Using functional quinoa ingredients for enhancing the nutritional value of bakery products

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Abstract. Quinoa, as semi-grain culture, has a high nutritional and biological content. Its chemical composition surpasses the traditional grain crops by many nutrients. This work aims to develop the technological recipe for bakery products from 1st-grade wheat flour enriched with quinoa ingredients in order to improve consumer quality and physicochemical parameters of the bread. A study of the nutritional value and physicochemical Quality of bread was carried out by introducing quinoa flour in the range of 5 to 30% in the recipe. An increase in the content of quinoa flour more than 15-20% led to a decrease in the volumetric yield of final products. For mitigate the negative impact of high concentrations of quinoa flour, dry wheat gluten was added in an amount of 0 – 5% to the bread recipe. Using the compositional uniform-rotatable experiment-planning program “MAT STAT” and a graphical interpretation of the results obtained, the receipt of wheat bread enriched with protein, dietary fibre, minerals and B vitamins was optimized. The enriched bread samples showed an increase in protein content from 7.0 to 11.5%, the content of dietary fibre increased and amounted to 16.2%, thiamine – 17.8%, magnesium – ~ 24.5%, iron – 16.7% and phosphorus – 19.4% of the daily requirement. Based on the results obtained, it is recommended to add quinoa and dry wheat gluten in an amount of 17 to 20% and 2%, respectively to the recipe.

1. Introduction

Analysis of the bakery market shows that in recent years a dramatic decrease in the consumption of traditional varieties of bread. This fact is due to the increased population demand for specialized and functional products with high nutritional value. The development and production of modern bakery products are based on achievements in the field of nutrition, contributing to the formation of a nutritional structure aimed at the prevention of various types of nutritional diseases. Current trends in the international food market are characterized by increased demand from the population for products of the "health &wellness" segment.

This group of products includes foods fortified with raw materials of plant-based functional ingredients, including that form the basis of the pyramid of healthy nutrition. The most valuable sources of multifunctional ingredients such as bioflavonoids, antioxidants, dietary fibre, vitamins,
minerals, polyunsaturated fatty acids, and several other nutrients, are traditional and non-traditional sources of plant raw materials.

Quinoa pseudo-grain culture has high nutritional and biological values that are close in its composition of vitamins and microelements to buckwheat but surpasses it in protein content and possess a high potential for consumption as a plant raw material component for the enrichment of bakery products.

The WHO pays great attention to ensuring the development of international sustainable food systems and international programs to stabilize the nutritional system of the world's population, associated with an irreversible and ever-increasing degree of urbanization. This situation requires a reconsidering of the problem as well as the implementation of a new integrated international approach for developing policies in the field of ensuring a healthy nutrition for the period up to 2050 [1].

WHO focuses on the need to implement the principles of healthy nutrition based on the diversification of crops to expand the range of ethnic foods in order to reduce animal fats, trans fats, easily digestible carbohydrates in the diet and increase the content of deficient functional food ingredients.

Currently, in Russia the volume of production and sale of fortified bakery products is insignificant, it makes up 3% of the total volume of bread sold, but there is a well-established trend of an annual increase in their volume by 20-30%, and an expansion of the assortment of fortified pieces of bread.

At the same time, there is a constantly increasing demand in the segment of bakery products, which in turn stimulates an increase in their production volumes. The development of the production of fortified bakery products is driven by the objectives outlined in the Federal project "Motivating citizens towards healthy lifestyles and avoiding harmful habits" as well as the Concept of ensuring the sanitary and epidemiological well-being of the population through the development of functional and specialized bread-making in the Russian Federation until 2020. It is planned to solve these tasks by developing innovative technologies and increasing production volume. An assortment of new-generation bakery products fortified with functional ingredients, including expanding the use of non-traditional vegetable raw materials [2, 3].

Much attention is given toward fortified food production to the quinoa pseudo-grain culture. Quinoa crops are widespread and produced in many countries of the world due to its high nutritional value. Quinoa is rich in proteins, essential amino acids, including lysine, which is deficient in crops, vitamins, trace elements, essential fatty acids, dietary fibre [4, 5, 6].

In recent years, quinoa began to be actively grown in the central and southern regions of Russia [7]. Depending on the variety and the place of growth, quinoa seeds can contain up to 17–20% protein, which is close in composition to the ideal protein. Quinoa proteins are mainly composed of 11S-type globulin called Chenopodium, which makes up about 37% of the total protein, as well as 2S-albumin, which makes up 35%.

Unlike other cereals, quinoa is rich in essential amino acids such as lysine, threonine, tryptophan, and valine. 100 g of quinoa contains a high BCAA content of amino acids: 0.84 g of leucine, 0.59 g of valine and 0.50 g of isoleucine. 100 g quinoa contains a high content of arginine 1.1 g, glycine - 0.60 g and methionine 0.31 g, which are necessary for the synthesis of creatine. Quinoa contains about 6-7% of fat-rich in Omega-3 and Omega-6 fatty acids. The content of dietary fibres ranges from 7-9%. Quinoa seeds are rich in fat- and water-soluble vitamins and minerals. An essential feature of quinoa is the lack of gluten in its composition, which increases the demand for this product in patients with celiac disease [8, 9, 10].

This work aims to develop the technology and recipe of bread made from flour wheaten of first grade fortified with functional quinoa ingredients, considering the high nutritional and biological value of quinoa seeds.

2. Materials and methods
The objects of research were: Extra class white quinoa flour (T.U. 10.61.22-004-05604978-2017), Flour wheaten of first grade (GOST R 26574), pressed baking yeast (GOST R 54731), edible salt
(GOST R 51574), white sugar (GOST 33222), sunflower oil (GOST 1129), dry wheat gluten (STO 53548590-025-2014) and drinking water (SanPiN 2.1.4.1074). The analysis of a two-component mixture of the Flour wheaten of first grade and quinoa flour was carried out by the method for determining the quantity and Quality of gluten using Russian standard (GOST 27839-2013).

Analysis of the organoleptic and physicochemical parameters of the finished bakery products was carried out in the centre of biochemical and microbiological research of the "Scientific Research Institute of the Baking Industry and Plekhanov Russian University of economics following Russian standards (GOST R 58233-2018).

Methods for determining organoleptic parameters and weight of products was carried out by Russian standard(GOST 27669-88 – baking wheat Flour). Method of trial laboratory bread baking was done by Russian standard (GOST 21094-75 – Bread and bakery products). Determination of humidity was carried out by (GOST 5669-96), determining porosity by(GOST 5670-96). The water-holding capacity of polydispersed plant powders was determined by the difference in the mass of water remaining in the supernatant after absorbing part of the fixed water quota during ageing under regulated conditions [10]. The content of dietary fibres, vitamins and minerals was carried out by the calculation method under the methodology developed by the State Research Institute of Industrial and Industrial Mathematical modelling of bread recipes was carried out using compositional uniform-rotatable experimental design (MAT STAT program); a graphical interpretation of the results of the study was obtained using the program (STATISTICA 7.0).

3. Results
The effect of introducing different concentrations of quinoa flour in the range from 5 to 30% on the changes in quantity and Quality of gluten as well as its effect on the protein-proteinase complex of wheat flour in the recipe mixture is presented in (Figure 1).

![Figure 1](image_url)

**Figure 1.** The effect of dosages of quinoa flour on: A – the quality of gluten; B – the amount of gluten.

When quinoa flour is added, gluten content decreases and its Quality decreases. This fact could be explained by the fact that the absence of gluten in quinoa flour led to a decrease in the related gluten content in the bread recipe.

The influence of the degree of fortification of wheat flour with the functional ingredients of quinoa on the organoleptic and Physico-chemical properties of bread was studied. Laboratory bread samples were prepared according to a traditional recipe with the addition of quinoa flour in portions of 5%, 10%, 15%, 20%, 25%, and 30%.

Besides the wheat flour, the recipe mixture includes quinoa flour 7.5%, deodorized refined sunflower oil 6%, edible salt 4.5%, and 6% white sugar and pressed baker's yeast [11].

The products were prepared randomly. All raw ingredients are per the recipe were kneaded in a laboratory dough mixing machine for 8-10 minutes, the dough was fermented for 90 minutes at a temperature of 28-30C until titratable acidity of the test was 3.0-3.50. Cutting and moulding the dough
was carried out manually. Ready dough pieces weighing 420g were placed in laboratory baking dishes and placed in a proofer at a temperature of 36-38C and air humidity of 75-80%. The readiness of the dough pieces was determined by appearance and by the speed of alignment of the test after pressing. Baking samples was carried out in an electric furnace for 20-25 minutes at a temperature of 170C. The appearance of finished products with longitudinal sections of bread samples in the context is shown in Figure 2.

![Figure 2](image)

**Figure 2.** The appearance of final products (A), longitudinal sections of final products (B), where 1 is controlled, 2 – 5% added quinoa flour, 3 – 10% added quinoa flour, 4 – 15% added quinoa flour, 5 – 20% added quinoa flour, 6 – 25% added.

We measured the specific volume, porosity, humidity and the acidity of all treatments including control (Figure 3).

![Figure 3](image)

**Figure 3.** The results of fortification with quinoa flour on the physicochemical properties of the final products in all treatments. Where, A – the percentage of porosity and humidity, B – Acidity degrees, and specific volume, in cm$^3$/g.

The results of comparative studies of organoleptic and physicochemical quality indicators of all treatments are presented in Table 1.

The analysis of the organoleptic properties of the studied treatments showed that when 20% or more quinoa flour is added, all the studied parameters decrease. In essence, the surface becomes uneven. Cracks appear on its surface. The colour acquires a darker shade, and porosity becomes uneven, clear aftertaste and smell of the additives.

Upon introducing of 5% of quinoa flour to the recipe of bakery products, the specific volume indicator increased by 9.8%, while introducing 10% increased the specific volume indicator by 1.4%, introducing 15% of quinoa flour increased the specific volume indicator only by 0.3%. However, with 20% of quinoa flour, the specific volume indicator decreased by 19.8% compared with the control sample. According to the results of the experiment, it was found that bakery products with the addition of quinoa flour in an amount of 15% by weight of flour were characterized by the best ratio of the degree of enrichment with functional quinoa ingredients and organoleptic and physicochemical quality indicators. Taking into account that introducing quinoa flour into a traditional wheat bread recipe resulted with a decrease in the gluten content in the final product, it does not permit the increase in the mass fractions of quinoa flour by more than 15%. It was decided to add dry gluten to the recipe
mixture for effectively increasing the mass fraction of quinoa flour and providing a higher level of the nutritional value of the bread.

**Table 1.** Influence of the mass fraction of quinoa flour in the recipe of fortified bread made from flour wheaten of first grade on the organoleptic properties of the treatments.

| Indicators | Control (without quinoa) | Treatments with different percentages of added quinoa flour |
|------------|--------------------------|----------------------------------------------------------|
|            |                          | 5  | 10  | 15  | 20  | 25  | 30  |          |
| Form       | corresponds with the form of bread | | | | | | |          |
| Surface (skin) | Smooth texture, without tearing or cracking, the color is light brown | not smooth in texture, without tearing or cracking, the color is dark brown | not smooth in texture, the surface is not even, there are some tearing, the color is dark brown |          |
| Crumb condition | Fully baked, not sticky, not wet to the touch, without lumps and traces of unclean, uniform porosity, no voids. | Fully baked, not sticky, not wet to the touch, without lumps and traces of unclean, uneven porosity. |          |
| Taste | the taste is characteristic of this type of product. | Pleasant, with a slight aftertaste. | Pleasant, with a moderate flavor of the additives | Pleasant, with an obvious flavor of the additives |
| Smell | the smell is characteristic of this type of product | with a slight smell of the additives. | with a medium-strong smell of the additives |          |

For optimize the mass fraction of quinoa flour and dry wheat gluten in the formulation of bakery products from wheat flour, mathematical modelling was carried out using compositionally uniform rotatable experimental planning program "MAT STAT" by exploiting the results obtained from baking bread with the addition of quinoa flour in the range from 15 to 25 % with increments of 2% and the introduction of dry wheat gluten from 1 to 3% with increments of 1%. A graphical interpretation of the results of the study was obtained using "STATISTICA 7.0" program; the results are presented in Figure 4.

Based on the results of the study, regression equations were obtained that adequately describe the dependence of the quality indicators of bakery products on the mass fraction of quinoa flour and dry wheat gluten.

Acidity=+3.1724-0.142588*x1+0.003536*x1
Porosity=+70.724-1.42588*x1+0.03536*x1
Specific volume =+2.34326+0.00499458*x1+0.00163504*x1
Water retention capacity =+167.895+49.4594*x1-9.75523*x2+0.314685*x2

where x1 is the mass fraction of quinoa flour, x2 is the mass fraction of gluten.

It was found that the optimal results in terms of specific volume, porosity, acidity and water holding capacity of bread were achieved by fortifying the traditional recipe mixture of bread with quinoa flour in the percentage of 17-20% and dry wheat gluten with 2%. Analysis of the results is
presented in Figure 4. The optimal ratios and dosages of quinoa flour and dry wheat gluten were established, which amounted to 17 – 20% and 2%, respectively.

![Graphical interpretation of the results obtained by "STATISTICA 7.0" program: A – specific volume; B – porosity; C – acidity, D – water retention capacity.](image)

**Figure 4.** Graphical interpretation of the results obtained by "STATISTICA 7.0" program: A – specific volume; B – porosity; C – acidity, D – water retention capacity.

**Table 2.** Nutritional value of the baked bread with quinoa flour.

| Nutritional value | Control | Bread according to the developed recipe | Daily requirement*, g/mg | Coverage of daily requirement, % |
|-------------------|---------|-----------------------------------------|--------------------------|---------------------------------|
| -Protein, g       | 7.70    | 11.51                                   | 75                       | 15.5                             |
| -Increase, %      | -       | 48.64                                   |                          |                                 |
| -Dietary fiber, g | 3.45    | 4.9                                     | 30                       | 16.33                           |
| -Increase, %      | -       | 30.4                                    | -                        |                                 |
| -Calcium, mg      | 21.19   | 28.02                                   | 1000                     | 2.80                            |
| -Increase, %      | -       | 32.23                                   | -                        |                                 |
| -Potassium, mg    | 130.39  | 203.49                                  | 3500                     | 5.81                            |
| -Increase, %      | -       | 76.76                                   | -                        |                                 |
| -Magnesium, mg    | 30.87   | 61.03                                   | 400                      | 24.5                            |
| -Increase, %      | -       | 98.00                                   | -                        |                                 |
| -Phosphorus, mg   | 86.30   | 154.90                                  | 800                      | 19.36                           |
| -Increase, %      | -       | 79.49                                   | -                        |                                 |
| -Iron, mg         | 1.51    | 2.25                                    | 14                       | 16.07                           |
| -Increase, %      | -       | 49.93                                   | -                        |                                 |
| -Thiamine, mg     | 0.18    | 0.25                                    | 1.4                      | 17.85                           |
| -Increase, %      | -       | 38.89                                   | -                        |                                 |
| -Riboflavin mg.   | 0.06    | 0.10                                    | 1.6                      | 6.25                            |
| Increase, %       | -       | 66.66                                   | -                        |                                 |
| Pyridoxine ,mg    | 0.15    | 0.20                                    | 15                       | 10                               |
| -Increase, %      | -       | 33.33                                   | -                        |                                 |
| Zinc ,mg          | 0.88    | 1.26                                    | 150                      | 0.84                            |
| -Increase, %      | -       | 43.18                                   | -                        |                                 |

*The average daily requirement for basic nutrients and energy [13].
Table 2 presents the estimated nutritional value of fortified wheat bread (17% quinoa flour and 2% of dry wheat gluten) compared with a control sample and calculated the degree of satisfaction of daily physiological needs for functional ingredients.

The content of the main functional ingredients in the fortified sample of wheat bread was calculated, using the international and national database of the chemical composition of food products per the methodology and computer program of the Research Institute of the bakery industry. Calculation of the chemical composition in 100 g of bakery products shows that the content of all the studied functional ingredients of fortified bread is higher than that of the control sample. The level of satisfaction of the daily requirement for basic nutrients was calculated following the Methodological Recommendations (MP 2.3.1.2432-08 Norms of physiological requirements for energy and nutrients for various groups of the population of the Russian Federation) [13]. In terms of organoleptic indicators of Quality, all the obtained treatment samples of fortified bread exceeded the control (bread without fortification with quinoa).

Figure 5. A and B shows the control treatment (bread without fortification with quinoa); B and D - Bread with the fortified with 17% quinoa flour and 2% dry wheat gluten.

4. The discussion of the results

According to the results, fortification of bread made from flour wheaten of first grade with quinoa flour in an amount between 15-20% led to a decrease in the volumetric yield of the final products. For mitigating the established negative effect of high concentrations of quinoa flour, dry wheat gluten in an amount of 2% was added to the enriched bread recipe.

Using dried gluten powder in order to increase the consumer properties of bread is justified and will be applied in the practice of baking [14]. We used compositionally uniform rotatable experimental planning program "MAT STAT" for exploiting the results. Graphical interpretation of the results was developed for the optimal formulation of wheat bread fortified with protein, dietary fibres, minerals and B vitamins. The clear elevations in the nutritional value amounted to more than 15% of the daily requirement, which under Russian GOST R 52349-2005 of Functional food products allows attributing them to functional ingredients. Fortified bread shows an increase in the protein content from 7.0 to 11.5%. While dietary fiber content reached 16.2% thiamine 17.8%, magnesium 24.5%, iron 16.7% and phosphorus 19.4%. of the daily requirement, respectively.

Based on the results of the study, the recipe of bread made from flour wheaten of first grade fortified with quinoa flour and dry wheat gluten in an amount of 17 to 20% and 2-3%, respectively is recommended. The data obtained correlate with the results of many researchers in the Russia Federation [6, 14, 18], and abroad, recommending the enrichment of bakery products with raw materials of plants origin, including quinoa ingredients [17, 19]. Other studies recommended the use of 20 to 40% raw materials of plants origin for the enrichment of bakery products [15, 16].

5. Conclusion

As a result of research, the recipe of bread made from wheat with quinoa flour was optimized by the enhanced organoleptic properties, physicochemical indicators, and the content of functional ingredients of the final product. The composition of the recipe components includes 83% flour
wheaten of first grade; 2% dry wheat gluten; 17% quinoa flour; pressed baking yeast – 17%; refined deodorized sunflower oil – 6%; edible salt – 4.5%; white sugar – 6%.

Samples of test bread baking produced according to this recipe exceeded the control samples of bread baked according to the traditional recipe in organoleptic and physicochemical quality indicators.

References
[1] Seto K C and Ramankutty N 2016 Hidden linkages between urbanization and food systems Science 352 (6288) 943-945
[2] 2013 Resolution of the Chief state sanitary doctor of the Russian Federation no 31 "About measures for prevention of the diseases caused by micronutrient deficiency, development of production of food products of functional and specialized purpose". Russian Newspaper 208(6184) (in Russian)
[3] Katznelson Yu and Levchenko S 2019 Bakery Market Overview Russian Food Market 5 8-13
[4] Eliseeva L G, Zhirkova E V, Ivanova T N and Kokorina D S 2019 The study of the biological value of quinoa groats of various brands Technology and commodity science of innovative food products 5 (58) 81-87
[5] Eliseeva L G, Kokorina D S and Zhirkova E V 2019 The significance and role of pseudo-grain quinoa culture as a food product Quality and safety of goods: from production to consumption. Materials of the International scientific-practical conference dedicated to the 60th anniversary of the revival of the department of merchandising and examination of goods (Moscow) 199-204
[6] Belyavskaya I G, Bogatyreva T G and Nefedova T S 2018 Using the flour of pseudo-grain quinoa culture in the technology of bakery products bread making of Russia 2 19-23
[7] Schekoldina T V, Rodionova L Ya, Chernikhovets E A 2016 Innovative culture of quinoa (Chenopodium quinoa) - prospects for growing in the Krasnodar Territory to create food of high nutritional value Scientific journal KubGAU 121 (07) 1-15
[8] Novikova D O, Nefedova T S and Belyavskaya I G 2017 Prospects for the use of quinoa in the baking industry Collection of a scientific conference by international participation “Development of the food and processing industry of Russia: personnel and science” (Moscow) 69 - 74
[9] Ohimain E I 2015 Recent advances in the production of partially substituted wheat and wheatless bread European Food Research and Technology 240 (2) 257-271
[10] Dakhili S, Abdolalizadeh L, Hosseini S M, Shojaee-Alibadi S and Mirmoghtadaie L 2019 Quinoa protein: Composition, structure and functional properties Food chemistry 299 125-161
[11] 2017 The method of determining the water-holding capacity of plant polydisperse powders STP 5-08 (Moscow: the Russian NIIHP)
[12] Kuzminsky R V, Patt V A, Kazanskaya L N and Konenkov I V 1989 Collection of technological instructions for the production of bread and bakery products (Moscow:Pressurestat)
[13] Methodical recommendations MR2.3.1.2432-08 2009 Norms of physiological needs for energy and nutrients for various groups of the population of the Russian Federation (Federal Center for Hygiene and Epidemiology of Rospotrebnadzor)
[14] Kolpakova V V and Kovalenok V A 2019 Relationship of the functional properties of dry wheat gluten with amino acid composition and its quality indicators Proceedings of the Voronezh State University of Engineering Technologies 1 (81) 173-180
[15] Kolomnikova Y P, Derkanosova A A, Manukovskaya M V and Litvinova E V 2015 Effect of non-traditional vegetable raw materials on the properties and biotechnological structure pastry Proceedings of the Voronezh State University of Engineering Technologies 3 157-160
[16] Ed. Bermejo JEH and León J 1994 Neglected crops: 1492 from a different perspective Plant Production and Protection FAO 26 205–209
[17] Lorenz K and Coulter L 1991 Quinoa flour in baked products Plant Foods for Human Nutrition 41 213-223
[18] Abdullaev M S and Nadtochiy L A 2016 Studying the possibility of using pseudo-grain quinoa culture as a part of recipes based on dairy raw materials *Almanac of scientific works of young scientists of the ITMO University* 4-5

[19] Abdullayeva M S and Nadtochiy L A 2016 Assessment of the nutritional value of quinoa culture *Symbol of science* 1 9-10

[20] Roslyakov Yu F, Vershinina O L and Gonchar V V 2010 Advanced studies of functional bakery technology *News of higher educational institutions. Food Technology* 1 (313) 123-124