

SUBSTANTIATION OF BASIC STAGES OF GLUTEN-FREE STEAMED BREAD PRODUCTION AND ITS INFLUENCE ON QUALITY OF FINISHED PRODUCT

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ABSTRACT

Development and introduction of high quality gluten-free products is one of the priorities of food industry. Feasibility of producing gluten-free steamed bread based on rice and corn flour using flaxseed, sunflower, sorghum and quinoa flour additives is proved in the article. Recommended ratios of flours are established: Frc:Ffs 95:5, Frc:Fsn 95:5, Fcn:Fqn 85:15, Fcn:Fsg 90:10. The parameters of dough kneading are studied and the influence of additives on relative elasticity, plasticity and resilience is established. Use of additives leads to a decrease in irreversible relative deformation of dough for 36 – 68% and relative plasticity for 16 – 18%, to increase of its elasticity relative resilience up to 2.3 times. Dough fermentation process is investigated. It is established that amount of carbon dioxide accumulated in gluten-free dough increases by 10 – 30%. Process of acid accumulation during fermentation is studied. A flow chart for the production of gluten-free steamed bread is proposed. The parameters for the production of gluten-free steamed bread were established and justified. Product is prepared in a single-phase method, adopted in practice of baking bread. The duration of dough mixing is 10 – 15 min, fermentation 20 – 35 min. Steam treatment is carried out under atmospheric pressure. Recommended steam processing time is 35 min for bread based on rice flour, 30 min for based on corn flour. In comparison with the traditional technological scheme, it is recommended to use a double boiler instead of an oven.

Keywords: gluten-free; steamed bread; rheology; dough slackness; fermentation

INTRODUCTION

The imbalance of the diet of the world population in modern economic conditions leads to a constant shortage of essential nutrients that are necessary for consumption, especially in case of diseases associated with gastrointestinal tract functioning. Unfortunately, today quality, biological value, safety and pricing of food products do not always meet the requirements of sick people. Therefore, the development and introduction of high quality gluten-free products is one of the priorities of food industry.

Production of specialized food products, free from certain ingredients, and gluten-free products are one of the largest segments of this market today. Use of structure-forming additives of polysaccharide nature in technologies of bakery, confectionery, macaroni products can simulate a structure similar to traditional flour products. The main drawback of such products is their reduced nutritional and biological value, lack of protein, vitamins and minerals. This problem can be solved by introduction of high protein ingredients, primarily soy isolates and concentrates, peanut protein isolates, lupine, caseinates, synthetic vitamins and trace elements, etc.

At present scientists have developed a wide range of gluten-free foods – breads, muffins, biscuits made of buckwheat and rice flour (Havrylova, 2007; Drobot, Mykhonic and Hryshenko, 2010; Kuznetsova, 2010; Lazorenko, 2013; Dorokhovych, Lazorenko and Omelyanchenko, 2014). However, the segment of Ukrainian market of steamed bread production is still not developed. The fact is that steamed bread is a traditional Chinese bread made from wheat flour or its mixture with rice. This product is widely distributed in the eastern countries (mainly in China, Japan, Korea, Thailand), as well as in the USA, Canada and some European countries (Huang et al., 1996). Its advantages include slowing of glucose absorption processes during steam treatment, which reduces glycemic index; absence of melanoid formation reaction, which reduces losses of lysine and other water-soluble amino acids; absence of harmful acrylamides that are not formed during steam treatment (Addo et al., 1991; Liu et al., 2012; Zhang et al., 2014; Huang and Miskelly, 2016; Fu, Chang and Shiau, 2015).

To create a competitive technology of steamed bread scientists are currently searching for the following directions:

- adaptation and correction of world experience in the production of steamed bread;
- expansion of raw material base and assortment of gluten-free steamed bread products;
- improvement of structural and mechanical properties of steamed bread.

Understanding the main aspects of regulating the nutritional value of gluten-free steamed bread, forming its quality, regulating the properties and expediency of using enriching flour raw materials will contribute to developing products with high nutritional and organoleptic quality indicators available to all population groups.

There are three main types of traditional steam bread in China: Northern Type, Southern Type and Taiwan Type. Northern steamed bread is used as the main food product, while Southern and Taiwan, with a sweet taste, are used most as desserts (Lin, Miskelly and Moss, 1990; Wang et al., 1995; Zhu et al., 1997; Fan et al., 2009; Hao and Trust, 2012; Ma et al., 2014; Fu, Shiau and Chang, 2014; Zhu, 2014; Wu and Shiau, 2015).

The variety of steamed bread technology can be combined according to such classification feature as a way of dough making into three main groups: sourdough, sponge and straight dough method.

The first method is usually used in domestic production and in small private enterprises. In this way, sourdough is added by 10% to the mass of flour, than a required amount of water is added and dough is mixed for 5 – 10 minutes. The fermentation lasts 3 hours at temperature of 26 – 28 °C and a relative humidity of 75%. Due to the presence of lactobacilli, dough pH is 3.7 – 4.0, so after fermentation 40% of Na₂CO₃ solution is used. To achieve the desired pH value of dough (6.4 – 6.7), on average, it is necessary to add a solution of Na₂CO₃ in an amount of 0.5% to the mass of flour. Neutralization of dough is critical in the production of steamed bread, since with excessive amounts of Na₂CO₃, color of products varies from yellow to dark gray, and the smell is expressed in alkaline. If the dough is not brought to the required pH, steamed bread has an acidic smell, low volume, unobtrusive appearance and excessively rigid structure. The introduction of an alkaline solution neutralizes acids that are released by lactobacilli when the dough precipitates, which helps to increase the release of carbon dioxide. Depending on the technology, the dough can be subjected to swirling after neutralization (Li et al., 2012, Wu and Shiau, 2015). The finished dough is rolled and twisted into a long baffle and divided into pieces weighing 100 – 130 g, and then formed in oblong or rounded billets. Further, the dough pieces are subjected to proofing for 30 minutes at a temperature of 32 – 36 °C and relative humidity of 75 – 80% and steamed for 15 – 20 minutes (Wu and Shiau, 2015).

Sponge dough method is widely used in steamed baking technology. The production process involves the following operations: sponge preparation, fermentation, dough kneading, rolling, forming, splitting into pieces, proofing and steaming. 80% of flour is mixed with yeast and water for sponge preparation. Yeasts are pressed or dried. After 60 minutes of fermentation at a temperature of 32 °C and

a relative humidity of 80%, 20% of flour is added together with other ingredients (Fu, Shiau and Chang, 2014; Li et al. 2015). There are two main advantages to using the sponge dough method. First, it is possible to develop a flexible fermentation schedule for different batches of bread; and secondly, the bread has a finely porous homogeneous structure of crumb and bright aroma. However, the sponge dough method requires higher labor costs, production space and a long process of production (Fu, Shiau and Chang, 2014; Zhang et al., 2014).

Straight dough method is much simpler than previous one, because of simplicity and speed of the process, and therefore the most widespread. Straight dough method of steamed bread preparation is significantly shorter than the first two, but rather sensitive to duration change of technological process in industrial production. For example, if a technological scheme is not developed sufficiently, one batch of dough can achieve the optimum fermentation, while others will be overfermented or underfermented. In addition, bread will have less homogeneous structure and lower organoleptic and technological characteristics than bread produced by sponge dough method or using sourdough (Kawamura-Konishi et al., 2013; Fu, Shiau and Chang, 2014).

The most important stage that results in the receipt of high quality products is bread proofing (Meredith, 1965; Chen and Gan, 1997; Moayedallaie, Mirzaei and Paterson, 2010). The degree of proofing affects the shape, color, structure and aroma of finished products. Traditionally, proofing of the dough pieces is carried out at a temperature of 32 – 37 °C and a relative humidity of 70 – 80%. In most cases, the optimal duration of the process is determined visually by pressing on the surface of a piece. It is believed that optimally fermented dough pieces have shining and elastic surface that quickly restores its shape after pressing (Meredith, 1965). However, this method of estimation lacks stability, so D. Chen (Chen et al., 2010) developed a standard method for evaluating the optimal duration of dough proofing. Under this method, 25 g of dough for the production of steamed bread is placed in a cylinder, diameter 3 cm and a volume of 45 mL. The amount of dough on average is 21 – 22 mL. After proofing, the final volume of dough for Southern steamed bread should be 38 mL, for Northern and Taiwan 45 mL (Hou, 1991).

The final stage of production is the steamed treatment of dough pieces. The pieces are placed in an oven with steam convector and stem for 15 – 30 minutes at atmospheric pressure (Sivaramakrishnan, Senge and Chattopadhyay, 2004).

The assessment of steamed bread quality is carried out by evaluation of the specific volume of products, organoleptic and consumer indicators. The standard specific volume of steamed bread of different types differs because of the differences in prescription composition. Southern steamed bread traditionally has a higher specific volume (average 3.5 – 3.7 mL.g⁻¹) than Northern (average 2.0 – 2.5 mL.g⁻¹) due to greater porosity. Steamed bread should have an elastic structure and quickly turn the shape on after pressing. High quality steamed bread should have a smooth and shiny surface of white color without yellow stains and symmetrical shape. Crumb of steam bread should be of white color, uniform fine porosity structure,

elastic and with high humidity (Turabi, Sumnu and Sahin, 2008; Kim et al., 2009).

Increasing cases of celiac disease diagnosis, as well as low quality of available gluten-free products, prompts researchers to find new ingredients and technologies that can replace gluten and improve the properties of gluten-free bakery products.

Many scientists around the world are working on the development of gluten-free products. The main areas of development are the exclusion or modification of gluten from gluten-free raw materials and the complete exclusion of gluten-free raw materials from prescription mixtures. Relatively to the first direction, today research is conducted on the selection of gluten-free wheat, using genetic engineering (Stoven, Murray and Marietta, 2012). However, the research data are under development. Therefore, the second direction of the solution of gluten-free products issue is more widespread. According to it, it is recommended to mix different types of gluten-free flour (mainly rice, corn, millet and buckwheat). The main problem of these technologies is to provide the structure of products, which is usually provided by gluten. In most cases, hydrocolloids (xanthan, gum, modified starches, etc.) (Lobacheva, 2013; Medvid et al., 2017), enzymes (for example, transglutaminase) (Shanina, Lobacheva and Gavrish, 2013; Lobacheva, 2015) and sourdough (Yeh et al., 2009) are suggested to be used to solve this problem.

As a rule, gluten-free flour mixtures include four groups of food components: flour with high content of starch and non-starch polysaccharides; emulsifiers, dough flufflers, flavor ingredients; hydrocolloids; high protein ingredients (Barsukova, Reshetnikov and Krasilnikov, 2011).

In our opinion, the most prospective enhancer of the bread structure made of rice flour (Frc) or corn flour (Fcn) is flour gluten-free raw materials with enriching action (FGFRM) – sorghum (Fsg), flaxseed (Ffs), quinoa (Fqn) and sunflower (Fsn) According to review of literary sources, the listed additives can improve structure of gluten-free products and their nutritional value due to the high content of complete proteins, as well as macro- and micronutrients. All of the given data relate to gluten-free bread, which is subject to baking, however, when steam is used for treatment, other thermal and biochemical processes can change the organoleptic, structural and mechanical properties of the final product, as well as its nutritional and biological value.

Scientific hypothesis

Conducted researches are aimed at determining the peculiarities of main stages behavior in gluten-free steamed bread production. Therefore, in order to achieve this goal, the primary task is to study the effect of FGFRM on the progress of main technological stages in steamed bread production, the structural and mechanical properties of dough, quality and consistency of final product.

MATERIAL AND METHODOLOGY

The following flour products are selected for experimental research and production testing:

- rice flour TM «Sto pudov»;
- corn flour TM «Sto pudov»;

- sorghum flour TM «Asparagus-LTD»;
- flaxseed defatted flour TM «Viva»;
- sunflower defatted flour TM «Efavit»;
- quinoa flour TM «Vivan».

For experimental studies flour is sieved through a laboratory nylon sieves with a hole size of 120 µm. The following ratio of components in flour mixes is selected:

- rice flour : flaxseed defatted flour (Frc:Ffs) – 95:5,
- rice flour : sunflower defatted flour (Frc:Fsn) – 95:5,
- corn flour : quinoa flour (Fcn:Fqn) – 85:15,
- corn flour : sorghum flour (Fcn:Fsg) – 90:10.

To obtain the liquid phase of dough, 1.75% of yeast is added to the mass of flour mixture in whole formulation of water (58 – 59% for bread based on rice flour and 63 – 64% for bread based on corn flour), salt is added in amount of 1.5% and stirred until a homogeneous solution is obtained. The flour mixture is moistened with a liquid phase to a given humidity and left for 25 – 30 minutes at a temperature of 30 – 35 °C for fermentation. After that, the dough pieces of 50 g are placed in baking pans pre-greased with sunflower oil, and left for 20 minutes at a temperature of 30 – 35 °C for proofing. Further, baking pans are placed in a laboratory steam oven TM «Moulinex» and subjected to steam treatment for 25 – 35 minutes. After that, bread is removed from baking pans and left at room temperature until it is completely drained.

Acidity of flour is determined by titrating water-flour suspension and aqueous-alcohol extract from the 0.1 N solution of NaOH in the presence of phenolphthalein (Fedin, 1989). Rheological properties of dough are investigated using the Tolstoy elastoplastometer. Irreversible deformation, relative elasticity, plasticity and resilience are determined according to the standard method (GOST, 1988).

Dough slackness is determined by (Fedin, 1989). The titrated and active acidity of dough is determined according to State standard DSTU 5024:2008 Total nitrogen of flour is determined by the Kjeldahl method (GOST, 1987). Amount of protein is found by multiplying the content of total nitrogen by a conversion factor of 6.25. Gas-forming ability and rate of gas formation are determined in parallel with degree of dough loosening by the method (Kuznetsova, 2010; Zapototska, Pichkur and Lysyj, 2013). Calculation of dry matters loss while fermentation is carried out in terms of glucose by the amount of CO₂ released during fermentation, using the fermentation Gay-Lusak equation for glucose (Drobot, Mykhonic and Hryshenko, 2011).

Loss of carbon dioxide during fermentation is found by integration of area under fermentation curves. Changes in dough volume during fermentation are determined using 500 mL measuring cylinder, which contained 10 g of dough and kept at a temperature of 30 – 35 °C. Volume of dough is fixed every 60 seconds during 60 minutes. Water-retaining ability of dough is determined using a moisture balance (Fedin, 1989).

Statistical analysis

Approximation of obtained experimental data was carried out using the least squares method, as well as MathCAD Prime 3.1 mathematical package and EXCEL 2016 spreadsheet packet, SPSS professional statistics version

17, statistical software Statistica 10.0. Degree of credibility for all experiment is 0.95.

RESULTS AND DISCUSSION

Dough mixing stage has a significant impact on the quality of finished products. During the mixing, structure of dough and subsequent structural and mechanical properties of products are formed. Dough has at the same time elastic-resilience and plastic-viscous properties. The phenomenon of resilience contributes to preservation of a given shape of products during formation, and elasticity allows to increase the productivity of dough kneading. Hydrocolloids addition significantly increased the gelatinization temperature (from 52.0 to 64.2 °C) and water absorption (from 56.22 to 66.50%) of dough (Liu et al., 2018).

To evaluate elastic-resilience and plastic-viscous properties of dough for gluten-free steamed bread, study is conducted on a Tolstoy elastoplastometer. The humidity of the prototype samples is 45%.

Figure 1 shows the loading and unloading curves of gluten-free dough based on rice and corn flour. At the loading part of the curve, three areas can be distinguished – instantaneous resilience deformation, high elastic deformation, and a section of system flow. It can be noted that flour additives affect the resistance of rice flour dough and increase its strength. The effectiveness flaxseed and sunflower flour is not significantly different. The obtained results of corn dough research show similar tendencies. First of all, introduction of FGFRM significantly affects the reduction of irreversible relative deformation by 36 – 68%.

Introduction of flaxseed or sunflower flour contributes to an increase in relative elasticity of dough and to a decrease in resilience (Table 1). This result can be explained by high fat content in flaxseed or sunflower flour.

The results indicate that addition of FGFRM to corn dough in all cases contributes to increasing of its elasticity. This tendency is positive because of significant fragility of corn dough. At the same time, the relative plasticity decreases slightly by 16 – 18% and relative resilience increases (up to 2.3 times when using sorghum flour).

Obtained data correlates well with studies of dough slackness (Figure 2). It was established that for 3 hours of dough relaxation with addition of FGFRM slackness is 11 – 23% less than control samples which agrees with the reduction of irreversible relative deformation.

Thus, improvement of rheological characteristics of gluten-free dough based on rice or corn flour with addition of sorghum, flaxseed, quinoa and sunflower flour is experimentally proved. Therefore, these types of FGFRM can be considered as prospective in terms of structure formation of dough for gluten-free bread. According to research of rheological characteristics of dough, the introduction of FGFRM leads to improvement of dough resilience and elasticity, therefore, the increase of kneading duration, used in traditional technology of steamed bread, has no grounds. Thus, it is recommended to knead dough for 5 – 10 minutes.

The viscoelastic properties of the different doughs strongly influenced the bread volume and the crumb texture. Thus, starch-based breads showed higher specific volume and lower hardness during fermentation (Martínez and Gómez, 2017).

The most important indicator of fermentation process efficiency is gas-forming ability, since this indicator directly affects the specific volume and porosity of final product. Change in dough acidity also has a great practical importance: with its increasing, the processes of protein swelling and peptization are intensified, which is accompanied by a change in their rheological properties (Kuznetsova, 2010; Drobot, Mykhonic and Hryshenko, 2011). Active acidity of dough determines the presence of sour taste in bakery products, as well as intensity of enzymatic processes and influences on activity of microorganisms (in particular, yeast).

An important factor that determines baking properties of flour raw materials is intensity of dough fermentation. Use in gluten-free dough formulation FGFRM in order to regulate its technological properties significantly influences fermentation intensity and activity of amylolytic enzymes of flour (Figure 3 and Figure 4). It should be noted that fermentation of gluten-free dough is more intense than wheat, so the study is conducted for 100 minutes. Results show that addition of FGFRM leads to an increase in the amount of carbon dioxide in gluten-free dough by 10 – 30%. We believe that this dependence is due to the sufficient amount of sugars in FGFRM, especially flaxseed and sorghum, which can provide high quality products during technological process. In comparison with advanced technologies which include ultrasound treatment and increase this index only by 6.7% (Luo et al., 2018), it is a significant result.

On the basis of experimental data on flour gas-forming ability, speed of gas formation in dough was calculated (Figure 4).

In order to establish recommended dough fermentation regimes, study of dough volume changes is conducted. It is found that the addition of FGFRM slightly shifts the peak of fermentation process (Figure 5).

The results of research show that use of FGFRM leads to a slight slowdown in the process of dough fermentation. In most cases, accumulation peak of carbon dioxide is shifted by 10 minutes. In all cases of FGFRM use gas-retaining ability increases, which correlates with an increase in specific volume and porosity of bread.

Thus it is determined that the recommended duration of fermentation of dough based on rice flour with addition of flaxseed is 35 – 40 minutes, with the addition of sunflower 20 – 30 minutes, dough based on corn flour with addition of quinoa or sorghum 25 – 35 minutes.

Intensity of acid accumulation in dough is estimated by changing the active and titrated acidity parameters during fermentation. The results of experimental studies are presented in Figure 6 and Figure 7.

It should be noted that for the use of FGFRM indices of initial and final acidity of dough are different, however, the intensity of acid accumulation process has a similar nature.

Table 1 Rheological characteristics of gluten-free dough with introduction of FGFRM (degree of credibility $\alpha = 0.95$).

Sample	Relative elasticity, Erel, %	Relative plasticity, Prel, %	Relative resilience, Rrel, %
Frc	3.56	84.51	11.93
Frc + Ffs	7.95	80.77	11.28
Frc + Fsn	11.72	83.45	4.83
Fcn	5.36	88.93	5.71
Fcn+ Fqn	21.17	72.77	6.06
Fcn + Fsg	12.73	74.09	13.18

Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – dough from mixture of corn flour and sorghum flour in ratio 90:10.

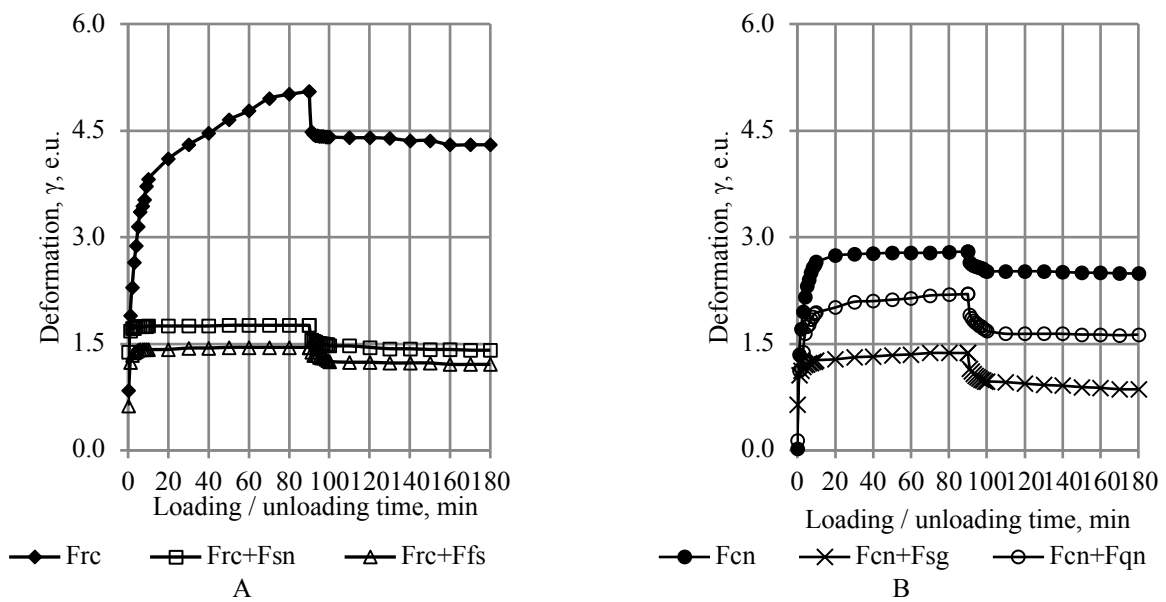


Figure 1 Loading and unloading curves based on rice (A) and corn (B) flour with introduction of FGFRM. Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – dough from mixture of corn flour and sorghum flour in ratio 90:10.

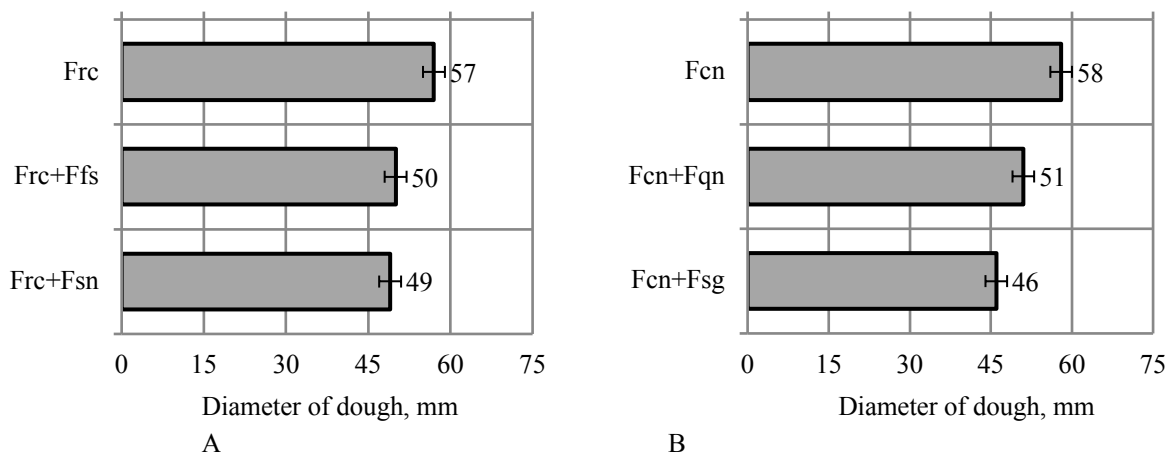


Figure 2 Influence of flour additives on dough slackness. Note: A – on the basis of rice flour, B – on the basis of corn flour.

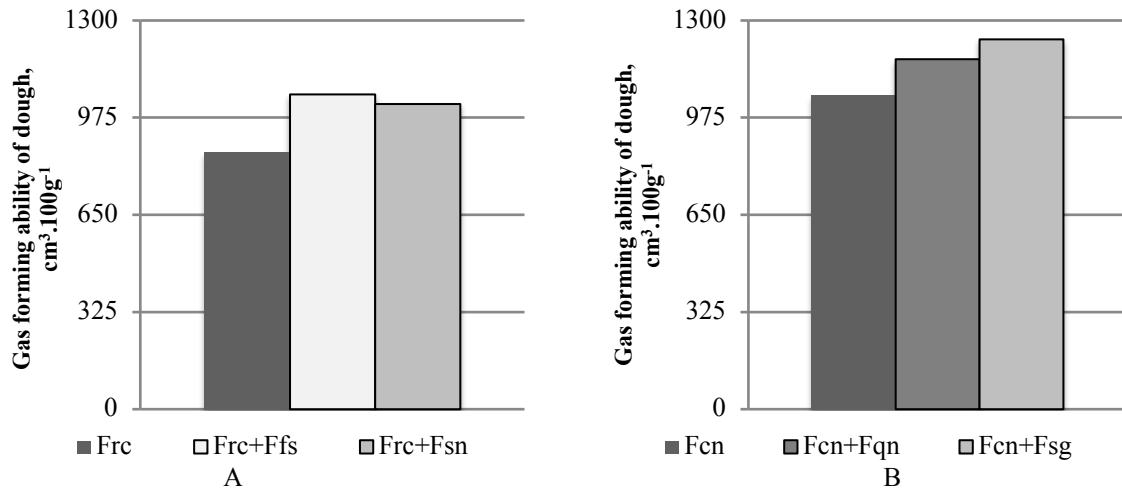


Figure 3 Change of gas forming ability of gluten-free dough on the basis of rice flour (A) and corn flour (B). Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – dough from mixture of corn flour and sorghum flour in ratio 90:10.

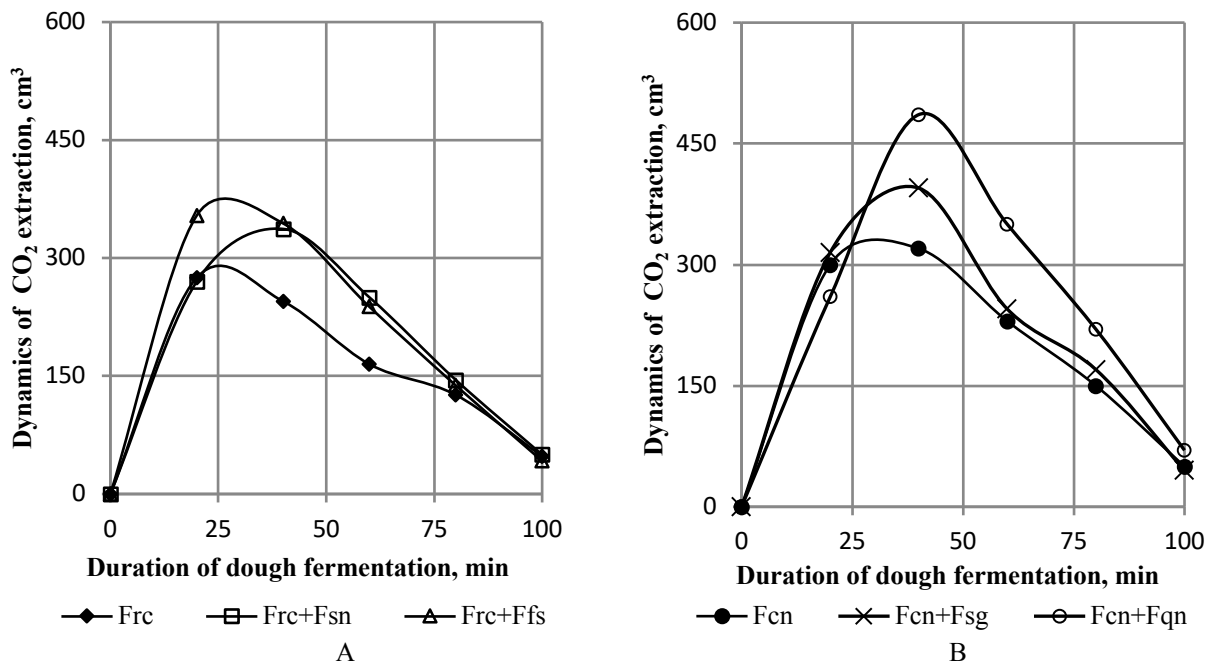


Figure 4 Kinetics of gas formation in gluten-free dough on the basis of rice flour (A) and corn flour (B). Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – dough from mixture of corn flour and sorghum flour in ratio 90:10.

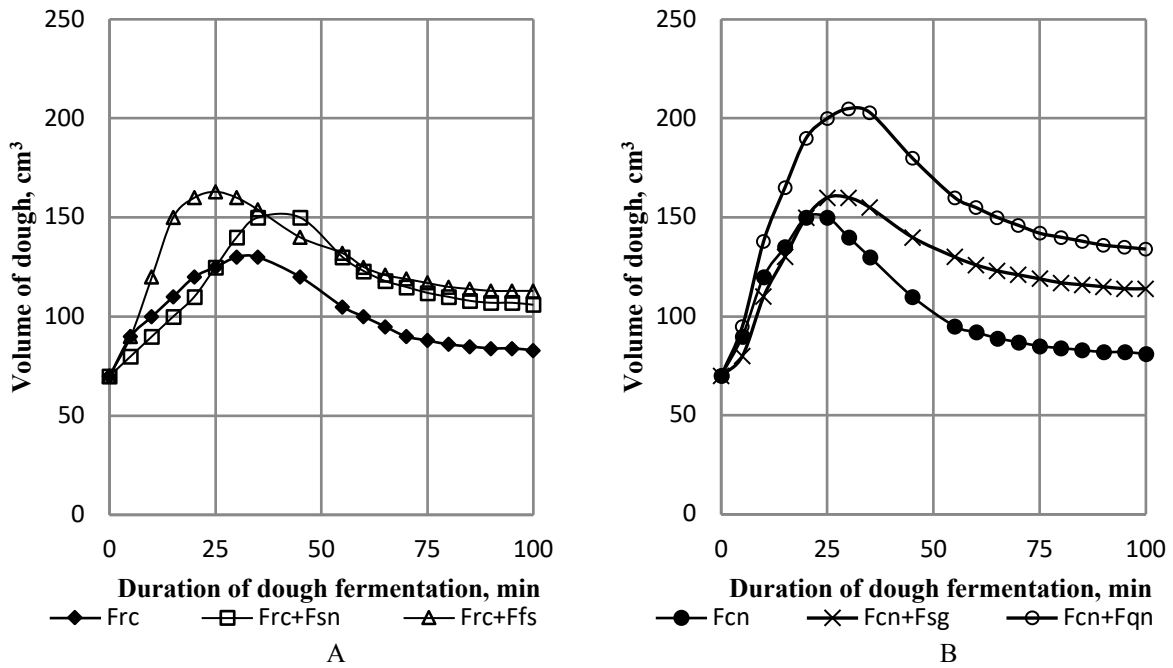


Figure 5 Change of volume of dough based on rice flour (A) and corn flour (B) during fermentation. Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – d ough from mixture of corn flour and sorgum flour in ratio 90:10.

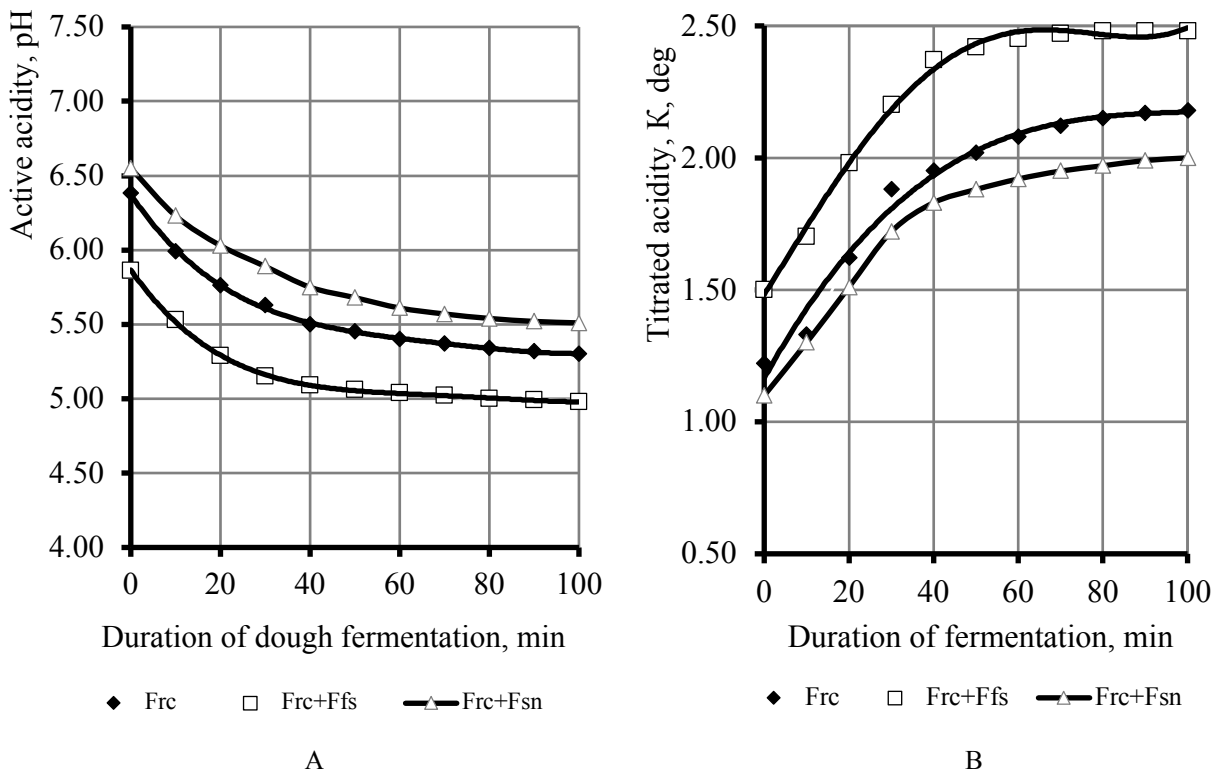


Figure 6 Change of active and titrated acidity of dough based on rice flour during fermentation. Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – dough from mixture of corn flour and sorgum flour in ratio 90:10.

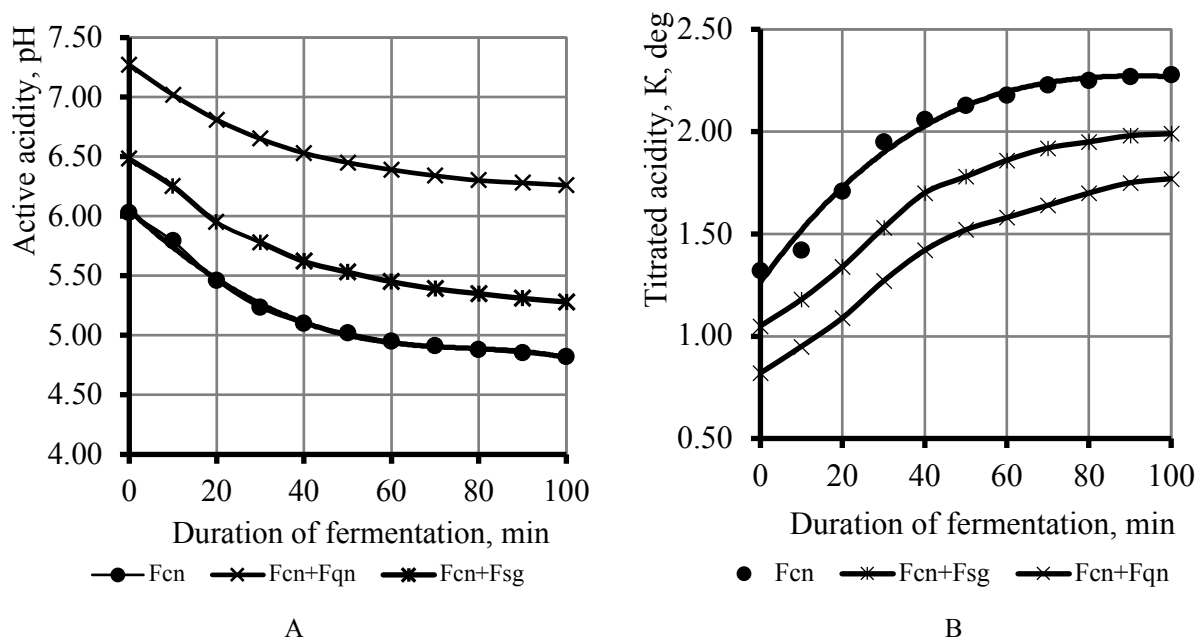


Figure 7 Change of active and titrated acidity of dough based on corn flour during fermentation. Note: FGFRM – flour gluten-free raw materials with enriching action, Frc – dough from rice flour, Frc + Ffs – dough from mixture of rice flour and flaxseed defatted flour in ratio 95:5, Frc + Fsn – dough from mixture of rice flour and sunflower defatted flour in ratio 95:5, Fcn – dough from corn flour, Fcn:Fqn – dough from mixture of corn flour and quinoa flour in ratio 85:15, Fcn:Fsg – dough from mixture of corn flour and sorghum flour in ratio 90:10.

Table 2 Quality of gluten-free steamed bread on the basis on the mixture of rice flour depending on durability of heat treatment (degree of credibility $\alpha = 0.95$).

Duration of stem treatment, min	Yield of bread, %	Quality characteristics of bread			
		Crust characteristics	Crumb characteristics	Aroma	Taste
on the basis of rice and flaxseed flour in the rate 95:5					
20	199.3	sticky, particularly separates from baking pan	sticky, not thoroughly baked		taste of unbaked dough
25	202.9	sticky, completely separates from baking pan	sticky inside, thoroughly baked closer to surface	yeast smell of unbaked dough	taste of not thoroughly baked dough
30	204.2				
35	205.6	moderately sticky	thoroughly baked, non-sticky	specific for rice bread	specific for rice bread
40	207.3				
on the basis of rice and sunflower flour in the rate 95:5					
20	195.4	sticky, particularly separates from baking pan	sticky, viscous, unbaked		taste of unbaked dough
25	198.8			yeast smell of unbaked dough	
30	200.5	insignificantly sticky	sticky, not thoroughly baked		taste of not thoroughly baked dough
35	201.2	non-sticky	thoroughly baked, non-sticky	specific for rice bread	specific for rice bread

Table 3 Quality of gluten-free steamed bread on the basis on the mixture of rice flour depending on durability of heat treatment (degree of credibility $\alpha = 0.95$).

Duration of stem treatment, min	Yield of bread, %	Quality characteristics of bread			
		Crust characteristics	Crumb characteristics	Aroma	Taste
on the basis of corn and sorghum flour in the rate 90:10					
20	203.5	sticky, completely separates from baking pan	sticky, viscous, unbaked	yeast smell of unbaked dough	taste of unbaked dough
25	204.4	insignificantly sticky	sticky, not thoroughly baked		
30	205.2		sticky, thoroughly baked		
35	205.9	non-sticky		specific for corn bread	specific for corn bread
40	206.0		thoroughly baked, non-sticky		
on the basis of corn and quinoa flour in the rate 85:15					
20	203.7	sticky, completely separates from baking pan	sticky, viscous, unbaked	yeast smell of unbaked dough	taste of unbaked dough
25	204.0	insignificantly sticky	sticky, not thoroughly baked		
30	205.8				
35	206.2	non-sticky	thoroughly baked, non-sticky	specific for corn bread	specific for corn bread
40	206.9				

It is noteworthy that flaxseed flour reduces active acidity of dough, and sunflower, on the contrary, increases this index. For 100 minutes of fermentation, the index of titrated acidity varies for a sample made from rice flour from 1.22 to 2.18 °H (a difference is 0.96 degrees) in sample Frc + Ffs – from 1.5 to 2.0 °H (difference is 0.50 degrees) in the sample Frc + Fsn – from 1.1 to 2.0 °N (difference is 0.9 degrees).

Change in active acidity of dough based on rice flour during fermentation is also identical. Thus, for 100 minutes of fermentation, the sample Frc has a pH value of 5.3, sample Frc + Ffs – 4.98, sample Frc + Fsn – 5.51.

Reducing pH value when we add flaxseed flour and higher values of the initial acidity of the sample Frc + Ffs are due to the accumulation of oxidation products of fats contained in this raw material.

Thus, according to the research complex, it can be concluded that dough with addition of FGFRM in the process of fermentation can provide necessary level of microbiological and enzymatic processes for obtaining bakery products with organoleptic properties of high quality.

Although the production of gluten free bread still remains a technological challenge, research continues to find innovative approaches to improve the quality of gluten free bread. Literature shows that an important aim is to imitate the gluten-network by combining several ingredients, from which hydrocolloids play a crucial role. Also crosslinking enzymes have been increasingly investigated. On the other hand, a carbohydrate network formed by arabinoxylans offers an innovative and more natural approach for improving gluten free products (Wang, Guo and Zhu, 2016; Bender and Schönlechner, 2020).

In production of gluten-free steamed bread baking process is replaced by steam treatment to prevent formation of acrylamides and other carcinogens and preserve food and biological value of final product. Steam treatment is more gentle mode, which is significantly different from traditional baking. When the processing time in the steam chamber increases, the quality is almost unchanged, but the cost is increased. Therefore, to assess the quality of steamed bread, it is important to find the value of heat treatment duration, in which film-like crust is formed on surface of products, the starch is gelatinized, proteins are denaturated, crumb loses excessive

adhesiveness and the products acquire good consumer properties.

Taking into account the foregoing, to determine the duration of heat treatment by steam, adhesiveness of surface of gluten-free bread, smell, taste and yield of finished products are determined with addition of FGFRM (Table 2 and Table 3).

Steam treatment of gluten-free steamed breads based on a mixture of rice and flaxseed flour for 20 minutes results in a sticky texture of the crumb and surface. Products can not be completely separated from baking pads. After 25 minutes after the start of heat treatment bread is well separated from baking pads, but there is increased adhesiveness in the middle of crumb. 30 minutes later bread is well baked throughout the volume, but still there is a yeast smell and taste of raw dough. Thus, recommended durability of heat treatment with steam of bread based on rice and flaxseed flour is in a ratio of 95:5, which is 35 minutes.

With an increase of steam treatment duration, the yield of finished products is slightly increased, which can be explained by moisture binding by biopolymers of flour raw materials. A similar trend is observed in the sample based on rice and sunflower flour in the ratio of 95:5. Study of gluten-free steamed breads based on corn and sorghum flour in the ratio of 90:10 and corn and quinoa flour in the ratio of 85:15 shows that good consistency of the crumb and surface can be achieved with steam treatment duration for 30 minutes. In such conditions, the smell and taste of bread corresponds to ready products. Recipes and methodologies are grouped by (main) starch source and list other ingredients, additives and treatments used (Masure, Fierens and Delcour, 2016). Additional ingredients significantly change quality of steamed bread. Thus, implementation of inuline, fresh steamed bread gained the highest score, possessing a lighter color, higher specific volume and softer texture (Kou et al., 2019). Use of bran is also able to rise quality of steamed bread, improving surface smoothness, crumb structure and stress relaxation scores (Ma, Lee and Baik, 2018).

The results confirm that it is possible to reach the full readiness of bread based on rice flour after 35 minutes of steam treatment, and on the basis of corn flour after 30 minutes.

According to the results of experimental studies, it is established that the technological stages of gluten-free steamed bread production do not undergo significant changes. A new kind of equipment is the steamer that is installed to replace the oven. Product is prepared in a single-phase method, adopted in practice of baking bread. The duration of dough mixing is 10 – 15 min, fermentation 20 – 35 min. Steam treatment is carried out under atmospheric pressure.

FGFRM is supplied to the plant bakery by flour tracks. Flour from cistern of a flour track is loaded into silos for storage under pressure through pipes and filter. Additional raw materials (salt, sugar) are dissolved and sent for storage in containers. Preparation of other raw materials for production is carried out in accordance with "Technological instructions for the production of bread and bakery products". Yeasts are diluted with water in containers and sent to a dosing station for liquid components, followed by dough preparation. When

working on the line, gluten-free flour from the silos is dispensed and supplied to scales automatically. Then flour enters the intake filter. The flour is cleaned from impurities on a screen with a magnetic trap. Next, a gluten-free flour mixture is formed. A better usage of cereal by-products as valuable ingredients in foods would aid the economics and the sustainability of cereal chain (Čukelj Mustač et al., 2020). Components of mixture are weighed on automatic scales, mixed in a screw mixer and loaded into silos. To knead dough, gluten-free flour is weighed and sent to a dough machine. Additional raw materials (solutions of salt, sugar, yeast) are sent to dough machine from containers, through the station for liquid components dispensing. Kneaded and fermented dough is sent to dough separator, with help of which portions of the dough of the same mass are received. After this, the manipulator, using a dividing table, stack the dough pieces of a certain mass and form into proofing cabinet. Proofing of dough pieces is carried out during 10 – 15 min at temperature of 30 – 32 °C and relative humidity of 65 – 70%. Dough pieces after proofing are put to the steamer for steam treatment. Products are treated with steam for 30 – 35 min at a temperature of 92 – 97 °C. Finished products get to the circulation table by drain device gutter of finished product, a stacker loads them to a container. Trays with products are loaded to truck. Gluten-free steamed bread can be packed in different ways, for example there is effective technology with use of vacuum degree (Xu et al., 2020).

CONCLUSION

Obtained results show that addition of FGFRM leads to a change in the main stages behavior of gluten-free steamed bread production.

Use of FGFRM leads to a decrease in irreversible relative deformation of dough for 36 – 68% and to increase of its elasticity. At the same time, the relative plasticity decreases by 16 – 18% and the relative resilience increases (up to 2.3 times when using sorghum flour). The recommended duration of dough mixing is 10 – 15 min.

In the presence of FGFRM, the amount of carbon dioxide accumulated in gluten-free dough increases by 10 – 30%.

Recommended duration of fermentation of rice flour dough with the addition of flaxseed is 35 – 40 minutes, with the addition of sunflower 20 – 30 minutes, for dough based on corn flour with the addition of quinoa or sorghum 25 – 35 min.

Use of FGFRM does not affect the intensity of acid accumulation process. It is established that flaxseed flour reduces active acidity of dough, and sunflower, sorghum and quinoa flour, on the contrary, increases this index.

Recommended steam processing time is 35 min for bread based on rice flour, 30 min for based on corn flour.

Technological scheme of production of gluten-free steamed bread is offered. Compared to the traditional one, it is recommended to use a steamer instead of oven.

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