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IMPROVING THE TECHNOLOGY OF GLUTEN-FREE BREAD WITH QUINOA FLOUR

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The object of this study is the technology of bread baking based on liquid sourdough and gluten-free flour mixture. The problem with this technology is that gluten-free raw materials do not contain gluten proteins, which ensure the elasticity and firmness of the dough and increase the porosity of the bread. To improve the structural and mechanical properties of the dough, new types of flour were introduced into the recipe compared to the analog recipe: quinoa, buckwheat, and oat. The positive effect of quinoa on dough quality has been known for a long time but the limitation in its use is the bitter taste caused by the content of saponins. A method of removing saponins using ultrasound (40 kHz, τ=20 min) has been proposed, which made it possible to remove 60 % of saponins and completely remove the bitterness of grains. At the same time, the content of proteins remained unchanged while the content of phenols decreased by only 0.1 mg GAE/g. The addition of 18 % (to the mass of the flour mixture) of quinoa flour and the reduction of the starch content in the recipe had a positive effect on the organoleptic parameters of the bread quality. The acidity of dough (4.4–5.2 °H) and bread (0.6 °H) decreased compared to the control sample, but it was sufficient for a normal fermentation process. Bread with quinoa flour had increased moisture (more than 66 %), which can negatively affect its stability during storage. An increase in the proportion of quinoa flour in the recipe by 5 % contributed to an increase in the porosity of the crumb by 2.1 %. The proposed technology for making gluten-free bread with Quartet quinoa flour based on liquid sourdough can be industrially implemented as it makes it possible to obtain a product with desirable consumer properties. The total duration of dough ripening was reduced by 1–1.5 hours, compared to the steam method, which increases the economic efficiency of the proposed technology

Keywords: flour mixture, saponins, quinoa, ultrasound treatment, liquid starter, spontaneous fermentation

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1. Introduction

Bread is a staple food consumed every day all over the world. The most popular raw material in the production of bread is wheat flour. The protein part of wheat flour (gluten) traps carbon dioxide, which is formed as a result of the action of yeast on the starch of the flour, owing to which the dough loosens. However, wheat flour is the cause of many allergic reactions. Improvements in diagnostic methods allow the identification of more people with celiac disease and other gluten-related disorders such as dermatitis herpetiformis, gluten ataxia, wheat allergy, and non-celiac gluten sensitivity [1]. The only safe treatment for these types of disorders is to follow a strict and permanent gluten-free diet for life.

The technology for the production of gluten-free bread has several problematic points. Gluten-free raw materials do not contain gluten proteins, which ensure the elasticity and firmness of the dough, as well as contribute to increasing the porosity of bread [2]. The disadvantage of gluten-free types of flour is their low nutritional value, due to the high content of starch, low content of proteins, dietary fibers, vitamins, and minerals [3]. Due to the properties of proteins in gluten-free flour, their use is limited. On the other hand, some types of gluten-free flour have a balanced composition of amino acids with high biological value [4].

The task to improve the technology of gluten-free bread remains completely unsolved. In particular, the search for raw materials and a rational recipe that could increase the porosity of bread and its nutritional value continues.

Therefore, research on the development of recipes and technology for making bread based on gluten-free raw materials is relevant.

2. Literature review and problem statement

The raw materials that can be interesting in the production of gluten-free bread include pseudocereal crops, in particular, quinoa. Research results confirm the exceptional nutritional value of quinoa, which is explained by its balanced composition, high content of protein, minerals, fiber, antioxidants, and vitamins [5]. The protein content of quinoa seeds ranges from 13.8 to 16.5 %, with an average of 15 %. Usually, albumins make up 35 %, and globulins – 37 % of the total number of proteins. Quinoa is known for the presence of all nine essential amino acids (phenylalanine, methionine, histidine, isoleucine, valine, leucine, lysine, threonine, tryptophan), which are necessary for human growth and development [6]. In addition, due to the absence of gliadins and gliadin-related protein fractions, it is classified as gluten-free and considered suitable for celiac patients [7].

It has been shown that quinoa contains lysine and methionine, vitamins B6 and B9, iron and calcium; the dietary fiber content in quinoa varies from 7.0 to 9.7 %, and according to other data from 3.0 to 52.0 % [8]. Various varieties of quinoa have been found to be rich in phenolic compounds, especially flavonoids, which are beneficial to humans. Studies have proven that quinoa is not toxic [9]. The consumption of quinoa has a positive effect on human health, in particular on the functions of the gastrointestinal tract, metabolism, and cardiovascular system [10]. Due to its high nutritional and biological value, quinoa is called the "golden grain", and NASA has identified it as the most suitable grain crop for the nutrition of astronauts.

On the other hand, quinoa contains many anti-nutrients such as saponins, phytic acid, tannins, and trypsin inhibitors.

Still unsolved are issues related to the removal of saponins, which give quinoa a bitter taste. They are mainly contained in the outer shell of the seeds (about 86 % of the total number of saponins). To evaluate quinoa as a raw material in the production of food products, a scale was developed for evaluating the bitterness of quinoa grains: 0 – absent, 2 – very weak, 4 – weak, 6 – moderate, 8 – strong, and 10 – very strong [11]. In addition, saponins can cause irritation of the digestive system. These factors are considered anti-nutritive. However, saponins have various medicinal benefits, such as antioxidant activity, antimicrobial agents, anti-inflammatory properties, and cytotoxic effects [12].

An option to overcome the problem of bitterness of quinoa grains is various ways of removing saponins from them. Dry methods of saponin removal include extrusion, roasting, and mechanical abrasion. But when rubbing and peeling, the biological value of quinoa flour decreases since a significant part of the dietary fibers is removed from it together with the bran. Bran is an industrial byproduct of quinoa processing and makes up from 8 % to 12 % of the grain mass [13]. However, it cannot be used as feed due to the high concentration of saponins, so the utilization of saponins from industrial waste is one of the pro-environmental aspects.

Wet methods involve soaking, extracting, and recirculating a large amount of water through the quinoa grains until an acceptable level of saponin is reached, at which no bitter taste is felt [14]. However, when using large volumes of water, there is a significant load on the ecosystem.

Ultrasonic technology is a new technological alternative, which is considered effective and profitable compared to traditional methods of saponin extraction. In earlier studies [15], ethanol was used as an extractant, which is unacceptable for further use of quinoa in bread production. It is worth noting that ultrasound treatment was mainly used to extract protein from quinoa grains [16]. This method has not been studied in detail regarding the effectiveness of removing saponins and reducing the bitterness of quinoa grains and quinoa flour.

The data available in the literature demonstrate the potential of using quinoa as a gluten-free raw material in the production of bread. Nevertheless, our review of the relevant literature revealed that no rational technique has yet been proposed for the removal of saponins from quinoa grains. There are no results of research on the possibility of combining the method of infusion in water and simultaneous treatment with ultrasound. This allows us to state that it is appropriate to conduct a study on devising a technique for removing saponins from quinoa grains and their use in the technology of gluten-free bread.

Three varieties of quinoa are officially registered in Ukraine, including in Sumy Oblast. Scientists at the Sumy National Agrarian University created the Quartet variety, which is characterized by a reduced content of saponins (2.8 %). However, there are practically no studies on the possibility of using this quinoa variety in the production of gluten-free bread. For the use of Quartet quinoa in the food industry, in particular, bread baking, it is advisable to conduct a detailed analysis of its chemical composition.

3. The aim and objectives of the study

The aim of our study is to improve the technology of gluten-free bread on liquid sourdough by using quinoa flour, purified from saponins. This could improve the quality of the dough and finished products. The research results would become the basis for industrial production of yeast-free gluten-free bread.

To achieve the goal, the following tasks are set:

– to investigate the content of saponins, phenol, and protein in unprocessed and processed in different ways Quartet quinoa grains;

– to analyze the organoleptic indicators of Quartet quinoa flour bread;

– to investigate the physical-chemical parameters of dough and bread with Quartet quinoa flour;

– to develop a technological scheme for the production of gluten-free bread with Quartet quinoa flour, purified from saponins.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of research is the technology of bread production based on sourdough and gluten-free flour mixture. The subject of the study is the technique for removing saponins from quinoa; indicators of the quality of dough and bread made from gluten-free raw materials.

The main working hypothesis of the study assumes that quinoa flour could become a full or partial substitute for starch in gluten-free bread recipes. By removing saponins from quinoa grains, flour with satisfactory organoleptic properties can be obtained, which will become a raw material that will provide the characteristic structural properties of bread and increase its biological value. Compared to wheat and barley starch, quinoa has a higher maximum viscosity, water absorption capacity, and higher swelling capacity, which will positively affect the quality of the dough. This assumption was partially correct since increasing the proportion of quinoa flour in the recipe made it possible to increase its porosity but led to a decrease in acidity. As a result, the dough's setting time increased.

4. 2. Materials

Experimental samples of bread were baked according to the recipes given in Table 1.

Table 1

Recipe of experimental samples of bread

Raw materials, g	Analog	Sample 1	Sample 2
Flour Mixture			
Rice flour	135	135	120
Quinoa flour	–	23	60
Flax flour	12	12	10
Buckwheat flour	–	–	60
Oatmeal	–	–	60
Psyllium	8	8	20
Total	155	178	330
Corn starch	115	92	60
Maltose	12	12	–
Honey	–	–	20
Salt	6	6	10
Olive oil	18	18	–
Leaven	137	137	200
Water	185	185	350
Total	628	628	970

The recipe proposed by other researchers [17] was taken as an analog since it contains components similar to the experimental sample 1, except for quinoa flour. During the production of sample 2, additional components were introduced into the recipe in order to reduce the amount of starch.

To make the flour mixture, the following were used: rice, oat, and buckwheat flour LLC "Cascade" (Ukraine), flax TM "Zemledar" (Ukraine), quinoa flour Quartet, psyllium FOP "Khramov V. M." (Ukraine), dry corn starch "Interstarch Ukraine" LLC. Flour from quinoa and flax was obtained by grinding grains on an LZM-1 laboratory disk mill to a coarseness that ensures complete passage of the material through a braided brass sieve No. 025 (0.25 mm).

Maltose TM "Eatofit" (Ukraine) and honey (sample 3) TM "EKO-MedOK" (Ukraine) were used as a substitute for sugar in the bread recipe (analog and sample 1).

A liquid leaven based on rice flour was created as a leavening agent under laboratory conditions. Rice flour (300 g) was mixed with water (375 g). Spontaneous sourdough fermentation took place for 7 days at a temperature of 4±2 °C. At the same time, every 24 hours, the starter was fed with rice flour and water (1 **%** by weight). To activate the leaven before use, it was incubated for 6 hours at 22±2 °C until pH 4.0 was reached, and then added to the dough as a leavening agent. The humidity of the sourdough was 70 %.

The well-mixed dough was fermented for 0.5 h at a temperature of 22.2±2 °C. After that, it was kneaded, placed in molds, and left for 5 hours at a temperature of 32±2 °C. Samples were baked for 1 hour at a temperature of 220±2 °C. After complete cooling, the samples were removed from the molds.

The following techniques were used to reduce the saponin content in quinoa grains. The grain sample (K1) was steeped in cold water (t=10±5 °C) for 30 min, dried, and ground. The infusion was carried out in three stages, replacing the water at each subsequent washing. After soaking, the quinoa grains were dried in a laboratory dryer to a mass fraction of moisture of 5–6 **%** (t=85±5 °C).

The grain sample (K2) was boiled in hot water (t=100±5 °C) for 10 min, dried in a laboratory dryer to a moisture content of 5–6 **%** (t=85±5 °C), and ground.

The grain sample (K3) was infused in a UCleaner TV02 ultrasonic bath with a power of 120 W (t=30±5 °C, 40 kHz, τ=20 min). The ratio of the components of the mixture (water and quinoa grains) in all samples was 1:1. After ultrasonic treatment, the soaking water was separated from the quinoa and dried in an infrared laboratory dryer to a mass fraction of moisture of 5–6 **%** (t=85±5 °C). Quartet quinoa without pretreatment was used as control (K).

4. 3. Study of the chemical composition of quinoa grains

The protein content was determined by the Kjeldahl method. The total content of phenols expressed in milligrams of gallic acid equivalents per gram of quinoa flour (mg GAE/g) was determined using a spectrophotometer Specol-11 (Germany) at a wavelength of 750 nm.

The foam method was used to determine the content of saponins. For this purpose, 0.50±0.02 g of quinoa grains were weighed and distilled into a test tube, 5.0 ml of distilled water was added. The tube was capped and shaken vigorously for 30 seconds. After stabilization of the foam, its height was measured. The content of saponins was calculated from the following formula, %:

$$S = \frac{0.0441 \times H}{m}, \quad (1)$$

where H is the height of the foam, cm; m is the mass of the sample, g

4. 4. Research of organoleptic indicators of experimental samples of bread

For the organoleptic evaluation, 10 non-professional tasters of different ages and genders were involved from among the lecturers and graduate students at the Sumy National Agrarian University (Ukraine), who had theoretical training and previous experience in sensory evaluation. Standard descriptors of organoleptic evaluation of bread were used. Evaluation was carried out on a 7-point scale: I dislike it very much – 1 point; I neutrally dislike it – 2 points; I slightly dislike it – 3 points; I neutrally like it – 4 points; moderately good – 5 points; good – 6 points, very good – 7 points.

4. 5. Study of physical-chemical indicators of the quality of dough and bread with quinoa flour Quartet

The study was conducted according to standard procedures [18]. The acidity of bread and dough was determined by alkalimetric titration of the extract using the phenolphthalein indicator, active acidity was determined using a pH meter (AD 11 pH meter Adwa). Moisture – by drying in a SESH-3M drying cabinet. To determine the porosity, 4 cylindrical recesses were made, each with a volume of 27 cm^3. The prepared recesses were weighed together with an accuracy of 0.01 g. Porosity was calculated from the following formula, %:

$$P = \frac{V - \frac{m}{\rho}}{V} \cdot 100, \quad (2)$$

where V is the total volume of recesses, cm^3; m – mass of the pulp notches, g; ρ is the density of the non-porous mass of the pulp, kg/m^3.

4. 6. Statistical analysis

Final results were expressed as mean ± standard deviation of measurements from three separate extracts, in three different studies. Comparison of group means and significance of differences between groups were tested by Student's t-test. Statistical significance was $p \leq 0.05$.

5. Results of the Quartet quinoa grain research

5. 1. Selection of a rational technique for removing saponins from Quartet quinoa grains and analysis of their chemical composition

The influence of the technique for processing quinoa grains on its composition according to some indicators was analyzed. The results of the study are given in Table 2.

Table 2

Results of investigating quinoa grains. Uncertainty, U (k=2, P=0.95)

Indicator ID	K	K1	K2	K3
Content of saponins, %	2.8±0.05	2.2±0.05	1.6±0.05	1.1±0.05
Phenol content, mg GAE/g	2.5±0.05	2.4±0.05	2.0±0.05	2.4±0.05
Mass fraction of protein, g/100 g	14.1±0.05	14.1±0.05	13.2±0.05	14.1±0.05

The results of our study showed that when using the cold infusion technique (sample K1), the content of saponins decreases by 21.5 %. A faint bitterness remains in the grains. The mass fraction of proteins in the grain does not change with this technique, and the content of phenols decreases by only 0.1 mg GAE/g, which indicates the preservation of the antioxidant properties of quinoa grains.

During the boiling process, the chemical composition of Quartet quinoa grains (sample K2) undergoes the most significant changes. Analysis revealed that sample K2 contains less proteins (by 0.9 %). This is probably due to their partial destruction and denaturation due to heat treatment. The content of phenolic compounds during boiling of quinoa grains decreases by 0.5 mg GAE/g, compared to the control. At the same time, the content of saponins is reduced by only 40 %, the bitterness is very weak.

The lowest content of saponins in quinoa grains is observed after their ultrasonic treatment (sample K3). It was established that this technique ensures the removal of more than 60 % of saponins; the bitterness completely disappears. However, the protein content remains unchanged, and the phenolic content is reduced by only 0.1 mg GAE/g. These compounds have anti-inflammatory and antioxidant properties, so they can help protect cells from oxidative damage by free radicals and reduce inflammation in the body.

Considering the results of the research, this technique can be considered rational.

5. 2. Results of the organoleptic evaluation of experimental samples of bread

An organoleptic evaluation of test samples (Fig. 1) of yeast-free gluten-free bread baked according to different recipes was carried out. The results are given in Table 3.

a *b* *c*

Fig. 1. Gluten-free bread: *a* – analog (does not contain quinoa flour); *b* – sample 1 (contains 13 % quinoa flour); *c* – sample 2 (contains 18 % quinoa flour)

Adding more quinoa flour and reducing the starch content had a positive effect on the organoleptic indicators of bread quality. The results of the organoleptic evaluation are given in Table 3.

Table 3

Organoleptic quality indicators of gluten-free bread. Uncertainty, U (k=2, P=0.95)

Name	Appearance	Smell	Taste	Color
Analog	1.4±0.05	3.5±0.05	2.8±0.05	1.5±0.05
Sample 1	6.2±0.05	6.1±0.05	5.8±0.05	6.9±0.05
Sample 2	6.8±0.05	7.2±0.05	6.9±0.05	7.1±0.05

The sample that did not contain quinoa flour received the lowest organoleptic evaluation points. Peeling of the crust from the pulp and increased stickiness were observed in it. In terms of appearance and color, tasters did not like the analog very much. In terms of taste, they did not like it neutrally. They didn't like the smell a bit.

Bread with a quinoa flour content of 13 % by weight of the flour mixture (sample 1) received a "good" rating in terms of appearance, smell, and color. The taste of this sample is rated as "moderately good".

The bread containing the highest amount of quinoa flour (sample 2) was good in appearance and taste, and very good in smell and color. The state of the pulp is characterized as moderately large, fairly uniform. The color of the pulp of sample 2 is brown. The speed of its assimilation by the human body depends on the condition of the crumb of the bread. The well-developed, uniform, thin-walled porosity of bread, as in sample 2, contributes to the maximum penetration of digestive juices and improves the digestibility of food.

5. 3. Results of the analysis of physical and chemical indicators of test samples of dough and bread

The results of our study of the physical and chemical indicators of quality of dough and bread are given in Table 4.

Table 4

Physical-chemical indicators of the quality of gluten-free products. Uncertainty, U (k=2, P=0.95)

Name of indicators	Experimental samples		
	Analog	Sample 1	Sample 2
Dough			
Acidity, °H	8.3±0.05	5.2±0.05	4.4±0.05
pH	3.7±0.05	3.9±0.05	5.1±0.05
Moisture content, %	67.9±0.05	68.1±0.05	67.4±0.05
Bread			
Moisture content, %	67.4±0.05	67.3±0.05	66.9±0.05
Acidity, °H	6.1±0.05	6.8±0.05	5.5±0.05
Pulp porosity, %	5±0.05	44.1±0.05	46.2±0.05
Crust thickness, mm	3.9±0.05	3.0±0.05	2.8±0.05

All samples were characterized by high moisture content. Too high humidity of the analog (67.4 %) caused increased stickiness and jamming of the crumb of the finished bread. Samples 1 and 2 also had high humidity (67.3, 66.9 %, respectively), which made it difficult to remove them from the molds. Increasing the amount of quinoa flour in the recipe by 5 % contributed to a decrease in its moisture content by 0.4 %. However, it still remained quite high, probably due to the use of liquid starter. An increase in the amount of flour mixture led to a decrease in porosity and the formation of too mushy bread.

Due to the addition of quinoa flour, the acidity of dough and bread decreased. The lowest acidity (4.4±0.05 °H) was found in the dough sample with 18 % quinoa flour content. Bread baked from this dough (sample 2) compared to other experimental samples also had 0.6 °H lower acidity than the sample without quinoa flour. The taste of the products depends on this indicator – excessively or insufficiently sour bread tastes unpleasant. The acidity of the dough in the range of 4.4–5.2 °H is sufficient for the normal fermentation process and ensures the taste of gluten-free products, characteristic of bread.

The high humidity of the dough had a positive effect on the porosity of the bread. Wet dough captures and retains air better. The porosity of the crumb in bread with quinoa flour (samples 1, 2) was significantly higher than that of the control sample. Sample 2 had the highest porosity – 46.2 %. Such porosity contributes to the preservation of freshness of bread and its better assimilation by the body.

5. 4. Development of a technological scheme for the production of gluten-free bread with Quartet quinoa flour

Taking into account that ultrasound treatment ensured the greatest removal of saponin from Quartet quinoa grains, a technological scheme for the production of gluten-free bread using this technique has been proposed (Fig. 2).

According to the technological scheme, a mixture of different types of flour is used to prepare the dough: rice, flax, buckwheat, oat, psyllium, as well as quinoa flour.

To reduce bitterness, quinoa grains are pre-soaked in clean drinking water (t=30±5 °C, 40 kHz, τ=20 min). The ratio of the components of the mixture (water and quinoa grains) should be 1:1. After ultrasonic treatment, the soaking water is separated, and the quinoa grains are dried to a mass fraction of moisture of 5–6 % (t=85±5 °C). Waste water containing saponins. It is being disposed of.

The dried grain is ground to a finely dispersed degree. The resulting flour is sent to the preparation of the flour mixture. Before kneading the dough, all loose components are sifted (sieve 0.25 mm).

All recipe components are added to the flour mixture to form a dough consistency. The dough ferments for 0.5 hours. Such a short duration of fermentation is due to the use of liquid rice sourdough as a leavening agent. To prepare sourdough, a mixture of rice flour and water is fermented for 7 days at a temperature of 4±2 °C. In the fermentation process, the starter is diluted daily with flour and water. Before direct use, the leaven is activated. To do this, it is placed in a room with a temperature of 22±2 °C. After a 6-hour incubation, the sourdough is mixed with the flour mixture and the rest of the recipe components.

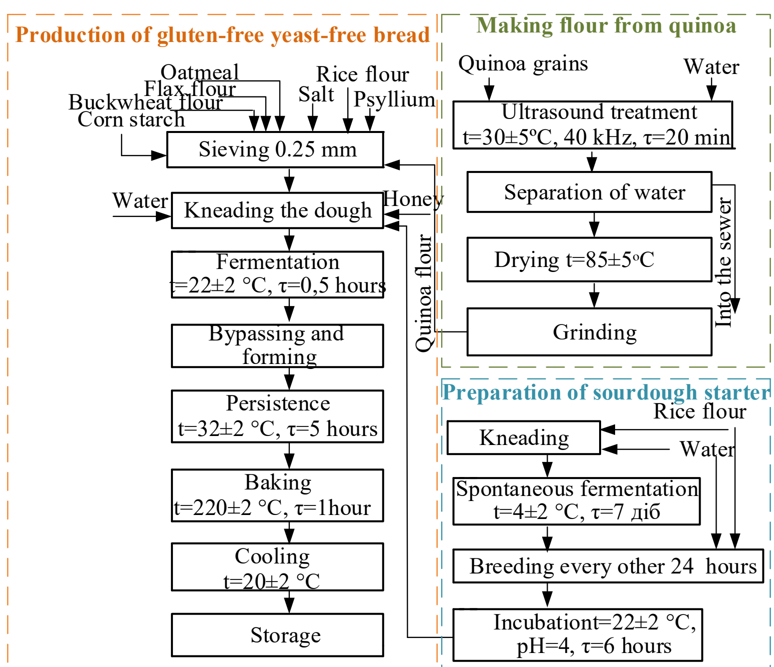

Fig. 2. Technological scheme for baking gluten-free bread with quinoa flour

The fermented dough is thoroughly kneaded and placed in molds for proofing at a temperature of 32±2 °C. The duration of aging is 5 hours. Bread baking lasts 1 hour at a temperature of 220±2 °C.

6. Discussion of research results regarding the feasibility of using quinoa flour in the production of gluten-free bread

The most important result of our study is that it proved the effectiveness of using ultrasound to remove saponins from Quartet quinoa grains and demonstrated the positive effect of quinoa flour on the quality of dough and bread. The composition of Quartet quinoa grains was investigated for the first time.

The proposed technique for reducing the bitterness of quinoa grains, which involves ultrasonic treatment and simultaneous short-term infusion, makes it possible to remove more than 60 % of saponins. Similar results were achieved by washing quinoa grains three times with an alkaline solution (pH=8) for 8 minutes [19]. However, with this technique, the protein content of quinoa grains decreases by 11.58 %. In addition, the alkaline solution negatively affects the organoleptic properties of quinoa grains. During ultrasonic treatment, the protein content remains unchanged (Table 2).

The content of free phenol in the process of treating Quartet quinoa grains with cold water and ultrasound practically did not change and amounted to 2.5–2.4 mg GAE/g, which is typical for colored quinoa seeds [20]. Some studies have shown that free phenolic compounds can be digested in the upper gastrointestinal tract, playing a protective role in the distal intestine [20]. Therefore, the presence of such a quantity of phenolic compounds in quinoa flour will have a positive effect on the nutritional value of bread made from it.

Products containing quinoa flour (samples 1 and 2) had a more attractive appearance (Fig. 1, *b, c*). The surface of the products was smooth, not contaminated, without large cracks and undermining. The crust color of all samples was uniform, not pale and not burnt. The color is golden yellow (analog), light brown (sample 1), and brown (sample 2). The crust thickness of bread with quinoa flour was slightly less (up to 3 mm) than that of bread made with a higher starch content – up to 4 mm. The condition of the crumb of the control sample (Fig. 1, *a*) was unsatisfactory, sticky, the structure was broken, and viscous.

The crumb of bread samples with quinoa flour had a more uniform, large, thin-walled porosity, without cavities and signs of non-brewing, tempering (Fig. 1, *b*, *c*). An increase in the content of quinoa flour in the recipe by 5 % contributed to an increase in its porosity by 2.1 % (Table 4). The color of the pulp of sample 2 is light brown, sample 3 is brown. The control sample tasted too sour but had a bready smell. The taste of sample 1 was characteristic of this product, the smell is characteristic of bread without extraneous shades, bitterness was not felt. Sample 3 had a pleasant taste with a nutty aftertaste, the smell is characteristic of bread without extraneous shades. These results are consistent with the results by other researchers [21] who used quinoa flour for the production of gluten-free bread.

The results of our study (Table 4) showed that the addition of quinoa flour led to a decrease in the acidity of the dough (by 3.1–3.9°H). Similar results were obtained by other scientists when developing gluten-free products [22]. Acidity contributes to the destruction of starch and makes it possible to reduce the duration of dough blanks, but the framework of the products had less structural support. A properly formed gluten frame ensures optimal gas retention of the dough. Considering that only gluten-free raw materials were used in the recipe, it can be assumed that such a decrease in acidity led to an increase in the duration of aging (5 hours). Despite the considerable duration of exposure, the structure of the finished products was sufficiently formed (sample 1, 2). It is worth noting that the total duration of fermentation and setting (5.5 hours) of the dough according to the proposed technology is 1–1.5 hours shorter than the duration of this process in the case of using the sponge technique of bread production (6.5–7 hours).

The moisture content of bread, as well as its recipe, determines its energy value and technical and economic performance indicators of enterprises. This indicator is also important for calculating the yield of bread. If the moisture content of bread increases by 1 %, its yield increases by 2–3 %. The moisture content of all experimental samples (66.9–67.4 %) was significantly higher than the moisture content of bread made from wheat and rye flour (42.0–51.0 %) according to typical recipes. Increasing the amount of quinoa flour in the recipe by 5 % contributed to a decrease in its moisture content by 0.4 %. Despite a fairly high moisture content, sample 2 containing 18 % quinoa flour was not sticky.

Increasing the amount of flour in the recipe had a positive effect on its porosity, which is consistent with previous results [21]. Sample 2 contained the highest crumb porosity (46.2 %±0.05). Due to this property, the bread is easier to chew, permeates with digestive juices, and is therefore more fully digested.

The practical significance of this study is the possibility of improving the technological properties of quinoa by reducing its bitterness. This will contribute to the further use of this crop in the production of bakery products and the expansion of the range of gluten-free products.

The advantages of this technique are that the technique makes it possible to reduce the content of saponins by 60 % without reducing the protein content.

Limitations of this study include the fact that the research was conducted using Quinoa Quartet. In the case of using a different type of quinoa, the data on the chemical composition and the effect of ultrasonic treatment on it may differ.

The disadvantage of the proposed technique is that the removal of bitterness from quinoa grains requires additional energy costs for drying and special equipment.

Further research may focus on analyzing the mineral and amino acid composition of Quinoa Quartet, as well as improving the technology of making gluten-free yeast-free bread in order to reduce its moisture content and completely remove starch from the recipe.

7. Conclusions

1. It was established that treatment of Quartet quinoa grains soaked in water (t=30 °C) with ultrasound (40 kHz, τ=20 min) makes it possible to remove more than 60 % of saponins and completely get rid of bitterness.

2. The organoleptic evaluation showed that with the addition of quinoa flour it is possible to obtain a product that is not inferior to bread made from gluten-containing raw materials in all respects. Sample 2, with the highest content of

quinoa flour (18 %), was rated at more than 6 points (good) in terms of appearance and taste. Most of the tasters rated the smell and color as "very good".

3. It has been shown that the addition of Quartet quinoa flour leads to a decrease in the acidity of bread (by 0.6°H compared to the control sample). Bread with quinoa flour is characterized by high moisture (more than 66 %), which leads to a shortening of its shelf life. However, these conclusions are preliminary and require experimental confirmation. An increase in the proportion of quinoa flour in the recipe by 5 % contributes to an increase in the porosity of the crumb by 2.1 %.

4. A technological scheme for the production of gluten-free bread with Quartet quinoa flour based on liquid sourdough, which can be industrially implemented, has been developed. The advantage of the improved technology is the reduction of the total duration of dough ripening by 1–1.5 hours compared to the sponge technique of making bread.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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