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PHYSICAL AND CHEMICAL PROCESSES DEVELOPING IN THE MASS OF COMPONENTS DURING DOUGH MIXING

E. Bayramov, Candidate of Technical Sciences
Associate Professor
A. Nabiev, Doctor of Biological Sciences, Professor
Department of Food Engineering and Expertise
Azerbaijan Technological University
103, Sh.I. Xatai av., Ganja, AZ2011, Azerbaijan

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Correspondence:

E. Bayramov
E-mail: eldaniz@rambler.ru

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Abstract. Physicochemical processes developing in the mass of components when making dough play a big part in the formation of its homogeneous structure. Moreover, the homogeneity of the dough structure, the degree of its orderliness and, consequently, the quality of the dough and finished products depend on how the working element of the dough mixer acts on the dough during its mixing and structure formation. During the formation of the dough structure, physicochemical processes of a very diverse nature develop. These processes, under the influence of the kneading element, clearly manifest themselves both when the dough structure is destroyed and when it is restored. The degree of destruction and restoration of the dough structure, its orderliness also depend on the properties of the components of the dough. During dough-mixing, in the conditions of mechanical action of the working element, flour and water play a specific role. Besides, important components are salt, yeast, sugar, and fats, if the latter two are provided for by the recipe. It should be noted that the optimum course of physicochemical processes in dough during its mixing, and, further on, of bread production processes depends on the ratio of flour and water. The scientific literature does not adequately describe the essence of the physicochemical processes developing in the mass of components during mixing and dough formation, that is why it is difficult to form theoretical aspects of this issue. In this article, physicochemical processes developing in the mass of components during dough-mixing are examined and detailed. We have shown that these processes include, in particular, swelling, dissolving, passing of flour polymers into a solution, their destruction, heat generation in the dough mass, etc. By regulating these processes, you can get dough with predetermined physical properties and, accordingly, bread of the desired quality. Though the article is but an overview, it is of practical interest. The above explanations expand knowledge about the physicochemical processes developing in the mass of components during mixing dough, allow improving or creating innovative dough-making technologies and design the working elements of dough-mixers.

Keywords: components, physicochemical processes, swelling, dissolving, working element, dough-mixing, dough, bread, dough-mixing machine.

Introduction. Formulation of the problem

Improving the dough-making technology is a social request, as people's health depends on the daily consumption of bread. That is why, conducting research to deepen theoretical knowledge of the dough-making technology, improving working elements, and solving practical problems of introducing a new design of a dough-mixing machine into production is of great importance. Dough preparation is one of the initial, but most important stages of the technological complex, since it is at these stages that the structure of the future product is formed. The achieved uniformity of the dough structure, the degree of its orderliness, and, consequently, the quality of the dough and of the finished products depend on the quality of the system obtained during the formation of the dough structure. The dough preparation stage includes such operations as dosing the recipe components, mixing the dough, its fermentation, punching (if necessary), and passing the dough on for further processing. Of all these operations, dough mixing is the most important process in the technology of baking. İn its essence, it is both a chemical and a technological process. Dough is mixed for a certain time in the working chamber of the dough-mixer. The operation consists in mixing the recipe components thoroughly, and in energy impacts, in particular, in mechanical treatment of the dough [1].

Energy impacts on the dough when it is being mixed in the working chamber of the dough-mixing machine causes physicochemical processes of a very diverse nature [2,3]. Dough formation is a result of physicochemical processes that develop simultaneously and depend on the duration, the intensity of mixing, the nature of the impact, the trajectory of the movement, the configuration of the working element of the dough-mixer, the temperature, and the quality and quantity of the dough recipe components [4]. Therefore, to understand clearly the mechanism of dough formation, it is necessary to consider the physicochemical processes developing during dough mixing. Analysis of the previous studies of dough mixing shows that researchers do not pay enough attention to the physicochemical processes that develop in the mass of components during dough mixing. The reason for the researchers' little attention is the lack of theoretical aspects that could help solve the problem.

We are developing a systematic approach to the analysis of the dough-mixing technology [5,6]. With this approach, regulating the physical and chemical processes developing in the mass of components in dough allows obtaining dough and bread with predetermined properties. This is an innovative and highly topical direction in baking.

In the scientific literature, it is noted that when mixing dough for a long time, under the influence of the working elements of the dough mixer, protein aggregates stretch out in the form of thin films and filaments. Hydrogen and hydrophobic bonds and salt bridges break, and large gluten aggregates depolymerize, as the –S–S– bonds between peptide chains break. This indicates that a spatial structural network forms during dough mixing as a result of disaggregation of protein macromolecules, of breaking all chemical bonds in them [7]. However, one cannot agree with this, since contact of flour with water and formation of a dough structure can cause breaks in the gluten threads. But this cannot be the central point in forming a three-dimensional protein-gluten network in the dough. We believe that it is necessary to assess in a different way the mechanical effect of the working elements of the dough mixer on the swollen proteins during dough mixing. I. e. dough mixing should be viewed not as a breaking factor for gluten proteins, but as a way to prepare them for sticking. Therefore, in order to find out the mechanism of formation of a three-dimensional sponge-and-netlike continuous structure of the dough, it is necessary to study the physicochemical processes developing in the mass of components in the dough during its mixing.

The purpose of the work is forming the theoretical aspects of the physicochemical processes developing in the mass of components during mixing and formation of dough in order to improve the technology and the working elements of dough mixers.

Research objectives:

1. Analysis and summarization of the previous studies in the field of dough-making.
2. Studying the nature of the physical and chemical processes developing in the mass of components in dough during its mixing and structure formation.
3. Establishing the role and effect of the components of dough during its mixing.

Analysis of recent research and publications

Analysis and summarization of the previous studies in the field of dough-making. The baking industry is facing a specific task: manufacturing high quality products and increasing their competitiveness using modern high-performance technologies.

The interest to the process of dough-making is reflected in numerous studies by such authors as L. Auerman, E. Verboloz, A. Lisovenko, I. Litovchenko, L. Puchkova, W. Bushuk, A. H. Bloksma and others.

L. Auerman, E. Verboloz [8-10] have found that when dough is mixed, its temperature rises, and part of mechanical energy transforms into heat. When working on low-speed dough mixers, the dough temperature rises slightly. A large amount of heat is released when working on high-speed dough mixers, which can lead to a deterioration in the physical properties of the dough. To prevent significant heating of the dough during its mixing, artificial cooling of the dough is used, which requires providing the devices with water jackets.

A. Lisovenko, I. Litovchenko [11,12] studied the intensification of the dough mixing process and improving batch-type dough mixers. They have found that with intensive dough mixing, it is necessary to determine the optimum energy consumption, since the dough becomes sticky and slack with excessive mechanical tretment.

W. Bushuk et al. [13] studied the changes in the rheological properties of wheat dough depending on the rate and intensity of the chemical processes that occur during dough making.

A. H. Bloksma [14] investigated the changes in the rheological properties of dough during the mechanical action of the working element in the process of making bread.

In their scientific paper, A. Vakar and V. Kolpakova note that the interaction of gliadin and glutenin and their individual differences form a unique gluten structure [15-17]. According to modern concepts, high molecular weight glutenin subunits (HMWGS) are of great importance for gluten elasticity and dough strength [18,19]. Besides the properties and interactions of the repeating zones in HMWGS, for the elasticity of gluten, the number and intermolecular distribution of –S–S– bonds is significant, too. Analysis of the sequences of disulphide-related peptides has shown a lot of interchain and intrachain –S–S – bonds in HMWGS [20].

However, the role of the disulphide structure of glutenin is not fully clear, and does not allow explaining the rheological properties of gluten only by the distribution of –S–S– bonds. There is a widespread opinion that disulphide-linked glutenin chains are responsible for the "elastic network" of gluten. However, in the studies by P. S. Belton, I. J. Colquhoun, J. M. Field, S. M. Gilbert, N. Wellner, and others, spectral analysis data indicate that non-covalent bonds, in particular hydrogen bonds, are also very important for the structure of the glutenin subunits and the entire polymer complex of proteins [21,22].

Studies show that protein macromolecules of strong and weak gluten form spatial structures with different packing density. Strong gluten is characterized by a denser packing of proteins than weak gluten, which is due to a large number of bonds (covalent, disulphide) that help stabilize its spatial structure. In weak gluten, supposedly the tertiary and quaternary structures of protein are somewhat damaged, and therefore its gluten network is less strong [8,23-25]. In strong gluten, there are more disulphide and hydrogen bonds than in weak. Wheat flour strength determining the strength of the gluten network when it is stretched determines its ability to form dough with certain structural and rheological properties. Changes in the rheological properties of semi-finished products at various stages of the technological process, the gas-holding and shape-holding capacity of dough pieces, and the porosity structure of the finished products depend on this characteristic.

So, the above information expands our knowledge, but does not allow fully predicting the behavior of gluten when the rheological properties of dough are formed. Further research is needed of how this property changes not only under the influence of various technological factors, but also due to physicochemical processes developing during dough mixing [26]. This will allow regulating the properties of the dough to ensure the proper quality of various types of bakery products.

The mechanism of dough structure formation during dough mixing. Dough is a complex colloidal heterogeneous system. In it, the solid, liquid, and gaseous phases are distinguished. The solid phase is moistened starch kernels, swollen water-insoluble gluten proteins, cellulose, and hemicelluloses. The liquid phase is a multicomponent solution consisting of water that is not bound to starch and proteins (about 1/3 of all the water used for dough mixing), water-soluble flour substances (sugars, water-soluble proteins, dextrins, mineral salts), water-soluble dough components prescribed in the recipe, peptized proteins, and pentosans. The gaseous phase is the air that enters the flour during its sifting and pneumatic conveying, as well as the air occluded by the kneading blades of the working element of the dough mixing machine, and the small quantities of carbon dioxide released by the yeast [27]. No doubt, the mass ratio of these phases determines the structural and mechanical properties of the dough significantly. An increase in the free liquid and gaseous phases weakens the dough, making it more liquid and more flowable, while an increase in the solid phase has the opposite effect.

The amount of gas in the dough increases during mixing. With a normal duration of dough mixing, the gas phase can make up to 10% of the dough volume, and with an increase in the duration of mixing, the content of the gas phase can reach 20% of the total volume of the dough. Part of the air is brought, in very small quantities, with water prior to the dough mixing. This gaseous phase formed in the dough during its mixing plays a significant role in the formation of the porosity of the crumb. When mixing, part of the air bubbles captured by the working elements of the dough mixer can, in the form of gas emulsion, be present in the liquid phase of the dough, and part, in the form of gas bubbles, can be included in the swollen proteins of the dough.

Dough is made mainly from flour, yeast, salt, and water, with the addition of other components, for example, sugar and fat, if the latter are provided for in the recipe. The structure of dough is equivalent to the structure of bread crumb, is its precursor at the stage when it has not been fixed by heat treatment in the oven.

Dough mixing is an operation necessary to turn the recipe components into a homogeneous mass with certain structural and mechanical properties that ensure the optimum course of the subsequent stages of bread production.

Depending on how the working element of the dough mixer acts on the dough during its mixing and structure formation, the developing physicochemical processes can tell in different ways on the dough quality. There are processes that contribute to the adsorptional and especially osmotic binding of water and swelling of flour polymers and, by this, increase the amount and volume of the solid phase. These processes improve the rheological properties of the dough, make it thicker in its texture, elastic and dry to the touch. And the processes that lead to disaggregation, inorganic swelling, peptization and dissolution of the dough components, thus increasing the liquid phase, worsen the rheological properties of the dough, make it more fluid in consistency, more viscous, sticky, and smearing [8]. Physicochemical processes developing in the mass of components include, in particular, swelling, dissolution, passing of flour polymers into solution, their destruction, heat generation in the mass of dough, etc.

In the process of forming the structure of the dough from the main components (flour, salt, yeast, and water), under the conditions of mechanical impacts during mixing, flour and water play a specific role. An important role is also played by auxiliary components (mainly sugar and fats), if they are provided for in the recipe. Since the predominant components in the dough composition are flour and water, their ratio determines the properties and quality of the dough, and the optimum course of further bread production processes. It should be noted that water is a binding component that unites flour particles in the structure of the dough. Besides, water is the solvent and the main plasticizer of the dough structure. The intensity of physicochemical processes depends on its mass fraction, state, activity, and chemical composition [27].

When making dough, the working element of a dough mixing machine stirs the flour particles, water, yeast suspension, saline solution, and other liquid components of the formulation, thus making them interact. First, the flour constituents (proteins, starch, mucus, sugar, etc.) begin to interact with water. The dissoluble components of the flour (sugar, mineral salts, water, and salt-soluble proteins) pass into the solution to form, together with the free water, the liquid phase of the dough.

The leading role in the structure formation of wheat flour dough belongs to the starch and, especially, the gluten proteins of flour. When flour contains about 10–12% of protein substances, the starch content reaches 60–65% or more. During dough mixing, they bind water and swell, and, as a result, there is a change in the size of flour particles and in the ratio of the volume of the recipe components.

The role of flour proteins in dough mixing. Despite their low content in flour, proteins play a decisive role in the formation of dough of normal consistency, and determine the rheological properties (elasticity, plasticity, and viscosity) of the dough. When making dough, a significant part of flour proteins does not dissolve in water, but swells in it well. Swelling, as the first stage of the dissolution process, is characteristic of many high molecular weight compounds, and does not always end in dissolution. For example, the albumin and globulin fractions of protein dissolve after swelling and pass into solution, while the gliadin and glutenin fractions swell but to a limited extent. The percentage of albumins is 5.2% of the total protein content; globulins 12.6%; prolamins 35.6%; glutelins 28.2%; insoluble protein (scleroproteins) 8.7%.

Albumin and globulin fractions of protein play a role in the structure and formation of dough during its mixing. As they are very hydrophilic, their colloidal solutions are of high elasticity and surface activity, i. e. have the ability of plasticization, foaming, and stabilizing the compounds of the dough structure. Water soluble products of protein hydrolysis (peptides and amino acids) plasticize the structure of proteins and flour dough, too [28].

In the formation of the gluten network, an important role is played by the gliadin and glutenin fractions of the protein [29]. They have unique physical properties and influence the formation time and the structure of gluten and dough [30]. Hydrated gliadin is a mass of liquid consistency, highly viscous, sticky, and non-elastic [31], i. e. it exhibits viscous behavior [32]. And hydrated glutenin is a heterogeneous mixture of polymers, consisting of a number of different subunits of high and low molecular weight glutenin, linked by disulphide bonds [32], a rubber-like mass, short-stretched, with high deformation resistance, elastic, and relatively "rigid" [8,33,34]. When in contact with water, these protein fractions swell and, acted upon by the working elements of a dough mixing machine, stretch into thin films, envelop the moistened starch kernels of flour, and stick together with the adjacent protein films that envelop other starch kernels. Thus, due to the adhesion forces, during dough mixing, a spatial elastic and plastic network is formed, which significantly tells on the mechanical properties (shear modulus, viscosity, and relaxation period) of the dough. This effect is explained by the fact that proteins have high hydrophilic properties in comparison with those of starch, the main active filler in the structural network of proteins.

It has been found that adding gliadins to the flour significantly reduces the gluten index, while adding glutenins increases it. When gliadin is added to flour (10 g/100 g), the height of the farinogram, i. e. the mixing tension decreases, indicating slackening of the dough. Adding gliadins to the flour leads to the shortest duration of dough mixing (3.5 to 2.02 min) to obtain dough with the optimum properties. This may be due to a change in the gliadin-glutenin balance in the dough and the interaction of gluten subfractions with flour components. However, adding glutenin to the flour (10 g/100 g) increases the duration of dough mixing. Besides, glutenin increases the stability of the dough up to 30 minutes, while adding gliadin significantly reduces its stability. Dough with glutenins added requires longer mixing and remains stable for a longer time than dough with gliadins. Glutenins are most effective when increasing the duration of mixing from 3.50 to 4.67 min [35].

Thus, the rheological properties of gluten of wheat flour are largely determined by the ratio of gliadins and glutenins. An excessive increase in this ratio causes a decrease in gluten. However, in the formation of the technological properties of flour, the glutenin fraction prevails over the gliadin fraction. That is why, to understand the structure of gluten, it is important to know the structure and methods of interaction of gluten proteins. Each protein fraction during the formation of gluten is responsible for a certain function, thus determining a certain property of gluten or dough.

The process of hydration of polymers, accompanied by the release of heat, can lead to their destruction.

Gluten proteins swell especially well at a temperature of about 30°C, absorbing water

2–2.5 times as much as their own mass. Of this amount of water, less than a quarter (about 25%) is bound in the adsorptional and the capillary way. The rest of the water (75%) is absorbed osmotically, which leads to swelling and a sharp increase in the volume of protein molecules in the dough. Crude gluten contains 30–35% of solids and 65–70% of moisture. Depending on the protein content in the flour, the amount of crude gluten ranges from 15 to 50% of the mass of the flour. Dry gluten contains 75–90% of proteins, 10–25% of starch, and other flour components absorbed by proteins during swelling: lipids, sugars, minerals, vitamins, etc. [27].

Swelling of structurally weak proteins can pass from the limited swelling stage to unlimited swelling, when protein peptization and an increase in the liquid phase of the dough take place.

Physico-chemical processes that occur during mixing and formation of dough do not end when the mixing is finished, but continue to develop intensively during fermentation of the dough. By the end of the dough mixing, only adsorptional binding of moisture by proteins, starch, and dietary fibre of flour practically stops.

With limited swelling of the proteins, the liquid phase in the dough reduces, and thus its rheological properties improve. On the contrary, with unlimited swelling and protein peptization, the transition of proteins to the liquid phase intensifies, and the rheological properties of dough worsen. Depending on the strength of wheat flour, these processes in the dough occur with different intensity. If the flour is strong, the process of limited swelling of the proteins in the dough is slower and reaches its optimum only by the end of the fermentation. That is why, to accelerate these processes and regulate the rheological properties of dough made from strong flour, it is necessary to increase the mechanical action of the working elements on the treated mass during its mixing in dough mixers. In the dough made from strong wheat flour, unlimited swelling and protein peptization occur to a lesser extent.

In the dough from weak flour, limited swelling proceeds relatively quickly. Due to the low structural strength of the protein, weakened by intensive proteolysis, unlimited swelling of proteins begins, passing then into the peptization process and increasing the amount of the liquid phase of the dough. This leads to deterioration in the rheological properties of the dough. Therefore, it is necessary to reduce the duration and intensity of the action of the working elements on the dough made from weak flour when mixing it in dough mixing machines.

The surface activity and high reactivity are determined by the presence of polar and nonpolar groups of atoms in the protein molecules. In the dough structure, they interact with carbohydrates, fats, lipoids, and water. Strong covalent bonds of the primary structure and the complex conformation make proteins highly resilient and strong. The content of non-polar atomic groups with weak dispersion bondsis responsible for high elasticity of proteins. The hydrophilic properties of proteins are explained not only by the presence of numerous ionic and polar atomic groups, but also by the corresponding mobility, i. e. the ability to capture mechanically and to bind firmly a significant amount of free water.

An increase in temperature (up to 40°C and higher) leads to the breaking of weak hydrogen bonds. As a result, the globular form of protein molecules gradually changes to the fibrillar one, with the formation of additional intermolecular bonds [28].

Due to the change in the shape and the formation of additional intermolecular bonds, the mechanical properties of hydrated and denatured proteins change.

The denaturation of hydrated proteins can be either reversible or irreversible and depends on the intensity of the physicochemical effects on the proteins. During mixing in dough mixing machines, as a result of mechanical impacts, protein molecules are deformed and oriented in the directional plane of these impacts. They form fibres and films in the bulk of the dough. In this process, protein molecules are stretch and are denatured. The dough aquires a creamy consistency. If the dough mixing is long enough for hydration of the flour protein and good gluten formation, it is best to determine the moment of mixing completion when the preset dough temperature is reached.

When the dough mixing is intense, the blade of the working element, cutting through the dough or pushing it on the walls of the working chamber, increases the temperature of the dough (mainly due to friction). Higher temperatures can lead to irreversible protein denaturation. So, in high-speed dough mixers, the process is accompanied by a rise in the dough temperature by 5–7°C, and in superhigh-speed mixers, by 10–20°C. Given that the swelling of proteins in the baking dough reaches its peak in the temperature range 20–30°C, a further temperature increase leads to a decrease in the swelling of gluten. The reduced swelling of gluten after an increase in the temperature above 30°C is explained by its denaturation. The gluten swelling is not explicitly osmotic and is mainly due to solvation of the hydrophilic groups of protein micelles. Weak gluten swells quickly, but the end effect of its swelling is lower. Strong gluten swells more slowly, but with a higher end effect.

The role of flour starch in making dough. When mixing dough and forming its structure, flour starch also plays a leading role. Like proteins, starch swells in two stages. At the first stage, water molecules are adsorbed on the surface of the flour particles due to the activity of hydrophilic groups of colloids. At the second stage, the swelling is osmotic in nature. The swelling and the water absorption capacity of starch depend on the dispersion of starch granules of the flour. Whole starch granules bind water mainly adsorptionally, never more than 44% of it on a dry matter basis, so their volume in the dough increases but very slightly. When grinding wheat into flour, about 15–20% of starch granules are damaged. Damaged starch granules can absorb up to 200% of water on a dry matter basis. Due to the significant quantitative predominance of starch in flour (its content usually reaches 70%), moisture is bound by proteins and flour starch almost equally. It has been established that if protein in flour is reduced, and, as a result, it has reduced water absorption capacity, it is possible, by subjecting it to additional grinding, to increase the number of mechanically damaged starch granules, and thus increase the water absorption capacity of the flour [36]. The structural and mechanical properties of the dough are also influenced by the ratio of the amylose fraction and amylopectin of starch, the content of which ranges 20–25% and 75–80%, respectively. When interacting with water, amylose absorbs moisture, dissolves, and passes into solution, but amylopectin only swells.

A sharp increase in the rate and in the effect of swelling of starch occurs in the range 50–60°C. It is obvious that the slight swelling that occurs at temperatures up to 50°C is due to surface solvation. Amylopectin plays a major role in binding water by starch. The action of amylose begins only when the temperature rises, when it, as a more readily soluble fraction of a starch granule, creates a large osmotic pressure inside this granule.

The role of cellulose and hemicellulose of flour in dough mixing. Active fillers of the dough structure, i. e. the carbohydrate network linking elements are such carbohydrates as cellulose and hemicelluloses. Their activity is manifested by certain interactions and reactions with water (or a solvent), proteins, fats, and grain lipoids. Cellulose and hemicelluloses bind a significant part of water due to their capillary structure. If there is not enough water in the dough, then its absorption by cellulose will prevent the swelling of proteins and hinder the formation of gluten, which affects the properties of the dough. That is why, dough from low-grade flour is mixed with a higher moisture content (46–49%) than dough from first-grade and high-grade flour (43–44%).

The molecular weight of cellulose is much higher than that of starch, its molecule has a slightly curved, flat shape. The significant molecular weight, and the slightly curved, flat shape of cellulose molecules allows their “crosslinking” into bundles and layers by means of numerous transverse hydrogen and other bonds, making the cellulose structure stronger. The presence of these bonds prevents cellulose from being elastic and flowable, and makes it rigid and brittle in the dry state. Cellulose is insoluble in water. It has a rigid capillary-porous structure that allows it to swell well in water. Swollen cellulose is no longer brittle and acquires plasticity.

Polymers of hemicelluloses (pentosans and hexosanes), when reacting with water, produce colloidal solutions with the viscosity several times higher than that of starch-flour paste and water-soluble proteins.

A lot of cellulose and hemicelluloses are contained in the shells and the aleurone layer of grain. They have a high water absorption capacity, and are thickeners of the dough structure, especially if the dough is made from wholegrain flour. To form a dough structure from this flour, with the necessary elasticity, viscosity, and plasticity that ensure a proper yield and shape of bread products, the dough should contain an increased amount of moisture. It is known that the higher the flour yield, the higher the moisture content of the crumb is, and the lower its volume and porosity. In the processes of preparing dough and bread products, cellulose and hemicelluloses are adsorbed on the surface of starch granules and globular proteins of grain, reduce their swelling in water, their aggregating ability, and the rate of hydrolysis by enzymes [28].

The role of pentosan flour in dough making. When mixing dough, an essential role is played by substances belonging to the group of soluble and water-insoluble pentosans. Solutions of water-soluble pentosans have a high viscosity, many times higher than that of protein solutions of the same concentration. The presence of water-soluble pentosans, consisting mainly of pentoses, but also containing a certain amount of hexoses, greatly increases the water absorption capacity of flour during mixing. When mixing dough, water-soluble pentosans (mucus) of flour are almost completely peptized and pass into solution, absorbing up to 1,500% of water on a dry matter basis. They play a large role in the formation of rye dough, as they can swell significantly and form viscous solutions. Water-insoluble pentosans are highly hydrophilic, absorbing water when swelling in an amount 10 times as large as their mass. Water-soluble pentosans significantly increase the duration of dough mixing, and insoluble ones increase the duration of mixing but slightly.

Our studies show that the distribution of water between granules (whole and damaged) of starch, gluten, and pentosans is not the same. When adding water in an amount of 96 g per 100 g of the dry matter of flour, whole and damaged starch granules, gluten, and pentosans absorb water in an amount of, respectively, 25.28, 18.4, 29.82, and 22.5 g per 100 g of flour. These values show that, to achieve the optimum rheological properties of the dough, it is very important how the water is distributed among the flour polymers in the dough during mixing [36].

The role of the recipe components in dough mixing. Active fillers of the dough structure, i. e. linking elements of the gluten network are also sugar. The main physicochemical properties of sugars that effect on the structure and mechanical properties of the dough are their ability to dissolve in water. Sugar solutions plasticize the structure of the dough: reduce its elasticity, viscosity. To obtain bakery products of normal shape and structure, when sugar is added to the dough, the amount of water added during mixing is reduced.

When mixing dough, along with the physicomechanical and colloidal processes, biochemical processes also take place, caused by the action of the enzymes of flour and yeast. The main biochemical processes are the hydrolytic decomposition of proteins under the action of proteolytic enzymes (proteolysis) and decomposition of starch under the influence of amylolytic enzymes (amylolysis). As a result of these processes, the number of substances capable of passing into the liquid phase of the dough increases, which leads to a change in its rheological properties.

Sugar and fats added during mixing reduce the swelling of colloids (proteins and starch) of flour and thereby, allow controlling its degree. They also have a significant effect on the structure of the dough and the quality of finished products.

A decrease in the swelling of flour colloids when sugar is added to the dough is explained by the fact that in an aqueous solution, sucrose molecules attract water molecules and are covered with hydration shells. At the same time, their intermolecular volume increases, the diffusion rate decreases during the osmotic swelling of flour colloids. The higher the sugar concentration in the liquid phase of the dough, the less of free water is involved in the swelling of the colloids of the flour.

The adsorption capacity of sugars affects the water absorption capacity and the duration of dough making. With the addition of 1% of sugar, the water absorption capacity of flour is reduced by 0.6%. Sugar added to the dough during mixing, increases the osmotic pressure in the liquid phase of the dough, which also reduces the swelling of the flour colloids. Sugar increases the peptization of gluten. So, by changing the ratio of sugar and water in the formulation of the product, it is possible to regulate the rheological properties of the dough.

The mechanism of interaction of flour lipids and fats added to the dough largely depends on the chemical composition and properties of the fat and flour used. An important role is played by triglycerides of fatty acids contained in the fat: saturated (mainly palmitic acid, depending on the type and grade of flour: for wheat from 0.3 to 0.28 g/100 g, for rye from 0.14 to 0.2 g/100 g) and unsaturated (mainly linoleic acid: for wheat flour from 0.48 to 0.89 g/100 g, for rye flour from 0.59 to 0.83 g/100 g). The more triglycerides of unsaturated fatty acids the fat contains, the more it is sorbed by proteins. Fats, depending on their composition and properties, change the structure of protein particles either by direct interaction with different chemical groups that are part of the macromolecules of protein or by effects on the structure indirectly, while being adsorbed on the surface of protein molecules. When making wheat flour, fats change the properties of starch due to the formation of complexes with the amylose fraction. Being adsorbed on the surface of protein micelles and starch granules, fat prevents the swelling of these colloids of flour and increases the content of the liquid phase of the dough. İt results in weakening of the connection among the components of the solid phase of the dough, which makes it more plastic. The thinner the fat films and the more of them are in the dough, the more porous the structure of finished products is. When mixing dough, the content of bound lipids increases. The degree of binding depends on the method of mixing, on the effort spent on it, and the environment in which dough is mixed.

The decrease in the swelling of flour colloids when fat is added to the dough is explained by the fact that fats adsorptively bind with starch and proteins, and thus block possible sites of adhesion of colloidal particles, weaken the mutual connection between them, and thereby prevent moisture from penetrating. This results in the reduced elasticity and the increased plasticity of the dough. Thus, by changing the fat content in the product formulation, it is possible to control the swelling of flour colloids, the structure and rheological properties of the dough.

Table salt, in the dosage traditional in bakery (up to 2.5%), increases the water absorption capacity of flour and the hydration of gluten, which facilitates its formation in the dough and reduces the content of free water in it. It has been found that gluten washed from dough together with salt is weaker than that from unsalted dough. And the amount of gluten washed from salted dough immediately after mixing is by 2–4% higher than that in the dough prepared without salt, which is accompanied by an increase in the hydration ability of gluten. The hydrating effect of the salt is especially pronounced when old flour is used or when stale cereal grain germs are added, since in this case, the dehydrating effect of fat decomposition products is neutralized. Under the influence of salt, the structure of the gluten protein is transformed. This is accompanied by a change in its composition and, therefore, in the physical properties of the dough. An increase in the dosage of salt during mixing causes an increase in the duration of dough formation, a slowdown in achieving its maximum elasticity, weakening of its consistency, and a decrease in the dough dilution during mixing. Salt improves the rheological properties of the dough when dough is made from baking wheat flour with weak and medium strength gluten.

Conclusion

Thus, the above said allows us to conclude that it is necessary to study thoroughly the physico-chemical processes developing in the mass of components during dough mixing. These processes include, in particular, swelling, dissolution, passing of flour polymers into solution, their destruction, heat generation in the dough mass, etc. Knowing the behavior of each component during dough making allows purposefully controlling these processes. By regulating them during dough mixing by introducing various components into the recipe and changing their properties and condition, you can get dough and, accordingly, bread with predetermined physical properties. So, to improve or create an innovative dough mixing technology, and to design the working elements of dough mixing machines, it is necessary to clarify the role and influence of individual major polymers of grain and flour in their interaction with the recipe components of bread during dough mixing.

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