A bun with a mixture of germinated cereals of wheat, oats, barley, and corn is an innovative product rich in dietary fiber, replaceable and essential amino acids, micro and macro elements, vitamins. In the process of germination, grains accumulate a large number of amylolytic and proteolytic enzymes, which worsen the structural and mechanical properties of the crumb of pastry products, as a result of which it becomes sticky and wrinkled. The experimental study reported in this work aimed to improve the organoleptic indicators and prolong the freshness of pastry products whose formulation includes a mixture of germinated grains.

The expediency has been proven of using the polycomponent mixture "Solodok" (Ukraine) in the amount of 3.0 % to the mass of flour in the production of pastry products in whose formulation 50 % of flour was replaced with a mixture of germinated grains. The application of the polycomponent mixture "Solodok" has a positive effect on the organoleptic and structural-mechanical properties of the product crumb. The composition of the polycomponent mixture includes safe food additives and ingredients such as ground cinnamon, dry wheat gluten, apple pectin, and ascorbic acid.

It has been proven that products with the addition of the polycomponent mixture retain freshness longer, which was confirmed by a lower rate of staleness, by 59.2 %, compared to control.

The stale processes in the case of using a polycomponent mixture are inhibited due to the greater accumulation of dextrins compared to control. Thus, the total content of dextrins in a pastry product is 1.668 % to DM (dry matter) while in the bun "Tsilyushcha", it is 2.443 % to DM.

The study results show the technological effectiveness of the use of the "Solodok" polycomponent mixture to slow down the staleness of products and provide products enriched with a mixture of germinated cereals with satisfactory consumer properties

Keywords: pastry products, staleness, freshness, polycomponent mixture, nutritional value, germinated grains, crumb

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DETERMINING THE EFFECT OF A MULTICOMPONENT MIXTURE ON THE QUALITY OF PASTRY PRODUCTS CONTAINING A MIXTURE OF GERMINATED GRAINS

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1. Introduction

Pastry products are produced in a variety of shapes and weights, have a pleasant sweet taste and aroma, as well as the elastic fine-porous structure of the crumb. The surface of many pastry products is smooth, glossy. Some pastry products are supplemented with eggs, sprinkled with powdered sugar, crumbs, poppy seeds, seeds of various crops, crushed nuts, etc. Some pastry products have a clear pattern at the surface in the form of squares, diamonds, or there is a clear pattern applied with a special stamp. The formulation of pastry products includes at least 14 % of sugar and fat, which can also be used for decoration, so these products are considered high caloric.

The main disadvantage of pastry products, especially small-piece, is a short selling period. Rapid staleness, which is caused by complex biochemical processes occurring in the high-polymer substances of the crumb, leads to a deterioration in structural and mechanical properties. Therefore, a relevant problem in the bakery industry is to prolong the freshness of bakery products, in particular, pastry products.

To reduce caloric content and prolong the freshness of pastry products, it is recommended to use unconventional raw materials, nutritional supplements, complex bakery improvers, polycomponent mixtures.

At present, it is quite common to have products that contain cereals in their composition [1]. Cereal crops are exactly the food product that provides our bodies with almost all vital biologically active substances and to whose consumption most of the population of Europe is adapted. The grains consist of proteins, carbohydrates, fats, organic acids, vitamins, and minerals. With the development of the germ in the process of germination, various enzymes are activated that convert complex compounds, namely starch, protein, into an easily digested form – sugars, amino acids.

A blend of germinated grains of wheat, oats, barley, and corn is a unique, innovative product. Special technology of soaking, germination, and drying makes it possible to preserve its natural properties. At the same time, all high molecular weight compounds (starch, proteins) are decomposed in the germinated grain with their transition to low molecular weight substances that are easily absorbed by the human body. A mixture of germinated wheat grains should not be confused with wheat germ, germinated wheat, and other similar products. The basis of the preparation of the mixture of germinated wheat grains is a completely new technological process, which was termed the "Process of fermented hydrolysis", whose development was completed in 2003 (TU U 15.8-0207938.034-2003) [2]. The production of a mixture of germinated grains involves soaking the grain to a moisture content of 42...48 % at temperature 14...23 °C, germination for 3...7 days. After that, they stop supplying fresh air, the grain temperature is maintained at 14...23 °C for 1...2 days, and they apply an enzymelike pause. The enzymatic pause is intended to maximize the activation of the effect of natural proteolytic enzymes; it is carried out in two stages. The first stage is to age the grains for 1...15 hours at a grain temperature of 45...54 °C. The second stage is aging for 1...8 hours at a temperature of 55...65 °C. Next, the grains are rinsed with water, disinfected, and dried to a humidity of 8...10 % with a gradual increase in temperature to 70...75 °C. Dried grain is crushed with the dispersion into cereal and flour fractions.

Germinated grains (a mixture of germinated grains) contain almost all essential amino acids while the content of vitamins (E, B, B2, B6, B12, PP, H, and others) increases by 5...10 or more times. Taking into consideration the fact that the germinated grains undergo heat treatment in a special mode (fermented hydrolysis), they almost completely preserve their natural properties. Grinding makes them convenient to use and allows for deeper fermentation so that one can get a large amount of sugar (maltose, glucose, fructose) and other nutrients [2, 3].

In order to intensify the technological process, prolong freshness, neutralize the effect of unconventional raw materials on the quality of dough and finished products, complex bakery improvers and polycomponent mixtures are used. Polycomponent mixtures are compositional additives with a multifunctional effect, which include several ingredients of different principles of action in a certain ratio. They consist of various quantities of enzyme preparations, oxidizers (ascorbic acid, calcium peroxide), reducing elements (1–cysteine), hydrocolloids (modified starch), surfactants, organic acids (citric, malic), mineral salts, etc. [4–6]. Polycomponent mixtures are produced in the form of powders or pastes, used in an amount from 0.1 to 3.5 % by weight of flour [7].

The range of polycomponent mixtures is very diverse, depending on the direction of their action. All components of polycomponent mixtures are carefully selected by activity and synergic action among themselves [8]. Complex bakery improvers and polycomponent mixtures operate throughout the technological process, so they are developed to solve certain issues.

The use of a mixture of germinated grains in the formulations of pastry products instead of flour would reduce their energy value and increase nutritional and biological value. The problem of using germinated grains in bakery formulations is the deterioration of organoleptic quality indicators, namely, the crumb of products becomes sticky and wrinkled due to the high autolytic activity of germinated grains. The solution to this issue may be to use such polycomponent mixtures that could inhibit the action of amylolytic enzymes and improve the rheological properties of the dough. Applying them requires scientific research to justify the effectiveness of their use.

2. Literature review and problem statement

To reduce the caloric content of pastry products, unconventional types of raw materials are used such as cereal seeds, fruit powders, whey, puree, fruit and berry juices, germinated wheat, germinated grain, etc. The inclusion of these ingredients predetermines their impact on the consumer properties of bakery products.

It was established in [9] that in the case of replacing 60 % of wheat flour with barley, the products' content of insoluble fiber increases by 700 %, that of soluble fiber – by 200 %. In addition, there is an increase in the total content of phenolic compounds and the antioxidant capacity of wheat bread, by 41.5 % and 45 %, respectively. When evaluating organoleptic indicators, such products had low scores, especially when it comes to taste. To improve organoleptic indicators, it is proposed to add parmesan, oregano, or sesame seeds to the recipe of products. The addition of sesame seeds (4 g/100 g, the base of flour) increased the sensory characteristics of bread, as well as increased antioxidant activity by 100 % and 130 %, respectively, compared to wheat bread. However, the cited work does not specify how to improve the physical and chemical performance of products.

In [10], it was established that adding to the formulation of products the germinated grains of oats, barley, wheat in the amount of up to 5.0 % to the mass of flour improves the specific volume of products while giving rise to the crumb stickiness. This is due to the high lipolytic and amylolytic activity of germinated grains. The cited work found that the smallest negative impact is exerted by the germinated grains of oats. Germinated grains of barley and wheat are characterized by high amylolytic and lipolytic activity, which gives rise to the sticky crumb that is wrinkled. The cited work failed to study the joint use of germinated grains of oats, barley, wheat in the technology of bakery products.

To avoid the crumb stickiness in the case of use, in the formulation of products, of the germinated grains of cereals, scientists recommend applying complex bakery improvers, polycomponent mixtures, food additives.

Under the trademark "BMB Blend" (Ukraine), modern polycomponent mixtures for bakery products, Cornex, are offered. These are polycomponent mixtures to produce unconventional bread varieties, which include a functional component and a taste component – those are various pieces of vegetables, paprika, tomato, cereal flakes, sunflower kernels, sesame. Such a polycomponent mixture would enrich and expand the range of products while not reducing the negative effects of amylolytic and proteolytic enzymes contained in sprouted grains if used in product formulations [11].

The French company Lesaffre recommends for long-term storage of butter products to use the complex bakery improver "Magimix" with a white label in order to extend their freshness to 2 months. It consists of specially selected monoglycerides, owing to which the process of starch retrograde slows down. The enzyme complex of this improver makes it possible to get an additional number of dextrins so that the crumb of products would retain their properties over a certain time. However, this complex bakery improver cannot be used for products whose formulation contains germinated grain, due to their high autolytic activity [12].

The Dutch company "Zeelandia" offers, to extend the freshness of bakery products, the complex bakery improver "Gamma Soft", which consists of soy flour, enzymes, emulsifier, ascorbic acid [13]. The use of germinated grains in the technology of pastry products darkens the crumb, so it is necessary to lighten it; however, the use of an improver containing soy flour would contribute to its even greater darkening.

The authors of work [14] found that the application of enzymes, emulsifiers, hydrocolloids, and oxidizers has a positive effect on the properties of bakery products made from germinated whole grain flour, namely the volume and hardness of products. The use of xylanase increases the specific volume of products, as well as the softness of the crumb, due to the hydrolysis of arabinoxylans. It was established that the use of α-amylase in such products may be expedient only under certain conditions. It has been proven that phytase can activate endogenous α-amylase, which could lead to greater amylolytic activity, which in turn increases the stickiness of the crumb. The positive effect of dry wheat gluten was established, which positively affects the structural and mechanical properties of bread whose formulation includes cereal products. DATEM and SSL emulsifiers can improve the volume, texture, and staleness of bread with cereal grains. The feasibility of combining several types of improvers was proven to ensure a more effective improvement in the quality of products due to their synergistic impact with joint use.

In [15], it was established that the dosage of cinnamon up to 4 % by weight of flour provides high consumer characteristics of products; however, a more pronounced aroma and taste of cinnamon can limit the range of consumers of such products. The use of 6 % cinnamon in the recipe causes a significant deterioration in the volume of products and gives them a flavor that is too intense. Determining the content of bisulfite-binding substances in the crumb and crust of products confirmed the improvement of the aroma of products with the introduction of cinnamon. The cited work does not show the effect of cinnamon on the structural and mechanical properties of the dough and on the process of staling.

In [16], it is established that the aroma of cinnamon, namely brown aldehyde, adversely affects the microflora of the dough. In order to increase the thermal stability of the aroma and reduce its interaction with yeast, scientists have developed microencapsulation technology using ultrasound. It was found that the encapsulated brown aldehyde had a high inhibiting effect on mold fungi with less impact on the Saccharomyces cerevisiae yeast growth. It would be advisable that the cited work should specify the composition of the dough system which was investigated. The authors of [17] studied the effect of pectin on gluten dough, namely changes in the aggregate properties of gluten, its rheological properties, and secondary structure. It has been found that the addition of pectin enhances the macromolecular aggregation of gluten and improves the rheological properties of the dough, causing a dense gluten mesh. The presence of pectin reduced the content of α-helix but increased the β-sheet and β-rotary structure of gluten, which indicates that pectin affects the level of hydration of gluten, which led to the formation of aggregated β-structures. The cited work contributes to a better understanding of the functionality of pectin in wheat flour dough. Unfortunately, the authors did not show the impact on the quality of finished products.

In [18], it was found that pectin with a high degree of methoxy groups is an effective food additive to improve the consumer properties of bakery products due to its high moisture-holding ability. However, the cited work does not indicate the optimal dosage of such pectin for various types of bakery products.

Study [19] focuses on the use of dry wheat gluten to enrich flour with protein and increase the amount of gluten in it, as well as adjust its quality. Its use causes an increase in the water-absorbing capacity of the dough, improving its structural and mechanical properties, increasing the volume, the porosity of bread, increasing the shape resistance and yield of finished products, prolonging the duration of their freshness. Along with this, the cited study does not provide recommendations for the use of dry wheat gluten in the formulations of complex bakery improvers and polycomponent mixtures.

The authors of [20] recommend the use of ascorbic acid as a safe dietary supplement with oxidative effect in bakery technology. Ascorbic acid contributes to the bleaching of the crumb, increasing the shape stability of dough semi-finished product during kneading and baking, improving the structural and mechanical properties of the dough. The optimal dosage of ascorbic acid is 0.001...0.01 % by weight of flour, depending on its strength, but its recommended content in the formulation composition for complex bakery improvers and polycomponent mixtures is not indicated.

Thus, it is advisable to direct scientific and practical research to improve the technology of making pastry products whose formulation contains germinated grains, provided that various food additives and ingredients are used jointly.

3. The aim and objectives of the study

The purpose of this work is to study the patterns of influence exerted by the polycomponent mixture that includes food additives and ingredients on the formation of consumer characteristics of pastry products whose formulation includes germinated grains.

To accomplish the aim, the following tasks have been set:

– to investigate the effect of the polycomponent mixture on the consumer properties of a pastry product in whose formulation 50 % of flour was replaced with MGC (a mixture of germinated cereals);

– to study the effect of the polycomponent mixture on the staling processes in a pastry product in whose formulation 50 % of flour was replaced with MGC.

4. The study materials and methods

4. 1. Examined objects and materials used in the experiment

To reduce the caloric content of a pastry product, a mixture of germinated cereals (MGC) of wheat, barley, oats, and corn, made by the company "CHOICE" (Ukraine), was chosen. Given the chemical composition of MGC, it can be argued that it is an effective source of soluble dietary fiber, proteins, vitamins, and minerals. However, a possible disadvantage of its use in the technology of baking is the high autolytic and proteolytic activity of enzymes, sugar-forming ability, and acidity, as well as low whiteness and gray color (Table 1). That must be taken into consideration when improving the technological process.

It was established that MGC has high autolytic activity and acidity, as well as low whiteness and gray color. The obtained data should be taken into consideration during the development of technological modes for making bakery products. It was established that MGC has a high water-absorption capacity (154 %) compared to flour (118 %), which can contribute to the binding of free moisture contained in bakery products. This is a prerequisite for prolonging the freshness of bakery products.

Table 1

Chemical composition, quality indicators, and technological properties of the mixture of germinated grains, n=3, p≥0.95, δ=3...5 %

Indicator	Content
Mass fraction of protein, %	12.3
Mass fraction of fat, %	2.6
including saturated fatty acids	1.0
Mass fraction of carbohydrates, %	56.9
including sugars	1.2
Mass fraction of dietary fiber, %	12.4
Mass fraction of ash, %	3.1
Minerals, mg/100 g	
sodium	16.0
calcium	19.3
phosphorus	151.4
potassium	242.0
magnesium	76.3
iron	2.3
Vitamins mg/100 g	
thiamine (B_1)	4.5
riboflavin (B_2)	4.1
niacin (PP)	4.6
Organoleptic indicators	
Color	Light brown
Smell	Characteristic smell of germinated components, without foreign odors, not musty, not moldy
Taste	Sweet, without foreign flavors
The content of mineral impurities	When chewing, one should not feel crunching
Physical-chemical parameters	
Mass fraction of moisture, %	13.0
Whiteness, device conditional unit	33.0
Acidity, degree	9.0
The size of the grind – residue on a sieve from a silk thread, No. 35 according to GOST 4403, %, no more	2.0
– residue on a sieve from a wire mesh, according to GOST 4403, %, no more	–
– passage through a sieve, according to GOST 4403, %, no more	80.0
Technological properties	
Autolytic activity, %, CP	72.0
Water absorption capacity, %	154

Table 2

Recipes of pastry products

Recipe component	Quantity, kg		
	control, bun	bun with the addition of 50 % MGC instead of flour	«Tsilyushcha» bun, with the addition of 50 % MGC instead of flour with PCM
First grade wheat flour	100.0	50.0	50.0
A mixture of germinated grains	–	50.0	50.0
Pressed baker's yeast	4.0	4.0	4.0
Kitchen salt	1.5	1.5	1.5
White crystalline sugar	15.0	15.0	15.0
Sunflower oil	10.0	10.0	10.0
Polycomponent mixture «Solodok»	–	–	3.0

The composition of the polycomponent mixture "Solodok" (PCM) includes:

– ground cinnamon, TM Mriya (Ukraine);

– dry wheat gluten, the Finnish company "Leipurin";

– Polish-made apple pectin;

– Chinese-made ascorbic acid.

The pastry product was made according to the recipes given in Table 2.

The dough for our products was prepared without fermentation by an accelerated technique replacing the fermentation operation with aging for 20 minutes.

4. 2. Methods to study the quality of the pastry product containing the polycomponent mixture "Solodok"

The organoleptic and physicochemical quality indicators of products were evaluated on the basis of the results from test laboratory baking. During the study, the dough with a moisture content of 34 % was prepared without fermentation by an accelerated technique. The dough was kneaded for 6 minutes in a kneading machine with a two-speed kneading. We molded dough pieces manually (rounded and placed in molds), the mass of the dough piece was 0.095 kg. The dough pieces were aged in an aging cabinet at the temperature of (38±2) °C and the relative humidity of (78±2) % over 50–60 minutes. The products were baked in the rack oven at the following parameters: temperature, 180...200 °C; duration, 15 min.

We evaluated the finished products for their appearance, the state of the crust, the structure of porosity, taste, smell, as well as the physicochemical parameters (specific volume, shape resistance, structural and mechanical properties of the crumb [21].

The staling process of the products' crumb was estimated according to the indicator of its deformation at the penetrometer AP 4/1 ("Feinmass" (Germany)) after 4 hours and 72 hours of storage [21].

The freshness of the products was evaluated organoleptically on an 8-point scale [22]. Five tasters – specialists in the bakery industry – took part in the assessment. Each indicator was evaluated on a five-point scale. Each score characterized a certain level of quality: "8" – excellent, "7–6" – good, "5–4" – satisfactory, "3" – not satisfactory enough, "2" – not satisfactory. The conclusion was made on the basis of the processing of expert assessments.

The color of the finished products was determined by the procedure from [23]. The essence of the method of computer colorimetry is to digitize the image of the examined sample and subsequently process it on a computer in order to control the quality of products by color, particle shape, or surface morphology [24]. The color of the pastry products s was evaluated according to the RGB color model.

The content of aromatic substances in the finished products was estimated by the number of bisulfite-binding compounds [20]. This method is based on the ability to bind aldehydes and some ketones with sodium bisulfite to form adducts. The method involves the preliminary removal of non-reacted bisulfite with iodine, followed by the destruction of adducts by sodium bicarbonate and the processing of bisulfite released, which is equivalent to the content of carbonyl compounds.

The degree of staleness was evaluated organoleptically by the area and rigidity of the under-crust layer. Scanning and graphics editors helped determine the average thickness of the under-crust layer [21].

We assessed the microstructure of the product crumb at the electron scanning microscope IEOLJSMM–200 (Japan) with a 1,000-time magnification. The experimental samples were pre-frozen, subjected to lyophilic drying and carbon spraying on the surface of the sample in a vacuum chamber.

The accumulation of dextrins in the finished products was investigated according to the procedure given in [25].

We determined the transition of moisture from the bound form to the free one by thermogravimetry using the Q-1000 derivatograph in the temperature range of 20...200 °C at the rate of heating the samples weighing 1.00 g of 1.25 °C/min. [20].

The foreign and harmful microflora in the finished products was determined according to standard procedures [26].

The results of our experimental studies were statistically processed using the standard Microsoft Office software package.

5. Results of studying the influence of the polycomponent mixture "Solodok" on the consumer properties of the pastry product

5. 1. Investigating the influence of the polycomponent mixture "Solodok" on the organoleptic and physicochemical indicators of the quality of bakery products

The study investigated the impact of PCM on the quality of the pastry product whose formulation includes MGC. The results of our research are given in Table 3.

The result of our study established that the developed PCM has a positive effect on the quality of the pastry product. With the use of PCM, the specific volume of the pastry products increases, compared to the product without PCM, by 5 %, and approaches the specific volume of the control. The introduction of MGC and PCM leads to a change in the traditional taste, the products acquire a pleasant taste of germinated cereals and cinnamon.

Further studies (Fig. 1) showed that in the control the staling was more intense than in a bun with the replacement of 50 % of the flour with MGC. The best in terms of freshness is the bun "Tsilyushcha", with the replacement of 50 % of the flour with MGC instead of the mass of flour made from PCM. The biggest difference in the degree of their freshness (2 points) was observed after 48 and 72 hours of storage. Although all samples received high scores after baking, note that after 24 hours of storage, the difference in assessing the degree of freshness between them changed and was 1 point. After 72 hours, the highest scores were given to products with PCM – 4 points compared to the control samples, which were given 2 and 3 points.

To confirm the positive effect of PCM on the color of the crumb, a computer colorimetric study was carried out, which was to digitize the images of the samples of products and to subsequently process them on a computer. The results of our analysis are given in Table 4 and shown in Fig. 2.

The resulting digital images were evaluated on the basis of coordinate values in the RGB system (Table 4).

The results of the analysis of bakery products indicate that the use of MGC in the formulation of pastry products in the amount of 50 % instead of flour darkens the crumb of the products. When using PCM, the color of the crumb becomes lighter, organoleptically, while the coordinate values in the RGB system are higher than those of a bun with the addition of 50 % MGC instead of flour mass. However, products with a PCM in the recipe would have a light brown color specific to the crumb of buttery products and a light brown crust.

Table 3

The influence of "Solodok" polycomponent mixture on the quality of pastry products n=3, p≥0.95, δ=3–5 %

Indicator	Sample		
	Control, no addition – bun	Bun enriched with 50 % MGC instead of flour weight	Bun enriched with 50 % MGC instead of flour weight and with the developed polycomponent mixture «Solodok»
Specific volume, cm^3/100 g	126	118	124
Acidity, degree	1.5	3.0	3.0
Mass fraction of sugar per DM, %	12.1	14.2	14.4
Mass fraction of fat per DM, %	9.0	9.2	9.1
Surface condition and color	Smooth without cracks, light golden color	Smooth without cracks, dark golden color	
Crumb color	Golden	Brown	Light brown
The porosity structure	Thin-walled, medium, uneven, elastic	Thin-walled, small, uneven, there is sticking of the crumb, inherent in the product of germinated grain	Thin-walled, medium, uneven, elastic
Taste and aroma	Characteristic of this type of product	Pleasant taste and aroma, the taste of sprouted cereals and cinnamon	

Note: n – the number of repeated experiments; p – reliable probability; δ – relative error

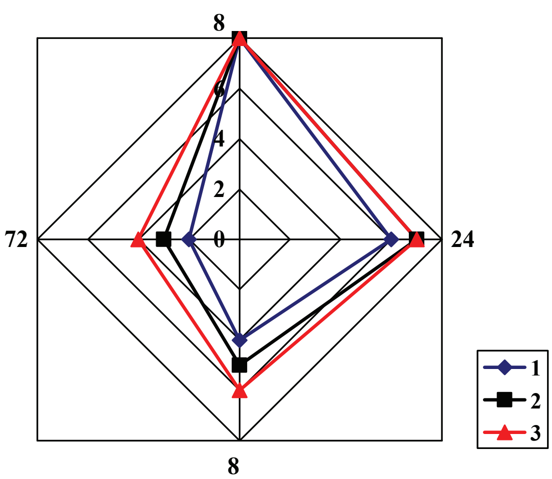


Fig. 1. PCM influence on a change in freshness degree: 1 – control bun; 2 – a bun with the addition of 50 % MGC instead of the mass of flour; 3 – "Tsilyushcha" bun with the addition of 50 % MGC instead of the mass of flour with PCM

The taste and aroma of bakery products largely affect their assimilation. The formation of flavoring compounds depends on the composition of the formulation, products of interaction of sugars, carbonyl compounds with amino acids and proteins, method of production. The main compounds that form the aroma of bakery products are carbonyl. Our study of carbonyl compounds showed (Table 5) that if PCM is added to the dough, the content of carbonyl compounds in the crumb and crust of bakery products increases. This is because PCM contains cinnamon, apple pectin, and dry wheat gluten, which contribute to a greater formation of the number of carbonyl compounds.

Table 4

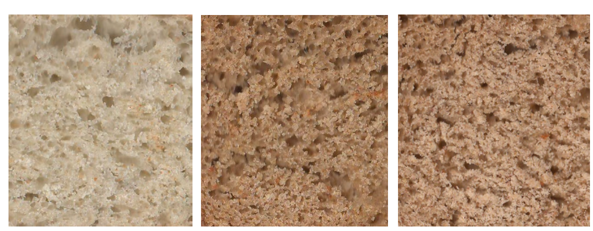
Characteristics of bakery samples in colored RGB models after 72 hours of storage n=3, p≥0.95, δ=3...5 %

Bakery product sample	RGB system color coordinates, unit		
	R	G	B
control bun	181	163	137
bun with the addition of 50 % MGC instead of flour	155	117	86
«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM	160	121	92

Table 5

Bisulfite-binding substance content, mg-equiv./100 g bread, n=3, p≥0.95, δ=3...5 %

Sampling region	Sample		
	control bun	bun with the addition of 50 % MGC instead of flour	«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM
in 4 hours			
Crumb	22.4	26.1	28.6
Crust	32.1	40.8	41.7
in 24 hours			
Crumb	18.7	24.8	27.1
Crust	31.8	36.5	38.1
in 48 hours			
Crumb	14.4	21.5	22.8
Crust	27.2	32.1	34.1
in 72 hours			
Crumb	11.5	17.5	20.1
Crust	20.1	26.2	29.6



a *b* *c*

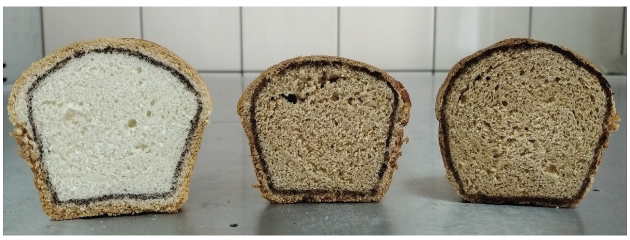
Fig. 2. Digital images of the samples of finished products: *a* – control bun; *b* – a bun with the addition of 50 % MGC instead of the mass of flour; *c* – "Tsilyushcha" bun with the addition of 50 % MGC instead of the mass of flour with PCM

Thus, in the case of using MGC, the content of carbonyl compounds in the finished products 4 hours after baking increases in the crumb and crust by 16.5 %, and by 27.1 % in the crust. When using PCM, the content of carbonyl compounds in the finished products increases, compared to control, in the crumb and crust by 27.7 %, and in the crust – by 29.9 %. The increase in the content of carbonyl compounds in pastry products with MGC and PCM correlates with the improvement of the color of the crust and the aroma of bread.

The effect on the taste of the bun has shown that the developed PCM does not change the traditional taste of the finished products.

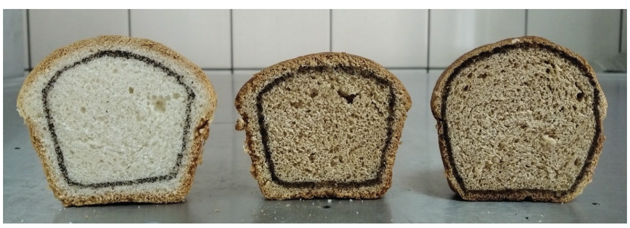
During baking, due to high temperatures, the surface of the products becomes crispier compared to the crumb. This phenomenon is explained by the creation of a gradient of relative humidity and moisture content between the crust and crumb, which causes the redistribution of moisture in the product.

Multicomponent foods are characterized by the process of moisture migration between the components. During storage, there is moisture migration between the crust and crumb. This explains the softening of the crust and hardening of the crumb, as well as the formation of a thicker under-crust layer Therefore, further research focused on studying the under-crust layer. The study results are shown in Fig. 3.



1 2 3

a



1 2 3

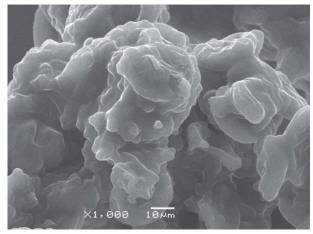
b

Fig. 3. Formation of an under-crust layer: *a* — after 4 hours of storage, *b* — after 72 hours of storage; 1 — control bun; 2 — a bun with the addition of 50 % MGC instead of the mass of flour; 3 — "Tsilyushcha" bun with the addition of 50 % MGC instead of the mass of flour with PCM

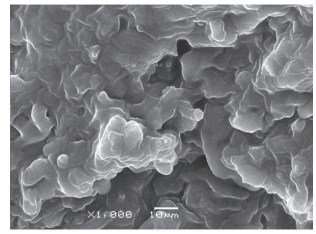
The study results have shown that the use of both MGC only and MGC and PCM at the same time has a positive effect on prolonging the freshness of products. This was confirmed by the formation of a smaller under-crust layer in the test samples compared to the control during storage for 72 hours. The thickness of the under-crust layer after 4 hours of storage in the bun with the addition of 50 % of MGC instead of flour mass is 2.38 mm, in the case of PCM use – 1.81 mm, and in the control sample – 4.83. After 72 hours of storage, the thickness of the under-crust layer in the control sample is 8.62, the bun with the addition of 50 % MGC instead of flour mass – 7.23 mm, in the case of PCM use – 2.95 mm.

Further studies involved the microscopic examination of the finished products after 72 hours of storage. The samples were stored unpacked at a temperature of (20±0) °C. The results are shown in Fig. 4.

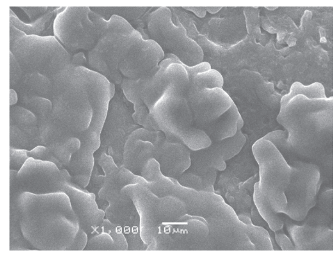
It was established that the pastry products during storage form a large number of voids between the pores, which confirms the formation of the crystalline structure of starch and protein compaction. In a sample containing only MGC, the crumb was characterized by fewer voids between the pores. In the case of using PCM, the crumb of the pastry products consists of patched swollen and partially gelatinized starch grains wrapped in a solid mass of coagulated proteins.



a



b



c

Fig. 4. The microstructure of bakery products with complex bakery improvers after 72 hours of storage: *a* — control bun; *b* — a bun with the addition of 50 % MGC instead of the mass of flour; *c* — "Tsilyushcha" bun with the addition of 50 % MGC instead of the mass of flour with PCM

5. 2. The influence of "Solodok" polycomponent mixture on the staling process during storage

When storing bakery products, the state of their crumb characteristically changes, namely its structural and mechanical properties. Changes in the state of the product crumb during storage were determined by its deformation after 4 and 72 hours of storage, using the penetrometer AP4/1 ("Feinmass" (Germany)). The study results are given in Table 6.

The study results (Table 6) confirmed the positive impact of PCM on the structural and mechanical properties of the crumb of the finished products. Thus, the rate of bread staling after 72 hours for a bun with the addition of 50 % MGC instead of flour mass is less, compared to control, by 19.7 %. In the case of PCM, the rate of bread staling after 72 hours is less, compared to control, by 59.2 %.

Replacing flour with germinated grains of cereals increases the amylolytic activity of the dough. This improves the fermentation processes of the dough due to the formation of a sufficient amount of sugars. Due to the additional formed sugars, as well as sugars introduced according to the recipe, the porosity of bakery products is thin, homogeneous, which helps improve their taste, the color of the crust, longer preservation of freshness. Due to the fact that there is a destruction of starch during the baking process, and taking into consideration that apple pectin is included in the PCM formulation, it was advisable to investigate a change in the number of dextrins in bakery products. In addition, high content of dextrin in finished products leads to sticking of the product crumb, which was observed in a bun with 50 % replacement of flour with MGC. We determined dextrins after 4 hours of cooling. The study results are given in Table 7.

Table 6

Deformation indicators of product crumb during storage, n=3, p≥0.95, δ=3...5 %

Bread sample, storage duration	Deformation type, device unit			Preserving freshness, %
	overall	plastic	elastic	
4-hour storage				
control bun	91	57	34	–
bun with the addition of 50 % MGC instead of flour weight	93	59	34	–
«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM	108	61	47	–
72-hour storage				
control bun	36	15	21	39.5
bun with the addition of 50 % MGC instead of flour weight	44	20	24	47.3
«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM	68	36	32	62.9

Table 7

Dextrin content in bakery products, n=3, p≥0.95, δ=3...5 %

Bakery product sample	Dextrin content per fraction, % per DM			Dextrin overall content
	amylodextrins	erythrodextrins	malto- and achrodextrins	
control bun	0.644	0.238	0.786	1.668
bun with the addition of 50 % MGC instead of flour weight	1.259	0.438	1.446	3.143
«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM	0.923	0.378	1.142	2.443

It was established that the total number of dextrins increases when using MGC, compared to control, by 88.4 %, due to the high amylolytic activity inherent in MGC. This explains the formation of a sticky crumb of the bun with the addition of 50 % MGC instead of the mass of flour. In the case of PCM, the total number of dextrins is reduced by 46.5 % compared to the bun without adding PCM. As a result of the MGC and PCM effect, there is an increase in low molecular weight dextrins, namely maltodextrins and achrodextrins. Thus, in the case of using only MGC, the content of maltodextrins and achrodextrins increases by 84.0 %, and, in the case of joint introduction of MGC and PCM, by 45.3 %.

The capacity of bakery products to keep freshness is associated with the content of bound water. For this purpose, the content of bound and free water in the crumb was calculated. We determined it with the help of a derivatograph. Analysis of thermogravimetric curves has made it possible to obtain quantitative characteristics of moisture distribution in the product crumb with additives, as well as changes in its condition during storage (Table 8).

Analysis of our data shows that the use of MGC and PCM helps increase the proportion of bound moisture and reduce the rate of its loss during storage. Thus, in the case of using MGC in the amount of 50 % instead of flour, the share of bound moisture increases by 9.4 %, with the addition of PCM – by 12.6 %. The loss of this moisture over 72 hours of storage by the control sample is 48.5 %, while with MGC – 43.3 %, and, during the joint introduction of MGC and PCM, 35.5 %.

Table 8

Kinetic parameters of product crumb derivatograms, n=3, p≥0.95, δ=3...5 %

Bakery product sample	Storage duration, hour	Mass fraction of moisture in the crumb, %	Mass fraction of moisture, % of total		Loss of bound moisture, %
			free	bound	
control bun	4	34.1	65.8	34.2	–
	72	32.5	82.4	17.6	48.5
bun with the addition of 50 % MGC instead of flour weight	4	34.0	62.6	37.4	–
	72	33.4	78.8	21.2	43.3
«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM	4	34.3	61.5	38.5	–
	72	33.5	75.2	24.8	35.5

It was advisable to investigate the impact of MGC and PCM on the microbiological indicators of the quality of finished products. The samples of bakery products studied were stored at temperatures (20±2) °C and relative humidity (75±2) %, unpacked. The quality was assessed after 72 hours of storage. The obtained data are given in Table 9.

Table 9 demonstrates that during the storage of pastry products for 72 hours, the amount of KMAFAM using PCM is smaller compared to the control and the product in which 50 % of the flour was replaced with MGC. There is an increase in the number of mold fungi and the number of spore-forming bacteria, but not exceeding the norm. Thus, the microbiological indicators of pastry products, subject to the use of PCM, are lower compared to control, which testifies to the increased stability during the storage of pastry products whose formulation includes MGC.

Table 9

The influence of "Solodok" polycomponent mixture on the microbiological indicators after 72 hours of storage of bakery products, n=3, p≥0.95, δ=3...5 %

Microbiological indicators, CFU/g	Sample		
	control bun	bun with the addition of 50 % MGC instead of flour weight	«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM
QMAFAM	$5.4 \cdot 10^3$	$4.4 \cdot 10^3$	$3.8 \cdot 10^3$
LAB (lactic acid bacteria)	$<10^3$		
Yeast	<100		
Molds	$0.2 \cdot 10^2$	$0.6 \cdot 10^2$	$0.5 \cdot 10^2$
Spore-forming bacteria	$10.2 \cdot 10^2$	$9.4 \cdot 10^2$	$10.2 \cdot 10^2$
Bacteria of the Escherichia coli group (coliform)	Not detected		
Putrefactive bacteria	$<10^3$		
Bacteria of the genus *Leuconostoc*	$<10^3$		

6. Discussion of results of using the polycomponent mixture "Solodok" in the recipe of a pastry product

The inclusion in the formulation of bakery products of germinated grains of cereals leads to the stickiness of the crumb, darkening of the crust and crumb, reducing the specific volume of products. To neutralize the negative impact exerted on the consumer properties of germinated grains, experts suggest applying a variety of technological measures. The most effective measure is the use of food additives, complex bakery improvers, polycomponent mixtures [10, 16, 17].

It was established that the use of PCM has a positive effect on the organoleptic and physicochemical indicators of the quality of pastry products (Table 3). This is because the PCM includes ground cinnamon, the brown aldehyde of which has a positive effect on the aroma and structural-mechanical properties of the dough [16]. The PCM includes dry wheat gluten and apple pectin, which improve the elasticity of the gluten-free frame [18, 19]. Their synergistic effect leads to an increase in the specific volume of pastry products, in the formulation of which 50 % of flour was replaced with MGC, compared to the product without PCM. The use of ascorbic acid in the PCM contributes to the lighting of the product crumb; as a result, the products have a lighter color and a pleasant perception [20].

Improving the aroma of pastry products (Table 5), namely an increase in the content of bisulfite-binding compounds is explained by the fact that due to the use of PCM, the brown cinnamon aldehyde is additionally introduced [16]. In addition, with dry wheat gluten, protein compounds are added that increase the content of carbonyl compounds and slow their release during storage. The use of apple pectin also contributes to the increase in carbonyl compounds as it contains them in its composition [27, 28].

Our study has established the positive effect of using PCM on prolonging the freshness of pastry products in the formulation of which 50 % of flour was replaced with a mixture of germinated grains. Together with PCM, moisture-retaining additives are added to the products, namely dry wheat gluten and apple pectin, which, in the storage process, retain bound moisture and prevent the transfer of moisture from the crumb to crust (Fig. 3). This is confirmed by the formation of a smaller under-crust layer in products with PCM.

Most often, the staling process is associated with the compaction of the starch structure, which occurs as a result of its retrogradation. At the same time, the volume of starch grains decreases, and voids appear between protein and starch molecules [29]. Micrographs have confirmed that the use of MGC and PCM contributes to the smaller formation of air layers in the crumb of pastry products, compared to the control sample (Fig. 4).

Improvement of deformation characteristics of pastry products (Table 6) in the case of MGC and PCM use is due to the introduction of gluten proteins and apple pectin into the dough system. They strengthen the structure of the product crumb due to the strengthening of hydration ties, which prevent the loss of moisture starch when storing products [18, 19].

During baking, starch destruction takes place, which contributes to the accumulation of dextrins, which contribute to prolonging the freshness of the finished products. With the high autolytic activity of dough during baking, a large number of high molecular weight and low molecular weight dextrins are formed, which causes the appearance of the stickiness of the crumb [30]. It was established that the total number of dextrins (Table 7) increases under the condition of using MGC, compared to the control, by 88.4 %, due to the high amylolytic activity inherent in MGC. This explains the formation of a sticky crumb of the bun with the addition of 50 % MGC instead of flour mass and worsens the consumer properties of products. In the case of PCM, the total number of dextrins is reduced compared to the bun with the addition of 50 % MGC instead of flour mass; however, this amount is greater, compared to control, by 46.5 %. Given this, the products form a darkened crumb. As a result of the MGC and PCM action, there is an increase in low molecular weight dextrins, namely maltodextrins and achrodextrins. In this regard, the staling process of pastry products is slowed down due to the formation by low molecular weight dextrins of a three-dimensional grid, which prevents the interaction of gluten and starch and the release of moisture by starch.

Analysis of moisture bond forms at the end of storage has established (Table 8) [31] that for all samples of products, there was a tendency to reduce osmotically- and absorbingly-bound moisture and increase the free moisture of microcapillaries. This decrease occurs to a lesser extent in the case of MGC separately and in the case of replacement of 50 % of the flour in the formulation of pastry products with PCM.

This correlates with our data on determining the overall deformation of the crumb and the thickness of the under-crust layer.

The use of PCM, which contains ground cinnamon, helps increase the stability of the pastry products, in the formulation of which 50 % of the flour is replaced with MGC, during storage.

Consequently, the developed PCM helps improve the preservation of product freshness for 72 hours when storing unpacked.

However, the effect of PCM on the shelf life of packaged pastry products, in the formulation of which 50 % of the flour is replaced with MGC, remains unclear.

Further research into this area could establish the safety of using PCM in organic products.

7. Conclusions

1. It was established that the use of the polycomponent mixture "Solodok" in the amount of 3.0 % by weight of flour in the formulation of the pastry product in which 50 % of the flour is replaced with a mixture of germinated grains leads to improved consumer properties. Namely, the stickiness of the product crumb is gone, there is the developed porosity, the preservation of product freshness, the increase in specific volume, the improvement of shape stability.

2. It was established that the polycomponent mixture "Solodok" prolongs the storage duration of pastry products in the formulation of which 50 % of the flour is replaced with a mixture of germinated grains up to 72 hours stored unpacked. It has been confirmed that after 72 hours of storage there is a smaller thickness of the under-crust layer of the product with PCM compared to control, namely in control – 7.23 mm, and when using PCM – 2.95 mm. It was established that the use of MGC and PCM reduces the number

of layers of air in the product crumb. It was found that the use of PCM in products containing MGC in the formulation reduces the overall content of dextrins, which reduces the stickiness of the crumb, as well as increases the content of low molecular weight dextrins, which slows down the staling process. It was established that the products with MGC and PCM lose less bound moisture compared to control.

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