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

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 calorific.

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...
Technology and Equipment of Food Production

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...63 °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), hydrolases (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 mono-glycerides, owing to which the process of starch retrograde
The presence of pectin decreases the level of hydration of gluten, which led to the formation of α-structures. The cited work contributes to a better understanding of the functionality of pectin in wheat flour. 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, $n=3, p \geq 0.95, \delta=3...5\%$

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass fraction of protein, %</td>
<td>12.3</td>
</tr>
<tr>
<td>Mass fraction of fat, %</td>
<td>2.6</td>
</tr>
<tr>
<td>including saturated fatty acids</td>
<td>1.0</td>
</tr>
<tr>
<td>Mass fraction of carbohydrates, %</td>
<td>56.9</td>
</tr>
<tr>
<td>including sugars</td>
<td>1.2</td>
</tr>
<tr>
<td>Mass fraction of dietary fiber, %</td>
<td>12.4</td>
</tr>
<tr>
<td>Mass fraction of ash, %</td>
<td>3.1</td>
</tr>
<tr>
<td>Minerals, mg/100 g</td>
<td></td>
</tr>
<tr>
<td>sodium</td>
<td>16.0</td>
</tr>
<tr>
<td>calcium</td>
<td>19.3</td>
</tr>
<tr>
<td>phosphorus</td>
<td>151.4</td>
</tr>
<tr>
<td>potassium</td>
<td>242.0</td>
</tr>
<tr>
<td>magnesium</td>
<td>76.3</td>
</tr>
<tr>
<td>iron</td>
<td>2.3</td>
</tr>
<tr>
<td>Vitamins mg/100 g</td>
<td></td>
</tr>
<tr>
<td>thiamine (B$_1$)</td>
<td>4.5</td>
</tr>
<tr>
<td>riboflavin (B$_2$)</td>
<td>4.1</td>
</tr>
<tr>
<td>niacin (PP)</td>
<td>4.6</td>
</tr>
<tr>
<td>Organoleptic indicators</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>Light brown</td>
</tr>
<tr>
<td>Smell</td>
<td>Characteristic smell of germinated components, without foreign odors, not musty, not moldy</td>
</tr>
<tr>
<td>Taste</td>
<td>Sweet, without foreign flavors</td>
</tr>
<tr>
<td>The content of mineral impurities</td>
<td>When chewing, one should not feel crunching</td>
</tr>
<tr>
<td>Physical-chemical parameters</td>
<td></td>
</tr>
<tr>
<td>Mass fraction of moisture, %</td>
<td>13.0</td>
</tr>
<tr>
<td>Whiteness, device conditional unit</td>
<td>33.0</td>
</tr>
<tr>
<td>Acidity, degree</td>
<td>9.0</td>
</tr>
<tr>
<td>The size of the grind</td>
<td></td>
</tr>
<tr>
<td>– residue on a sieve from a silk thread, No. 35 according to GOST 4403, %, no more</td>
<td>2.0</td>
</tr>
<tr>
<td>– residue on a sieve from a wire mesh, according to GOST 4403, %, no more</td>
<td>–</td>
</tr>
<tr>
<td>– passage through a sieve, according to GOST 4403, %, no more</td>
<td>80.0</td>
</tr>
<tr>
<td>Technological properties</td>
<td></td>
</tr>
<tr>
<td>Autolytic activity, %, CP</td>
<td>72.0</td>
</tr>
<tr>
<td>Water absorption capacity, %</td>
<td>154</td>
</tr>
</tbody>
</table>

**Table 2**

Recipes of pastry products

<table>
<thead>
<tr>
<th>Recipe component</th>
<th>Quantity, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control, bun</td>
</tr>
<tr>
<td>First grade wheat flour</td>
<td>100.0</td>
</tr>
<tr>
<td>A mixture of germinated grains</td>
<td>–</td>
</tr>
<tr>
<td>Pressed baker’s yeast</td>
<td>4.0</td>
</tr>
<tr>
<td>Kitchen salt</td>
<td>1.5</td>
</tr>
<tr>
<td>White crystalline sugar</td>
<td>15.0</td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>10.0</td>
</tr>
<tr>
<td>Polymorphic mixture «Solodok»</td>
<td>–</td>
</tr>
</tbody>
</table>
The composition of the polycomponent mixture “Solo-
dok” (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 fer-
mentation by an accelerated technique replacing the fer-
teration operation with aging for 20 minutes.

4. 2. Methods to study the quality of the pastry prod-
uct containing the polycomponent mixture “Solo-
dok”
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 mois-
ture 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 mold-
ed 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 param-
eters: 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 penetrom-
eter AP 4/1 ("Feinmass" (Germany)) after 4 hours and 72 hours
of storage [21].
The freshness of the products was evaluated organolep-
tically 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 charac-
terized 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 prod-
ucts was estimated by the number of bisulfit-binding com-
ounds [20]. This method is based on the ability to bind alde-
hydes and some ketones with sodium bisulfite to form adducts.
The method involves the preliminary removal of non-reacted
bisulfit 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 prod-
ucts was determined according to standard procedures [26].
The results of our experimental studies were statistical-
ically processed using the standard Microsoft Office
software package.

5. Results of studying the influence of the polycomponent
mixture “Solo-
dok” on the consumer properties
of the pastry product

5. 1. Investigating the influence of the polycomponent
mixture “Solo-
dok” on the organoleptic and physico-
chemical 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 prod-
uct. 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 fresh-
ness 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 studies 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 sys-
tem 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.
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 3

The influence of "Solodok" polycomponent mixture on the quality of pastry products  \( n=3, \rho \geq 0.95, \delta = 3-5 \% \)

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

Note: \( n \) – the number of repeated experiments; \( \rho \) – reliable probability; \( \delta \) – relative error

### Table 4

Characteristics of bakery samples in colored RGB models after 72 hours of storage \( n=3, \rho \geq 0.95, \delta = 3-5 \% \)

<table>
<thead>
<tr>
<th>Bakery product sample</th>
<th>RGB system color coordinates, unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control bun</td>
<td>R</td>
</tr>
<tr>
<td>bun with the addition of 50 % MGC instead of flour</td>
<td>181</td>
</tr>
<tr>
<td>«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM</td>
<td>160</td>
</tr>
</tbody>
</table>

### Table 5

Bisulfite-binding substance content, mg-equiv./100 g bread, \( n=3, \rho \geq 0.95, \delta = 3-5 \% \)

<table>
<thead>
<tr>
<th>Sampling region</th>
<th>Sample</th>
<th>4 hours</th>
<th>24 hours</th>
<th>48 hours</th>
<th>72 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crumb</td>
<td>Bun with the addition of 50 % MGC instead of flour</td>
<td>22.4</td>
<td>24.8</td>
<td>31.8</td>
<td>11.5</td>
</tr>
<tr>
<td>Crust</td>
<td>Bun with the addition of 50 % MGC instead of flour with PCM</td>
<td>26.1</td>
<td>24.8</td>
<td>36.5</td>
<td>17.5</td>
</tr>
</tbody>
</table>

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 crisper 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.

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 % MGC instead of the mass of flour is 2.38 mm, in the case of PCM use – 1.81 mm, and in the control sample – 4.83 mm. After 72 hours of storage, the thickness of the under-crust layer in the control sample is 8.62 mm, 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.

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.
The loss of this moisture over 72 hours of storage by the control ture increases by 9.4%, with the addition of PCM – by 12.6%. In the amount of 50 % instead of flour, the share of bound mois-
ture rate of its loss during storage. Thus, in the case of using MGC helps increase the proportion of bound moisture and reduce the
joint introduction of MGC and PCM, 35.5%.

Analysis of thermogravimetric curves has made it possible to calculate. We determined it with the help of a derivatograph.

The obtained data are given in Table 9.

Table 6

<table>
<thead>
<tr>
<th>Bread sample, storage duration</th>
<th>Deformation type, device unit</th>
<th>Preserving freshness, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>overall</td>
<td>plastic</td>
</tr>
<tr>
<td>4-hour storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>control bun</td>
<td>91</td>
<td>57</td>
</tr>
<tr>
<td>bun with the addition of 50 % MGC instead of flour weight</td>
<td>93</td>
<td>59</td>
</tr>
<tr>
<td>«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM</td>
<td>108</td>
<td>61</td>
</tr>
<tr>
<td>22-hour storage</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 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

<table>
<thead>
<tr>
<th>Bakery product sample</th>
<th>Dextrin content per fraction, % per DM</th>
<th>Dextrin overall content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>amylodextrins</td>
<td>erythro- dextrins</td>
</tr>
<tr>
<td>control bun</td>
<td>0.644</td>
<td>0.238</td>
</tr>
<tr>
<td>bun with the addition of 50 % MGC instead of flour weight</td>
<td>1.259</td>
<td>0.438</td>
</tr>
<tr>
<td>«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM</td>
<td>0.923</td>
<td>0.378</td>
</tr>
</tbody>
</table>

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 8

<table>
<thead>
<tr>
<th>Bakery product sample</th>
<th>Storage duration, hour</th>
<th>Mass fraction of moisture in the crumb, %</th>
<th>Mass fraction of moisture, % of total</th>
<th>Loss of bound moisture, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>free</td>
<td>bound</td>
<td></td>
</tr>
<tr>
<td>control bun</td>
<td>4</td>
<td>34.1</td>
<td>65.8</td>
<td>34.2</td>
</tr>
<tr>
<td>bun with the addition of 50 % MGC instead of flour weight</td>
<td>72</td>
<td>32.5</td>
<td>82.4</td>
<td>17.6</td>
</tr>
<tr>
<td>«Tsilyushcha» bun with the addition of 50 % MGC instead of flour with PCM</td>
<td>72</td>
<td>33.4</td>
<td>78.8</td>
<td>21.2</td>
</tr>
</tbody>
</table>

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 8.

Table 9

<table>
<thead>
<tr>
<th>Microbiological indicators, CFU/g</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control bun</td>
</tr>
<tr>
<td>QMAFAM</td>
<td>5.4·10³</td>
</tr>
<tr>
<td>LAB (lactic acid bacteria)</td>
<td>&lt;10³</td>
</tr>
<tr>
<td>Yeast</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Molds</td>
<td>0.2·10²</td>
</tr>
<tr>
<td>Spore-forming bacteria</td>
<td>10.2·10²</td>
</tr>
<tr>
<td>Bacteria of the genus Escherichia coli group (coliform)</td>
<td>Not detected</td>
</tr>
<tr>
<td>Putrefactive bacteria</td>
<td>&lt;10³</td>
</tr>
<tr>
<td>Bacteria of the genus Leuconostoe</td>
<td>&lt;10³</td>
</tr>
</tbody>
</table>
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 bisulfit-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 carboxyl compounds and slow their release during storage. The use of apple pectin also contributes to the increase in carboxyl 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 acrodextrins. 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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