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EFFECT OF FLOUR MADE FROM WAXY WHEAT ON THE STRUCTURAL–MECHANICAL PROPERTIES OF DOUGH FOR HARDTACKS WITHOUT SUGAR

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Проведено аналіз проблем, що виникають при виробництві борошняних виробів без цукру або зі зниженим його вмістом. Досліджено технологічні властивості борошна з нових видів пшениці – ваксі сорту Софійка, обумовлені станом його білково-протеїназного комплексу. При оцінці сили даного борошна за структурно-механічними властивостями утворюваного з нього тіста встановлено, що воно характеризується як більш слабке порівняно з хлібопекарським борошном. Обґрунтовано переваги використання більш слабкого безамілозного борошна для виробництва виробів із дріжджового тіста, в тому числі галет, при заміні цукру на порошок топінамбура. Менший прояв пружних властивостей утворюваного із борошна ваксі-пшениці тіста поряд з характерною для нього високою газоутворювальною здатністю дозволить частково нівелювати труднощі, що виникають при виробництві виробів на дріжджах. В рамках проведених досліджень визначено вплив борошна з пшениці ваксі і порошку топінамбура в залежності від стадії його внесення на зміну структурно-механічних і поверхневих властивостей тіста для галет без цукру в ході його технологічної обробки – вилежування-вистоювання і прокатки. Під час вилежування спостерігається зменшення граничної напруги зсуву та підвищення здатності тіста до прилипання. Прокатка супроводжується зворотнім впливом – збільшенням його міцності та зниженням адгезійної напруги. Показана доцільність внесення порошку топінамбура в рівних долях на стадіях замісу опари і тіста при виробництві галет – дані зразки характеризувались більш розпушеною структурою в порівнянні зі зразком, для приготування якого порошок топінамбура вносили при замісі опари. Встановлено, що сумісне використання борошна з пшениці ваксі з порошком топінамбура при приготуванні напівфабрикатів для галет без цукру сприяє отриманню тіста з меншими міцнісними, адгезійними властивостями і пружністю та добре розпушеною структурою в порівнянні з контролем

Ключові слова: борошно з пшениці ваксі, структурно-механічні властивості тіста, галети без цукру

1. Introduction

The current trend of forming a healthy diet necessitates creating foods without sugar (sucrose) or with its reduced content. This situation is predetermined by several reasons. First of all, by the negative impact of excessive consumption of sugar (sucrose) and other fast-absorbable carbohydrates on the human body, as it leads to the risk of cardiovascular diseases, obesity, diabetes, etc., which is confirmed by a wide range of scientific studies [1, 2]. In addition, by the existing problem of imbalance between energy expenditures and the calorie intake of the modern human. Extending the range of products with reduced sugar content and energy value by changing the formulation would make it possible to limit the intake of fast-absorbable carbohydrates and reduce the carbohydrate load on the body [3].

It is important to note that the exclusion of sugar from the formulation of pastry, confectionary, bakery products leads to significant changes in the traditional organoleptic characteristics of products that a consumer is used to. This is accompanied by a decrease in demand and often leads to that the manufacturers attempting to resolve this problem apply synthetic sweeteners, correcting agents, food additives and improvers. It is known that sugar takes the role not only of a flavoring additive in the composition of flour-based products, but it also significantly affects the course of technological process, formation of properties of semi-finished products, the structure and color of finished food [4, 5].

Therefore, the search for, and justification of, the choice of natural raw materials and technological solutions aimed at the preservation of organoleptic properties of flour-based confectionery products when lowering or excluding sugar from formulation is a relevant task [6].

2. Literature review and problem statement

A considerable range of bakery products with reduced sugar content and glycemic index has been developed [7–9]. The most common way to reduce glycemicity and energy cost of products in the above studies is to use in the production of various sweeteners, different in technological properties, origin, composition, sweetness, calorie content, etc. [7]. Thus, the integrated use of isomalt, maltodextrin, and stevia instead of sugar at a ratio of 6:2.5:0.6 in the production of butter biscuits made it possible to obtain products that in terms of organoleptic characteristics are most similar to reference samples [8]. It was established that in order to reduce the sugar content of such confectionery as sponge cakes, stuffed waffles, muffins, it is appropriate to introduce oligofructose, polydextrose or a mixture of erythritol and sucralose instead of sugar. The application of such sweeteners allows the preservation of the loose and porous structure of the crumb characteristic of these products. However, in terms of the organoleptic characteristics, the most appreciated were products based on xylitol, maltitol and lactitol [5]. In addition, when making biscuits with reduced sugar-content, it was proposed to introduce xylitol, acesulfame and sucralose. Such products could be recommended for consumers who are overweight or have the type 2 diabetes; based on a sensory analysis they were characterized by lower scores compared to samples of cookies based on sucrose [9].

However, despite the widespread use of sweeteners in the production of foodstuffs and beverages, there are studies that indicate their contradictory effects on the human body [10]. The authors warn of the risk of changes in the intestinal microbiota and the emergence of intolerance to glucose in healthy people when consuming the synthesized sweeteners [11]. Several polyols are not allowed to use in the manufacture of baked products [4]. Scientists argue about the need for further studies into determining the mechanisms of influence of these sweeteners on the human metabolism, selecting their optimum dosages, taking into consideration the physiological and technological properties, as well as investigating their modifications in the food making process [12].

Given this, adjusting the rate of digestibility and supply of glucose to blood during consumption of food is more expedient through the introduction into the formulation of hard-to- or indigestible polysaccharides and replacement of digestible carbohydrates with them. This is a more physiological and effective way of reducing the carbohydrate load on the human body during consumption of flour-based products [13, 14].

The complexity of developing confectionary products with lowered content or no sugar (sucrose) is related to its important technological functions, significant influence on the production process, and products specifications [4, 15].

First, owing to its dehydrating properties, sugar restricts the swelling of hydrocolloids, the gluten of flour. That makes it possible, depending on its content, to regulate the degree of development of the gluten frame, to obtain dough with different elastic-plastic-viscous properties and flour-based products with a predefined texture [5, 15]. Therefore, reducing or eliminating sugar from their formulations will be accompanied by a change in the structural-mechanical properties of semi-finished products toward the greater manifestations of elastic properties. That would subsequently complicate its processing on equipment at enterprises, could cause problems at moulding, deformation of dough pieces and, as a consequence, obtaining products with characteristics that are not inherent to them. The excessive elasticity of dough when obtaining products with a reduced sugar content is compounded by the fact that flour milling enterprises are aimed at providing their key customers in the baking industry with "strong" flour. Whereas the production of flour confectionery products mostly requires flour with weak-quality gluten [4, 16].

Second, the presence of up to 6 % of sugar in the formulation of the yeast-based products, owing to the decomposition of sucrose into the rapidly fermentable glucose and fructose, contributes to the activation of the fermentative microflora of dough, increasing the gas formation [4]. The exclusion of sugar from formulation deprives the yeast cells of additional feeding and slows the alcohol fermentation.

In addition, owing to the more complete swelling of hydrocolloids of flour when excluding sugar from the formulation, the proportion of the liquid phase in the dough reduces, which is also inhibiting to the vital activity of yeast [15, 17]. In addition, that results in obtaining a product with a small volume, with low porosity.

Third, in addition to giving the sweet taste to finished products, the presence of sugar in the formulation ensures a pleasant surface color, from gold to yellow-brown [5, 15]. This is due to the caramelization process and the participation of sugars in the Maillard reaction with the formation of melanoidins during baking [4, 17].

The specified technological significance of sugar must be considered to justify the selection of natural raw sources when developing formulations and improving technology for flour-based confectionery products with a reduced sugar content.

Of particular interest as natural ingredients that could be used for the correction of metabolic disorders and the replacement of digestible carbohydrates are the inulin-containing raw materials. These include the products of processing the Jerusalem artichoke, chicory, yakon, scorzonera, etc. [18]. An analysis of chemical composition of basic plant sources of inulin shows the advantages of the Jerusalem artichoke and the products of its processing as components when developing food products with reduced sugar content [19]. In addition, the use of the Jerusalem artichoke processing products as a physiologically functional ingredient in the manufacture of bakery and pastry goods does not entail significant changes in the technological process [20].

Among flour-based confectionery products, in order to create products with reduced sugar content by introducing the powdered Jerusalem artichoke instead of sugar, we have chosen hardtacks. A special feature of this product is the use of yeast to ensure their porosity, and a relatively low content of sugar and fat. This product is in demand due to low cost, long storage, and convenience when consumed.

Table 1

Organoleptic assessment of hardtacks with reduced sugar content based on BWF

Indicator title	Samples of hardtacks	
	BWF+S	BWF+JAP
Shape	Regular	
Surface	Smooth, no foreign inclusions	
Color	Light brown	Pale yellow, not saturated enough
View at break	Properly baked, with uniform porosity, no bubbles, layered	Properly baked, without bubbles, with underdeveloped porosity
Taste and aroma	Without foreign smells and taste	Not pronounced, without foreign smells and taste

The finished products, when compared to control, were characterized by the unsaturated color, underdeveloped structure, despite adequate gas-formation in semi-finished products [21], by the unpronounced taste and aroma. Such a decline in quality is probably due to a change in the structural-mechanical properties of dough and an insufficient amount of coloring and flavor and aromatic substances formed at baking.

One of the ways to stabilize the quality of flour products with reduced sugar content could be the use of flour made from waxy (amylose-free) wheat (WWF), which is characterized by high gas and sugar-forming ability. The expediency of using it in the manufacture of cupcakes based on yeast was proven. Replacing 60 % of bread-making wheat flour with the amylose-free wheat contributed to the intensification of fermentation and reducing the duration of technological stages in the production of these foods and the stabilization of their quality [22]. Earlier studies showed that when preparing semi-finished products for making hardtacks with the introduction of the powdered Jerusalem artichoke instead of sugar, replacing the baking wheat flour with the amylose-free waxy wheat contributes to the intensification of fermentation, their maturation. This is evidenced by the increase in the amount of released carbon dioxide, an increase in the titratable acidity and elevating force of these samples compared to control [23].

In addition, the results of study into technological properties of the waxy wheat by authors of [24] demonstrated a lower capability of swelling of its gluten proteins, which would probably contribute to the lower manifestation of their elastic properties.

Replacing sugar in the formulation of flour products, in addition to the significant impact on the course of biochemical and microbiological processes, largely determines colloidal processes and structure formation in the semi-finished products, which subsequently affects the formation of quality of the finished products. Therefore, in order to determine the expediency of using WWF in the technology of hardtacks with reduced sugar-content instead of BWF, it is necessary to determine the structural-mechanical properties of dough.

Studying the influence of the comprehensive use of flour from the waxy wheat and the Jerusalem artichoke powder on structure formation and surface properties of dough for hardtacks without sugar would make it possible to substantiate the technological recommendations for their production and the possibility to process and form dough masses at existing equipment.

3. The aim and objectives of the study

The aim of this study was to examine the effect of flour made from waxy wheat on the structural-mechanical properties of dough with sugar replaced with the Jerusalem artichoke powder in order to substantiate the feasibility of their comprehensive application in the technology of hardtacks without sugar.

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

– to determine the technological properties of flour made from waxy wheat predetermined by the protein-proteinase complex;

– to substantiate the choice of raw ingredients for making hardtacks with reduced sugar content;

– to establish the effect of replacing baking wheat flour with WWF on the structural-mechanical and surface characteristics of dough for hardtacks;

– to substantiate the technological recommendations aimed at stabilizing the quality of yeast semi-finished products for hardtacks with reduced sugar content.

4. Materials and methods to study the properties of flour and dough for hardtacks.

4. 1. The examined objects and materials that were used in the study

Experimental part of this work was carried out at the laboratories of the Department of Technology of Bread, Confectionery, Macaroni products and Food concentrates, at a research laboratory of Odessa National Academy of Food Technologies (Ukraine).

The subject of research was flour made from waxy wheat, yeast dough for hardtacks with reduced sugar content, and control samples.

When making the hardtacks with reduced sugar content, we introduced, instead of sugar, the powder from the Jerusalem artichoke variety “Interest” (Table 2).

Table 2

Chemical composition of the Jerusalem artichoke powder

Indicator title	Content, %
Polysaccharides of inulin nature	72...77
Protein	7...7.2
Cellulose	10
Pectin substances	1.1

In terms of the mineral composition, the Jerusalem artichoke tubers are rich in potassium (47.7 % of the total ash), phosphorus (3.7 % of the total ash) and magnesium (from 13 to 46 mg/100 g). The Jerusalem artichoke also contains the elevated amounts of silicon – 49 μg/100 g, iron – 31 μg/100 g, and zinc – 22.6 mg/100 g. A given inulin-containing raw material includes multivitamins; it contains: carotene – 12.42 mg/kg, vitamin C – 42...318 mg/kg, B1 – 7.6 mg/kg, B2 – 0.8...3 mg/kg, PP – 10.7...27.2 mg/kg, choline – 1,936...3,100 mg/kg [25].

In the course of the study, we replaced BWF in the formulation of hardtacks without sugar with flour made from the waxy wheat of variety Sofiyka (WWF), which is cultivated in the south of Ukraine [26].

4. 2. Research methods into the properties of the waxy wheat flour and dough for hardtacks

In the course of our work, we examined the technological properties of WWF, which are predetermined by the state of the protein-proteinase complex. These properties were assessed based on the quantitative and qualitative characteristics of gluten, as well as the structural-mechanical properties of dough that were determined at the farinograph Brabender mod RSM65NG Nr127 and the extensograph Brabender Nr172515 type 860000 [27].

We determined the limiting shear stress (τ) for semi-finished products at the penetrometer AR-4/1 using the method of actual penetration applying a metal cone with angle (α) at the top 30°. Specific work of the elastic forces of dough (A) was investigated using the penetrometer AR-4/1 applying metallic plates. The magnitude of shear stress limit, derived at penetration, was calculated from the Rehbinder formula.

Adhesive tension (T) was determined using an adhesion gauge, a device that makes it possible to characterize the degree of adhesion of materials, different in structure, at their surface contact. Adhesive tension was determined using the method of normal detachment of a steel plate from a structured body (dough mass). A characteristic of adhesion in this case was the force of detachment – P, related to the contact area – S [16].

The results obtained were statistically processed using the standard Microsoft Office software package. The examined materials and methods are described in more detail in [28].

5. Results of studying the properties of amylose-free flour and the structural-mechanical properties of hardtack dough

5. 1. Studying the technological properties of the waxy wheat flour predetermined by the protein-proteinase complex

The character of forming confectionery dough, especially that with the elastic-plastic properties, is substantially affected by the technological properties of flour used, predetermined by the protein-proteinase complex.

A comparative assessment of baking wheat flour and amylose-free flour for the quantity and quality of gluten showed that the crude gluten content in WWF is 11.5 % lower than that of BWF (Table 3).

Table 3

Amount and quality indicators of gluten (n=5, $P\leq$0.95)

Quality indicators	BWF	WWF
Content of crude gluten, %	25.2	22.3
Plasticity for IDK, device units	60.0	65.0
Hydration capability, %	107.0	185.0
Elasticity	Good	Good
Extensibility above a ruler, cm	10.0	11.0

The results obtained are possibly related to the chemical composition of flour made from waxy wheat, specifically lower protein content. Significant impact on the quantitative characteristics of gluten made from WWF is exerted, probably, by a higher content of branched arabinoxylan fraction in the composition of its mucus (1.73 % for WWF and 1.26 % for BWF) [29]. The high degree of polymerization of a given polysaccharide contributes to the formation of pentosane complexes with protein substances in the presence of water, which probably prevents the formation of gluten [17]. The limited swelling of gluten is probably contributed to by the high water-binding capability of WWF mucus and the starch grains, damaged at milling, that compete when absorbing water, whose significant amount is characteristic of a given flour [30].

The hydration capability of gluten from the amylose-free wheat flour is much higher compared to that of BWF, specifically by 72.3 %, which could also be attributed to the residual content of mucus in the washed-off gluten. In this case, the elasticity of the examined samples differed slightly, while the WWF gluten was characterized by the lower resistance to compression.

It should be noted that the quantity and the qualitative characteristics of the washed-off gluten do not fully reflect the technological properties of WWF predetermined by the state of the protein-proteinase complex. Therefore, we assessed the strength of wheat flour based on the structural-mechanical properties of dough, formed from it, during kneading and when deforming the uniaxial stretching (Table 4).

It was established that the waxy wheat flour manifests itself as a weaker one compared to baking flour.

It was established that the dough plasticity of the waxy wheat flour at the deformation of uniaxial stretching after 135 minutes of fermentation is lower by 235 device units (by 3 times) than that of control sample. Such comprehensive indicators of the flour strength as energy and the valorimetric number for amylose-free flour are 1.2 and 3 times lower than those of baking flour. The indicated results of the evaluation of flour strength demonstrate that the waxy wheat flour manifests itself as the weaker one compared to baking flour.

The exclusion of sugar from the formulation of hardtacks will be accompanied by an increase in the elasticity of dough resulting from the more complete swelling and development of the gluten frame. That would subsequently have a negative impact on the course of its processing, on the shaping of dough pieces and the quality of products. Using strong flour will exacerbate these difficulties.

Therefore, when manufacturing hardtacks with reduced sugar content, it is more favorable to use, as shown by study into technological characteristics based on the structural-mechanical properties of dough, the weaker flour made from waxy wheat.

Lesser manifestation of elastic properties of the dough, formed from WWF, along with the high gas-forming ability, characteristic of it [26], would partially level off the problems that arise in the manufacture of yeast-based products without sugar.

Table 4

Results of determining the strength of flour based on the structural-mechanical properties of dough (n=5, $P\leq$0.95)

Flour sample	Indicator title								
	using a farinograph					using an extensograph (Bferm=135 min)			
	Dough formation time, min	Elasticity, far. units	Stability, min	Liquification, far. units	Valorimetric number, device units	Plasticity (tensile strength) P, ext. units	Stretchability L, mm	Ratio P/L	Energy, cm^2
BWF	5.0	70.0	8.0	55.0	61	350	105	3.3	80
WWF	6.5	40.0	5.0	70.0	51	115	55	2.1	26

5. 2. Determining the strength properties of dough for hardtacks made from amylose-free flour depending on the stage of introducing the Jerusalem artichoke powder

When preparing the semi-finished products for hardtacks with the introduction of JAP, instead of sugar, to the formulation, the baking wheat flour was replaced with flour made from waxy wheat. To substantiate the stage of introducing the Jerusalem artichoke powder in the production of sugar-free hardtacks, it was added only to the sponge dough (variant 1) or in equal shares at the stage of kneading the sponge dough and regular dough (variant 2).

The amount of water, introduced for kneading the hardtack dough without sugar, given an increase, by 1.1 times (by 6 %), in the water-absorbing capacity of flour when replacing the formulation amount of sugar (C) with JAP [24], was increased to obtain its required consistency.

The technology of hardtacks implies the stages of sponge dough preparation and the preparation of dough with subsequent resting-proofing and repeated rolling to give it a layered structure. In this case, the technological parameters of production process depend on the grade of flour used and the ratio of formulation components [15].

In order to substantiate the expediency of, and technological recommendations for, the use of new kinds of raw materials in the technology of flour-based confectionery, it is necessary to study their impact on the formation of the structural-rheological characteristics of confectionery dough. These properties predetermine the processing and formation of masses at existing equipment, as well as quality of the resulting products. In the course of study, dough rests for 150 min at t=32...35 °C followed by rolling after 90 min of proofing.

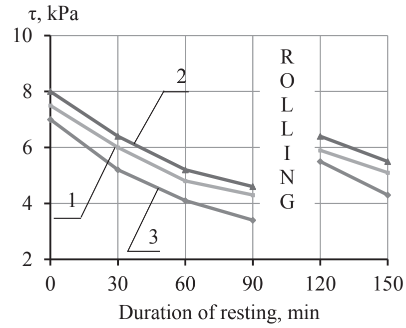
Studying a change in the shear stress limit of dough for hardtacks during its technological processing (Fig. 1) has shown that there is a decrease in its strength at resting-proofing. The indicated changes are predetermined by the microbiological, biochemical and colloidal processes that occur in dough.

In the semi-finished hardtack products, there occurs, during resting, the disaggregation and peptization of proteins, the hydrolysis of starch and, in contrast to the elastic-plastic dough on chemical baking powder, the fermentation process, that is, the loosening of a semi-finished product. This is accompanied by a decrease in the shear stress limit of the hardtack yeast dough.

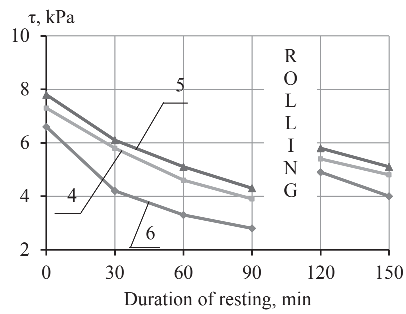
The rolling of dough, intended to uniformly distribute the bubbles of carbon dioxide and air and to give it a layered structure, leads to the increased shear stress limit. It could be possibly related to the stresses arising from a mechanical impact, to pressing out the bubbles of carbonic gas and dough compaction under the influence of shear and compression deformations.

The introduction of JAP instead of sugar is accompanied, despite a relatively high gas-formation and an increase in the amount of water, added at kneading [24, 27], by the enhanced strength of dough, by 8 % for variant 1 of kneading, and by 9.5 % for variant 2, respectively. This may be due to, on the one hand, by the more complete swelling of gluten proteins as a result of excluding sugar from the formulation, on the other hand, by an increase in the number of dietary fibers in dough introduced with the powder. In other words, the higher content of hydrated non-starch polysaccharides from the Jerusalem artichoke powder in the dough could also lead to an increase in strength properties.

In this case, the shear stress limit of the hardtack dough with JAP when replacing with the amylose-free wheat flour decreased by 15.7 % with the introduction of the inulin-containing raw material to sponge dough (variant 1) and by 16.7 % for variant 2 compared with the BWF-based dough. This is probably due to the intensification of gas formation in a semi-finished product when replacing baking wheat flour with amylose-free flour, which contributes to obtaining the dough with a looser structure.



a



b

Fig. 1. Change in the strength properties of hardtack dough at resting, where *a* – variant 1: 1 – WF+S; 2 – BWF+JAP; 3 – WWF+JAP; *b* – variant 2: 4 – BWF+S; 5 – BWF+JAP; 6 – WWF+JAP

5. 3. Influence of the waxy wheat flour on the elastic properties of dough for hardtacks without sugar

The results of determining specific work of elastic forces at the end of the dough resting (Fig. 2) indicate that its elasticity, in contrast to a shear stress limit, reduces when replacing sugar (S) with JAP. Thus, in the end of resting the dough based on BWF, specific work of elastic forces was 2.2×10^{-2} J for variant 1 of introducing JAP, and 1.9×10^{-2} J for variant 2.

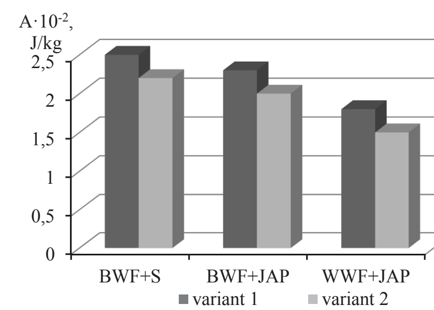


Fig. 2. Specific work of elastic forces of dough for hardtacks after resting

This trend is likely to be associated with an increase in the polysaccharides in dough, that compete with proteins for water when introducing JAP, which restricts the swelling of gluten. It should be noted that the decrease in the elasticity of dough in the case of replacing sugar with JAP is observed at a simultaneous increase in the shear stress limit. This suggests that the strengthening of a given sample of dough is predetermined not by the formation of the more developed gluten a result of excluding sugar from the mass, but an increase in the content of proportion of dietary fiber in it.

In addition, the higher acidity of semi-finished products with JAP [21, 23] contributes to an increase in the degree of proteins peptization [17] and, as a consequence, to a decrease in the elasticity of dough.

Using WWF for making hardtacks is accompanied by the formation of dough with a lower strength and specific work of elastic forces. This is obviously due to the fact that the amylose-free flour is weaker in strength and demonstrates the elastic properties to a lesser extent compared to baking flour (Table 2).

5. 4. Change in the adhesion tension of dough for hardtacks when using the waxy wheat flour and the Jerusalem artichoke powder

The results of studying a change in the surface properties of hardtack dough when using WWF and JAP (Fig. 3) indicate a decrease in the adhesion tension compared to control. Thus, for the dough during the kneading of which we introduced the inulin-containing raw materials only to the sponge dough (variant 1), the examined indicator decreased by 11.5 %. When introducing JAP instead of sugar (S) in equal shares at the stage of kneading the sponge dough and regular dough (variant 2), the adhesive tension was lower by 28 %.

The dependencies constructed are probably predetermined by the higher water-absorbing capacity of ПТ and WWF. This leads to a decrease in the amount of free moisture in dough, reduces the magnitude of capillary force between contacting surfaces and, as a consequence, of the adhesion tension [30].

The improvement of adhesion properties in the process of dough resting is most likely related to the hydrolysis of protein substances, starch and other polysaccharides, occurring at its maturation, which is accompanied by an increase in the share of the liquid phase. After rolling, there is a decrease in the adhesion tension of dough, which obviously could be explained by a decrease in the amount of free moisture at the surface of the mass as a result of its redistribution under mechanical impact [4]. The greater adhesion of dough masses when introducing JAP to the sponge dough (variant 1) is possibly due to a greater depth of biochemical transformations, depolymerization of polysaccharides in the Jerusalem artichoke as a result of that the entire amount is kept in semi-finished products over a prolonged period of time.

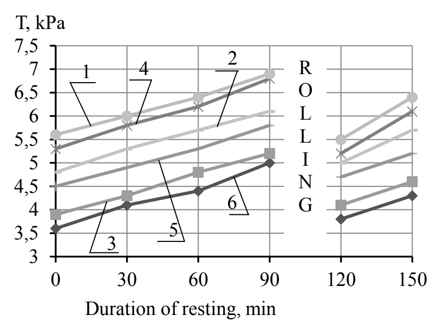


Fig. 3. Change in the adhesion tension of hardtack dough at resting with the introduction of 100 % sugar or JAP to the sponge dough: 1 – BWF+S; 2 – BWF+JAP; 3 – WWF+JAP; the introduction of sugar or JAP in equal shares to the sponge dough and dough: 4 – BWF+S; 5 – BWF+JAP; 6 – WWF+JAP

6. Discussion of results of studying the structural-rheological properties of dough for hardtacks without sugar

Determining the technological properties of WWF predetermined by the state of the protein-proteinase complex has showed that the quantitative and qualitative characteristics of its gluten are significantly different (a lower gluten content, high hydration capacity) compared to baking flour. This is probably due to its genetic characteristics and chemical composition [26].

Based on the results of analysis of farinograms, it was found that the use of WWF is accompanied by an increase in the time of dough formation. This is obviously due to the large amount of water-insoluble pentosanes included in the composition of amylose-free flour compared to BWF. These polysaccharides, due to their viscous and water-binding properties, slow the hydration of proteins, prevent the development of dough gluten, slowing the process of its formation and reducing stability. In addition, the WWF pentosans, when adsorbing on gluten proteins, could prevent their aggregation and the process of their forming the filmy and fibrous structures. This is accompanied by a decrease in elasticity, stability, and an increase in the degree of dilution of dough, and, as a consequence, by a lower value for the valorimetric number, thereby indicating a lesser strength of WWF compared to BWF.

A decrease in the elasticity and stability of dough based on WWF, an increase in the degree of its dilution is also likely to be associated with a lower content of gluten-containing proteins in its composition.

With a less content of gliadin and glutenin fractions, the ratio between the surfaces of flour biopolymers is such that the existing flour protein is not sufficient to bind the entire mass of starch grains in the bound dough mass. Given that this protein plays a leading role in the formation of dough, this reduces the stability and structural strength of dough [17].

It should be noted that an increase in the degree of liquefaction of dough made from WWF, in addition to a lesser mass percentage of gluten, could be contributed to by an increase in the content of low molecular dextrins. Their formation is due to a higher susceptibility of starch grains in flour made from amylose-free wheat to the action of amylolytic enzymes [23].

The results of digital processing of the extensograms of dough after 135 minutes of fermentation confirm research findings based on data acquired at the farinograph. They also demonstrate a lower strength of flour made from waxy wheat – the dough made from WWF is characterized by lower elasticity, stretchability, energy (the area of the extensogram), which is a comprehensive indicator for the strength of flour.

Replacing baking flour with the amylose-free flours is also accompanied by a decrease in elasticity, lower strength and specific work of the elastic forces of dough for sugar-free hardtacks, which could be attributed to a significant increase in the volume of carbon dioxide released during alcohol fermentation [23, 24]. The carbonic acid, formed from carbon dioxide, as well as the higher acidity, accelerates the peptization of proteins. In addition, this tendency is predetermined by the fact that a given flour refers to that weaker in strength, which determines the reduction of its elastic properties compared to BWF.

A comparative analysis of the impact of various variants of introducing JAP on the structural-mechanical properties of hardtack dough has shown the advantage of the step-wise addition of the inulin-containing raw material (variant 2).

The dough that is prepared when introducing JAP both to the sponge dough and regular dough has a looser structure in comparison with the samples during the beading of which JAP was introduced only to the sponge dough. This is evidenced by the reduction of strength and elastic properties of semi-finished products.

The dependences obtained are most likely attributable to a larger value for the ultimate acidity and the amount of carbon dioxide released during resting when introducing JAP in equal shares to the sponge dough and regular dough [23]. That promotes better loosening and relaxing the structure of dough.

In the case of introducing the entire amount of JAP at the first stage of dough preparation (variant 1), most products of the inversion of carbohydrates are fermented by yeast already in the sponge dough. The lower content of sugars in dough, which are available for fermentation, leads to a decrease in the intensity of gassing at the stage of resting-proofing.

The results obtained make it possible to predict the quality of the finished product in the case of the combined use of WWF and JAP in the production of sugar-free hardtacks, as well as to develop appropriate technological recommendations. In order to better substantiate the feasibility of adding these formulation components to the production of hardtacks without sugar, the further studies could address the exploration of their impact on the organoleptic and physicochemical quality indicators of finished products.

Thus, the use of WWF and JAP make it possible to obtain the well-loosened dough for hardtacks without sugar, characterized by the lower strength and elasticity compared to baking flour. This, together with high gas formation, would partially neutralize the problems arising from the exclusion of sugar from the formulation. In this case, the Jerusalem artichoke powder is recommended to be introduced in stages, by equal shares at the stags of kneading the sponge dough and dough. The results of our study indicate the advantage of their comprehensive application in the technology of flour-based confectionery products on yeast with a reduced sugar content.

7. Conclusions

1. It has been established that such integrated indicators of the flour strength as energy and valorimetric number for the amylose-free flour are 1.2 and 3 times less than those for baking flour. This suggests that in terms of the structural-mechanical properties of the dough made from it, this flour is weaker in strength compared to baking flour.

2. We have substantiated the advantage of using the amylose-free wheat flour as that that is weaker in strength for the production of bakery products on yeast with reduced sugar content. The elasticity of the dough made from the flour of waxy wheat, at a deformation of the uniaxial stretching, is 3 times lower after 135 min of fermentation than that of control sample. That would partially level off the increased elastic properties of hardtack dough when reducing or excluding sugar from the formulation.

It was determined that replacing sugar with the Jerusalem artichoke powder in the formulation for hardtacks based on baking flour contributes to an increase in the strength of dough while the elastic and adhesive properties decrease. At the end of resting, specific work of elastic forces of dough based on BWF was 9.1 % lower at the stage-wise introduction of JAP, and 8 % smaller when introducing the powder only to the sponge dough. An increase in the strength of dough when replacing sugar with the Jerusalem artichoke powder amounted to 8 % and 9.5 %, depending on the variant of introducing the inulin-containing raw materials.

3. It is shown that in the process of resting-proofing of hardtack dough, there is a decrease in strength and an increase in adhesion tension. Rolling the dough is accompanied by an increase in shear stress limit by 38.5...39.4 %, and a decrease in adhesion tension by 18.7...20 %, depending on the grade of wheat flour and the variant of introducing JAP.

It has been established that the use of flour made from waxy wheat contributes to obtaining the hardtack dough without sugar with the Jerusalem artichoke powder with a well-loosened structure and the lower strength, adhesive properties, elasticity. The adhesive tension of dough without sugar when using WWF instead of baking wheat flour reduced, depending on the technique for introducing the Jerusalem artichoke powder, by 11.5 % and 2 8 %. The shear stress limit of dough with the Jerusalem artichoke powder and WWF decreased by 15.7 % when introducing the inulin-containing raw material to the sponge dough, and by 16.7 % when introducing it both to the sponge dough and dough.

4. The expediency of introducing the Jerusalem artichoke powder in equal parts at the stages of kneading the sponge dough and regular dough has been substantiated. It is shown that these samples of dough are characterized by the looser structure, as evidenced by a decrease in the shear stress limit and elastic properties. Thus, the strength of the hardtack dough at the stage-wise introduction of the inulin-containing raw materials is 7.5 % lower in comparison with the dough whose preparation involved the introduction of the Jerusalem artichoke powder only to the sponge dough. Specific work of elastic forces of dough for hardtacks at the recommended stage-wise introduction of BWF is 16.7 % smaller.

References

1. Sugar and Health // Houses of Parliament. The Parliamentary Office of Science and Technology. 2015. URL: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0493
2. Guideline: Sugars intake for adults and children. World Health Organization. 2015. URL: http://www.who.int/iris/handle/10665/149782
3. Gut feedback mechanisms and food intake: a physiological approach to slow carbohydrate bioavailability / Zhang G., Hasek L. Y., Lee B.-H., Hamaker B. R. // Food & Function. 2015. Vol. 6, Issue 4. P. 1072–1089. doi: https://doi.org/10.1039/c4fo00803k
4. Manley D. Manley's Technology of Biscuits, Crackers and Cookies. Woodhead Publishing Limited. Cambridge, 2011. 632 p. doi: https://doi.org/10.1533/9780857093646
5. Sugar replacement in sweetened bakery goods / Struck S., Jaros D., Brennan C. S., Rohm H. // International Journal of Food Science & Technology. 2014. Vol. 49, Issue 9. P. 1963–1676. doi: https://doi.org/10.1111/ijfs.12617

6. Effect of Fruit Pomace Addition on Shortbread Cookies to Improve Their Physical and Nutritional Values / Tańska M., Roszkowska B., Czaplicki S., Borowska E. J., Bojarska J., Dąbrowska A. // Plant Foods for Human Nutrition. 2016. Vol. 71, Issue 3. P. 307–313. doi: https://doi.org/10.1007/s11130-016-0561-6
7. Otsinka yakosti tsukrozaminnykiv za kompleksnym pokaznykom / Dorokhovych A. M., Dorokhovych V. V., Kokhan O. O., Mazur L. S., Bozhok O. S. // Kharchova promyslovist. 2016. Issue 20. P. 34–40. URL: http://nbuv.gov.ua/UJRN/Khp_2016_20_7
8. Evaluation of dough rheology and quality of sugar-free biscuits: Isomalt, maltodextrin, and stevia / Pourmohammadi K., Najafi H., Pourmohammadi K., Majzoobi M., Koocheki A., Farahnaki A. // Carpathian Journal of Food Science and Technology. 2017. Vol. 9, Issue 4. P. 119–130.
9. Properties of Sugar-Free Cookies with Xylitol, Sucralose, Acesulfame K and Their Blends / Kutyła-Kupidura E. M., Sikora M., Krystyjan M., Dobosz A., Kowalski S., Pysz M., Tomasik P. // Journal of Food Process Engineering. 2015. Vol. 39, Issue 4. P. 321–329. doi: https://doi.org/10.1111/jfpe.12222
10. Fernandez M. L., Santos M. E. S. M. Effects of consuming sweeteners on metabolic disorders // Journal of Nutrition, Food Research and Technology. 2018. Vol. 1, Issue 2. P. 34–38. doi: https://doi.org/10.30881/jnfrt.00008
11. Artificial sweeteners induce glucose intolerance by altering the gut microbiota / Suez J., Korem T., Zeevi D., Zilberman-Schapira G., Thaiss C. A., Maza O. et. al. // Nature. 2014. Vol. 514, Issue 7521. P. 181–186. doi: https://doi.org/10.1038/nature13793
12. Zeynep F., Sifa T. Determination of the effects of some artificial sweeteners on human peripheral lymphocytes using the comet assay // Journal of Toxicology and Environmental Health Sciences. 2014. Vol. 6, Issue 8. P. 147–153. doi: https://doi.org/10.5897/jtehs2014.0313
13. Ayerton D. K. Sekrety pitaniya. Moscow, 2009. 300 p.
14. Meidjie A. Metabolic Response of Slowly Absorbed Carbohydrates in Type 2 Diabetes Mellitus. Springer, 2016. 135 p. doi: https://doi.org/10.1007/978-3-319-27898-8
15. Dragilev A. I., Sezanaev Ya. M. Proizvodstvo muchnyh konditerskih izdeliy. Moscow, 2000. 446 p.
16. Tekhnolohiya kondyterskoho vyrobnytstva. Praktykum: navch. pos. / Iorhachova K. H., Makarova O. V., Hordiienko L. V., Korkach H. V. Odessa, 2011. 208 p.
17. Drobot V. I. Tekhnolohiya khlibopekarskoho vyrobnytstva. Kyiv, 2002. 365 p.
18. Davis C. Inulin: Chemical Properties, Uses & Health Benefits. Nova Science Publishers Inc, 2017. 120 p.
19. Kays S., Nottingham S. Biology and Chemistry of Jerusalem Artichoke: Helianthus tuberosus L. CRC Press, 2007. 496 p. doi: https://doi.org/10.1201/9781420044966
20. Iorgacheva E. G., Makarova O. V., Hvostenko E. V. Ispol'zovanie inulinsoderzhashchego syr'ya v tekhnologii hlebobulochnyh i konditerskih izdeliy // Kharchova nauka i tekhnolohiya. 2010. Issue 1. P. 13–17.
21. Vliyanie inulinsoderzhashchego syr'ya na process brozheniya polufabrikatov dlya galet / Iorgacheva E. G., Makarova O. V., Hvostenko E. V., Gromova A. V. // Kharchova nauka i tekhnolohiya. 2011. Issue 1. P. 6–9.
22. Iorgachova K., Makarova O., Khvostenko K. The rationale of selecting pastries to be made with waxy wheat flour // Eastern-European Journal of Enterprise Technologies. 2016. Vol. 2, Issue 11 (80). P. 12–18. doi: https://doi.org/10.15587/1729-4061.2016.65756
23. Intensification of fermentation of semi-finished products of hardtracks with lowered sugar content / Iorgachova K., Makarova O., Fateeva A., Khvostenko K. // Technics, technologies and education. Yambol of Trakia University, 2017. P. 363–367.
24. Comparison of Structural Development and Biochemical Accumulation of Waxy and Non-waxy Wheat Caryopses / Yu X. R., Zhou L., Zhang J., Yu H., Gao D. R., Zhang B. Q. et. al. // Cereal Research Communications. 2015. Vol. 43, Issue 2. P. 307–317. doi: https://doi.org/10.1556/crc.2014.0038
25. Lekarstvennoe rastenie topinambur. URL: http://www.malva-topinambur.com
26. Rybalka O. I. Yakist pshenytsi ta yii polipshennia. Kyiv, 2011. 495 p.
27. Lebedenko T. Ye., Pshenyshniuk H. F., Sokolova N. Yu. Tekhnolohiya khlibopekarskoho vyrobnytstva. Praktykum. Odessa, 2014. 392 p.
28. Iorgachova K., Makarova O., Khvostenko K. The study of technological properties of waxy wheat flour and its influence on refined sugar-free hardtack`s dough // EUREKA: Life Sciences. 2018. Issue 5. P. 54–62. doi: http://dx.doi.org/10.21303/2504-5695.2018.00721
29. Faridi H., Faubion J. M. Dough rheology and baked product texture. Springer, 1990. 628 p. doi: https://doi.org/10.1007/978-1-4613-0861-4
30. Guan L. Wet-milling of waxy wheat flours and characteristics of waxy wheat starch. Kansas, 2008. 95 p.