Для людей похилого віку дієтологи рекомендують споживати хлібобулочні вироби вчорашнього випікання та збагачені мінеральними речовинам. Тому актуальною проблемою хлібопекарської промисловості є подовження свіжості хлібобулочних виробів геродієтичного призначення. Для вирішення поставленої задачі рекомендовано використовувати харчові добавки та інгредієнти зі статусом GRAS і комплексні хлібопекарські поліпшувачі. Для подовження свіжості булочних виробів розроблено комплексний хлібопекарський поліпшувач «Мінеральна Свіжість +», до складу якого включено білу фармакопейну глину, карбоксиметилцелюлозу, емульгатор, ферментний препарат амілолітичної дії, аскорбінову кислоту, мальтодекстрин, яблучний пектин. Доведено технологічну ефективність використання комплексного хлібопекарського поліпшувача «Мінеральна Свіжість +» для уповільнення черствіння виробів. Встановлено, що оптимальне дозування поліпшувача становить 1,5 % до маси борошна.

Визначено закономірності впливу комплексного хлібопекарського поліпшувача «Мінеральна Свіжість +» на формування структурно-механічних властивостей тіста. Встановлено, що внесення його в тісто приводить до збільшення кількості клейковини в тісті та поліпшення її пружних властивостей, покращує пластичні властивості тіста, що зумовлює скорочення тривалості замішування тіста. Зважаючи на інтенсифікацію процесу бродіння тіста у разі використання поліпшувача, рекомендовано його застосовувати у прискорених технологіях, а саме – процес бродіння замінювати процесом відлежування, який триває 30 хв.

Доведено, що вироби з доданням комплексного хлібопекарського поліпшувача «Мінеральна Свіжість +» краще зберігають свіжість, що підтверджено зменшенням кришкуватості, збільшенням загальної деформації м'якушки та її гідрофільних властивостей. Відмічено позитивний вплив використання комплексного хлібопекарського поліпшувача «Мінеральна Свіжість +» на мікробіологічні показники, що вказує на гальмування процесів мікробіологічного псування виробів.

Результати комплексу досліджень доводять доцільність використання комплексного хлібопекарського поліпшувача «Мінеральна Свіжість +» у технології булочних виробів для подовження тривалості їх свіжості до 72 год зберігання в не упакованому вигляді

Ключові слова: комплексний хлібопекарський поліпшувач, батон нарізний, черствіння, клейковина, структурно-механічні властивості тіста

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RESEARCH INTO EFFECTIVENESS OF USING THE INTEGRATED BREAD BAKING IMPROVER «MINERAL FRESHNESS +» TO SLOW DOWN THE STALING OF BAKERY PRODUCTS

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1. Introduction

The need to develop technologies of bakery products for gerodietary purposes is caused by to the socio-economic status of elderly people and the demographic situation due to the global and progressive aging of humanity [1]. Bread and bakery products predominate in the diet of elderly people, so nutritionists recommend consuming the products that were baked the day before, rather than freshly baked [2]. It is related to worsening of the process of digestion [3]. Rapid staling of bakery products during their storage occurs as a result of the processes of staling, drying and microbiological spoilage [4].

The effective measure for extension of the bread storage term is the use of alternative raw materials, food additives, integrated bakery improvers, which along with the slowing down the staling process, increase the nutritional value of bread, enrich it with substances that are important for human life [5]. The composition of integrated bakery improvers is very diverse, depending on the orientation of their actions [6].

It is known that to provide bakery products with gerodietary properties, it is necessary to enrich them with mineral substances, such as calcium, magnesium, ferrum, silicon, and potassium [7].

White pharmacopoeian clay, which contains silicon oxide, magnesium oxide, iron oxide, potassium oxide, manganese oxide, sodium oxide, and calcium oxide, is optimal in the market of biologically active additives due to its mineral composition. Such mineral composition can provide an organism with a natural complex of macro- and microelements, which will contribute to restoration of the protective functions of the body and to balanced work of its all systems and organs [8].

Given the above, the development of integrated bakery improver, the basic filler of which will be white pharmacopoeian clay, is relevant. It is also relevant to explore the impact of the developed integrated bakery improver on regularities of formation of structural and mechanical properties of dough and prolongation of freshness of bakery products in case of its use.

2. Literature review and problem statement

Elderly people need to obtain sufficient mineral substances with food. The basic minerals that are necessary to supplement the diet include Ca, K, Mg, Na, Fe, Zn, Co, Cu, Mn, and Se [8–10].

White pharmakopoeian clay of such trademarks as «Naturalissimo» (Ukraine), «NANOKremnevit» (company KREMNEVIT®, Ukraine), Kaolin (Kaolin Cosmetics, Russia) is proposed to the market of biological dietary additives as mineral complexes). It is a unique product for health, since it acts at the cellular level, it performs two major functions: cleans the organism from slag, toxins and radioactive nuclides and fills it with necessary nutrients [11].

The composition of white pharmacopeian clay includes components that help provide the organism with a natural complex of macro- and microelements that contribute to restoration of protective functions of the organism and balanced work of its all systems and organs, specifically:

– silicon oxide. Silicon is a component of connective tissue, which is important for promotion of health, youthfulness and vitality of the organism [9];

– magnesium oxide. Magnesium is an essential component of all cells and tissues, together with ions of other elements in maintaining ionic equilibrium of liquid media of the organism; it is a part of enzymes related to the exchange of phosphorus and carbohydrates; activates phosphatase of plasma and bones and is involved in the process of neuromuscular excitability [12];

– iron oxide. Iron is involved in the hemogenesis processes, in particular, it is an essential component of the non-protein part of hemoglobin and the tissues of the brain and endocrine glands, like those of the whole body, cannot be supplied with oxygen without it [13, 14];

– calcium oxide. Calcium always enters the «union» with phosphorus. Approximately 99 % of the total calcium and 70...77 % of phosphorus in our organism are a part of the skeleton. These elements are inseparable friends: salts of phosphorus and calcium cannot be assimilated without each other. It is necessary to maintain constantly the ratio of these two minerals, while vitamin D is responsible for their balance in blood. If the ratio of these two microelements is broken, the organism for its survival will be forced to take calcium from «bone reserve» – teeth, nails, large joints or to build bone from a «substitute» [15, 16];

– manganese oxide. Manganese helps activate the enzymes necessary for proper use of biotin, vitamins B and C by the body, it is needed for the normal bone structure, and for formation of thyroxine, the main hormone of the thyroid gland. It is required for proper digestion and food assimilation [17];

– sodium oxide. Sodium is a necessary element of interstitial fluid, it is contained in smaller quantities inside the cells. Sodium provides transmission of nerve impulses. It participates in maintaining a constant pH level. It is contained in all the cells of the organism [9, 18];

– potassium oxide. Potassium in the organism contributes to mental clarity, improving the supply of oxygen to the brain, helps get rid of toxins and toxic substances, helps lower blood pressure, as well as during the allergy treatment. Potassium is necessary for optimum energy, health of nerves, physical strength and endurance [18–20].

Therefore, the use of white pharmacopeian clay in bakery technology will lead to enhancement of their mineral composition. Thus, it is advisable to use it in products for gerodietary purposes. Since white pharmakopoeian clay is produced in the form of powder, it is advisable to use it as a basic filler in the formulation of a complex bakery improver.

Bakery staling process depends on many factors, specifically, components of the formulation, quality of raw materials, maintenance of the technological process, and storage conditions of finished products [5].

Studying the processes of a change of biopolymers state in bread during its staling is the focus of paper [5], the role of improvers in the mechanism of staling was explored in paper [6]. The use of non-conventional raw materials with the aim of extension of storage terms was studied in article [21]. Effective methods of establishing the processes of bakery products staling are discussed in paper [22].

It was found that it is possible to slow down the process of staling by inhibiting the loss of osmotically bound water, which fills the intermolecular space of denaturized protein and swollen gelatinized starch [5]. So, it is necessary to introduce in the formulation of bakery products the ingredients and nutritional supplements that absorb and hold osmotically bound moisture.

Because bakery products are an everyday staple of elderly people, it is recommended to use natural and safe raw materials and apply food additives that have the GRAS status [9]. The generally accepted security status of GRAS (Generally Recognized As Safe) is a regulatory designation, first represented by the Office of Food and Drug Administration of the United States (FDA) in the framework of 1985. The GRAS Status is assigned to the food ingredient that may not cause damage to the human body [23]. These food ingredients and additives include carboxyl methylcellulose, maltodextrin, apple pectin, dry wheat gluten, ascorbic acid, and lecithin [24, 25].

Dietary supplement carboxyl methylcellulose (466) is simple ether of glycolic acid and cellulose and is used as an emulsifier, stabilizer and thickener in the food industry. As a rule, sodium salt is used in bread and bakery industry because it is not soluble in water [26, 27]. It also prevents lumping, so it should be used in the production of integrated bakery improvers [25].

It is known from literary sources that to extend duration of storage of bakery products, it is advisable to use maltodextrin. Its use contributes to an increase in moisture retention degree and to softening the polymer lattice of starch, which decreases the starch retrogradation rate. Dietary supplement of maltodextrin (E459) is a carbohydrate that consists of a molecule of glucose, maltose, maltotriose and dextrin and has properties similar to starch syrups with a low dextrose equivalent [26–28]. Thus, this food supplement should be used in the production of integrated bakery improvers for extension of freshness retention of bakery products.

The addition of apple pectin significantly increases the amount of bakery products, improves the structure of the crumb, as well as extends freshness retention [26]. It is advisable to use pectin with high a degree of substitution with methoxylic groups due to its high moisture-retaining ability [27]. The use of this food ingredient is advisable in the production of bakery products of extended storage term and integrated baking improvers.

Effectiveness of application of dry wheat gluten lies in improvement of moisture-absorbing ability of dough, enhancement of rheological properties of semi-finished products and quality indicators of finished products, extension of their term of freshness retention [29]. This is due to the additional introduction of proteins into the dough system, which binds greater amount of moisture. That is why dry wheat gluten is used in almost all formulations of integrated bakery improvers as a basic filler or an ingredient of directed action [29].

It is known from literary sources that one of the natural oxidizers in the bakery technology is ascorbic acid, which is used in integrated bakery improvers [16, 17].

Starch retrogradation (transition of partially gelatinized starch from amorphous to crystalline state) plays the important role in the process of staling. From literary sources it is known that maltogenic amylase inhibits staling [30]. Enzymatic preparation Novamil 1500 MG of the Danish company Novozymes is purified maltogenic α-amylase, produced by *Bacillus subtilis*, obtained by the method of genetic engineering. This enzymatic preparation contributes to significant accumulation of maltose in dough, which has a positive effect on the process of staling inhibition due to formation of thin-walled homogenous porosity [30]. In this regard, it is advisable to use enzymatic preparation Novamil 1500 MG in production of the integrated bakery improver to extend freshness of bakery products.

In case of using white pharmacopeian clay, specific volume of bakery products decreases [31]. To enhance specific volume of baked products, amylolytic, hemicellulose enzyme preparations, which significantly increase the content of reducing sugars in bread, enhance physical properties of dough [24, 32]. For production of the integrated bakery improver, it is possible to select enzyme preparation Alphamalt VC 5000 of German company «Muhlenchemie», which is cleaned pure fungi α-amylase [6, 24, 32].

It is known from literary sources that emulsifiers improve the porosity structure of bakery products, increase specific volume and extend the storage term. One of natural emulsifiers is lecithin, so it was advisable to use it in the production of integrated bakery improvers [33].

At the National University of Food Technologies (Kyiv, Ukraine), the integrated baking improver «Mineral Freshness +» was developed to extend freshness of bakery products. White pharmakopoeian clay and safe food additives, which have the GRAS status, were used as the basic filler.

In paper [31], it was noted that it is appropriate to use white pharmacopeian clay in bakery products for gerodietary purposes as a mineral enriching agent. Along with this, its effect on deterioration of the volume and porosity of bakery products was emphasized. Therefore, to improve organoleptic and physical and chemical indicators of quality of the products with white pharmacopeian clay, the integrated bakery improver «Mineral Freshness +», based on it, was proposed. To establish a joint impact of the components of the integrated bakery improver «Mineral Freshness +», it is necessary to explore changes in the structural and mechanical properties of dough, quality indicators of bakery products and its impact on the process of staling during storage.

3. The aim and objectives of the study

The aim of this work was to substantiate the appropriateness of using the integrated bakery improver «Mineral Freshness +» to extend freshness of bakery products.

To accomplish the set aim, the following tasks were to be solved:

– to set the optimum dosage of the integrated bakery improver «Mineral Freshness +» in the formulation of bakery products, specifically, of white loaf «Mineral Freshness»;

– to explore the impact of the integrated bakery improver «Mineral Freshness +» on the structural and mechanical properties of dough and quality of gluten;

– to study the impact of the integrated bakery improver «Mineral Freshness +» on the processes of staling of white loaf «Mineral Freshness».

4. Materials and methods to study the influence of the integrated bakery improver on quality of bakery products

4. 1. The studied objects and materials used in the experiment

The integrated bakery improver «Mineral Freshness +» includes: white pharmakopoeian clay, enzymatic preparation Novamil 1500 MG, enzymatic preparation Betamalt 25 FBD, dry wheat gluten, apple pectin, carboxymethylcellulose, maltodextrin, lecithin, and ascorbic acid.

Wheat loaf «Mineral Freshness» was manufactured from whole wheat flour of the highest grade by the accelerated method according to the formulation:

– wheat flour of the highest grade – 100 kg;
– pressed baking yeast – 3.0 kg;
– food kitchen salt – 1.5 kg;
– table margarine – 2.0 kg;
– white crystalline sugar – 2.0 kg.

White pharmakopoeian clay of the Ukrainian company «Naturalissimo» was used as the primary filler to develop the integrated bakery improver «Mineral Freshness +» as the primary filler. Since the quality and composition of bakery products depend on the composition of properties of the used components, physical and chemical indicators of white pharmacopeian clay were established, Table 1.

Comparative evaluation of chemical composition revealed that the use of white pharmacopeian clay in the technology of bakery products will enrich them with such mineral substances as silica, sodium, aluminum, calcium, potassium and iron [34].

Table 1

Physical and chemical indicators of wheat flour and white pharmacopeian clay $n = 3$, $p \leq 0.95$

Indicator	Wheat flour of the highest grade	White pharmacopeian clay
Mass fraction of moisture, %	13.5	14.0
Mass fraction of protein, %	10.3	–
Mass fraction of mono- and disaccharides, %	0.2	–
Mass fraction of starch, %	68.7	–
Mass fraction of fiber, %	0.1	–
Mass fraction of fat, %	1.1	–
Mass fraction of ash, insoluble of hydrochloric acid, %	0.5	86.0
Mineral substances, mg/100 g:		
Magnesium	16	11.000
Silica		2,053.300
Aluminum		661.993
Potassium	122	15.86
Calcium	18	19.4
Mangan		0.647
Zink		0.451
Ferrum	1.2	71.86
Cuprum		0.321
Chromium		0.330
Vanadium		0.647
Phosphorus	86	1.294
Sodium	10	11.653
Titrated acidity, °T	0.8	0.4
Solubility index, cm^3	–	0.5
Relative solubility rate, %	–	38.0
Packing degree, %, at dimensions of sift pores of 250 micron	–	17.6
Whiteness, conv. units	89.6	91.4

It should be noted that white pharmakopoeian clay matches the whiteness of wheat flour of the highest grade, so it will not lead to darkening of bakery products. It was found that white pharmakopoeian clay has a low lump-forming tendency (the packing degree is less than 3.0 %), which makes it possible to use it in the production of integrated bakery improvers.

To produce the integrated bakery improver, we used the enzymatic preparation Novamil 1500 MG of the Danish company Novozymes, enzymatic preparation Alphamalt VC 5000 (5000 SKB/g) of the German company «Muhlenchemie», dry wheat gluten «VITEN» of the Latvian company «Roquette», carboxylmethylcellulose of the Ukrainian company «Himpostach», apple pectin of Ukrainian production, maltodextrin of a Polish company, fat-free sunflower lecithin, produced by the Ukrainian company «BIOLER» and ascorbic acid produced in China.

4. 2. Methods for studying the quality of bakery products with an integrated bakery improver

Laboratory baking was carried out to explore the indicators of the technological process, biochemical, physical and chemical changes in the dough and bread quality indicators. The dough was prepared in the accelerated way with mass fraction of moisture of 42 %. The dough was kneaded in the two-rate dough machine. The dough rested for 30 min. The dough was treated manually, dough pieces were settled in the thermostat at the temperature of (38 ± 2) °C and at relative humidity of (78 ± 2) % up to readiness. The products were baked in a chamber oven at the temperature of 220...240 °C.

Gas production in semi-finished products was determined on device AH-1M [35]. The resilient-elastic characteristics of the dough were studied at the farinograph by «Brabender» company (Germany) [36]. The indicators, obtained using the farinograph, made it possible to determine, along with the characteristic of structural-mechanical properties, the amount of water required to produce dough of the desired texture. The bread quality was estimated according to physical-chemical (specific volume, shape-stability, structural-mechanical properties of crumb) and organoleptic parameters (view, crust surface state, porosity structure, taste, and smell).

The duration of product freshness retention was studied by observing a change of structural and mechanical properties of crumb. Its general deformation after 48 h of storage was determined at penetrometer UP 4/1. The integrated quality indicator was assessed by point estimation of quality bakery products [35]. The staling degree of products was studied by bread crumb swelling and its crumbling. The staler the bread, the less the crumb swells. The degree of staling is expressed by magnitude of specific swelling in cm^3 of the swollen mass per 1 g of dry substance of the studied sample [36].

The outside and harmful microflora in the finished products was determined using the standard techniques [37].

The results of experimental research were subjected to statistical processing with the use of the standard packages of Microsoft Office software.

5. Results of studying the quality of bakery products when adding the integrated bakery improver

The test laboratory baking was performed in order to evaluate the quality of the wheat loaf with the integrated bakery improver «Mineral Freshness +» and its optimal dosing.

During the study, the dough from flour of the highest grade was prepared with addition of the integrated bakery improver in the amount of 1.0; 1.5; 2.0 % to the mass of flour. The control sample was the sample without the improver prepared according to the formulation shown above. The results of the research are shown in Table 2. A comprehensive quality indicator was determined based on the results of the score estimate.

Based on the comprehensive quality indicator, it was found that the optimal dosage of the integrated bakery improver «Mineral Freshness +» is 1.5 % of the flour weight.

The amount and quality of gluten is the main prerequisite for the production of bakery products of high quality. Decreased amount and quality of gluten is the main cause of a small volume of dough and bakery products, even of flour has a normal gas formation ability, and thus it is one of the reasons for staling of bakery products.

We conducted the study to establish the impact of addition of the integrated bakery improver «Mineral Freshness +» on the content and quality of gluten. The study was conducted at the optimal dosage of the integrated bakery improver «Mineral Freshness +» of 1.5 % of flour weight. The results are shown in Table 3.

Table 2

Quality indicators of wheat loaf with the integrated bakery improver «Mineral Freshness +» $n=3$, $p\leq0.95$

Quality indicator of bread	Weight coefficient	Control sample without additives	Dosage of integrated bakery improver «Mineral Freshness +», % to flour mass		
			1.0	1.5	2.0
Specific volume, cm^3 per 100 g of bread	2.0	326	334	346	352
		3.8	4.0	4.2	4.2
Shape retaining (H:D)	2.0	0.37	0.43	0.44	0.43
		3.4	4.4	4.8	4.6
Shape regularity	1.0	0.38	0.43	0.44	0.42
		4.0	5.0	5.0	5.0
Crust color	1.0	Light golden	Golden		Dark golden
		3.0	5.0	5.0	4.0
Staling after 72 h, unit of device	3.0	38	81	82	86
		2.4	4.2	4.2	4.4
Crumbling, %	3.0	10.2	7.5	6.2	6.9
		3.4	4.0	4.2	4.2
Crust surface state	1.0	Smooth, separate small bubbles, barely remarkable minor cracks	Perfectly smooth, without bubbles and cracks, glossy		Smooth, separate small bubbles, barely remarkable minor cracks
		4.0	5.0	5.0	4.0
Crumb color	1.0	Light	Very light		
		4.0	5.0	5.0	5.0
Porosity structure	1.0	Small and medium pores, distributed rather evenly	Small pores, thin-walled, perfectly distributed around the whole surface		Small and medium pores, distributed rather evenly
		4.0	5.0	5.0	4.0
Phenological properties of crumb	1.0	Soft, elastic	Very soft, tender, elastic		
		4.0	5.0	5.0	5.0
Bread smell	1.5	Intensively pronounced, characteristic of bread			
		5.0	5.0	5.0	5.0
Bread taste	1.5	Intensively pronounced, characteristic of bread			
		5.0	5.0	5.0	5.0
Mouth-feel property of crumb	1.0	Easy to chew		Very tender, elastic, easily chewed	
		4.0	4.0	5.0	5.0
Comprehensive quality indicator		73.8	90.4	93.2	90.4

Table 3

Amount and quality of gluten $n=3$, $p\leq0.95$

Quality indicators	Control	Integrated bakery improver «Mineral Freshness +»
Gluten content:		
raw, %	29.5	30.5
dry, %	10.8	11.2
Gluten quality:		
color	Light	Light
distensibility	Good	Good
elasticity	Good	Good
Plasticity, unit of the device, index deformation gluten	64.3	72.6
hydration ability, %	164.5	182.3

As Table 3 shows, if we use the integrated bakery improver «Mineral Freshness +», the amount of gluten, its hydration ability and elasticity increase.

Structural and mechanical properties of dough determine the formation of the volume, porosity, and crumb structure of bakery products, staling rate, as well as the behavior of the dough during its processing.

Bakery dough takes an intermediate place between a perfectly elastic body and truly viscous fluid due to the fact that it simultaneously has resilient-elastic and viscous-plastic properties.

Dough elasticity inhibits the volume development, it contributes to maintaining the regular shape in already formed pieces. Elasticity of dough causes formation of the foam-like structure that plays an important role in the processes of its fermentation, formation and baking.

Elastic-resilient dough properties were determined using a farinograph of the company «Brabender». The study used wheat flour of the highest grade, of medium strength (batch No. 1) and high strength (batch No. 2), to which the integrated bakery improver «Mineral Freshness +» was added in the amount of 1.5 % of flour weight.

As the data of Table 4 show, with the introduction of the IBI «Mineral Freshness +» to high strength flour, water-absorbing ability of dough increases, duration of dough development decreases, and resistance is improved. Positive impact of a weakening effect of the additive in case of using strong flour is proved by the fact that the results were close to the sample with the use of the medium strength flour.

The colloidal system, such as dough, is characterized (along with resilient-elastic) by viscous-plastic properties. During dough fermentation, it accumulates residual deformation, i. e. non-reverse deformation of viscous flow, which causes a shift of dough layers relative to each other due to destruction of the structural network.

The property of dough pieces to retain their shape, as well as the impossibility of formation of running products with a flat surface depends on the shape-retaining ability.

The shape-retaining ability of dough pieces is influenced by the

quality of wheat gluten and, to a certain extent, by other components of the formulation. For example, in the presence of salt, hydration of gluten increases and content of free water in liquid phase decreases, which is why the shape-retaining ability of dough is improved and it liquefies less in the process of maturing. Due to dehydration ability of sugar in the dough, on the contrary, the content of free water increases and it liquefies, adhesion increases and shape-retaining ability decreases. The dough, which has fat in its formulation, has an improved shape-stability, despite a lower consistency than dough without fat.

Table 4

Structural and mechanical properties of dough with introduction of food additives and ingredients $n=2$, $p\leq 0.95$

Indicators	Batch No. 1 (medium strength flour)	Batch No. 2 (high strength flour)	Integrated bakery improver «Mineral Freshness +»
Texture, units of device	500	500	500
Water absorption capacity, $cm^3/100$ g	63.0	55.4	64.0
Duration of dough development, min	6 min 36 s	8 min 26 s	6 min 10 s
Dough stability, min.	5.4	7	6
Liquefaction, units of device, after 10 min after beginning	40	20	80
Elasticity, units of device	70	50	60

That is why an indirect evidence of changes that occur in the dough with the integrated bakery improver «Mineral Freshness +» can be the running of a dough ball. Results of the conducted research are shown in Fig. 1. The data above show that in case of adding the integrated bakery improver «Mineral Freshness+», the dough from high strength flour weakens, these results approach the data retrieved from medium-strength flour.

Dough maturing is determined by deep changes in carbohydrate-amylase and protein-proteinase complexes of flour due to biochemical, microbiological and other processes that occur in it. Intensity of these processes largely depends on the quality of flour. They are influenced by additives, introduced for some purpose.

It is possible to make a conclusion on the influence of additives on intensity of alcohol fermentation in dough by the amount of released carbon dioxide during fermentation and settling. Fig. 2 shows the pattern of the release of carbon dioxide within 120 min. Fig. 3 shows the amount of carbon dioxide, released within every 30 min separately.

Dough was prepared by the straight method, and the integrated bakery improver «Mineral Freshness +» was introduced in dough. Mass fraction of moisture in dough was 42.0 %. Given the fact that dough rests for 30 min, duration of settling of dough pieces is about 50 minutes, so gas production was determined within 120 min.

An analysis of research results revealed (Fig. 2) that gas production increases significantly in the dough with the integrated bakery improver «Mineral Freshness +».

Based on the experimental data, by means of table processor MS Excel, we performed approximation of discretely assigned functions by polynomial dependences by 2–4 degree for curve 1 (flour batch No. 1 (medium strength), curve 2 (flour batch No. 2 (high strength) and curve 3 (integrated bakery improver «Mineral Freshness +»).

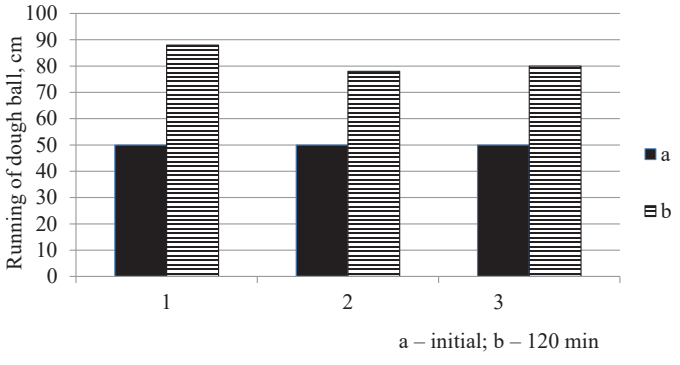


Fig. 1. Running of a dough ball: 1 – flour batch No. 1 (medium strength); 2 – flour batch No. 2 (high strength); 3 – integrated bakery improver «Mineral Freshness +» – 1.5 % of the flour weight

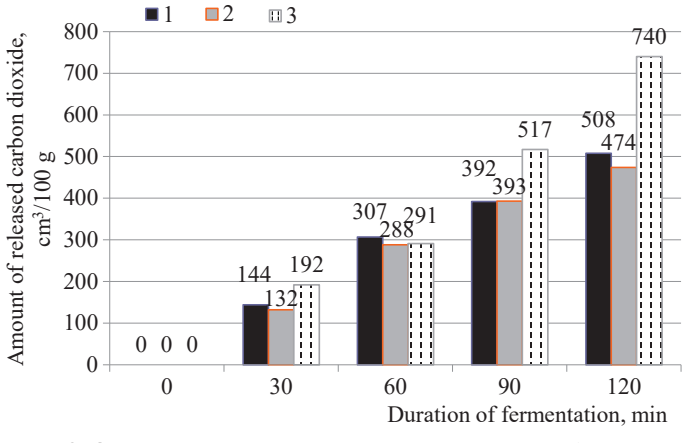


Fig. 2. Gas production in dough: 1 – flour batch No. 1 (medium strength); 2 – flour batch No. 2 (high strength); 3 – integrated bakery improver «Mineral Freshness +» – 1.5 % of flour weight

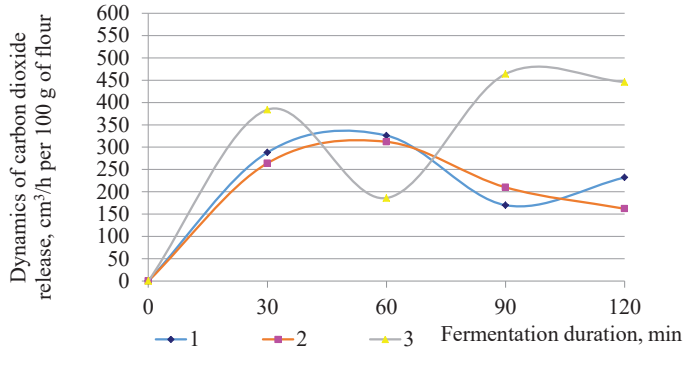


Fig. 3. Dynamics of gas production: 1 – flour batch No. 1 (medium strength); 2 – flour batch No. 2 (high strength); 3 – IBI «Mineral Freshness +» – 1.5 % of flour weight

The resulting approximating polynomials quite accurately reproduce the processes of production and the dynamics of carbon dioxide release for every 30 min separately within 120 min with accuracy of $R^2 = 0.99$ and $R^2 = 1$:

– for curve 1 (flour batch No. 1 (medium strength):

$$Y1 = 2E\text{-}05X^4\text{-}0{,}003X^3 + 0{,}0113X^2 + 11{,}422X\text{-}6E\text{-}1014{,}514;$$

$$R^2 = 1;$$

– for curve 2 (flour batch No. 2 (high strength):

$$Y2 = 2E\text{–}05X^4 - 0{,}0235X^3 - 1{,}8431X^2 + 49{,}506X - 1E - 109;$$

$$R^2 = 1;$$

– for curve 3 (with integrated bakery improver «Mineral Freshness+»):

$$Y3 = 0{,}0008X^3 - 0{,}2144X^2 + 14{,}721X - 1{,}9714;$$

$$R^2 = 0{,}9953.$$

An analysis of the dynamics of gas production in dough with additives (Fig. 3) revealed that in the case of adding integrated bakery improver «Mineral Freshness+» two extremums are observed. In this sample, the first extremum reaches its maximum 15...18 min earlier in comparison with other samples. It is a basis for reducing the duration of maturing of the dough with explored additives in accelerated technologies.

Freshness is considered to be the main indicator of consumer properties of finished products.

During bread storage, we observe a decrease in its quality indicators associated with the process of staling and drying. Bread becomes hard, crumbled, its elasticity decreases, taste and smell are lost.

Changes in the properties of bread during its storage are associated with the complex physical and chemical, colloidal and biochemical processes that occur in the bread components and loss of moisture.

Bread staling is primarily related to the processes of changing in the state of starch, which during storage transfers from the amorphous state to the crystalline. There is starch retrogradation, which is associated with the aggregation of molecules of amylopectin and amylose.

An important role in this process belongs to aging of gluten, denaturized in the process of baking, which gives off moisture and, as result, its hydration ability decreases, which leads to the compactness of the crumb structure.

With the loss of freshness, there are physical and chemical changes of crumb – resistance to compression increases and elasticity decreases. That is why the duration of freshness retention by the products was explored by a change in structural-mechanical properties of crumb. Its crumbling, swelling, elastic and plastic deformations after 4, 24, 48 and 72 hours of storage were determined on penetrometer AP 4/1.

Bakery products were prepared by the straight method without additives with adding to dough of the components of the integrated bakery improver «Mineral Freshness +» in the amount of 1.5 % of the weight of flour.

Experiments were carried out 4, 24, 48 and 72 hours after baking the products. The results of the research are shown in Table 5.

Table 5

Indicators of crumb deformation in products during storage $n = 3$, $p \le 0.95$

Kind of deformation, storage term	Control	Integrated bakery improver «Mineral Freshness +»
4 hours:		
general	82	116
plastic	52	76
elastic	30	40
24 hours:		
general	73	109
plastic	48	75
elastic	25	34
Freshness retention, %	89.0	93.4
48 hours:		
general	60	99
plastic	40	68
elastic	20	31
Freshness retention, %	73.0	85.3
72 hours:		
general	46	87
plastic	34	61
elastic	12	26
Freshness retention, %	56.1	75.0

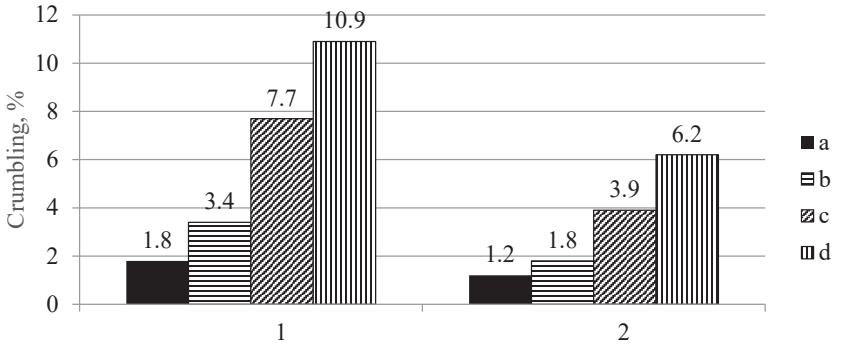
Comparative analysis of the degree of freshness retention by the examined samples revealed a positive influence of the integrated bakery improver «Mineral Freshness +» on this process. As the data from Table 6 show, if we add in the dough the integrated bakery improver «Mineral Freshness +», the general, plastic and elastic deformation of crumb improves. The examined additives contribute to improvement of freshness retention by products, loss of freshness of the wheat loaf with the use of the integrated bakery improver «Mineral Freshness +» after 72 hours is by 18.9 % less in comparison with the control sample.

In the process of storage, physical and mechanical properties of crumb change since the pores lose their strength, which is accompanied by an increase in crumbling of the crumb. The results of the research prove (Fig. 4) that the value of crumbling decreases in case of using the integrated bakery improver «Mineral Freshness +» in comparison with the control sample by 50...54 % at duration of storage of 24 and 48 hours and by 57 % – 72 hours.

It is possible to judge on freshness of product by a change in hydrophilic properties of colloids of crumb during their storage.

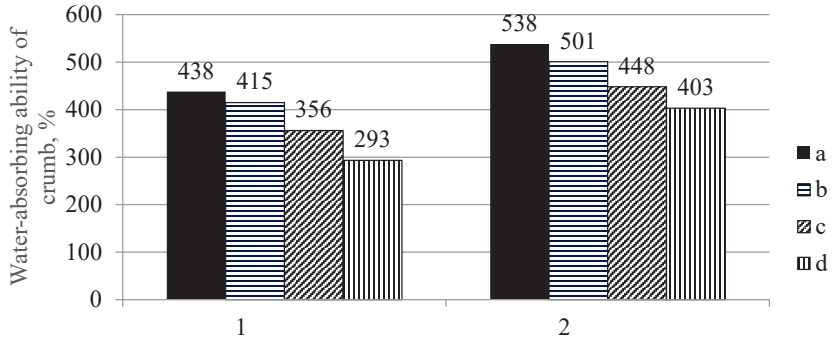
During the storage of bakery products, hydrophily of their crumb decreases. A decrease in hydrophily of crumb influences its ability to swell and absorb water, as well as the ability of colloids and other substances to transfer to the aqueous solution.

That is why we determined the amount of water, which is absorbed by the crumb in % of dry substances of the product (water-absorbing ability of the crumb). We determined it after 4, 24, 48 and 72 h after baking. The results of the research are shown in Fig. 5.



a – after 4 h; b – after 24 h; c – after 48 h; d – after 72 h

Fig. 4. Crumbling, %: 1 – control sample; 2 – integrated bakery improver «Mineral Freshness +»



a – after 4 h; b – after 24 h; c – after 48 h; d – after 72 h

Fig. 5. Water-absorbing ability of crumb, %: 1 – control sample; 2 – with integrated bakery improver «Mineral Freshness +»

It was found (Fig. 5) that at an increase in storage term, water-absorbing ability of crumb of the products decreases. However, this decrease is more significant for the control sample.

Binding water by the crumb of the products that were introduced with the integrated bakery improver «Mineral Freshness +» decreased in the process of storage. This decrease within three days of storage was 24.7 % in comparison with the control sample (33 %), which indicates slowing down aging of hydrocolloids of the products.

Thus, the studies showed that the use of an integrated improver «Mineral Freshness +» is expedient because all indicators of dough and the wheat loaf improve, and, most importantly, the wheat loaf retains freshness within 72 hours.

In the case of adding the improver, no changes in traditional taste were observed.

We conducted experiments to determine the microbiological indicators of the finished products using the integrated bakery improver «Mineral Freshness+». The results of research are given in Table 6.

Table 6 shows that during the storage of the wheat loaf for 72 h, the amount of KMAFAM is smaller in comparison with the control sample when we use the integrated bakery improver «Mineral Freshness +», but the number of mold fungi increases. The quantity of spore-forming bacteria also increases, but it does not exceed the norm.

Thus, by the microbiological indicators, the wheat loaf with the use of the integrated bakery improver «Mineral Freshness +» has better indicators in comparison with the control sample, which is a proof of that the wheat loaf retains freshness.

Table 6

Influence of IBI «Mineral Freshness» on the quality of finished products $n=3$, $p\leq 0.95$

Microbiological indicators, CFO/g	Control sample without additives		With the integrated bakery improver «Mineral Freshness +»	
	4 hours after baking	72 hours after baking	4 hours after baking	72 hours after baking
KMAFAM QMAFAnM	1.4×10^3	4.0×10^3	2.0×10^3	3.1×10^3
Lactobacilli	$<10^3$	$<10^3$	$<10^3$	$<10^3$
Yeasts	<100	<100	<100	<100
Mold fungi	<100	$0.1\cdot10^2$	<100	$1.0\cdot10^2$
Spore-forming bacteria	$9.0\cdot10^2$	$10.0\cdot10^2$	$7.2\cdot10^2$	$8.2\cdot10^2$
Escherichia coli	not found	not found	not found	not found
Putrefactive bacteria	$<10^3$	$<10^3$	$<10^3$	$<10^3$
Leuconostoc bacteria	$<10^3$	$<10^3$	$<10^3$	$<10^3$

6. Discussion of results of using the integrated bakery improver «Mineral Freshness +» for the formulation of bakery products

It was found that the optimal dosage of the integrated bakery improver «Mineral Freshness +», which positively

affects organoleptic, physical and chemical quality indicators of the wheat loaf, is 1.5 % of the weight of flour.

In case of using the integrated bakery improver «Mineral Freshness +», the amount of raw and dry gluten increases, it is related to the additional introduction of dry wheat gluten, proteins of which form complexes with flour proteins, resulting in an increase in the amount of gluten and quality enhancement, specifically, distensibility and elasticity improve and hydration capacity increases.

The results of analysis of the faringograms showed that in the case of using the integrated bakery improver «Mineral Freshness +», the water-absorbing ability increases due to adding dry wheat gluten, maltodextrin, apple pectin and carbomethylcellulose, which absorb and retain free water. An increase in liquefaction and elasticity of dough is observed. This is due to the fact that the formulation of the improver includes lecithin and maltodextrin that promote better distribution of fat between the gluten films of the dough system. Liquefaction of the dough system is influenced by white pharmakopoeian clay, which weakens the gluten frame in the process of dough kneading and resting.

The shape-retaining ability of dough is of great importance for bakery products. If we use the integrated bakery improver «Mineral Freshness +», running of the dough ball from the high strength flour approaches the data obtained for the medium strength flour. This is due to the use in the formulation of an integrated improver lecithin, maltodextrin, and white pharmacopeian clay that contribute to dough subdivision. This is a consequence of the fact that reducing sugars maltodextrin interact with protein substances of flour, resulting in oxidation of sulfhydryl groups in the flour proteins, accompanied by protein structure ordering. The obtained data correlate with the data from farinograph.

Gas production in the dough considerably increases with the developed integrated bakery improver. This is related to enrichment of the nourishing medium with maltose, dextrin that are introduced additionally with improvers due to the use of maltodextrin, as well as through the use of the enzymatic preparation of amylase action, which accelerates enzymatic hydrolysis of starch to maltose, intensifying its alcohol fermentation in the dough. Due to this fact, the first extremum of gas production dynamics in the sample with the improver starts earlier than in the other samples. That is why if we use the integrated bakery improver «Mineral Freshness +», it is recommended to use accelerated technologies.

The use of the integrated bakery improver «Mineral Freshness +» helps slow down the staling process in bakery products. This is due to the use in the improver's formulation of food additives and the ingredients, which have high water-absorbing ability, specifically, carboxymethylcellulose, which only swells and does not dissolve in water and thus retains water well. Maltodextrin is water soluble hydrocolloid, which increases the degree of moisture retention, as well as forms a three-dimensional lattice, which inhibits the interaction of starch and protein, resulting in slower retrogradation of starch. Along with this, enzymatic preparation of maltogenic α-amylase influences a decrease in the rate of recrystallization of amylopectin fractions of starch, which also delays its retrogradation.

In the process of storage, we can observe a positive impact of the use of developed integrated bakery improver on microbiological indicators of the wheat loaf, namely, microbiological purity improves and its stability during storage increases.

Application of the integrated bakery improver «Mineral Freshness +» makes it possible to prolong freshness of bakery products up to 72 h of storage without being packed. That enables the extension of the range of bakery products for gerodietary purposes.

However, the extent of digestion of bakery products proteins in case of using the developed integrated bakery improver remains unclear.

Further research regarding the establishment of storage terms for the developed integrated bakery improver and the selection of a package container for its storage appears to be promising.

7. Conclusions

1. Based on the conducted research, point evaluation and calculation of the comprehensive quality indicator, it was found that the optimal dosage of the developed integrated bakery improver «Mineral Freshness +» in manufacturing bakery products is 1.5 % of the weight of flour.

2. It was established that in case we use the integrated bakery improver «Mineral Freshness +», the amount of gluten increases and its quality improves. Water-absorbing ability of dough improves, which is a prerequisite for the extension of freshness retention by bakery products. The fermentation process becomes more intensive, which makes it possible to implement technological process using the accelerated technologies.

3. The use of the optimal dosage of the developed integrated bakery improver «Mineral Freshness +» improves the quality of bakery products, extends the storage term up to 72 hours without being packed. This is proved by a decrease in crumbling, an increase in general deformation of crumb and its hydrophilic properties, as well as by microbiological purity of the finished products.

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