of change of the studied indicator is similar, but the initial values are higher than the corresponding values at 25 ºC, and the final values are lower. The angular velocity index increased linearly with a change in shear stress.

Conclusion. The conducted research show that electrochemically activated water has a significant impact on the functional and technological properties and rheological characteristics of semi-finished products, in particular corn starch suspensions, which in turn will have an impact on some indicators and structure of food products with this raw material.

Introduction

Studying the regularities of the physico-chemical and biochemical processes in the human body, first of all, attention is paid to water and food products as factors which cause the course of these processes. Water is a sensor of physical and chemical factors of influence in the environment and human body. These factors cause changes in physical and chemical properties of water and its biological activity (Ivanov et. al, 2021). The statistical conclusion of the WHO indicates that 70% of diseases in the world are associated with poor-quality drinking water (WHO, 2022).

The biological activity of water caused by increased electronic or proton activity is related to the fact that water is a quantum-mechanical system consisting of free and associated water phases (Cejka et. al., 2017; Tamaki et. al., 2016).

The association of charged dipole water molecules in clusters is carried out due to hydrogen bonds between different electric poles of neighboring water molecules. After the destruction of associates in the aqueous medium, when heated, H_2O monomolecules appear in large quantities (Iino et. al., 2009).

Saturated with molecular hydrogen water has a positive effect on the human body, but molecular hydrogen has a low solubility in water. Due to the high diffusivity of hydrogen, its concentration in water is unstable and changes rapidly, approaching zero under normal conditions. In this regard, hydrogen water involves either immediate use or special storage conditions (Kurokawa et. al., 2011).

It was established that under the influence of non-reagent factors such as electromagnetic field, light radiation, heating, cooling or freezing with subsequent thawing, a change in the kinetics of chemical and biochemical reactions in water occurs. Such changes influence on its solubility, as well as biological activity. This takes place under the condition of constancy of the elemental chemical composition of the factors associated with the consumption of external energy (Mghaiouini et. al., 2020).

One of the most effective methods of water activation is electrochemical activation. The essence of the process is the electrophysical and electrochemical action on the aqueous solution of ions and molecules in the space charge zone in the immediate vicinity of the surface of the electrodes under conditions of non-equilibrium transfer of charges through the "electrode-electrolyte" interface by electrons (Ignatov et. al., 2015). At the same time, water is saturated with oxygen, changes own energy state, accelerates the removal of metabolic waste and promotes the most complete assimilation of nutrients by the human body from the substrate prepared with its use (Ignatov et. al., 2019).

Products of the starch-molasses industry are used in many branches of the food industry. The most common is the use of corn starch as an emulsifier and thickener (Silva et al., 2021).

Native corn starch has low thermal stability, high tendency to retrograde and low resistance to shear force. To solve this problem, it needs to be modified to improve its application in food industry. Hydrothermal modification is one of the physical modifications by heating the starch above the gelatinization temperature with a limited water content (Marta et al., 2022).

The task of studying the possibilities of drinking water acquiring signs of nutritional (biological) value by optimizing the content of macro- and microelements with biogenic properties in water and the influence of this water on the structure and characteristics of semi-finished and ready products is relevant. These tasks can be solved by developing new and improving existing methods of activating water used in the food industry and ways of using it in the manufacturing of food products.

Therefore, the aim of research is to determine the influence of electrochemically activated water (catholith and anolyte) on the rheological indicators of corn starch suspensions under different temperature regimes.

Materials and methods

Materials

Electrochemically activated water obtained by the electrochemical method was used for the research. To obtain electrochemically activated water, tap water was used (supplier – JSC "Kyivvodokanal"), which was characterized by redox potential (RP) = +224, pH=6. For activation, tap water is passed through the diaphragm electrolyzer. Two experimental samples of activated water were obtained with different set parameters of PR: catholyte (RP = -542±20, pH = 10) and anolyte (RP = +767±15, pH = 3).

Corn starch suspensions were prepared in the ratio of corn starch:water – 1:10 using catholyte and anolyte at a temperature of t = 23±2 ºC (the temperature at which starch modification begins), the suspensions were kept for 2 hours to ensure starch hydration. The control was a suspension sample prepared with tap water.

Methods

Water-absorbing ability of starch

Test samples weighing 0.5 g were placed in a beaker and dispersed in 50 ml of water. Samples were placed in pre-weighed centrifuge tubes and left for 30 minutes at room temperature. After that, the suspension was centrifuged for 30 min at 3500 rpm. The upper layer with water was removed and dried in a thermostat (drying cabinet) for 25 minutes at a temperature of 50 ºC to remove the remaining excess moisture. Then it was re-weighed.

Water-absorbing ability (WAA) was expressed in ml of absorbed moisture in 1 g of dry sample or %, which was determined by the formula:

$$WAA = (W_2 – W_1)\cdot 2$$

where W_1 is the mass of the test tube with a dry weight of the test sample;

W_2 is mass of the sample with tube after centrifugation (Silva et al., 2016).

Moisture-retaining ability of starch

Test samples weighing 0.5 g were placed in a heat-resistant beaker and dispersed in 50 ml of water.Samples were left for 30 minutes at room temperature. Next, the mixture was subjected to heat treatment in a water bath for 30 minutes (with constant stirring) to a temperature of 95±2 ºC in the center. Then they were cooled to a temperature of 10±2 ºC, placed in pre-weighed centrifuge tubes and centrifuged for 30 min at 3500 rpm. The upper layer with water was removed and dried in a thermostat (drying cabinet) for 25 minutes at a temperature of 50 ºC to remove the remaining excess moisture. Then it was re-weighed.

Moisture retaining ability (MRA) was expressed in ml of retained moisture in 1 g of dry sample or %, which was determined by the formula:

$$MRA = (W_2 – W_1)\cdot 2$$

where W_1 is the mass of the test tube with a dry weight of the test sample;

W_2 is the mass of the sample with tube after centrifugation (Silva et al., 2016).

Fat-absorbing ability of starch

Test samples weighing 0.5 g were placed in a beaker and dispersed in 15 ml of refined sunflower oil for 60 seconds. Then they were placed in weighed centrifuge tubes and kept at room temperature for 10 minutes, after which they were centrifuged for 30 minutes at 3500 rpm. The upper layer of the separated oil was removed, and the test tubes were left at an angle of 45º for 10 min to drain the remaining oil and weighed.

Fat-absorbing ability (FAA) was expressed in ml of absorbed oil in 1 g of dry sample or %, which was determined by the formula:

$FAA = (W_2 – W_1)·2$

where W_1 is the mass of the test tube with a dry weight of the test sample;

W_2 is mass of the sample with tube after centrifugation (Silva et al., 2016).

Fat- retaining ability of starch

Test samples weighing 0.5 g were placed in a heat-resistant beaker and dispersed in 15 ml of refined sunflower oil for 60 seconds. Then the mixture was kept at room temperature for 10 minutes. Then it was subjected to heat treatment in a water bath for 30 minutes (with constant stirring) to a temperature of 95±2 ºC in the center, followed by cooling to a temperature of 10±2 ºC. After that, it was centrifuged for 30 minutes at 3500 rpm. The upper layer of the separated oil was removed, and the test tubes were left at an angle of 45º for 10 min to drain the remaining oil. Afret that tubes with sample were weighed.

Fat-retaining ability (FRA) was expressed in ml of retained oil in 1 g of dry sample or %, which was determined by the formula:

$FRA = (W_2 – W_1) ·2$

where W_1 is the mass of the test tube with a dry weight of the test sample;

W_2 is mass of the sample with tube after centrifugation (Silva et al., 2016).

Rheological characteristics of starch suspensions

For conducting rheological research, suspensions were analyzed at temperatures of 25 and 68 ºC. Changes in the structure and rheological characteristics of corn starch were investigated after its modification using tap water and activated water. This study not only shows the ability of starch to swell and gelatinize, but also the change in the rheological characteristics of starch suspensions, which will make it possible to expand the use of activated water for the process of starch modification. Heat treatment was applied at 68 ºC, since this value is the average value of the temperature range of gelatinization of corn starch. In the temperature range of 25 – 68 ºC, starch gradually changed from one state to another (Malumba et al., 2010).

Determination of rheological characteristics was carried out on a Kinexus Pro+ rheometer. Using the Starch Paddle Plastic 2 Blade geometry, which is a coaxial cylinder with a paddle stirrer (PC34 SL0007 SS) mounted on a vertical shaft. The prepared suspension was placed in a cylinder at a height of 70 mm, the stirrer was lowered and brought to a temperature of 25 ºC. Viscosity and flow curves were determined by changing the shear rate with its gradual increase (0.1–100 s^{-1}) and shear stress (0–200 Pa), with 10 measurement points per decade. Each step was maintained until a steady state was reached in the minimum time. Similarly, the experiment was conducted after heating the suspension to 68 ºC (Alvarez et al., 2015).

Statistical analysis

All experiments were carried out in triplicate. The results are given as mean±standard deviation (SD). Differences were considered to be significant at validity of α=0.95. Statistical analysis was performed using XLstat (2020 version) software.

Results and discussion

Before using raw materials in food technologies, it is necessary to know their characteristics, because they can affect the structure and properties of products containing them. The rheological characteristics of starch suspensions are largely influenced by the functional features of the raw materials. Studies of water-absorbing (WAA), moisture-retaining (MRA), fat-absorbing (FAA) and fat-retaining (FRA) ability showed (Table 1) that corn starch has high water-absorbing ability - it is able to retain water 6.18 times more than its own weight, in particular due to small particle sizes (from 20 to 400 μm). This indicates that when using it in the recipes of food products, it is necessary to increase the amount of water. However, the moisture- retaining ability is low – it can hold water 0.58 times more than its own weight, which indicates that this component will not contribute to the product's long-term preservation of a wet state. The ability of starch to absorb and retain fat is 1.5 and 1.3 times more compared to its own weight, respectively.

Table 1

Functional and technological properties of corn starch

Indicator	Value, %
Water-absorbing ability	618±5
Moisture-retaining ability	58±1
Fat-absorbing ability	152±3
Fat-retaining ability	136±3

It is important not only to analyze the functional and technological properties of starch, but also the influence of electrochemically activated water on the studied parameters (Table 2).

Table 2

Functional and technological properties of corn starch when using electrochemically activated water

Indicator	Value, %
Water-absorbing ability (catholite)	592±5
Moisture-retaining ability (catholite)	48±1
Water-absorbing ability (anolyte)	636±5
Moisture-retaining ability (anolyte)	94±1

When adding catholyte to dry starch water-absorbing ability and moisture-retaining ability of starch decreased by 26% and 10%, and when anolyte is added it increased by 18% and 36%. This is due to various properties of water, in particular, pH. Starch is more able to absorb water in an acidic medium (anolyte) than in an alkaline one (catholite). In addition, the salts present in the catholyte prevent its absorption by starch granules (Han et. al., 2009).

Due to the peculiarities of the chemical structure and the ability to swell and gelatinize when heated in the presence of water, starch plays a decisive role in the formation of the structure and consumer properties of many products. Studies of the dependence of the change in shear stress (σ) on the shear rate (γ) of corn starch suspensions (Figure 1) showed a linear increase in the indicator.

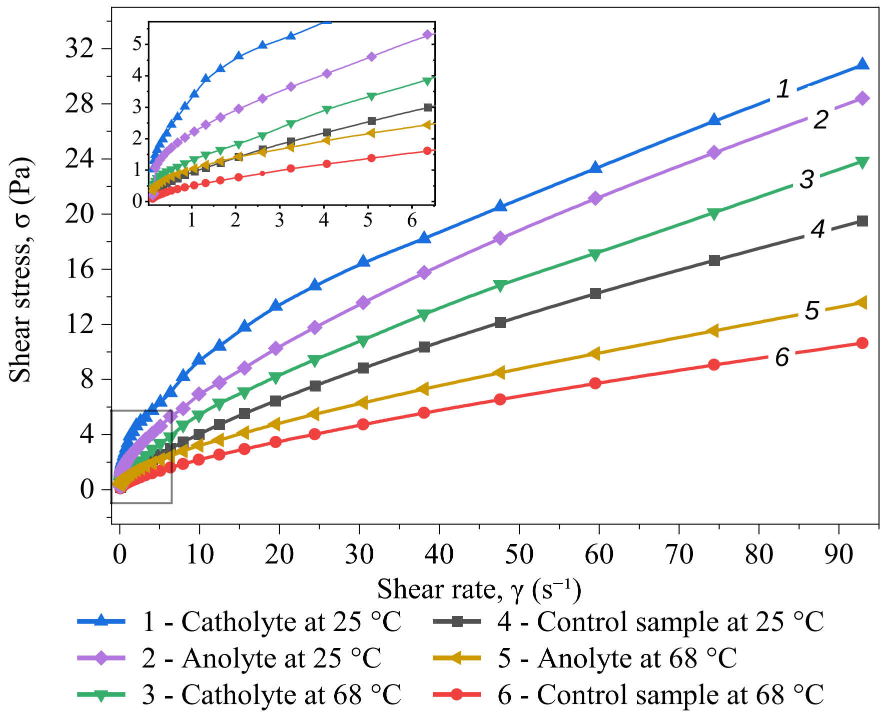

Figure 1. The dependence of the change in shear stress on the shear rate

As the shear rate increased in the entire range, the trajectory of change in shear stress of samples was similar. The samples had a lower shear stress at the gelatinization temperature: control sample, suspension on the anolyte and catholyte – 0–11 Pa, 0–14 Pa, and 0–24 Pa, respectively. At a temperature of 25 ºC the change was greater – 0–19 Pa, 0–28 Pa and 0–31 Pa, respectively. Analysis of the dependence of shear viscosity (η) on shear rate (γ) (Figure 2) showed that at zero shear rate, the initial shear viscosity of suspensions at 25 ºC and at 68 ºC on catholyte and anolyte was higher than for the control sample. At 25 ºC it was 8.6 Pa, 5.9 Pa and 1.6 Pa, respectively. At 68 ºC it was 3.8 Pa, 2.9 Pa and 0.8 Pa, respectively. This is explained by the fact that the increase in viscosity at zero shear rate partially corresponds to a higher degree of flocculation, since the formation of non-permanent loose aggregates from starch particles is more active when activated water is used (Fall et. al., 2017).

As the shear rate increases and the hydrodynamic forces become large enough to deform and break the flocs, a rapid decrease in viscosity occurs (McClements, 2005).

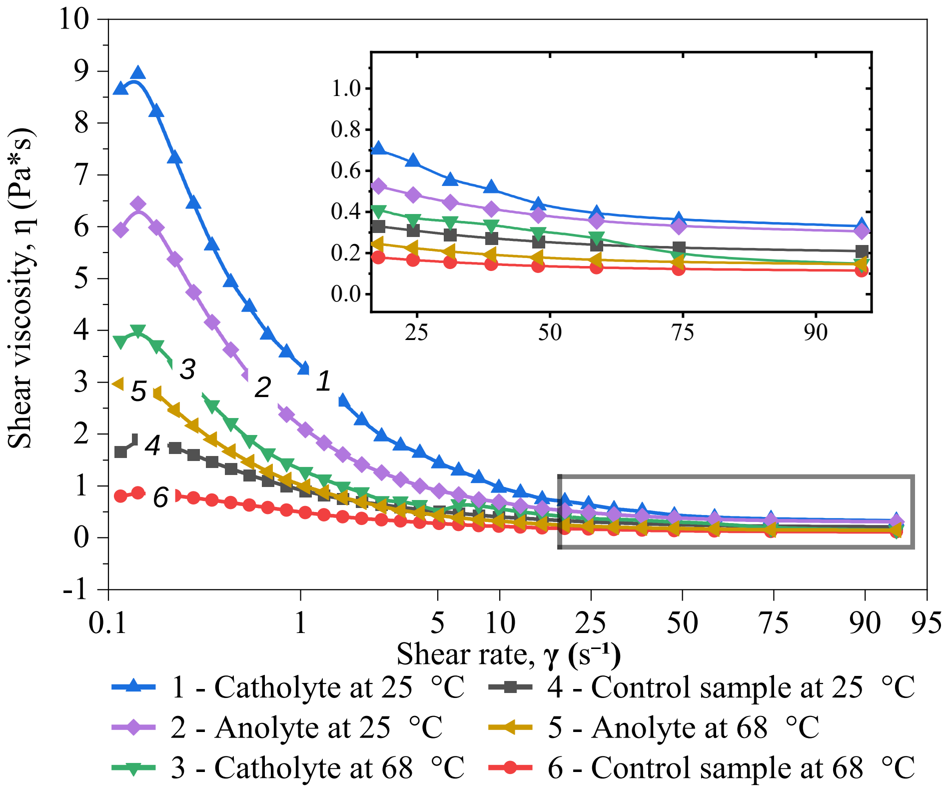

Figure 2. The dependence of the change in shear viscosity on the shear rate

When the shear rate increased to 50 s^{-1}, the shear viscosity of the samples gradually decreased: for the control sample it was slower, and for the samples of suspensions on activated water it was more rapid.

However, when the shear rate was more than 50 s^{-1}, all samples acquired almost the same shear viscosity. The nature of the change was hyperbolic and typical for all samples. However, the degree of change of the investigated parameter was not the same: for the sample on the catholyte at 25 °C the indicator decreased by 8.3 Pa·s, at 68 °C – by 3.7 Pa·s; for sample on anolyte – by 5.6 and 2.8 Pa·s; for sample on tap water – by 1.4 and 0.7 Pa·s.

Studies of the dependence of the change in angular velocity (θ′) on the shear stress (σ) for corn starch suspensions (Figure 3) showed an almost linear increase of the indicator.

The angular velocity when analyzing samples of suspensions prepared on activated water at a temperature of 25 °C was lower over the entire range of shear rate change than at a temperature of 68 °C. The same trend was observed for the control samples, but the values for them were quantitatively higher.

The values for samples at a temperature of 25 °C changed to a lesser extent: on catholyte – 0–0.2 rad/s, on anolyte – 0–0.3 rad/s, on tap water – 0–0.7 rad/s. At a temperature of 68 °C, the increase of the studied indicator was more rapid, but the dependence was clearly observed: on catholyte, anolyte and tap water – 0–0.6 rad/s, 0–0.8 rad/s and 0–1.3 rad/s in accordance.

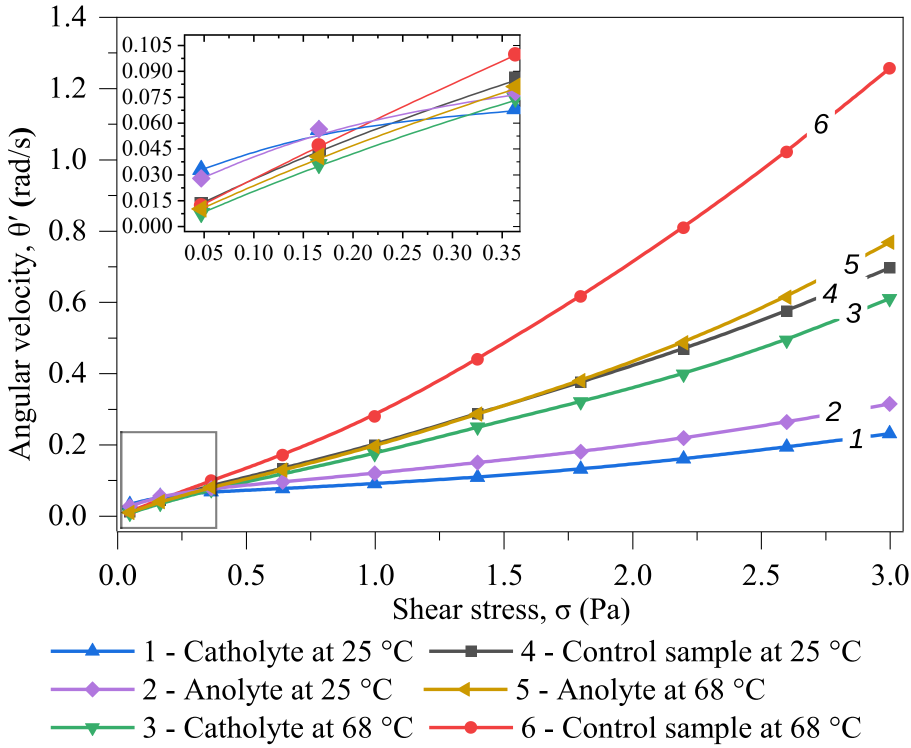

Figure 3. Dependence of the change in angular velocity on the shear stress

The flow curves of starch suspensions are shown in Figure 4. The analysis of the curves allows to make a conclusion about the strength of structural bonds in starch systems.

The initial shear viscosity (η) of suspensions at 25 °C on the catholyte and anolyte at zero shear stress (σ) was lower than of the control sample, which is explained by the fact that the initial viscosity is the result of hydration of amorphous starch. Hydrophilic groups cannot migrate to the interfacial area in the continuous phase (Taherian et al., 2008).

However, as the shear stress increased, its values change along the trajectory of the parabola, having the highest values at the final stage (1.7 and 1.3 Pa·s compared to the control sample – 0.6 Pa·s). This is facilitated by molecular rearrangements that accelerated the mobility between starch molecules when interacting with activated water and led to greater flexibility of the starch chain, which increased their ability to bind water molecules (Donmez et al., 2021).

At a temperature 68 °C the trend of change of the studied indicator is similar, but the initial values are higher than the corresponding values at 25 °C: 0.5 Pa·s and 0.4 Pa·s for control sample, 0.8 Pa·s and 0.2 Pa·s for sample on catholyte, 0.6 Pa·s and 0.2 Pa·s for sample on anolyte. On the contrary, the final values were lower: 0.3 Pa·s and 0.5 Pa·s for control sample, 0.6 Pa·s and 1.7 Pa·s for sample on catholyte, 0.5 Pa·s and 1.3 Pa·s for sample on anolyte. This is explained by the fact that high temperature and external force contributed to the entry of water molecules into starch granules (Shi et al., 2021).

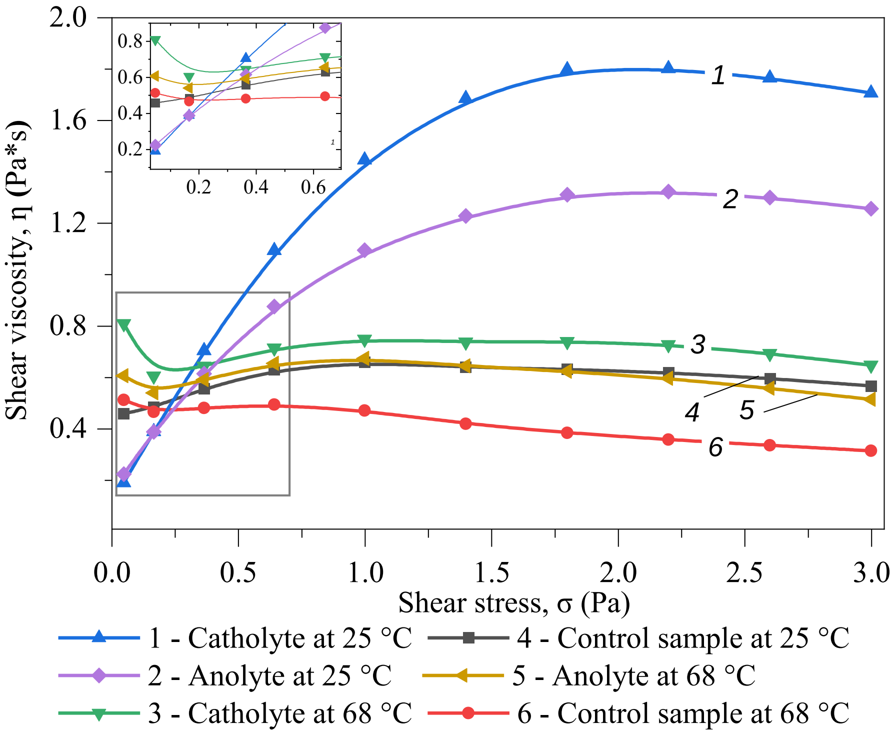

Figure 4. Dependence of shear viscosity on shear stress

Thus, on the basis of the conducted research, it was established that the electrochemical activation of water modifies its chemical composition and properties, contributes to changing the functional and technological properties of raw materials with its content, in particular corn starch. Electrochemical activation of water also has a significant effect on the rheological parameters of starch suspensions. This, in turn, will be reflected in the structural and mechanical properties of food products with the content of this semi-finished product in its composition and will form the structure of the product.

Conclusion

1. The functional and technological properties of food products are significantly influenced by the properties of raw materials. Corn starch has a high water absorption ability – it can hold water 6.18 times more than its own weight. The moisture-retaining ability is low – it can hold water 0.58 times more than its own weight. The ability to absorb and retain fat with starch is 1.5 and 1.3 times more than its own weight, respectively.
2. When adding catholyte water-absorbing ability and moisture-retaining ability of starch decreased by 26% and 10%, and when anolyte is added, it increased by 18% and 36%.

Starch is able to absorb more water in an acidic medium (anolyte) than in an alkaline one (catholite).

3. When the shear rate changes, the shear stress of starch suspensions also changes, namely, in the shear rate range of 0.1–100 s^{-1}, the shear stress increased linearly. At the temperature of gelatinization shear stress was 0–10.6 Pa, 0–13.6 Pa and 0–23.8 Pa for control sample, sample on the anolyte and catholyte, respectively. At a temperature of 25 ºC, the change was greater – 0–19.5 Pa, 0–28.4 Pa, and 0–30.8 Pa, respectively.
4. At zero shear rate, the initial shear viscosity of suspensions at 25 ºC and at 68 ºC on the catholyte and anolyte was higher than of the control sample. When the shear rate increased above 50 s^{-1}, all samples acquired almost the same shear viscosity. The degree of change of the studied parameter was not the same: for the sample on the catholyte at 25 ºC – by 8.3 Pa·s, at 68 ºC – by 3.7 Pa·s; on anolyte – by 5.6 and 2.8 Pa·s; on tap water – by 1.4 and 0.7 Pa·s.
5. When the shear stress changed at 25 ºC, the shear viscosity values increased, having the highest values at the final stage on the catholyte and anolyte – 1.7 and 13 Pa·s compared to the control sample – 0.6 Pa·s. At 68 ºC, the trend of change of the studied indicator was similar, but the initial values were higher than the corresponding values at 25 ºC, and the final values were lower.
6. The angular velocity indicator increased linearly with a change in shear stress. For samples at a temperature of 25 ºC, changes were in the range of 0–0.2 rad/s on catholyte, 0–0.3 rad/s on anolyte, 0–0.7 rad/s on tap water. At a temperature of 68 ºC: on catholyte, anolyte and tap water – 0–0.6 rad/s, 0–0.8 rad/s and 0–1.3 rad/s, respectively.
7. It was established that the electrochemical activation of water modifies its chemical composition and properties, contributes to changing the functional and technological properties of raw materials with its content, in particular corn starch. Electrochemical activation of water also has a significant effect on the rheological parameters of starch suspensions. This, in turn, will be reflected in the structural and mechanical properties of food products with the content of this semi-finished product in its composition and will form the structure of the product.

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Protein substances of oat bran and their influence on conformational transformations in dough and bread from wheat flour

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Abstract

Introduction. The aim of the work was to determine the degree of completeness of protein substances of oat bran and its influence on conformational transformations in the structure of dough semi-finished products and bread made from wheat flour.

Materials and methods. Oat bran, its amino acid composition and influence on the content of protein substances in bread were investigated. Conformational transformations of structural elements in dough and bread were investigated by infrared spectroscopy in the near-infrared region.

Results and discussion. The content of essential amino acids in oat bran is significantly higher than in premium wheat flour. The limiting amino acid in wheat flour is lysine, the amino acid score of which is 0.44. In oat bran the limiting amino acid is methionine, the amino acid score of which is 1.14, and the amino acid score of lysine is much higher than in wheat flour – 1.62. The limiting amino acid in bread is lysine, the amino acid score of which is 0.46. With an increase in the percentage of replacement of wheat flour with oat bran, the amino acid score of lysine increased by 19.5–52.2%. This indicates that the protein of this raw material helps to increase the level of essential amino acids in bread, which enriches its protein profile. The obtained spectra of the dough samples after kneading showed that the introduction of oat bran does not cause conformational changes in the dough system, since not enough time passed for the interaction of the biopolymers of the raw materials. The infrared spectra of the dough at a wavelength of 2100 nm showed that the dietary fibers of oat bran delay the development of the gluten network, the structure of the protein matrix of the dough with bran will be less stable and more weakened than that of the control sample.

Conclusion. The introduction of oat bran with a higher content of protein, dietary fiber and a complete amino acid profile into the recipe of wheat bread helps to improve the biological value of bread with this raw material. However, the deterioration of the development of the gluten framework of the dough, and therefore of the specific volume, porosity and dimensional stability of bread, requires the use of technological methods to minimize the negative impact of bran on the quality of finished bakery products.

Introduction

The problem of ensuring food security in the world is acute. Also, one of the vectors is orientation towards the sustainable development of production. In this concept, the disposal of food industry waste occupies an important place.

Waste-free production and the use of processed products of various crops are becoming widespread. From this point of view, bran is a valuable raw material (Ivanov et. al., 2021). Their use is recommended, in particular, in the technology of bakery production as a source of dietary fiber, which is especially necessary for people suffering from diseases of the gastrointestinal tract, such as irritable bowel syndrome (IBS).

Bran of various plants are used. Wheat bran is known to have a negative effect on the dough structure, resulting in a decrease in the specific volume of bread, which was confirmed using a 2D image analysis method, where wheat bran was observed to change the pore size distribution in the bread crumb. The properties of the dough, such as stickiness and extensibility, decreased with the increase in the amount of bran. Wheat bran increased dough aeration during kneading (Packkia-Doss et. al., 2019).

The results of using corn bran showed that their mixture with wheat flour has more water absorption and water retention capacity by 4–7% compared to wheat flour. However, the gas-holding capacity of the dough from such a mixture decreased. This led to a decrease in the volume of bread. In addition, moisture content and hardness increased with the addition of corn bran. The water activity of bread increased slightly with the addition of corn bran after 4 days of storage. The consumer properties of bread improved (Hussain et. al., 2021).

The use of barley bran in the amount of 25% instead of wheat flour increased the water absorption capacity of the dough to 71.5%, and also reduced the retrogradation of starch by 26.44%. The composite flour contained up to three times more β-glucan and significantly more total phenolics, including flavonoids. The content of slowly digestible and resistant starch increased. Inclusion of barley bran reduced starch retrogradation due to more amount of soluble starch and soluble amylose (Gujral et. al., 2018).

Oat bran is a more valuable source of protein and dietary fiber than hulled oat products (Sterna et. al., 2016; Zhong et. al., 2019). When adding oat bran to bread, the specific volume decreased with an increase in the amount of bran. In addition, a change in the fatty acid profile was observed, namely an increase in the content of unsaturated fatty acids, as well as an increase in the amount of dietary fiber.

Oat bran has good biological properties. The results showed that bran contains a large amount of β-glucan, which can be easily extracted. In addition, a decrease in the level of glucose in the blood of rats and a better digestibility of products with oat bran were found (Khan et. al., 2020).

It was established that the addition of bran to wheat dough reduces the density of the dough at the end of kneading mainly due to the increased water absorption capacity. Size of the bran particles has a small effect on this indicator. The addition of oat bran reduced the gas-holding capacity of the dough and the volume of the bread, indicating that oat bran exerted its effect mainly during proofing (Campbell et. al., 2008).

The effect of bran addition on gluten secondary structure and water behavior in wheat dough can be studied using Fourier transform infrared spectroscopy. Studies in the frequency range of 700-4000 cm^{-1} revealed that the addition of wheat bran to wheat dough caused a redistribution of bound water in the gluten-bran system. This redistribution of water affected the secondary structure of gluten in the dough, as evidenced by changes in the spectrum of the second derivative in the amide I region. In the hydrated state, the β-turn (in the form of a β-helix) was the main secondary structure (60%) in the wheat dough. The addition of bran caused the transformation of β-helices into β-sheets and random structures. However, the degree of this transformation in the presence of bran was proportional to the moisture content in the dough. This study showed that when wheat bran is added to gluten dough, the redistribution of water contributes to the partial dehydration of gluten and the transformation of β-helices into intermolecular β-sheet structures. This trans-conformation can be the reason for the low quality of bread with bran (Bock et. al., 2013). However, no data were found on the study of the influence of oat bran on the conformational transformations in the gluten network of the dough.

Therefore, the aim of the work was to determine the degree of completeness of the protein substances of oat bran and their influence on the conformational transformations in the structure of dough semi-finished products and bread made from wheat flour.

Materials and methods

Materials

The materials for research were premium wheat flour and oat bran.

Dough samples were prepared from wheat flour, pressed baker's yeast in the amount of 3% by weight of flour and salt in the amount of 1.5% by weight of flour. Samples were also prepared with replacement of wheat flour in the recipe with oat bran in the amount of 5%, 7%, 10% and 15%. The control was a sample without additional raw materials.

Essential amino acid composition

Method of ion exchange chromatography was used for determination of amino acid composition in oat bran, wheat flour and bread (Litvynchuk et. al., 2022). The first stage is hydrolysis of proteins and the second is determination of their quantitative estimation using automatic analyzer of amino acids (T-339, Mikrotechna, Czech Republic). polystyrene sulfonate ion ex-change resins were used in Li- citrate buffer one column mode. Li-citrate buffers have pH 2.75±0.01; pH 2.95±0.01; pH 3.2±0.02; pH 3.8±0.02; pH 5.0±0.2. The elutions of amino acids conduct in turn by these buffers. Amino acids were detected using photometer (Unicam SP 800, Great Britain) at a wave-length of 560 nm by a rectification with a ninhydrin solution. The results of detection were regis-tered by a variplotter in form the peaks of absorption of light of ninhydrin-positive substances in an eluent. These peaks are in direct ratio concentrations of this substance in solution. Temperature of thermostatic was T1=38.5 °C; T2= 65 °C. Correlation of solution of ninhydrin reagent and eluents was 1 to 2. The prototype was diluted in Li-citrate buffer by pH 2.2±0.02 and inflicted on an ion exchange column. The mass of every amino acid expressed as g per 100 g protein. Amino acid SCORE is expected according to the certificate scale of THEO/WHO (Choi et. al., 2012).

Near-infrared reflection spectroscopy

Infrapid spectrometer (Labor-Mim, Hungary) was used to research the reflection spectra from shredded samples and a smooth surface in near infrared range from 1330 to 2370 nm. Firstly, the spectrometer recorded the reflectance spectrum from reference I0, secondly a reflection spectrum from the researched sample. The spectra are represented as the reflectivity of R in relative units (the ratio of the intensities I/I0 = R), depending on the wavelength in nm (Shevchenko et. al, 2022). The intensity of reflection was measured in wheat flour, oat bran, lecithin, in dough after kneading and after 3.5 hours of fermentation and in bread. The reflection intensity was expressed through the recalculation of relative reflection coefficient to spectral index (Yip et. al, 2012).

Statistical analysis

The data represents the mean of a minimum three replicates ± standard deviation (S.D.). Graphical presentation of experimental data was performed using standard statistical processing programs – Microsoft Excel 2010.

Results and discussion

Essential amino acid composition of wheat flour and oat bran

The main nutrients contained in the raw materials play a decisive role in forming the properties of the dough system, in particular the gluten frame, and the quality of bread. The chemical composition of wheat flour and oat bran differs significantly. Oat bran has an increased content of protein – 17.1% and dietary fiber – 15.4% compared to premium wheat flour – 11.3% and 3.5%, respectively. The protein content and composition of raw materials affects not only the formation of the structural and mechanical properties of the dough, but also determines the protein composition of the finished bread (Amjid et. al, 2013).

It was established that the content of essential amino acids (EAA) in oat bran is significantly higher than in wheat flour (Table 1). This will enrich the protein profile of bread with this raw material. The limiting amino acid in wheat flour is lysine, the amino acid score of which is 0.44. In oat bran, the limiting amino acid is methionine, the amino acid score of which is 1.14, and the amino acid score of lysine is much higher than in flour – 1.62.

The fact that the amino acid score of the limiting amino acid in oat bran is higher than 1 indicates that the protein of this raw material is complete, which makes it possible to predict an increase in the digestibility of protein in bread when bran is added to the recipe.

Table 1

Amino acid composition of oat bran and premium wheat flour (g/100 g of the raw material)

EAA	Premium wheat flour	Oat bran
Valin	0.42±0.01	0.96±0.01
Isoleucine	0.36±0.01	0.67±0.01
Leucine	0.71±0.02	1.37±0.02
Lysine	0.23±0.01	0.76±0.01
Methionine	0.40±0.01	0.34±0.01
Threonine	0.28±0.01	0.50±0.01
Tryptophan	0.13±0.01	0.33±0.01
Phenylalanine	0.52±0.01	0.91±0.01

The amino acid composition of raw materials determines the biological value of finished bakery products. The amino acid profile of bread baked with the replacement of part of wheat flour with rice flour was determined. The results are shown in Table 2. The amino acid score of each amino acid in the bread samples was also calculated (Table 3).

Table 2

Amino acid composition of bread baked with replacement of part of wheat flour with oat bran (g/100 g of bread)

EAA	Control sample	Oat bran to replace wheat flour, %			
		5	7	10	15
Leucine	0.71	0.77	0.79	0.83	0.88
Isoleucine	0.39	0.42	0.43	0.44	0.47
Methionine	0.31	0.32	0.32	0.32	0.33
Lysine	0.23	0.28	0.30	0.32	0.36
Phenylalanine	0.68	0.70	0.71	0.73	0.75
Threonine	0.28	0.30	0.31	0.32	0.34
Valin	0.43	0.41	0.41	0.40	0.39
Tryptophan	0.09	0.11	0.12	0.13	0.15

Table 3

Amino acid score of amino acids in bread baked with replacement of part of wheat flour with oat bran

EAA	Control sample	Oat bran to replace wheat flour, %			
		5	7	10	15
Leucine	1.11	1.19	1.23	1.27	1.35
Isoleucine	1.06	1.13	1.15	1.19	1.25
Methionine	0.97	0.98	0.98	0.99	1.00
Lysine	0.46	0.55	0.58	0.63	0.70
Phenylalanine	1.23	1.27	1.28	1.30	1.34
Threonine	0.77	0.82	0.84	0.86	0.91
Valin	0.93	0.90	0.89	0.87	0.84
Tryptophan	0.98	1.19	1.27	1.38	1.57

The limiting amino acid in bread is lysine, the amino acid score of which is 0.46. With an increase in the percentage of replacement wheat flour with oat bran, the amino acid score of lysine increased by 19.5–52.2%. This indicates that the protein of this raw material helps to increase the level of essential amino acids in bread, which enriches its protein profile.

The difference in the chemical composition of wheat flour and oat bran should affect the change in the basic structural units of dough and bread with these components in the recipe. To identify and analyze these components, it is advisable to use the reflection spectrum in the near infrared region (Baslar et. al., 2011). Dough and bread samples were prepared with the minimum and maximum researched replacement of wheat flour with oat bran – 5% (Figure 1) and 15% (Figure 2).

All six spectra (control dough sample and dough samples with 5% replacement of wheat flour with oat bran (after kneading and after 3.5 hours of fermentation), as well as finished bread samples) have a similar character and the same extremes. However, there are differences in the intensity of reflection that identifies them.

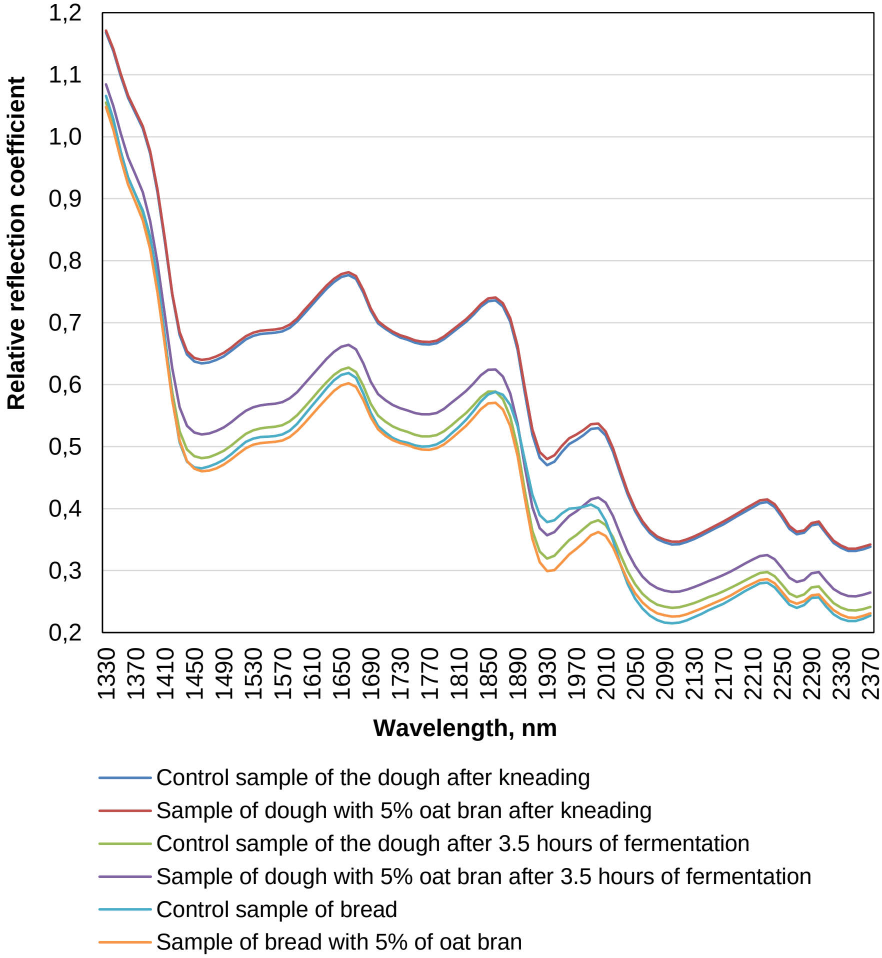

Figure 1. Reflection spectra of dough samples (after kneading and after 3.5 hours of fermentation) and bread samples with 5% replacement of wheat flour with oat bran

The obtained spectra showed that the control sample of the dough after kneading and the sample of the dough with 5% replacement of wheat flour with oat bran are completely identical throughout the investigated wavelength interval, that is, the spectra are completely superimposed on each other. Even their initial reflection intensity value was the same. This indicates that such a small percentage of substitution does not cause conformational transformations in the dough system. In addition, it takes time for the interaction of the biopolymers of the raw materials, and since the analysis of the samples was done immediately after mixing, not enough time had passed for such an interaction. The lowest extremum is observed at a wavelength of 2100 nm for all samples. This length characterizes the state of the protein substances of the dough (Kröncke et. al., 2022). The relative reflection coefficient is 0.37.

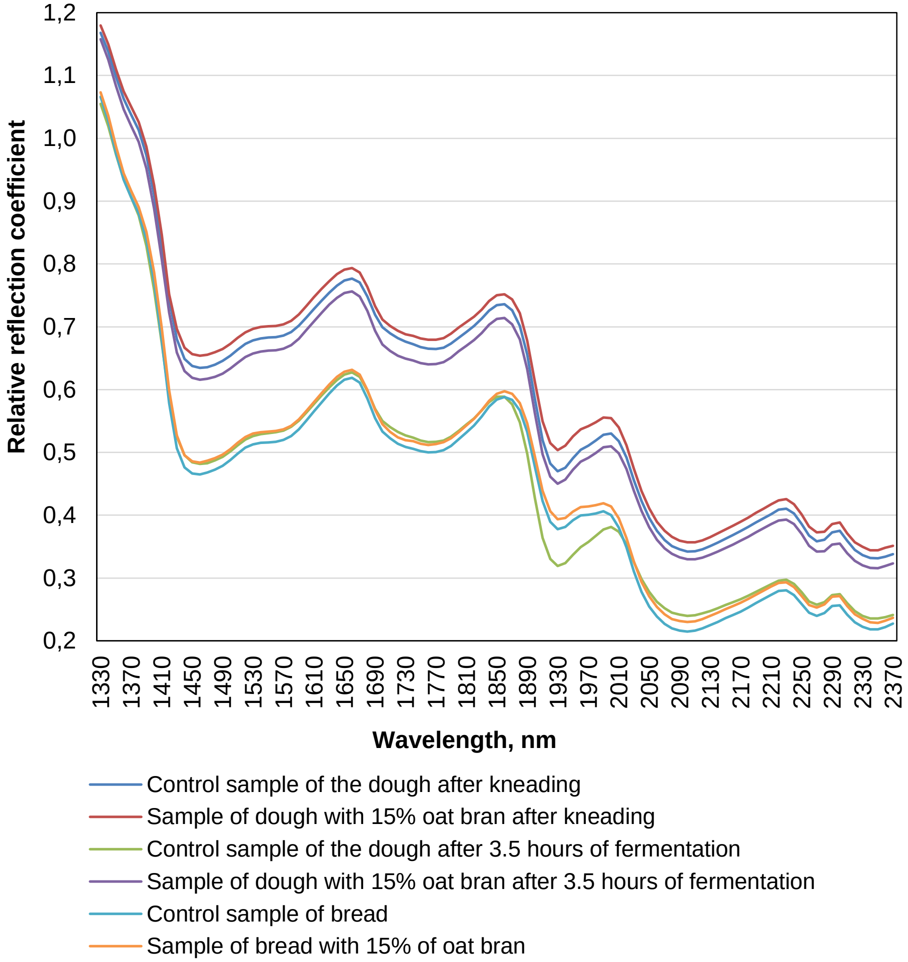

Figure 2. Reflection spectra of dough samples (after kneading and after 3.5 hours of fermentation) and bread samples with 15% replacement of wheat flour with oat bran

Spectra of samples of the dough after 3.5 hours. fermentation are situated below on the graph. This indicates the course of conformational processes in the dough during fermentation. Moreover, the dough sample after fermentation with the replacement of flour with 5% oat bran is characterized by a greater intensity of reflection than the fermented control sample. That is, replacing part of the flour with oat bran affects the conformational transformations in the dough system. At a wavelength of 2100 nm, the value of the relative reflectance of the sample with replacement and the control sample was 0.28 and 0.25, respectively. This is explained by the fact that oat bran, which has a globular structure of proteins, due to which they do not participate in the formation of gluten, and also contain a large amount of dietary fibers, are embedded in the gluten framework formed by the gluten proteins of flour and delay its development (Alfaris et. al., 2022). Technologicaly it can be predicted that the structure of the protein matrix of bran dough will be less stable and more weakened.

The infrared spectra of the baked bread samples conditionally match, not taking into account differences due to different humidity at a wavelength of 1930 nm. This is explained by the fact that high temperatures lead to the destruction of protein macromolecules with the splitting of peptide bonds when baking bread (Zhou et. al., 2021). It is also observed that the indicated spectra of bread are located close to the fermented control dough sample (however, in terms of the intensity of reflection, they are lower). This is explained by the fact that the determining role in the formation of the final structure of the bread frame is played by the components of the flour, content of which is major in the recipe. At the same time, although oat bran in the studied amount affects the structural and mechanical properties of the products, it is not capable of significantly changing them.

In general, the spectra have a similar character as when replacing 5%, but the spectra obtained with the replacement of 15% flour with bran can be conditionally divided into two groups. The first (with a higher reflection intensity) includes three spectra: for two samples of dough after kneading (both control sample and with replacement of 15% oat bran) and a sample of dough with 15% oat bran after 3.5 h of fermentation. The relative reflectance of this sample at the wavelength of 2100 nm is 0.35, which is significantly higher than that of the control sample and the sample with 5% replacement. This is explained by the fact that a greater amount of dietary fiber delays the development of the gluten network to a greater extent and more α – protein structures move to β – structures (Jing et. al., 2016).

The second group has a lower initial reflection intensity (by 0.12 units). The three reflection spectra of this group, which include bread samples and a control sample of fermented dough, also conditionally coincide with each other. Their difference is manifested only at the wavelength of 1930 nm, which is due to the different moisture content in the samples. From a technological point of view, the addition of 15% oat bran will contribute to less dilution of the dough ball during the fermentation process and better shape retention.

Thus, it can be concluded that the introduction of oat bran with a higher content of protein, dietary fiber and a complete amino acid profile into the recipe of wheat bread helps to improve the biological value of bread with this raw material. Also, the addition of bran affects the structural elements of the dough and the structural and mechanical properties of bread. However, the deterioration of the development of the gluten framework of the dough, and therefore of the specific volume, porosity and dimensional stability of bread, requires the use of technological methods to minimize the negative impact of bran on the quality of finished bakery products.

Conclusion

1. It was established that the content of essential amino acids in oat bran is significantly higher than in wheat flour. The limiting amino acid in wheat flour is lysine, the amino acid score of which is 0.44. In oat bran, the limiting amino acid is methionine, the amino acid score of which is 1.14, and the amino acid score of lysine is much higher than in flour – 1.62.
2. The limiting amino acid in bread is lysine, the amino acid score of which is 0.46. With an increase in the percentage of replacement of wheat flour with oat bran, the amino acid score of lysine increased by 19.5-52.2%. This indicates that the protein of this raw material helps to increase the level of essential amino acids in bread, which enriches its protein profile.

3. The obtained spectra of the dough samples after kneading showed that the introduction of oat bran does not cause conformational transformations in the dough system, since not enough time passed for the interaction of the biopolymers of the raw materials.
4. The infrared spectra of the dough at a wavelength of 2100 nm showed that the dietary fibers of oat bran delay the development of the gluten network, the structure of the protein matrix of the dough with bran will be less stable and more weakened than that of the control sample.
5. The introduction of oat bran with a higher content of protein, dietary fibers and a complete amino acid profile into the recipe of wheat bread helps to improve the biological value of bread with this raw material. However, the deterioration of the development of the gluten framework of the dough, and therefore of the specific volume, porosity and dimensional stability of bread, requires the use of technological methods to minimize the negative impact of bran on the quality of finished bakery products.

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Effects of mono- and disaccharides on fruit gel formation

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Abstract

Introduction. The type of added sugar is important in the structuring of fruit gels. Effects of glucose, fructose or sucrose on fruit gel for their further use in confectionery technologies were studied.

Materials and methods. Formulations for fruit gels, which included applesauce, sugar and molasses, fruit stews and structured fruit gels, were used in the research. Rheological properties were determined on a rotary viscometer; gel-forming ability by the method of sensory evaluation; resilient and plastic properties by using a structurometer ST-1; amounts of free and bound moisture were estimated on a Q-1500 derivatograph.

Results and discussion. The higher values of the effective viscosity of studied recipe mixes at a temperature of 20±2 °C are characteristic of systems with glucose within the range of values of shear stress P=2.601-17.918, Pa. The lowest values are observed for prescription mixes with fructose, which is explained by different solubility of sugars. When the research temperature increased to 65±2 °C, the solubility of sugars and the relation between the viscosity curves were changed.

The highest values of effective viscosity are characteristic of mixes with sucrose, somewhat lower for mixes with glucose and fructose. At the same time, the strength of the internal structural framework formed, for the model mass with sucrose was 114.73 Pa, with glucose 23.12 Pa, and with fructose 35.0 Pa.

Fruit gels on sucrose and glucose are easily removed from the molds, do not stick, have a dry surface, that is, they are characterized by excellent gel-forming ability under the same cooking conditions. The gel on fructose is difficult to remove from the mold and it requires an increased time for gel formation. It has been shown that fruit gels withstand different loads before breaking: the required force to break a fruit gel with sucrose is 50 N, with glucose 35 N, with fructose 30 N.

According to derivatographic studies and calculations of the content of bound water in gels, a larger part of it was found for fruit gels with sucrose. This exceeds the indicator for the gel with glucose by 2.2%, and with fructose by 4.3%.

Conclusions. The gels with sucrose had higher values of effective viscosity compared to gels with identical amounts of glucose or fructose. The strength of fruit gels with sucrose was higher in terms of the force required to break the jelly, and the overall deformation was smaller. Additionally, gels with sucrose had a lower amount of free moisture.

Introduction

Fruit gels, the basis of fruit and berry marmalade, are one of the most valuable confectionery products with a rich vitamin and mineral complex (Konar et al., 2022; Wolf, 2016). The formation of fruit gel is carried out due to the association of pectin macromolecules of the fruit part of the recipe mixture of components, which is achieved by the formation of hydrogen bonds between non-dissociated carboxyl groups and secondary alcohol groups, as well as due to hydrophobic interactions of methyl ether groups (Nath et al., 2022; Zhang T. et al., 2021).

The presence of dehydrating substances in the solution is important for the formation of fruit gels. It reduces the solvation of pectin macromolecules and the structural formation of the gel framework occurs along the dehydrated areas of the pectin molecule (Chevalier et al., 2019; Feng et al., 2023). Sugar is such a substance for fruit gels (Burey P. et al., 2008). The amount of sugar is determined by the degree of methylation and the amount of pectin in the fruit puree (Nussinovitch et al., 2013). The higher the degree of methylation and the greater the amount of pectin, the more sugar is needed to create gelling conditions. However, if the amount of sugar is disproportionately higher than the optimal one, the strength of the gels decreases, and gel formation is accelerated (Basu et al., 2023). On the contrary, if the amount of sugar is less than necessary, the gels acquire greater strength and hardness (Abboud et al., 2020).

The type of used sugar is important (Ivanov et al., 2021). To a greater extent, the confectionery industry uses sucrose, glucose, and fructose, so scientists are quite actively studying the issue of forming pectin gels with various sugars (Jiang et al., 2021; Qi J. et al., 2021). The study of the rheological properties of gels of highly methylation pectin with sucrose, glucose, fructose showed that gels with glucose or fructose were characterized by a higher dynamic modulus of resiliency, viscosity, and lower fluidity compared to gels with sucrose, which indicates more binding of water in them (Vithanage et al., 2010)). The higher strength of high-methoxyl pectin (H-pectin) gels with fructose compared to sucrose was established (Patruni et al., 2023). It is explained by better dehydration of pectin molecules in the presence of fructose, an increase in the number of desolvated areas of its macromolecule and thereby promoting their cleavage among themselves. It was determined that the effective viscosity of pectin gel in apple sauce with glucose and fructose was 1.3 times higher than the viscosity of pectin gel with sucrose (Dorohovich et al., 2016). The thixotropic properties of such gels with the mechanical method of transitioning the gel into a sol make it possible to restore the structure by 85-90%.

It was found that the weakening of the pectin gel’s strength with fructose compared to the gel with sucrose is explained by the lower ability of the monosaccharide to retain water. It means to reduce its polarity to a lesser extent, which does not contribute to the aggregation of hydrophilic pectin molecules and the formation of gels (Avetisyan, 2015). The results of studying the formation of low-methoxyl pectin (L-pectin) jelly and sugars (sucrose, glucose and fructose) established the absence of a correlation between the adsorption of water by sugars and the strength of jelly. The mechanism of formation of L-pectin gels differs from the mechanism of H-pectin in the presence of calcium ions in the medium, which contribute to the formation of bonds between pectin chains. The authors investigated the difference in the structure of gels with mono- and disaccharides and found that there is no correlation between the adsorption of water by sugars and the strength of gels. According to scientists, the structure of gels on the number of interactions between sugars and pectin with calcium cations. (Manuel et al., 2002).

The structuring of fruit gels is a complex mechanism with the participation of many accompanying substances in addition to pectin. Added sugar has a significant effect on the regimes and parameters of the formation of fruit pectin gel, as well as on its structural and mechanical properties. Effects of glucose, fructose or sucrose on fruit gel formation for their further use in confectionery technologies were studied.

Materials and methods

Preparation of samples

The following substances were used for the research: white crystalline sugar (Agroprodinvest, Ukraine), fructose (Golden-Farm, Ukraine), glucose (Twell Sansino, China), starch molasses (Intercorn Corn Processing Industry CJSC, Ukraine), aseptic applesauce (Juice Plant Kodymsky, Ukraine). The characteristics of the main raw materials were determined under laboratory conditions and are presented in Table 1.

Table 1

Characteristics of the main raw materials

Raw material	Sensory properties			Mass fraction of dry substances, %
	Colour	Smell	Taste	
White crystalline sugar	white	characteristic of sugar, without extraneous smell	sweet, without extraneous aftertaste	99.60±0.5
Fructose	snow white		very sweet, without extraneous aftertaste	97.40±0.5
Glucose			sweet, without extraneous aftertaste	89.20±0.4
Aseptic applesauce	yellowish, with a dull green tint	extraneous smell is not allowed	sweet and sour, characteristic of an apple	15.00±0.08
Starch molasses	transparent, colorless	odorless	sweet, clean, without extraneous aftertaste	78.00±0.4

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

Model systems: model recipe mixes and fruit gels were prepared to study rheological properties. Model recipe mixes for fruit gels included applesauce, sugar, and molasses. In the control sample, 130 g of applesauce, 100 g of white sugar (sucrose) and 8 g of molasses were used. Glucose or fructose was added to the experimental samples in the equal amounts of sucrose on a dry basis.

To prepare model fruit gels, model recipe mixes were boiled to a dry matter content of 63% and cooled to a temperature of 20±2 ˚C.

Research methods

To study the structural and mechanical properties of fruit gels, they were poured into molds and left for 40 minutes in the laboratory at temperature 20±2 °C, then they were placed in a refrigerator for 2 hours at temperature 10±2 °C. The gel-forming capacity of fruit gels was determined by sensory characteristics such as appearance, surface condition, ease of removal from the mold. The structural and mechanical properties of the obtained fruit gels, namely general deformation, resilience and plasticity of gel-like masses were determined using a ST-1 structuremeter, the principle of which is based on measuring the mechanical load on the indenter nozzle, immersing it at a given speed into the prepared sample of the product. To measure the structural and mechanical properties, samples of cylindrical fruit gels with a diameter of 0.03 m and a height of 0.05 m were prepared.

The following values were set: contact force F_0 = 0.5 N; table movement speed v = 100 mm/min; maximum force, load to the sample, F = 5-5.5 N.

Based on the results of the calculations, compression-unloading curves were constructed – graphs of the dependence of the load force F, H, on the depth of penetration into the gel h, m (Figure 1):

h_1 is the total deformation, m;

h_2 is the plastic deformation, m;

h_3 is the resilience deformation, m;

a is the compression curve;

b is the unloading curve.

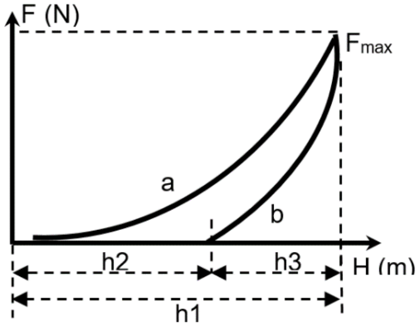


Figure 1. Compression-unloading curve

The starting and final point of the load was marked on the compression curve, a, and the total deformation h1 was determined. The final point of the measurements was marked on the unloading curve, b, at which the value of the plastic deformation, h2, was determined. The resilience deformation h3 was determined by calculation, as the difference between the general and plastic deformations, h1 and h2, the ratio of resilience deformation to plastic deformation h3/h2.

The viscosity characteristics of model recipe mixes and fruit gels were determined on the rotating viscometer (Chandra et al., 2010; Qi T. et al., 2023).

During the research, the shear stress was calculated according to the following formula:

$$\tau = Z \times \alpha,$$

τ is a shear stress, Pa;

Z is the constant of the measuring pair;

α is the value read from the scale of the recording device.

The effective viscosity of the practically intact, η_0, Pa·s, and practically destroyed, η_m, Pa·s, system was calculated using the formula:

$$\eta = \tau / \gamma$$

γ is the shear rate, s^{-1}.

Based on the obtained calculation results, rheological viscosity curves $\eta = f(\gamma)$ were constructed. They were used to determine the nature of the destruction and the beginning of the fluidity of the system.

The amount of free and bound moisture in fruit gels was studied using a Q-1500 derivatograph. Temperature, T, mass change, TG, rate of mass change, DTG, and heat capacity change, DTA, were measured in the test sample as a function of time. The amount of total moisture content, Δm, was determined as the amount of mass that was separated when the sample was heated to a temperature of 150 °C, because the chemical composition of the samples is destroyed when heated at temperature >150 °C. The moisture that is released when the samples are heated to their boiling temperature was considered as a free moisture, and moisture released after their boiling temperature was considered as a bound moisture.

Statistical processing of the data was performed, including the determination of standard deviation (±SD), with triplicate replication for each analysis. The determination of the indicator was realized using the Excel 2007 program from the Microsoft Package (Microsoft Corporation, USA).

Results and discussion

Analyzing the rheological indicators of model recipe mixes and marmalade masses it was found that there were differences in the values of the effective viscosity of the test samples (Tables 2, 3; Figures 2, 3).

Table 2

Rheological characteristics of recipe mixes for fruit gels

Recipe mix of fruit gel	Effective viscosity of almost indestructible system, Pa·s	Strength of structural frame, P_m, Pa	Strength of structural connections, P_{k1}/P_{k2}	Destruction of structure, P_m/P_{k1}
Sample 1 (with sucrose)	6.07±0,03	10.26±0,05	0.50±0,003	3.55±0,02
Sample 2 (with glucose)	7.80±0,04	15.32±0,07	0.45±0,002	2.65±0,01
Sample 3 (with fructose)	4.28±0,02	5.78±0,03	0.36±0,002	4.00±0,02

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

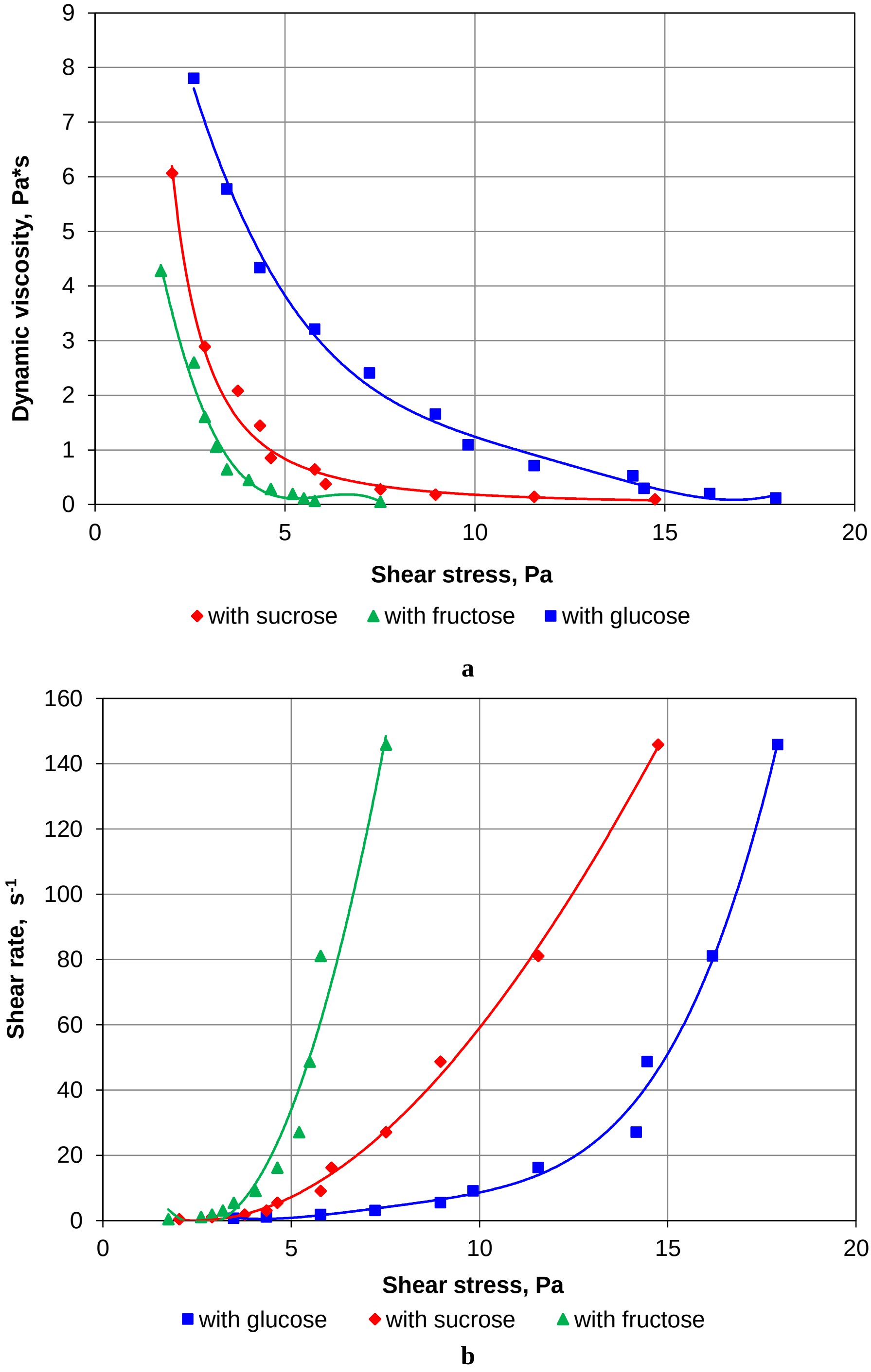


Figure 2. Rheological curves of viscosity (a) and fluidity (b) of model recipe mixes for fruit gels at temperature 20 °C with various types of sugars

Table 3

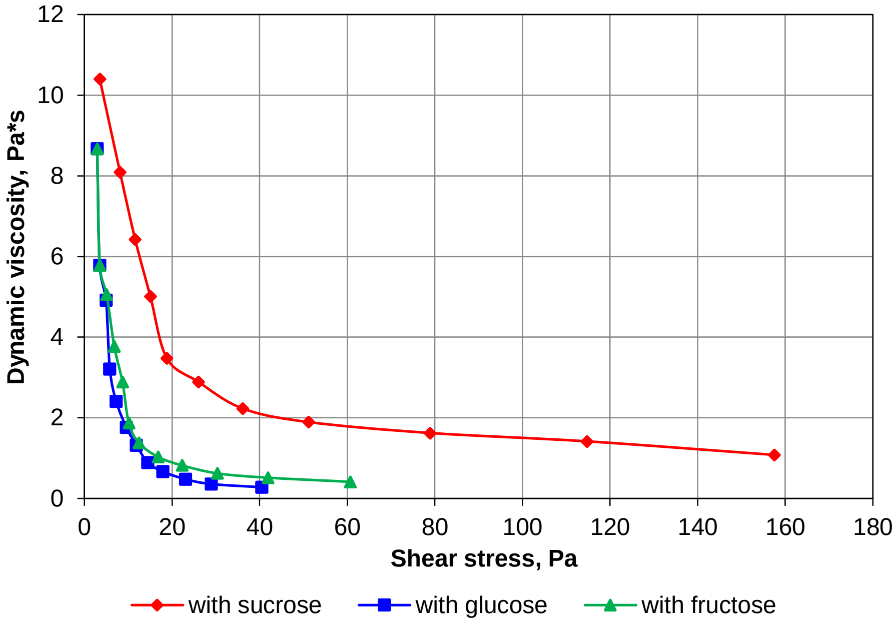
Rheological characteristics of fruit gels

Recipe of fruit gels	Effective viscosity of almost indestructible system, Pa·s	Strength of structural frame, P_m, Pa	Strength of structural connections, P_{k1}/P_{k2}	Destruction of structure, P_m/P_{k1}
Sample 1 (with sucrose)	10.41±0.05	114.73±0.57	0.05±0.0003	39.70±0.2
Sample 2 (with glucose)	8.67±0.04	23.12±0.12	0.24±0.001	6.67±0.03
Sample 3 (with fructose)	8.25±0.04	35.00±0.18	0.24±0.001	10.10±0.05

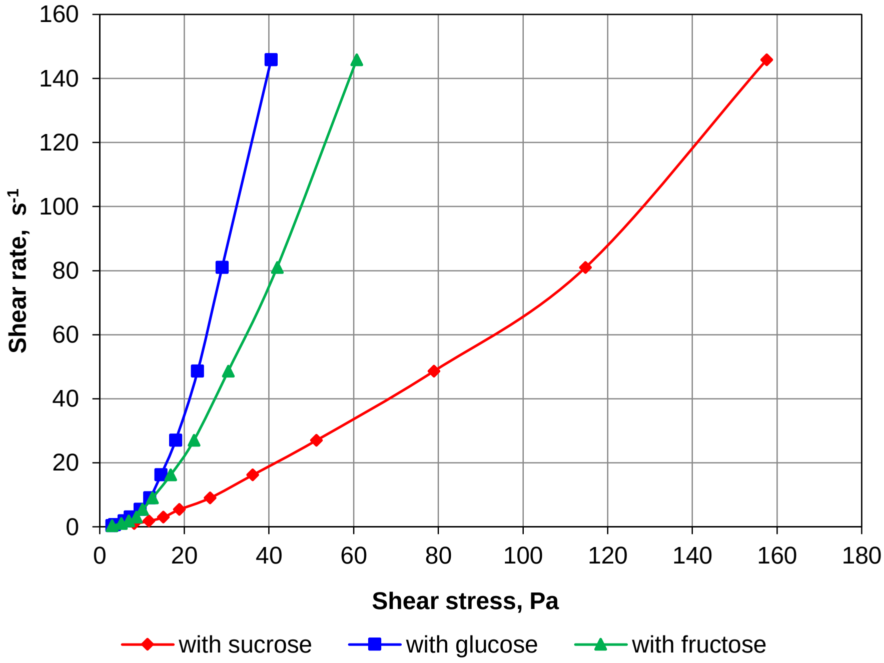
*Results given as: M ± SD (mean ± standard deviation) of triplicate trials.

In model formulations, higher effective viscosity values were characteristic of systems with glucose within all values of shear stress. The lowest values were observed for formulations with fructose. Such differences are explained by the different solubility of sugars at the temperature of the studies (Zhang et al., 2021). Thus, according to literature data, at a temperature of 25 °C, the solubility of fructose is 74.6-78.9%, sucrose – 63–67%, glucose – 43.7–52.5%, which confirms the lowest solubility of glucose at the temperature of preparation of prescription mixes (Wang et al., 2019). Therefore, the recipe mix with glucose contains a significant part of undissolved sugar crystals, which leads to an increase in effective viscosity. Fructose is characterized by the highest dissolution coefficient, which allows sugar molecules to hydrate to a greater extent in the medium, and the recipe mix has the lowest values of effective viscosity among the presented samples.

Sugars are in a completely dissolved state in fruit gels subjected to boiling, that is, their solubility changes (Zhang et al., 2021). The solubility of sucrose became 77%, glucose – 81-82%, fructose – 85.6-88.1% at a temperature in the range from 60 to 90 $^{\circ C}$, which naturally leaves an imprint on the change of dependence between viscosity curves of fruit gels. As can be seen, the highest values of the effective viscosity are characteristic of the samples with sucrose, even they are lower for the samples with glucose and fructose. However, the resulting fruit gels were cooled after boiling. It means that the partial gelation of the systems and the influence of sugar on the gelation of pectin substances are a more significant factor affecting the experimental index (Dorohovich et al., 2016). Despite the fact that the framework of the gel-like structure is not yet fixed, and the molecules are in in a rather mobile state, sugars and pectin substances form complex compounds. Therefore, the viscosity will depend on the integrity and strength of the complex formed. The location of the viscosity curve for the model system with sucrose above the curves for the fruit gels with monosaccharides may indicate greater cohesion and strength of the formed gel structure, a higher rate of gelation of pectin substances with sucrose. This conclusion can be confirmed by the strength index of the formed structural frame, P_m (Table 2), which is 114.73 Pa for the fruit gel with sucrose, 23.12 Pa for the fruit gel with glucose, and 35.0 Pa for the fruit gel with fructose.



a



b

Figure 3. Rheological curves of viscosity (a) and fluidity (b) of fruit gels at temperature 20 °C with various sugars

The obtained results confirmed that the viscosity of pectin fruit gels with disaccharides is higher than the viscosity of gels with monosaccharides.

The gel-forming ability and the structural and mechanical properties of fruit gels were determined (Tables 4, 5).

Table 4

Gel-forming ability of fruit gels

Gel quality indicators	Sample 1 (with sucrose)	Sample 2 (with glucose)	Sample 3 (with fructose)
Ease of removal from the forms	The gel is easily removed from the molds		The gel is difficult to remove from the forms, it requires an increase in time for gel formation
Surface condition	The surface is smooth and glossy	The surface is smooth	Glossy surface, sticky
Detachment from the surface	Does not stick	Does not stick	Stick
Gel-forming ability	Excellent	Excellent	Satisfactory

It was found that fruit gels with sucrose and glucose were easily removed from the molds, did not stick, and had a dry surface under the same cooking conditions. This means that they have an excellent gel-forming ability. The mass on fructose required an increased gelation time, the formed gel stuck to the mold when removed, and was characterized by satisfactory strength.

Analysis of the structural and mechanical properties of fruit gels made it possible to single out the sample on sucrose as a stronger system in comparison with the samples on glucose and fructose. The maximum force to break gels is 50 N for fruit gel with sucrose, 35 N with glucose, 30 N with fructose. That is, the sample with sucrose withstands higher loads until complete destruction compared to the samples with monosaccharides, which indicates a more structured framework of its gels.

The studied samples are characterized by different resilient and plastic deformation values. The lowest plasticity and the highest value of resilient deformation were found for the sample with glucose, which can be explained by the low solubility of sugar in the systems after the gel cooling. Glucose molecules begin to change their crystal lattice, thereby influencing the strengthening of the entire structure (Archut et al., 2023). Fructose is characterized by increased solubility (compared to sucrose at 20 ˚C), so the values of resilient deformation of gel with fructose are lower compared to glucose, but somewhat higher compared to sucrose. For example, at a load of 30 N, the elastic deformation for gels with sucrose is 13.88%, for gels with fructose – 18.4%, for gels with glucose – 21.9%.

In order to explain the difference in the structural and mechanical properties of the experimental fruit gels and to confirm the conclusion regarding the relationship between the activity of water and the gelation of masses, an analysis of the moisture content in fruit gels was carried out using a derivatograph (Fig. 4, Table 6). The figures show the curves of changes in mass, TG, with increasing temperature, T, over a period of 0 to 40 minutes.

Table 5

Structural and mechanical properties of fruit gels

Sample	Load force, N	Deformation		
		General, unit	Plastic, %	Flexible, %
Sample 1 (with sucrose)	5	5.06	93.60	6.4
	10	11.73	93.55	6.45
	15	13.26	92.29	7.71
	20	14.07	90.47	9.53
	25	17.99	89.27	10.73
	30	20.02	86.11	13.89
	35	21.74	82.65	17.35
	40	22.43	82.38	17.62
	45	23.24	81.62	18.38
	50	25.38	80.32	19.68
	55	The structure of the gel is destroyed		
Sample 2 (with glucose)	5	6.34	94.60	5.40
	10	10.74	87.00	13.00
	15	11.94	84.67	15.33
	20	13.00	84.00	16.00
	25	14.19	82.36	17.65
	30	17.95	78.05	21.95
	35	18.95	76.56	23.44
	40	The structure of the gel is destroyed		
Sample 3 (with fructose)	5	6.45	89.4	10.6
	10	11.33	87.97	12.03
	15	12.61	86.51	13.49
	20	13.73	86.16	13.84
	25	14.86	85.26	14.74
	30	19.03	81.6	18.40
	35	The structure of the gel is destroyed		

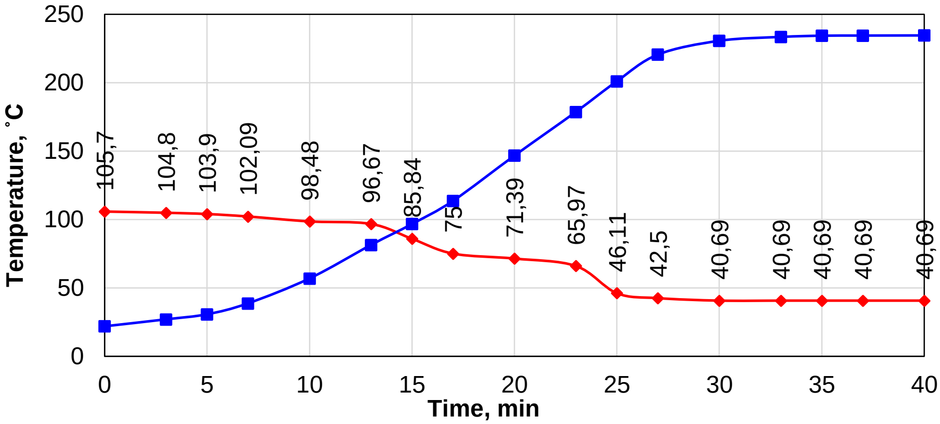
Table 6

Content of free and bound moisture in fruit gels

Model fruit gels	Moisture content, %	
	free	bounded
Sample 1(with sucrose)	24.03±0.12	75.97±0.38
Sample 2 (with glucose)	25.71±0.13	74.29±0.37
Sample 3 (with fructose)	27.28±0.14	72.72±0.36

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

The results showed that the content of bound moisture in the samples of fruit gel with sucrose was greater compared to the samples of gels based on monosaccharides. That is, a more resilient framework of pectin jellies is formed with the disaccharide sucrose, in which there is less water activity compared to systems based on glucose or fructose. Thus, according to calculations, the content of bound water in a gel with sucrose exceeds by 2.2% content of bound water in a gel with glucose and 4.3% – in a gel with fructose.



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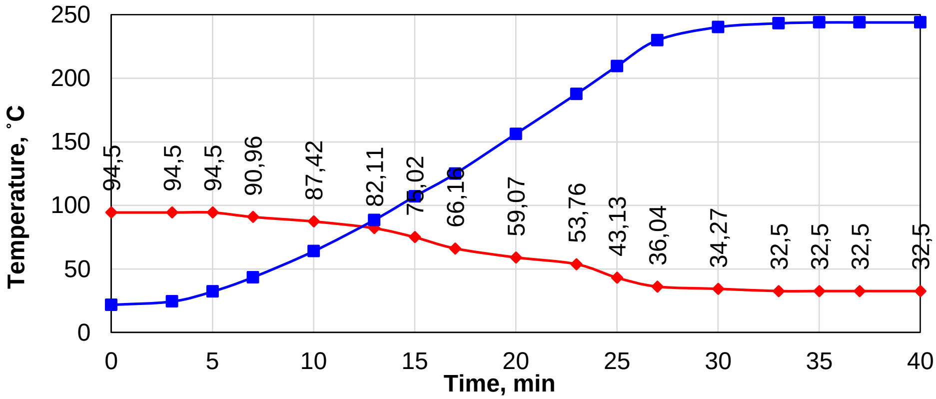

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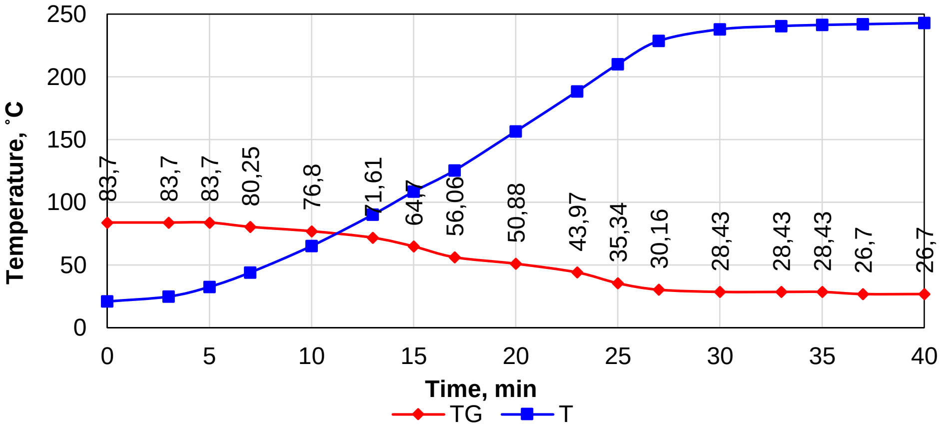

c

Figure 4. Change of mass of fruit gels samples with sucrose (a), glucose (b), fructose (c) under different temperature:
TG is the curves of mass, T is the curves of temperature.

Conclusions

Scientific data were obtained that showed the relationship between the rheological parameters of fruit gels with different colors, strength and total deformation and the amount of bound water.

It was found that the samples of gels with higher values of effective viscosity prior to structure formation form the gel framework faster, acquire greater strength after the final setting and are characterized by a slightly higher content of bound moisture. Gel with sucrose before structuring have higher values of effective viscosity compared to gels with glucose or fructose. The strength of fruit gels on sucrose is higher in terms of the force required to break through the jelly, and the overall deformation of the samples is correspondingly lower. Samples of gels with sucrose have a lower amount of free moisture.

The obtained results show the dependence of the rheological properties of fruit masses, the quality of their gelatinization, structural and mechanical properties on the sugar used and are important for the production of jelly-like confectionery.

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Automated power supply control system for a food industry enterprise using a photovoltaic plant and energy storage

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Abstract

Introduction. Studies were carried out on the power supply control process of a food industry enterprise using a photoelectric plant and electric energy storage to ensure the efficiency of transmission and use of electrical energy.

Materials and methods. The studies were carried out using the methods of modern theory of automatic control and system analysis of control processes.

Results and discussion. The main stages of the power supply control process using a photovoltaic plant and an energy storage system are defined: basic control functions – registration of electric energy consumption, forecasting of electric energy generation using a photovoltaic plant, forecasting of electric energy consumption, determination of parameters of the electric energy storage system, analysis power supply system modes; conditions for providing control functions – information on solar radiation; data on electric energy generation using photovoltaic plant, data on electric energy consumption, limitations and tariffs for electric energy, requirements for the accuracy of forecasting electricity consumption and generation of electric energy using photovoltaic plant, data on energy storage system (current charge, maximum and minimum permissible charges), decision-making on optimization of power supply; organizational and technical mechanisms for the implementation of management functions – information and computing complex, energy dispatcher, chief energy engineer; the database of the electrical supply control system, which is used to prepare decisions; basic information flows that ensure the management of electricity supply – forecast values of meteorological data, current data on electric energy consumption, management actions on the regulation of photovoltaic plant and energy storage system, current data on power supply mode parameters; current data on power supply configuration; control actions on optimization of power supply regimes, management actions on the management of electricity quality indicators; control actions for changing the configuration of the power supply. The functional scheme of power supply control using photovoltaic plant and energy storage system is presented and the requirements for individual units are formulated. The synthesis of the food industry enterprise power supply control system is carried out using the method of ensuring compatibility through sequential integration. In order to ensure energy-efficient power supply of food industry enterprise and optimal use of photovoltaic plant and energy storage system, optimization of modes is carried out using dynamic programming methods.

Conclusion. The development of control systems for power supply of food industry enterprise using photovoltaic plant and energy storage system based on system analysis and compatibility with the use of mode optimization using dynamic programming methods ensures high efficiency of power supply and rational modes of use of photovoltaic plant and energy storage system.

Introduction

The problem of reducing CO_2 emissions, ensuring the reliability of electricity supply and normative indicators of the quality of electric energy, reducing the consumption of electric energy, is relevant for food industry enterprises, as it allows to increase the efficiency of the use of generating capacities, reduce the costs of paying for electric energy and the energy intensity of products that issued by enterprises. To ensure the reduction of CO_2 emissions and electric energy consumption from the network in system of power supply. Food industry enterprise must use photovoltaic plants and electrical energy storage systems, forecast electric energy generation at photovoltaic plants and its consumption at food industry enterprise, and optimize energy storage system and power supply modes.

A number of research are devoted to the issue of power supply management of industrial enterprises using photovoltaic plants and energy storage system.

The method of power supply control using photovoltaic plants and energy storage system to reduce power consumption peaks is presented in Felder et al., 2013. The main idea of the approach is to ensure the efficiency of the power supply by charging the battery only during a fixed period of time. Surplus electric energy generated by photovoltaic plants is stored in battery for a period of time. As a result, losses from the reduction of photovoltaic plants generation may be reduced even without forecasts of photovoltaic plants generation and electric energy consumption. The disadvantage is the impossibility of achieving the maximum degree of electric energy self-sufficiency using photovoltaic plants and energy storage system.

Another way of efficient power supply is by reducing power peaks from the grid (Zeh et al., 2014). The battery charges at a constant rate throughout the day. In order to obtain the maximum amount of energy for the next day, during the period between sunset and sunrise, the battery is discharged at constant power to the lower charge limit. The disadvantage of this method is that the use of this method in the summer months often leads to the active discharge of battery into the network, reducing the self-sufficiency factor. This work also indicates a method of peak smoothing using a battery charged from a solar power plant power peaks. To generate peak smoothing signals, forecasted values of photovoltaic plant power and consumption, as well as iterative methods and linear programming methods are used. The disadvantage of this method is that it does not take into account power losses in the power supply system and the number of battery operation cycles.

Moshövel et al. (2015) proposed a method of ensuring energy-efficient modes of power supply by optimizing the modes of use of the battery by charging it taking into account the state of its charge. The setting for charging the battery is formed depending on the forecast value of the photovoltaic plant power and load. The disadvantage of this method is the impossibility of ensuring energy-efficient modes of the power supply system and taking into account the real state of the battery.

Litjeni et al. (2018) analysed the impact of the forecast on the quality of the system of operational management of electric energy with photovoltaic plants and energy storage system using model-predictive operational in order to minimize the loss from the reduction of electric energy generation of photovoltaic plants. The proposed control method does not ensure the limitation of load peaks from the network and the limitation of the influence of forecast inaccuracies on the modes of the power supply system.

Angenendt et al. (2016) represent an approach to the operational management of the power supply system, which ensures the minimization of losses when reducing the generation of the photovoltaic plants and the optimization of the service life of the battery. The presented method does not ensure the limitation of network load peaks and the optimization of power supply system modes.

Nge et al. (2010) proposed a system of operational management of electricity supply based on priorities. The proposed control system does not provide a high level of self-sufficiency and limitation of network load peaks.

Riffonneau et al. (2009) proposed a deterministic approach to power supply control in order to minimize electric energy costs, taking into account the current capacity of the FES and consumers, variable tariffs for electric energy. The proposed approach does not ensure the optimization of power supply modes and normative indicators of the quality of electric energy.

Park et al. (2012) presented a two-stage operational control method based on priorities to minimize electricity costs taking into account component losses and variable electricity prices. The presented method does not provide a limitation of the peak load of the network, taking into account the real state of battery and electric energy losses in the enterprise network.

Hafiz et al. (2018) develop operational management to minimize operational costs, taking into account variable tariffs for electric energy. The authors show that due to operational control using dynamic programming, it is possible to optimize the size of the battery. However, the method does not ensure high self-sufficiency of the system and taking into account the charge-discharge cycles of the battery.

An et al. (2015) present a method of managing the power supply system using dynamic programming methods and taking into account variable tariffs for electric energy and changes in the battery parameters due to their aging. The disadvantage of the method is that it does not provide optimal methods of photovoltaic plant operation and limits network load peaks.

Ranaweera et al. (2015) developed a multi-stage power supply system control method using photovoltaic plants and consumption forecasts, which takes into account the aging of batteries and ensures the minimization of electricity consumption and the maximum power supplied to the network. The method does not provide high power supply and does not take into account the operating modes of the power supply system.

Keerthisinghe et al. (2014) present a two-stage process of operational control of the power supply system in order to minimize operating costs using mixed integer and dynamic programming systems. The proposed system does not provide an effective level of self-sufficiency and does not take into account changes in the battery parameters due to its aging.

Riffonneau et al. (2011) described a control system that ensures the minimization of electricity costs taking into account the maximum power supplied to the network and taking into account the aging of the battery. The presented method does not ensure high self-sufficiency and consideration of electric energy losses in the elements of the power supply system

Li et al. (2014) proposed a method of operational management of the power supply system, using "fast dynamic programming", which ensures the minimization of operating costs, taking into account the aging of the battery. An analysis of the load power profiles and battery state of charge for individual days and their impact on the control system was performed. The presented method does not ensure the limitation of network load peaks and does not take into account the modes of the power supply system.

The analysis of the considered research showed that the control systems presented in them perform only the battery control function in order to ensure the minimization of electric energy costs, taking into account the battery charge state. However, these systems do not implement the functions of controlling the power supply system using photovoltaic plants and energy storage system as a whole, do not ensure the optimization of power supply system modes and maintenance of standard electric energy quality indicators, which allow obtaining the main economic effect of the system's operation.

The purpose of the research: is to synthesize an automated power supply control system of a food industry enterprise using photovoltaic plants and energy storage system based on a system analysis of the process of managing generation, transmission, distribution and consumption of electric energy, ensuring the sequence of integration and compatibility of individual components.

Materials and methods

Materials

It is considering automated power supply control system for a food industry enterprise using a photovoltaic plant and energy storage system to ensure the efficiency of transmission and use of electrical energy.

Methods

The research was conducted in the following order:

– The tasks of managing the electricity supply of the food industry enterprise with the use of photovoltaic plants and energy storage system are formulated;
– A system analysis of the process of controlling the electricity supply of the food industry enterprise using photovoltaic plants and energy storage system was performed;
– The criteria for managing the electricity supply of the food industry enterprise with the use of photovoltaic plants and energy storage system are formulated;
– A developed algorithm for controlling the electricity supply of the food industry enterprise using photovoltaic plants and energy storage system with the help of dynamic programming;
– A functional scheme for controlling the electricity supply of the food industry enterprise using photovoltaic plants and energy storage system was developed.
– The method of dynamic programming was used to optimize the electricity supply process using photovoltaic plants and energy storage system.

Results and discussion

Recently, there has been widespread use of photovoltaic plants and energy storage system in power supply systems of industrial and civil facilities. The stochastic nature of photovoltaic plants generation, limitations on the state of charge and limitations of battery charge cycles, specific aging conditions of the battery, operation of power supply systems in the conditions of the electricity market of energy (Baliuta et al., 2020) determine the formation of new approaches to the synthesis of power supply control systems of food industry enterprises using photovoltaic plants and energy storage system.

The main approaches to the synthesis of power supply control systems are described in (Baliuta et al., 2018; 2020; Cheremisin et al., 2012; Korolev et al., 2015; Kopylova et al., 2020; Steimle et al., 2006; Zinkevych et al., 2022). The presented approaches to the synthesis of the control system do not allow to take into account: the stochastic nature of electric energy generation, limitations on the charge-discharge of battery, features of power distribution in systems with photovoltaic plants and energy storage system.

Thus, it is necessary to develop food industry enterprise power supply control systems using photovoltaic plants and energy storage system based on system analysis methods that allow determining the main input and output information flows, actions that ensure the formation of the main control functions, information flows that provide control functions.

In addition, it is necessary to formulate the objective function and choose optimization methods that will provide optimal power supply modes for food industry enterprise using photovoltaic plants and energy storage system.

The task of managing the power supply of the food industry enterprise using photovoltaic plants and energy storage system is to minimize the set of technical and economic criteria (Baliuta et al., 2018):

- by the cost of consumed electric energy:

$$F_1(X) = K_w(t) + K_B(t) + K_{PN}(t) \tag{1}$$

K_W represents the criterion of electricity costs, including electricity tariffs k_{EGP} and preferential tariffs k_{FIT}. K_{PN} meets the power supply configuration criteria. If the power P_{Grid}, that is brought up, above the limit $P_{Grid,max}$, K_{PN} increases in proportion to the supplied power. The third criterion K_B takes the effects of battery aging into account.

– for power (energy) losses in the enterprise's electrical network, arising as a result of reactive energy flows:

$$F_2(X) = \sum_{j=1}^{M}\sum_{i=1}^{I_j}\{[Q^2(t) - \sum_{g_{ij}=1}^{G_{ij}} Q_{g_{ij}}(t)h_{g_{ij}}]\}R_{ij} \Big/ U_{ij}^2(t)\ ; \tag{2}$$

with limitations:

– by the active load of the enterprise:

$$\sum_{i=1}^{I_1} P_{enterprise}^{C}(t+t^*) - \sum_{j=1}^{J}\sum_{i=1}^{I_j} P_{enterprise_{ij}}^{C}(t+t^*)k_{ij} \le P_{limit}\ ;$$

– by reactive load of the enterprise:

$$Q_{\min}(t) \le \sum_{i=1}^{I_1}[Q_{enterprise}^{C}(t+t^*) - \sum_{g_{j1}=1}^{G_{i1}} Q_{gi_1}(t)h_{g_{i1}}] \le Q_{\max}(t)\ ;$$

– by to the voltage on the receivers of electrical energy:

$U_{ij\min} \le U_{ij}(t) \le U_{ij\max}$; (5)

– by to the parameters of the quality of electric energy:

$$\delta U_y \le \delta U_y^{(norm)}; \tag{6}$$

$$\delta U_t \le \delta U_t^{(norm)}; \tag{7}$$

$$k_{U2} \le k_{U2}^{(norm)};\ \ k_{U0} \le k_{U0}^{(norm)}; \tag{8}$$

$$k_U \le k_U^{(norm)}; \tag{9}$$

$$k_{U(n)} \le k_{U(n)}^{(norm)}; \tag{10}$$

where $\delta U_y, \delta U_t$ - fixed deviation and voltage change range; k_{U2}, k_{U0} - coefficients of asymmetry in reverse and zero sequences; $k_U, k_{U(n)}$ - distortion coefficients of the sinusoid and the n-th harmonic component of the voltage curve.

System analysis of process of controlling electricity supply food industry enterprise using photovoltaic plants and energy storage system

Electricity supply management in the form of a subsystem is a part of the automated control system food industry enterprise and determines the effectiveness of its electricity supply.

The process of managing organizational and technical objects at the theoretical-multiple level can be represented in the form of reflections of individual actions (Baliuta et al., 2018).

$$C_k : \{M \times G \times Y \times T_{en}\} \to T_{au}, k = \overline{1, K} \quad (11)$$

where: T_{en} i T_{au} – sets of incoming and outgoing information flows; $T = T_{en} \cup T_{au}$ – actions to form possible combinations of the main information flows; M – actions to form the main management functions; G i Y – accordingly, actions on the formation of possible combinations of mechanisms for the implementation of control functions and basic conditions.

The following information is used and the following actions are performed during the process of controlling the electricity supply of the food industry enterprise using photovoltaic plants and energy storage system:

Information used to ensure the formation of basic conditions for implementation of control functions:

G_1 - data on power schedules and electric energy costs for food industry enterprise (normative acts); G_2 – tariffs and restrictions on electric energy contained in the contract for the supply of electric energy on food industry enterprise; G_3 – requirements for the accuracy of metrological forecasts; G_4 - requirements for the accuracy of the electricity consumption forecast; G_5 - requirements for the accuracy of the generation forecast of electric energy of photovoltaic plants; G_6 - data on the state of the battery of energy storage system; G_7 - data on the evaluation of the effectiveness of the use of photovoltaic plants and energy storage system; G_8 – data on requirements for quality indicators of electric energy; G_9 – the order of interaction of the control system with the database management system; G_{10} – data on the evaluation of the regime energy storage system.; G_{11} – data on the evaluation of the regime of photovoltaic plants; G_{12} – data on the evaluation of the regime of energy storage system.

Actions ensuring formation of main control functions:

M_1 – verification of measurement data for reliability; registration of electric energy received from the network, generated by the photovoltaic plants, accumulated in the energy storage system, consumed by the power supply; registration of the state of the electrical network of food industry enterprise and indicators of the quality of electric energy; M_2 - choice of model and forecasting of consumption of electric energy by food industry enterprise; M_3 - choice of model and forecasting of electric energy generation by photovoltaic plants; M_4 - choice of model and forecasting of the state of the energy storage system; M_5 – analysis of the electrical network configuration; calculation of power supply mode and parameters of electric energy quality; M_6 - formation of a database for controlling the electrical consumption of food industry enterprise and maintaining it in an up-to-date state; M_7 – formation of decisions regarding: electric energy consumption from photovoltaic plants, energy storage system and electric network; delivery of electric energy from photovoltaic plants (energy storage system) to electric networks; the maximum power consumption of the food industry enterprise; M_8 – formation of decisions on optimization of power supply operating modes, choice of electrical network configuration, increase of indicators of the quality of electric energy; M_9 – forming decisions regarding the capacity generated by the photovoltaic plants; M_{10} – formation of decisions regarding the power received from energy storage system.

Main elements and mechanisms that implement control functions:

Y_1 – information on the status and regimes of the power supply, which is provided by the information and computing complex of the chief energy service; Y_2 – restrictions on the configuration of the electrical network, the implementation of power consumption standards, power supply operation modes; indicators of the quality of electric energy, which are formed by the energy dispatcher; Y_3 – restrictions on meeting the requirements of the power system and the reliability of electricity supply, which are formed by the chief energy engineer; Y_4 – data on consumption and capacity of electric energy, generation of electric energy by food industry enterprise, charge energy storage system, quality parameters of electric energy, state of power supply elements and power supply configuration provided by sensors; Y_5 – information for the preparation of decisions on power supply management, which is provided by the database of the American Chemical Society (ACS).

Main information flows that provide control functions:

T_1 – forecast values of air humidity, illumination and ambient temperature coming from the weather station; T_2 – data on the current consumption of electric energy by food industry enterprise; T_3 – current data on the volumes of products produced by divisions and the enterprise; T_4 – restrictions on the volumes of electric energy and power from the power system; T_5 – current data about the ambient temperature; T_6 – forecast values of consumption electric energy on food industry enterprise; T_7 - expenditure plan electric energy for the food industry enterprise; T_8 - making a decision on electric energy expenses; T_9 – management actions to regulate electric energy costs; T_{10} – data on current indicators of the quality of electric energy; T_{11} – data about the current mode parameters of power supply; T_{12} – data about the current configuration of the power supply; T_{13} – data on indicators of the quality of electric energy management; T_{14} – data on the management of changes in the configuration of power supply; T_{15} – management data on the optimization of regimes of power supply; T_{16} - data on photovoltaic plant management; T_{17} - data on energy storage system management; T_{18} - data on the state of the photovoltaic plants; T_{19} - data on the state of energy storage system, T_{20} – forecast values of electric energy generation by photovoltaic plants.

We will present the results of the system analysis of the food industry enterprise power supply management process in the form of displays of individual actions:

– verification of measurement information for reliability, registration of electric energy consumption, assessment of the state of the electric network and indicators of the quality of electric energy:

$$C_1 : \{M_1 \times (T_1, T_2) \times G_3 \times (Y_1, Y_2, Y_5)\} \rightarrow (T_2, T_4); \quad (12)$$

– model selection and electricity consumption forecasting:

$$C_2 : \{M_2 \times (T_2, T_3, T_5) \times (G_1, G_3, G_5) \times Y_1\} \rightarrow T_6; \quad (13)$$

– choosing a model and forecasting the electric energy generation by the photovoltaic plants:

$$C_3 : \{M_3 \times (T_1, T_5) \times (G_3, G_7) \times Y_4\} \rightarrow T_{20}; \quad (14)$$

– choosing a model and forecasting the condition of the battery of energy storage system:

$$C_4 : \{M_4 \times (T_2, T_{10}) \times (G_6, G_{12}) \times Y_4\} \rightarrow T_{19}; \quad (15)$$

– analysis of power supply, indicators of the quality of electric energy and power supply reliability modes:

$$C_5 : \{M_5 \times (T_4, T_6, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{17}, T_{18}) \times (Y_1, Y_2, Y_3, Y_4, Y_5)\} \rightarrow T_{10}, T_{11}, T_{12}, T_{18}; \quad (16)$$

– making a decision on the volume of electric energy consumption:

$$C_6 : \{M_7 \times (T_2, T_4, T_5, T_{14}) \times (G_1, G_2, G_{11}, G_{12}) \times (Y_1, Y_2, Y_3, Y_4)\} \rightarrow T_8, T_9; \quad (17)$$

– decision-making regarding configuration changes, optimization of power supply modes, normalization of indicators of the quality of electric energy:

$$C_7 : \{M_8 \times (T_9, T_{11}, T_{12}, T_{18}, T_{19}) \times (G_{10}, G_{11}, G_{12}) \times (Y_1, Y_2, Y_4, Y_5)\} \rightarrow T_{13}, T_{14}, T_{16}, T_{17}; \quad (18)$$

– formation and maintenance of the electric energy cost management database in an up-to-date state:

$$\begin{aligned} C_8 : &\{M_6 \times (T_3, T_4, T_7, T_8, T_{10}, T_{11}, T_{12}, T_{18}, T_{19}) \times G_9 \times (Y_1, Y_2, Y_3, Y_5)\} \\ &\rightarrow T_2, T_3, T_6, T_7, T_{10}, T_{18}, T_{19}; \end{aligned} \quad (19)$$

– making a decision on the volume of electric energy generation by photovoltaic plants:

$$C_9 : \left\{ \begin{aligned} &(M_3, M_7) \times (T_1, T_2, T_4, T_5, T_{11}, T_{18}, T_{19}) \times (G_1, G_6, G_{11}, G_{12}) \\ &\times (Y_1, Y_3, Y_2, Y_4) \end{aligned} \right\} \rightarrow T_{16}; \quad (20)$$

– making a decision on the volumes of electric energy from energy storage system:

$$C_{10} : \left\{ \begin{aligned} &(M_4, M_7) \times (T_2, T_4, T_8, T_{16}, T_{18}, T_{19}) \times (G_1, G_6, G_7, G_{11}, G_{12}) \\ &\times (Y_1, Y_2, Y_3, Y_4) \end{aligned} \right\} \rightarrow T_{17}; \quad (21)$$

The decomposition of the power supply control system of the food industry enterprise using photovoltaic plants and energy storage system is performed, which provides its presentation and reflects information interaction, conditions and mechanisms.

Approaches to building an automated power supply control system

The purpose of managing the power supply of the food industry enterprise using photovoltaic plants and energy storage system is the efficient (reliable and economical) supply and use of electricity at the food industry enterprise.

Using the decomposition method, the control task is divided into several separate subtasks: the control task of photovoltaic plants and energy storage system; the task of managing the modes of the enterprise's electric network; the problem of voltage regulation and reactive power compensation.

Methods of solving problems of mode control, voltage regulation and reactive power compensation are described in (Baliuta et al., 2018; 2020; Yovbak et al., 2021).

For the control of photovoltaic plants and energy storage system, predicted values of generation by photovoltaic plants and load capacity are used, as well as mathematical models of individual elements (Kuevda et al., 2021; Zinkevych et al., 2022). The goal of optimization is to determine the SOC trajectory on next day, taking into account the goals of "power costs", "offloading the network" and "increased battery life".

The cost function for electrical energy in the food industry enterprise power supply system using photovoltaic plants and energy storage system is as follows:

$$\varphi = K_{wP} + K_{wQ} + K_{AB} + K_{\Delta PN} + K_{Z} \tag{22}$$

K_{WP} represents the criterion of costs for active electricity; K_{WQ} represents the cost criterion for reactive electricity and power; $K_{\Delta PN}$ takes into account restrictions on active power consumed or supplied to the network; K_{AB} takes into account the impact of battery aging on the efficiency of the energy storage system.

When optimizing the operation of the power supply system with photovoltaic plants and energy storage system, it is necessary to take into account the state of charge (SOC) of the battery of energy storage system, the permissible degree of charge and discharge of the battery of energy storage system, the permissible number of cycles of charge and discharge of the battery of energy storage system.

Initially, the number of complete cycles will be interpreted as costs. Second, SOC dwell time will also be associated with costs. Starting at SOC 50% from €0 costs increase linearly up to SOC limits ($SOC_{Batt,\ min}$ and $SOC_{Batt,}$).

The task of optimization consists in minimizing the objective function J on the time horizon T:

$$\min J = \sum_{n=1}^{T} \varphi(SOC, n) \tag{23}$$

The limitations used in the optimization can be obtained from the features of the lithium-ion battery. To ensure safe battery operation, SOC and P_{Batt} power are limited as follows:

$$SOC_{Batt,\min} \le SOC_{Batt} \le SOC_{Batt,\max} \tag{24}$$

$$P_{Batt,\min} \le P_{Batt} \le P_{Batt,\max} \tag{25}$$

In addition, at high SOCs, many Li-ion batteries show accelerated aging. To overcome these problems, the proposed improved concepts are based on rules, which allows to further unload the grid by reducing the maximum power supplied and obtaining a fully charged battery in the evening. Considering additional criteria such as battery life, variable energy prices, variable feed-in tariffs and load balancing, optimization-based concepts are used. Recently, dynamic programming has been used to solve such multi-criteria optimization tasks. Using this model-based approach, nonlinear equations (such as the SOC-OCV curve) can be easily considered, there are no restrictions on the design of the objective function, and finally, the optimization result is a global optimum depending on the discretization. Referring to the principle of optimality, it is proposed (Bellman, 2010), the optimization task is divided into subtasks. Each sub-problem is solved and then combined to formulate an overall solution.

The weighted sum approach is used to solve the multi-criteria optimization problem. Weighting coefficients are chosen taking into account expert knowledge.

When optimizing by the method of dynamic programming, the cost function g determines the cost of transition from state x[k] to state x[k+1] (Bellman, 2010):

$$J = g(x[N]) + \sum_{k=0}^{N-1} g(x[k], u[k]) \tag{26}$$

The state variable x represents the state of charge of the battery, and the control variable u corresponds to the battery capacity. Costs for the transition g consist of the target functional shares: electricity costs $C_{ELCOSTS}$, maximum input power to the network $C_{P,NET}$, the maximum set power from the network $C_{P,CONS}$, battery capacity C_{CYCLE}, values up to 50% state of charge C_{SOC} and losses in the system C_{COSTS}:

$$g = C_{ELCOSTS} + \delta \cdot C_{P,NET} + \varepsilon \cdot C_{P,CONS} + \lambda \cdot C_{SOC} + \mu \cdot C_{\mathrm{CYCLE}} + C_{COSTS} \tag{27}$$

The weighted sum approach is used to solve this multi-criteria optimization task. Weighting coefficients (δ , ε , λ , μ) are chosen taking into account expert knowledge.

Multi-criteria optimization involves solving several optimization problems with different time horizons: current, short-term, and long-term.

Long-term optimization, works with a time horizon of one month. The purpose of this optimization is to coordinate the aging of the battery and ensure its operating conditions (degree of charge and discharge, number of cycles) that optimize the service life of the battery. On the basis of the residual capacity of the lithium-ion battery, the address correction of the short-term optimization is carried out by adapting the weight coefficients of the objective function. This makes it possible to respond to changes in power of photovoltaic plants (PPP) and consumer behaviour, to compensate for unexpected deviations in the aging characteristics of lithium-ion batteries, and to adapt to different economic conditions. In addition, long-term optimization adjusts the parameters of the online simulation model. The basis of this is state diagnostics, the task of which is to identify the model parameters of the online simulation model during operation.

The level of short-term optimization creates the optimal power flow distribution for the power supply system using photovoltaic plants and energy storage system with a time resolution of 15 minutes. This ensures maximum use of solar energy, reduction of power peaks from the grid on the consumer's side, avoidance of power losses from the shutdown of photovoltaic modules, and minimized electricity costs. The observation horizon is within a few hours. Dynamic programming is used to determine the optimal power flow distribution. Re-optimization using model-predictive control allows you to take into account updated forecast information and compensate for the resulting model and forecast errors.

The current optimization shapes the value of the power of the battery depending on the target power of the network and ensures the efficient operation of the entire system. In addition, the limitation of the maximum charging and discharging capacity is ensured. Instant optimization works every second.

To ensure the conditions of operation of the accumulator battery, it is advisable to use a combined approach when choosing an accumulator battery. It should be taken into account that storage batteries are used to reduce (cut off) rapidly changing peak loads of network power and to power consumer loads that change relatively slowly. Thus, it is advisable to use two storage batteries: one storage battery with a large capacity is designed to cover the peak load of the network, and the other storage battery with a large capacity (charge) with a low self-discharge rate and lower installation costs.

Evaluation criteria are defined to assess the functioning of the operational management process and to quantify the impact of the studied setting parameters.

Degree of self-sufficiency k_{SSUFF} determines the share of annual consumption that can be covered by a photovoltaic system. This criterion is directly related to the costs of purchasing electricity. The higher the level of self-sufficiency, the less additional energy needs to be obtained from the grid. As a result, the cost of purchasing electricity is also reduced.

$$k_{SSUFF} = \frac{E_{CONS} - E_{\mathrm{NETWORK}}}{E_{CONS}} \cdot 100\% \tag{28}$$

The coefficient of own consumption k_{OCONS} shows how large a proportion of the self-consumed photovoltaic energy is in relation to the available photovoltaic energy E_{PPP}. The lower the losses during the disconnection of the photovoltaic plants E_{DISPPP} and photovoltaic energy fed into the grid $E_{FROMNET}$, the higher the level of self-consumption.

$$k_{OCONS} = \frac{E_{PPP} - E_{DISPPP} - E_{FROMNET}}{E_{PPP}} \cdot 100\% \tag{29}$$

Reduction losses k_{REDPPP} show how much photovoltaic energy cannot be used. If the maximum feed-in limit is exceeded, the PV plant no longer operates at the point of maximum output power.

$$k_{REDPPP} = \frac{E_{DISPPP}}{E_{PPP}} \cdot 100\% \tag{30}$$

The maximum power consumed from the network $k_{NET,max}$ means the quarter-hour maximum power received from the grid P_{CONS}.

$$k_{NET,max} = \max\left(P_{CONS}\right) \tag{31}$$

Full battery cycle k_{bcycle} is a measure of the use of a lithium-ion battery. It is calculated based on the battery capacity P_{Batt} in relation to the nominal energy density E_{Batt}.

$$k_{bcycle} = \frac{\int \left|P_{Batt}\right| dt}{2 \cdot E_{Batt}} \tag{32}$$

Automated control system of power supply

On the basis of the tasks of controlling the power supply of the food industry enterprise, control tasks and methods of controlling the photovoltaic plants and energy storage system, a functional scheme of the automated control system of the power supply of the food industry enterprise using the photovoltaic plants and energy storage system was developed (Fig. 1).

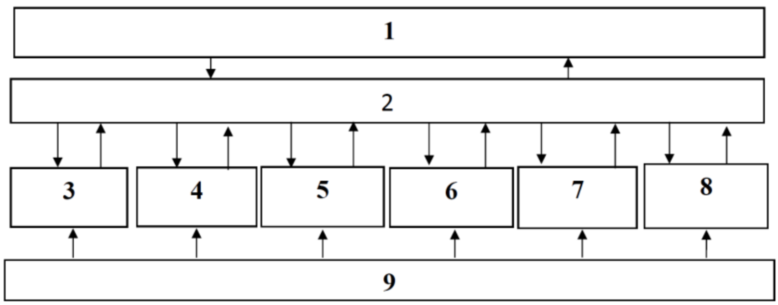

Figure 1. Functional diagram of power consumption and power supply control of food industrial enterprise:

1 – Database of the American Chemical Society of the food industry enterprise energy industry;
2 – Database of control of power supply of food industry enterprise;

3 – Unit for monitoring electricity consumption, electrical loads, generation capacity of photovoltaic plants: automatic transmission of data from electric energy metering devices and control of the reliability of information is carried out;
4 – Block of forecasting of electric load and generation of photovoltaic plants: the forecast (daily, monthly and annual) of food industry enterprise is performed;
5 – photovoltaic plants condition control unit;
6 – Block of control over the state of battery;
7 – Block of optimization of energy supply system modes based on measured values of voltage, active and reactive power;
8 – Block of control of indicators of the quality of electric energy with the help of measuring devices and selection of means of ensuring normative indicators of the quality of electric energy;
9 – Organizational and technical means of controlling the power supply of the food industry enterprise.

It is formulated the requirements for individual functional subsystems (blocks) of the automated control of the power supply of the food industry enterprise based on the performed system analysis.

Functional unit for monitoring electricity consumption, electrical loads, generation capacity of photovoltaic plants

It controls the reliability of information and automatically transmits data from electric energy metering devices, as well as meteorological data. The time interval of reading and transmitting data is determined taking into account the requirements for the accuracy of the calculation of the parameters describing the process of power supply of the food industry enterprise.

Control of the reliability of information at the initial stage involves the analysis of a priori data on the parameters of power supply regimes: permissible limits of parameter changes, the nature of their changes over time, and consistency. Additional reliability control is also carried out, which consists in checking the dependencies between the parameters of the power supply of the food industry enterprise.

Functional unit for forecasting the electric load and generation of photovoltaic plants

The forecast (daily, monthly and annual) of the food industry enterprise load, as well as the electric energy generation schedule from the photovoltaic plants is carried out based on forecast meteorological data. Forecasting is carried out using statistical and intelligent models.

Functional monitoring of the state of photovoltaic plants

On the basis of the automation of information collection and processing, the load of the photovoltaic plants, the parameters of photocells and inverters, the efficiency of their work is estimated, and the parameters of mathematical models are specified.

Functional unit for monitoring state of battery

Based on the automation of information collection and processing, the current charge of the battery, the permissible minimum and maximum charge, the number of permissible charge and discharge cycles, the degree of aging of the battery, and the parameters of the mathematical model are specified.

Functional unit for optimization of power supply modes

With the use of mathematical models based on the values of voltage, active and reactive power measured at the nodal points of the power supply, as well as the network voltage, the capacities of the photovoltaic plants and energy storage system, ensures the formation of rational levels of voltage and losses of electrical energy in the distribution electrical networks of the food industry enterprise.

Functional unit of control of indicators of the quality of electric energy

Based on the indicators of measuring devices installed at different hierarchical levels of the power supply, indicators of the quality of electric energy are determined, using mathematical models, methods of managing technical means of ensuring regulatory indicators of the quality of electric energy are determined.

Appropriate control algorithms are being developed to ensure the functioning of functional blocks.

Organizational and technical means of controlling the power supply of food industry enterprise.

The construction of automated control system power supply of the food industry enterprise is carried out on the platform of a real –time operating system, since it involves the management of food industry enterprise, energy storage system, means of providing indicators of the quality of electric energy in real time. The collection of information and its primary processing is carried out using programmable logic controllers. Programmable logic controllers are distributed at control points and are software compatible with the MS Windows platform.

Construction of automated control system power supply of the food industry enterprise is carried out on the basis of an information model of data, which is built according to the object –oriented principle: all objects of the power supply system, which are control objects in the model are represented by some objects.

Data models are built using CIM (Common Information Model, standard MEK 61968, 61970). This allows you to unify the description of objects, integrate software from different manufacturers within the enterprise, and transfer Common Information Model schemes between applications.

In this way, an approach to the construction of an automated control system for power supply of food industry enterprise using photovoltaic plants and energy storage system is proposed, which involves the creation of a multi –level control system that corresponds to the hierarchical structure of the power supply system, the use of information systems, local and centralized control systems, the application of intelligent control algorithms, and ensures effective use power of photovoltaic plants and energy storage system, as well as achieving high efficiency of the electricity supply system.

The integration of automated control system power supply of the food industry enterprise is carried out by using hardware and software tools that combine disparate functions (accounting of electric energy, voltage regulation, management of power supply modes, management of indicators of the quality of electric energy on the basis of uniform data exchange protocols and communication channels; costs for ensuring their compatibility and interaction and evaluation of the effect obtained as a result of the joint and coordinated functioning of the American Chemical Society.

Conclusion

When creating a food industry enterprise power supply control system, it is advisable to use the decomposition of the control process and methods of system analysis, which allows you to determine the main stages of the management process; conditions for providing control functions; basic information flows that provide power supply control, organizational and technical mechanisms for implementing management functions. In order to ensure effective power supply modes of the food industry enterprise using photovoltaic plants and energy storage system, it is necessary to conduct control based on mathematical models using dynamic programming methods. This will make it possible to make maximum use of the energy obtained from the photovoltaic plants, ensure energy – efficient operation modes of the battery of energy storage system and reduce the peak loads of the network power. The synthesis of the automated control system of the power supply of the food industry enterprise using photovoltaic plants and energy storage system is expediently carried out using the method of compatibility and integration to ensure functional, informational, software and technical integration of system elements. In order to build automated control system power supply of the food industry enterprise, it is necessary to use an information model of the data, built using the Common Information Model information model according to the object – oriented principle.

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Анотації

Харчові технології

Функціонально-технологічні властивості білкових інгредієнтів у складі морозива сироваткового

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Вступ. Робота присвячена дослідженню фізико-хімічних характеристик сумішей сироваткового морозива з білоквмісними інгредієнтами.

Матеріали та методи. В'язкісно-швидкісні характеристики сумішей досліджували методом ротаційної віскозиметрії. Пінозбитість та піностійкість сумішей морозива визначали за допомогою загальновідомих методів.

Результати та обговорення. Обґрунтовано доцільність використання білкових інгредієнтів у складі сумішей морозива сироваткового для підвищення його харчової цінності. Встановлено, що ізолят сироваткових білків (3–5%), міцелярний казеїн (3%) і концентрат сироваткових білків (3%) підвищують пінозбитість сумішей сироваткового морозива, в той час як ізолят соєвих білків знижує її. Найвищий показник піностійкості, що становив 57.6–58.4%, був зафіксований за використання 3–5% ізоляту сироваткових білків. За результатами аналізу реограм течії сумішей морозива з різними білковими інгредієнтами їх віднесено до харчових систем з коагуляційною структурою, що відрізняється вираженими тиксотропними властивостями. У разі застосування міцелярного казеїну, концентрату сироваткових білків та ізоляту сироваткових білків тиксотропна здатність сумішей підвищується від 58.2% до 62.2–72.2%. Ізолят соєвого білка не виявляє вказану технологічну активність. Найвища тиксотропність сумішей спостерігається у разі використання 3% міцелярного казеїну та 3–5% ізоляту сироваткових білків за рахунок їх специфічної здатності утворювати просторову коагуляційну структуру, яка самочинно відновлює структуру після зруйнування за рахунок наявності чисельних низькоенергетичних зв'язків. Концентрат сироваткових білків відзначається помірною дією на реологічні характеристики сумішей, в той час як присутність ізоляту соєвого білку призводить до часткової втрати здатності сумішей до самочинного відновлення зруйнованої структури.

Доведено можливість підвищення загального вмісту білку у морозиві від 3,45% до 6.02–7,81% за рахунок застосування технологічно ефективних молочно-білкових інгредієнтів.

Висновки. Міцелярний казеїн та ізолят сироваткових білків у складі морозива сироваткового виявляють високу технологічну активність і значно покращують показники якості готового продукту.

Ключові слова: *морозиво, концентрат сироватки, білок, пінозбитість, піностійкість, тиксотропність.*

Обґрунтування технології хліба пшеничного збагаченого сумішшю пророщених зерен з використанням полікомпонентної суміші

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Вступ. Метою дослідження є обґрунтування складу полікомпонентної суміші для покращання органолептичних властивостей та подовження свіжості хліба з пшеничного борошна з додаванням суміші пророщених зерен.

Матеріали і методи. Вплив полікомпонентної суміші на процеси черствіння досліджували зміною деформації м'якушки виробів, формуванням підскоринкового шару, накопичення ароматичних речовин та декстринів.

Результати і обговорення. Рекомендована рецептура полікомпонентної суміші включає: суха молочна сироватка збагачена Mn та Mg, суха пшенична клейковина, інуліну цикорію кабоксиметилцелюлоза, молочна кислота, фосфатидний концентрат, ферментний препарат Deltamalt FN-A50. Для виробництва хліба пшеничного, до рецептури якого внесено 15 % до маси борошна суміші пророщених зерен, доцільно вносити полікомпонентну суміш в кількості 1,8 % до маси борошна. За встановленого дозування покращуються органолептичні показники та питомий об'єм виробів збагачених сумішшю пророщених зерен порівняно з виробами з сумішшю пророщених зерен. За раціонального дозування полікомпонентної суміші покращується загальна, пластична і пружна деформація м'якушки виробів, зменшується кришкуватість м'якушки та підскоринковий шар. Втрата свіжості хліба збагаченого СПЗ через 72 години зменшується на 5,7 %, що на 44,3 % менше порівняно з контрольним зразком. У хлібі в рецептурі якого міститься 15 % до маси борошна суміші пророщених зерен використання полікомпонентної сумішші збільшує накопичення низькомолекулярних декстринів порівняно з контролем на 77,6 %.

Висновки. Використання розробленої полікомпонентної суміші позитивно впливає на якість хліба пшеничного збагаченого сумішшю пророщених зерен та подовжує його свіжість до 72 год без упакування.

Ключові слова: *хліб, суміш, пророщені, зерно, свіжість, полікомпонентний, добавка.*

Вплив електрохімічно активованої води на реологічні показники крохмальних суспензій

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Вступ. Метою роботи є визначення впливу електрохімічно активованої води (католіту та аноліту) на зміну реологічних показників суспензій кукурудзяного крохмалю за різних температурних режимів.

Матеріали і методи. Було досліджено функціонально–технологічні властивості кукурудзяного крохмалю за показниками водопоглинальної, вологоутримувальної, жиропоглинальної та жироутримувальної здатності, а також впливу електрохімічно активованої води на ці показники в порівнянні зі звичайною водопровідною водою. Реологічні характеристики крохмальних суспензій, приготованих на електрохімічно активованій воді, визначали при різних температурах на реометрі Kinexus Pro+.

Результати і обговорення. Електрохімічно активована вода зумовлює зміну функціонально–технологічних властивостей кукурудзяного крохмалю: водопоглинальна та вологоутримувальна здатності крохмалю, приготованого на католіті, знижується на 26 % та 10 %, а при додаванні аноліту – підвищується на 18 % та 36 %, порівняно зі зразком на водопровідній воді. Крохмаль в більшій мірі проявляє здатність поглинати воду в кислому середовищі (аноліту), ніж у лужному (католіту). Електрохімічно активована вода також має значний вплив на реологічні показники крохмальних суспензій: при зміні швидкості зсуву в діапазоні 0,1–100 с$^{-1}$ напруга зсуву збільшувалась лінійно. При температурі клейстеризації: контроль, на аноліті та католіті – 0–10,6 Па, 0–13,6 Па та 0–23,8 Па відповідно. При температурі 25 ºС зміна була більшою – 0–19,5 Па, 0–28,4 Па та 0–30,8 Па відповідно. При нульовій швидкості зсуву початкова в’язкість зсуву суспензій і при 25 ºС і при 68 ºС на католіті та аноліті вища за контрольний зразок. При зміні напруження зсуву при 25 ºС значення в’язкості зсуву збільшуються, маючи найвищі значення на кінцевому етапі на католіті та аноліті – 1,7 та 13 Па·с у порівнянні з контролем – 0,6 Па·с. При 68 ºС тенденція зміни досліджуваного показника аналогічна, однак початкові значення вищі, ніж відповідні значення при 25 ºС, а кінцеві нижчі. Показник кутової швидкості збільшувався лінійно при зміні напруження зсуву.

Висновки. Проведені дослідження свідчать, що електрохімічно активована вода має значний вплив на функціонально–технологічні властивості та реологічні характеристики напівфабрикатів, зокрема суспензій кукурудзяного крохмалю, що у свою чергу матиме вплив на відповідні показники та структуру харчових продуктів з цією сировиною.

Ключові слова: *активація, аноліт, католіт, крохмаль, суспензія, реологія*.

Білкові речовини вівсяних висівок та їхній вплив на конформаційні перетворення в тісті та хлібі з пшеничного борошна

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Вступ. Метою роботи було визначення ступеню повноцінності білкових речовин вівсяних висівок та їхній вплив на конформаційні перетворення в структурі тістових напівфабрикатів і хліба з пшеничного борошна.

Матеріали і методи. Було досліджено вівсяні висівки, їхній амінокислотний склад та вилив на вміст білкових речовин в хлібі. Конформаційні перетворення структурних елементів в тісті та хлібі були досліджені методом інфрачервоної спектроскопії у ближній інфрачервоній області.

Результати і обговорення. Встановлено, що вміст незамінних амінокислот у вівсяних висівках значно вище, ніж у борошні пшеничному. Лімітуючою амінокислотою у пшеничному борошні є лізин, амінокислотний скор якого 0,44. У вівсяних висівках лімітуючою амінокислотою є метіонін, амінокислотний скор якого 1,14, а амінокислотний скор лізину набагато вищий, ніж у борошні – 1,62. Лімітуючою амінокислотою у хлібі є лізин, амінокислотний скор якого 0,46. Зі збільшенням відсотку заміни пшеничного борошна вівсяними висівками амінокислотний скор лізину підвищився на 19,5–52,2%. Це свідчить про те, що білок даної сировини сприяє підвищенню рівня незамінних амінокислот у хлібі, що збагачує його білковий профіль. Отримані спектри зразків тіста після замішування показали, що внесення вівсяних висівок не викликає конформаційних перетворень в тістовій системі, оскільки не пройшло достатньо часу для взаємодії біополімерів сировини. Інфрачервоні спектри тіста на довжині хвилі 2100 нм показали, що харчові волокна вівсяних висівок затримують розвиток глютенової мережі, структура білкової матриці тіста з висівками буде менш стабільною та більш послабленою, ніж контрольного зразка.

Висновки. Внесення в рецептуру пшеничного хліба вівсяних висівок з більшим вмістом білка, харчових волокон та повноцінним амінокислотним профілем сприяє покращенню біологічної цінності хліба з цією сировиною. Однак погіршення розвитку клейковинного каркасу тіста, а отже і питомого об'єму, пористості та формостійкості хліба потребує застосування технологічних прийомів для мінімізації негативного впливу висівок на якість готових хлібобулочних виробів.

Ключові слова: *хліб, вівсяні висівки, клейковина, амінокислота, ІС.*

Закономірності структуроутворення фруктових гелів з моно- і дисахаридами

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Вступ. У структуроутворенні фруктових гелів важливе значення має вид цукру, що додається. Представляє інтерес вивчення відмінностей процесу гелеутворення фруктових гелів з сахарозою, глюкозою, фруктозою з метою застосування наукових даних в технологіях кондитерських виробів.

Матеріали та методи. Для досліджень використовували рецептурні суміші для фруктових гелів, які включали яблучне пюре, цукор і патоку, фруктові уварені маси і структуровані фруктові гелі. Реологічні властивості визначали на ротаційному віскозиметрі, гелеутворювальну здатність – органолептично, пружно-пластичні властивості – за допомогою структурометра, дослідження кількості вільної та зв'язаної вологи – на дериватографі.

Результати і обговорення. Визначено, що вищі значення ефективної в'язкості модельних рецептурних сумішей за температури 20±2 °С характерні системам із глюкозою в межах значень напруги зсуву Р=2,601–17,918 Па. Найменші значення спостерігаються для рецептурних сумішей із фруктозою, що пов'язано із різною розчинністю цукрів. За підвищення температури досліджень до 65±2 °С відбувається зміна розчинності цукрів і змінюється залежність між кривими в'язкості, – найбільші значення ефективної в'язкості характерні зразкам із сахарозою, дещо менші – для зразків із глюкозою і фруктозою. При цьому міцність внутрішнього утвореного структурного каркасу, P_m, для модельної маси з сахарозою складає 114,73 Па, для модельної маси з глюкозою – 23,12 Па, для модельної маси з фруктозою – 35,0 Па.

Встановлено, що за рівнозначних умов уварювання фруктові гелі на сахарозі й глюкозі добре виймаються із форм, не прилипають, мають суху поверхню, тобто характеризуються відмінною гелеутворювальною здатністю. Гель на фруктозі погано виймається із форми і потребує збільшеного часу гелеутворення. Досліджено, що фруктові гелі витримують різне навантаження до прориву: сила, необхідна для прориву фруктового гелю із сахарозою дорівнює 50 Н, з глюкозою – 35 Н, з фруктозою – 30 Н.

За дериватографічними дослідженнями і розрахунками вмісту зв'язаної води в гелях установлено більшу її частку для фруктових гелів із сахарозою. Це перевищує дослідний показник для гелю із глюкозою на 2,2%, з фруктозою – на 4,3%.

Висновки. Гелі із сахарозою мають вищі значення ефективної в'язкості у порівнянні з гелями з ідентичною кількістю глюкози або фруктози. Міцність фруктових гелів на сахарозі вища за значеннями сили, що необхідна до прориву драглів, а загальна деформація менша. Зразки гелів із сахарозою мають меншу кількість вільної вологи.

Ключові слова: *фруктовий гель, гелеутворення, пектин, сахароза, фруктоза, глюкоза.*

Процеси, обладнання і системи контролю

Системний аналіз автоматизованої системи керування електропостачанням підприємства харчової промисловості з використанням фотоелектричної установки та накопичувача

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Вступ. Проведені дослідження процесу керування електрозабезпеченням підприємства харчової промисловості з використанням фотоелектростанції та накопичувача електричної енергії для забезпечення ефективності передавання та використання електричної енергії.

Матеріали і методи. Дослідження виконані з використанням методів сучасної теорії автоматичного керування та системного аналізу процесів керування.

Результати і обговорення. Визначені основні етапи процесу керування електрзабезпеченням з використанням фотоелектростанції (ФЕС) та системи накопичення електричної енергії (СНЕ): базові функції керування – реєстрація споживання електричної енергії (ЕЕ), прогнозування генерації ЕЕ з використанням ФЕС, прогнозування споживання ЕЕ, визначення параметрів СНЕ, проведення аналізу режимів системи електрозабезпечення; умови забезпечення функцій керування – інформація про сонячне випромінювання; дані про генерацію ЕЕ за допомогою ФЕС, дані про споживання ЕЕ, обмеження та тарифи на ЕЕ, вимоги до точності прогнозу електроспоживання та генерації ЕЕ за допомогою ФЕС, дані про СНЕ (поточний заряд, допустимий максимальний та мінімальний заряди) прийняття рішення по оптимізації режимів системи електрозабезпечення (СЕЗ); організаційно-технічні механізми реалізації функцій керування – інформаційно-обчислювальний комплекс, енергодиспетчер, головний енергетик; база даних (БД) АСУ електрозабезпеченням, яка використовується для підготовки рішень; базові інформаційні потоки, які забезпечують керування електрозабезпеченням – прогнозні значення метеоданих, поточні дані про споживання ЕЕ, керувальні дії з регулювання ФЕС та СНЕ, поточні дані про параметри режиму СЕЗ; поточні дані про конфігурацію СЕЗ; керувальні діяння з оптимізації режимів СЕЗ, керуючі діяння з керування ПЯЕЕ; керувальні діяння зміни конфігурації СЕП. Представлена функціональна схема керування електрозабезпеченням з використанням ФЕС та СНЕ і сформульовані вимоги до окремих блоків. Синтез системи керування електрозабезпеченням ПХП проводиться з використанням методу забезпечення сумісності шляхом послідовної інтеграції. Для забезпечення енергоефективного електрозабезпечення ПХП та оптимального використання ФЕС та НЕС проводиться оптимізація режимів з використанням методів динамічного програмування.

Висновок. Розробка систем керування електрозабезпеченням ПХП з використанням ФЕС та СНЕ на основі системного аналізу та сумісності з використанням оптимізації режимів за допомогою методів динамічного програмування, забезпечує високу ефективність електрозабезпечення та раціональні режими використання ФЕС та НЕС.

Ключові слова: *електроенергія, керування, електрозабезпечення, фотоелектростанція, накопичувач.*

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Author contributions

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

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Book

Deegan C. (2000), *Financial Accounting Theory*, McGraw-Hill Book Company, Sydney.

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Coffin J.M. (1999), Molecular biology of HIV, In: Crandell K.A. ed., *The evolution of HIV*, Johns Hopkins Press, Baltimore, pp. 3-40.

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Conference paper

Arych M. (2018), Insurance's impact on food safety and food security, *Resource and Energy Saving Technologies of Production and Packing of Food Products as the Main Fundamentals of Their Competitiveness: Proceedings of the 7th International Specialized Scientific and Practical Conference, September 13, 2018,* NUFT, Kyiv, pp. 52-57.

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Place footnotes to tables below the table body and indicate them with superscript lowercase letters.

Place table after its first mentioned in the text.

Ensure that the data presented in tables do not duplicate results described elsewhere in the article.

Suggesting / excluding reviewers

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Submission

Email for all submissions and other inquiries:

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Ukrainian Journal of Food Science публікує оригінальні наукові статті, короткі повідомлення, оглядові статті, новини та огляди літератури.

Тематика публікацій в **Ukrainian Journal of Food Science:**

Харчова інженерія	Нанотехнології
Харчова хімія	Процеси та обладнання
Мікробіологія	Економіка і управління
Властивості харчових продуктів	Автоматизація процесів
Якість та безпека харчових продуктів	Упаковка для харчових продуктів
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Періодичність журналу 2 номери на рік (червень, грудень).

Результати досліджень, представлені в журналі, повинні бути новими, мати зв'язок з харчовою наукою і представляти інтерес для міжнародного наукового співтовариства.

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Ukrainian Journal of Food Science включено у перелік наукових фахових видань України з технічних наук, в якому можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора і кандидата наук (Наказ Міністерства освіти і науки України № 793 від 04.07.2014)

Рецензія рукопису статті. Наукові статті, представлені для публікації в «**Ukrainian Journal of Food Science**» проходять «подвійне сліпе рецензування» (рецензент не знає, чию статтю рецензує, і, відповідно, автор не знає рецензента) двома вченими, призначеними редакційною колегією: один є членом редколегії, інший – незалежний учений.

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Вимоги до оформлення статей

Мова статей – англійська.

Мінімальний обсяг статті – **10 сторінок** формату А4 (без врахування анотацій і списку літератури)**.**

Для всіх елементів статті шрифт – **Times New Roman**, кегль – **14**, інтервал – 1.

Всі поля сторінки – по 2 см.

Структура статті:

1. **Назва статті.**
2. Автори статті (ім’я та прізвище повністю, приклад: Денис Озерянко).
3. *Установа, в якій виконана робота*.
4. Анотація. **Обов’язкова** структура анотації:
   - Вступ (2–3 рядки).
   - Матеріали та методи (до 5 рядків)
   - Результати та обговорення (пів сторінки).
   - Висновки (2–3 рядки).
5. Ключові слова (3–5 слів, але не словосполучень).

Пункти 2–6 виконати англійською і українською мовами.

6. Основний текст статті. Має включати такі обов’язкові розділи:
   - Вступ
   - Матеріали та методи
   - Результати та обговорення
   - Висновки
   - Література.

За необхідності можна додавати інші розділи та розбивати їх на підрозділи.

7. Авторська довідка (Прізвище, ім’я та по батькові, вчений ступінь та звання, місце роботи, електронна адреса або телефон).
8. Контактні дані автора, до якого за необхідності буде звертатись редакція журналу.

Рисунки виконуються якісно. Скановані рисунки не приймаються. Розмір тексту на рисунках повинен бути **співрозмірним** (!) тексту статті. **Фотографії можна використовувати лише за їх значної наукової цінності.**

Фон графіків, діаграм – лише білий. Колір елементів рисунку (лінії, сітка, текст) – чорний (не сірий).

Рисунки та графіки EXCEL з графіками додатково подаються в окремих файлах.

Скорочені назви фізичних величин в тексті та на графіках позначаються латинськими літерами відповідно до системи СІ.

У списку літератури повинні переважати англомовні статті та монографії, які опубліковані після 2010 року.

Оформлення цитат у тексті статті:

Кількість авторів статті	Приклад цитування у тексті
1 автор	(Arych, 2019)
2 і більше авторів	(Bazopol et al., 2021)

Приклад тексту із цитуванням: It is known (Bazopol et al., 2006; Kuievda, 2020), the product yield depends on temperature, but, there are some exceptions (Arych, 2019).

У цитуваннях необхідно вказувати одне джерело, звідки взято інформацію.
Список літератури сортується за алфавітом, літературні джерела не нумеруються.

Правила оформлення списку літератури

В Ukrainian Food Journalвзято за основу загальноприйняте в світі спрощене оформлення списку літератури згідно стандарту Garvard. Всі елементи посилання розділяються **лише комами**.

1. Посилання на статтю:
Автори А.А. (рік видання), Назва статті, *Назва журналу (курсивом)*, Том (номер), сторінки, DOI.
Ініціали пишуться після прізвища.
Всі елементи посилання розділяються комами.

1. Приклад:
Popovici C., Gitin L., Alexe P. (2013), Characterization of walnut (Juglans regia L.) green husk extract obtained by supercritical carbon dioxide fluid extraction, *Journal of Food and Packaging Science, Technique and Technologies,* 2(2), pp. 104–108.

2. Посилання на книгу:
Автори (рік), *Назва книги (курсивом)*, Видавництво, Місто.
Ініціали пишуться після прізвища.
Всі елементи посилання розділяються комами.
Приклад:

2. Wen-Ching Yang (2003), *Handbook of fluidization and fluid-particle systems,* Marcel Dekker, New York.

Посилання на електронний ресурс:

Виконується аналогічно посиланню на книгу або статтю. Після оформлення даних про публікацію пишуться слова **Available at:** та вказується електронна адреса.
Приклади:

(2013), *Svitovi naukovometrychni bazy*, Available at: http://www.nas.gov.ua/publications/q_a /Pages/scopus.aspx

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

Список літератури оформлюється лише латиницею. Елементи списку українською та російською мовою потрібно транслітерувати. Для транслітерації з української мови використовується паспортний стандарт.

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Детальні інструкції для авторів розміщені на сайті:

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