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DEVISING AN APPROACH TO ASSESSING THE QUALITY OF GLUTEN-FREE BREAD OF NEW RECIPES

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This study investigates the quality of gluten-free bread. In Ukraine, the range of gluten-free products remains limited. This paper determines the possibility of improving the laboratory assessment of gluten-free bread to further define the rational use of gluten-free flour in bread baking with guaranteed stability of the product structure.

The recommended approach to assessing the quality of gluten-free bread involves a 5-point assessment scale containing the following indicators: physical appearance (shape, surface, color of the crust); crumb condition (consistency, structure, color); taste; and smell. The devised weighting factors take into account the smaller volume and porosity of products made from gluten-free raw materials compared to wheat bread.

The combination of non-traditional raw materials (quinoa, buckwheat, corn flour) with an improved quality assessment system made it possible not only to develop a competitive recipe for gluten-free bread but also form a unified approach to controlling its quality. Thus, the positive results are attributed to the high nutritional properties of quinoa and buckwheat, as well as the functional characteristics of psyllium and starch, which compensate for the absence of gluten proteins. Structure-forming agents – xanthan gum, starch, and psyllium – and their amounts are recommended to ensure dimensional stability and improve the texture of the product. The proposed recipe ratios (quinoa flour as the main raw material in combination with buckwheat and corn flour and the addition of 1.0% psyllium powder or 1:3 of the amount of starch) and an improved approach to evaluation could be used in laboratory practice, during industrial and small-scale production of gluten-free bakery products, as well as in the development of other types of functional grain flour products

Keywords: gluten-free flour, quinoa, psyllium, optimization of bread recipes, organoleptic evaluation criteria

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1. Introduction

Bread has been and remains the staple food of people all over the world. Bakery products are part of the daily diet not only in countries with developed economies but also in countries with low levels of development at remote corners of the world. Therefore, it can be expected that the market for bread and bakery products will develop rapidly in various directions [1].

Celiac disease affects 1 in 133 people in the world. Epidemiological studies show that in the near future celiac disease will develop in 1 in 100 people [2]. Scientists and manufacturers around the world are focused on the development of gluten-free bakery products. The issue of making these products is acute in Ukraine but the needs of the population are mostly met by imported products. Currently, very few gluten-free bakery products are made in Ukraine, so scientific research on this topic is important.

Sensory characteristics of bread, such as texture, taste, and smell, are of great importance to consumers. During the production of gluten-free products, it is necessary to take into account a number of issues, such as insufficient quality, low storage stability, and high cost. Work [3] emphasizes the need for further research and development of new technologies to solve these problems, taking into account the future prospects for the evolution of this industry.

Therefore, it is a relevant task to carry out studies on the rational use of gluten-free flour, expanding the range of gluten-free bakery products, as well as establishing optimal evaluation criteria.

2. Literature review and problem statement

There are formulations of gluten-free bread with the addition of rice flour [4]; it is also proposed to use starch with the addition of various types of gluten-free flour: corn, buckwheat, chickpea, bean, millet, and psyllium as a stabilizer [5]. According to the authors of these papers, the recipe they developed makes it possible to get bread of improved quality, nutritional value, and organoleptic indicators that satisfy consumers of gluten-free bread [4, 5]. The issues of ensuring the stability of the structure and uniformity of the porosity of the bread remain unresolved.

It has been shown that the recipe for gluten-free bread from hemp cake flour makes it possible to get bread with increased medicinal properties, makes it possible to improve the antioxidant composition and nutritional quality of gluten-free sourdough bread, while maintaining good sensory acceptability [6], which is still inferior to wheat bread.

The issue of consumer value of bakery products has always been relevant and has been considered in many studies [7], while the modern baking industry is evolving in many directions, one of which is the production of gluten-free bread [8]. The authors of [7, 8] emphasize the importance of increasing the consumer appeal of gluten-free bread through optimal selection of raw materials.

Promising raw materials in baking gluten-free products are the most common alternatives to wheat and rye flour – corn and buckwheat flour [9]. Quinoa has many positive properties for human health [10] and can contribute to improving metabolism, the functioning of the cardiovascular system and the gastrointestinal tract of a person [11]. The issues of studying the quality of gluten-free products from this raw material remain unresolved.

Sensory characteristics of gluten-free products, such as texture, taste, and smell, are of great importance to consumers. Issues related to the small volume and uneven texture of gluten-free bread remain unresolved. It has been shown that the addition of white quinoa flour to replace 40% of rice and corn flour makes it possible to slightly increase the volume, uniformity of the crumb, and improve the quality and sensory characteristics of gluten-free bread [12].

In work [13], the possibility of adding psyllium to such food products as dairy (yogurt), products derived from fruits, gluten-free bread was considered. Studies were also conducted on the ability of psyllium husk powder to improve the quality and shelf life of gluten-free bread [14]. However, further study is needed to optimize the dosage of structuring agents, in particular psyllium, to ensure stable quality and reproducibility of results under industrial conditions.

In [15], a methodology for making bread with the addition of rice flour or husks was proposed, which was used to assess the quality. The researchers also conducted an organoleptic assessment of the bread using a panel of sensors who assessed the taste, aroma, texture, and appearance of the bread. The lack of a unified methodology for laboratory evaluation of the baking properties of gluten-free composite mixtures complicates the objective assessment of such products.

Thus, individual studies on the use of quinoa, buckwheat, corn flour, as well as starch and psyllium husk powder, indicate the prospects for the use of such ingredients in the technology of bakery products. At the same time, the question of the influence of their complex use in the composition of the recipe on the quality of bread remains unstudied. Further research should be aimed at improving laboratory evaluation of gluten-free bread to further determine the rational use of gluten-free flour in bread baking with guaranteed structural stability and uniform texture of products.

3. The aim and objectives of the study

The aim of our study is to devise an approach to assessing the quality of gluten-free bread based on composite mixtures of quinoa, buckwheat, and corn flour and consumer characteristics of the finished product. This will increase the objectivity and reproducibility of gluten-free bread evaluation.

To achieve this goal, the following tasks were set:

– to devise a technique for scoring the quality of gluten-free bread taking into account weighting factors;

– to define the organoleptic indicators of gluten-free bread for various recipe combinations of non-traditional types of flour (quinoa, buckwheat, corn) and structuring agents (xanthan gum, psyllium, starch).

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the quality of gluten-free bread.

The subject of the study is the influence of the composition of a composite gluten-free mixture of quinoa, buckwheat, and corn flour, as well as structure-forming agents (xanthan gum, psyllium, starch) on the formation of structural-mechanical and sensory characteristics of gluten-free bread and the effectiveness of an improved approach to assessing its quality.

The combination of quinoa, buckwheat, and corn flour in certain recipe ratios with the use of structure-forming agents improves the structure, dimensional stability, and sensory properties of gluten-free bread, and an improved approach to organoleptic evaluation increases the objectivity of determining its baking characteristics.

Non-traditional types of flour can partially or completely replace wheat flour in gluten-free mixtures; structure-forming agents in certain concentrations compensate for the absence of gluten proteins; the use of a scoring system with weighting factors minimizes the subjectivity of sensory analysis.

The research focuses on the analysis of the main organoleptic and structural indicators without taking into account physicochemical parameters; the influence of external technological factors and the economic efficiency of the production process are not taken into account.

4. 2. Researched materials and equipment used in the experiment

Quinoa seeds (*Chenopodium quinoa*) were introduced at the National Botanical Garden named after Hryshko, the NAS of Ukraine; corn and buckwheat grains were hybrid varieties grown in the Southern Forest-Steppe of Ukraine. The study was conducted at the Department of Food Technologies, Uman National University.

The raw materials and materials used during the study, in terms of quality and safety, meet the requirements of regulatory documentation.

The entire study is conditionally divided into stages: production of test baking and analysis of test baking of bread.

The quality of the products is affected by the composition of protein-containing, starch-containing raw materials, the presence of sugar, fat, and acidity of the dough [5]. That is why the studies used different types of gluten-free flour in different ratios, which differ in chemical composition. To determine the ratio of recipe components of gluten-free bread that provide the necessary properties of the dough, the experimental method was used (Table 1).

Table 1

Dough composition

Raw materials	Raw material consumption, g						
	Variant						
	1 (control)	2	3	4	5	6	7
Quinoa flour grade I	100.0	99.25	99.0	98.75	50.0	50.0	33.3
Psyllium	–	0.75	1.0	1.25	–	–	–
Potato starch	–	–	–	–	–	50.0	33.3
Corn starch	–	–	–	–	50.0	–	33.3
Raw materials	Variant						
	1 (control)	II*	III	IV*[1-3]	5	VI*[1-3]	VII*[1-3]
Quinoa flour grade I	100.0	–	–	50.0	50.0	–	33.3
Gluten-free flour*	–	100.0	–	50.0	–	50.0	33.3
Corn starch	–	–	100.0	–	50.0	50.0	33.3

Note: [1] – buckwheat No. 1 (green grain); [2] – buckwheat No. 2 (grain subjected to hydrothermal treatment (HTT)); [3] – corn.

Experimental bread samples were developed with different ratios of first-grade quinoa flour, buckwheat, and corn flour. Buckwheat was of two types: from green buckwheat groats and subjected to HTT. Since gluten-free raw materials, unlike wheat flour, do not contain gluten proteins, structure-forming agents (various hydrocolloids) were added to the dough: xanthan gum, starch, psyllium.

When studying the possibility of using gluten-free flour in baking, it is necessary to understand which components of the recipe and in what dosage can improve the nutritional value of finished products. Considering the recipe amount of drinking water during dough mixing, the moisture content of the recipe flour components and the results of the experiment (Fig. 1), psyllium powder was added in dry form at a concentration of 0.75%, 1.00, and 1.25% by weight of flour raw materials (Table 1).

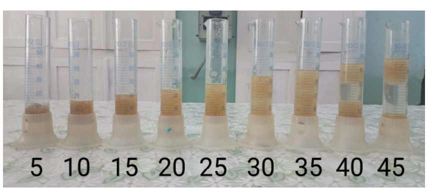

Fig. 1. Photograph of dissolving 1 g of psyllium powder in water, ml

In addition, for the preparation of the dough, table salt was used – 1.50%, sunflower oil – 1.35%, sugar – 1.25%, dry baker's yeast – 0.625%, xanthan gum – 0.50%, drinking water – the rest. After preparing the dough, it was subjected to fermentation – placed in a thermostat for 150–180 min, then the dough was processed, shaped, placed in a mold and placed in a thermostat again. The end of the dough proofing was determined organoleptically. The bread was baked with the baking chamber humidified (Brabender, 6 kW, 380 V) at a temperature of 200–220°C for 15–20 min. A total of 19 samples of gluten-free bread were studied (Table 1), the control experimental sample was 100% quinoa flour. Parameters and modes of proofing and baking bread were selected as a result of experimental studies.

The room where the organoleptic tests were conducted met generally accepted requirements: sufficiently spacious, with a constant temperature (18–20°C) and relative humidity (70–75%). There is no extraneous sound in the room. The laboratory for conducting tests is located in the northern part of the building; windows relative to the floor surface are about 35%, the walls are white. At the workplaces, the illumination is at least 500 Lk with diffused daylight and light from fluorescent lamps that meet the requirements of regulatory documentation. There is an additional room for preparing samples for analysis.

5. Results of research on the quality of gluten-free bread of new recipes

5. 1. Devising a technique for organoleptic assessment of the quality of gluten-free bread

Several techniques for organoleptic assessment of bread made from wheat flour, rye flour, or their mixture are known [16–19].

To determine the organoleptic indicators of bread products, a 5-point evaluation scale is more often used, taking into account the weighting coefficient, developed in accordance with the requirements from DSTU 7517:2014 "Bread made from wheat flour. General technical conditions" and DSTU 4583:2006 "Bread made from rye and a mixture of rye and wheat flour. General technical conditions".

However, the described methods were developed to assess the quality of bread made from flour of grains containing gluten.

The range of bakery products is constantly updated. General methodologies [16–19] do not allow us to objectively determine the quality of gluten-free bread. The color and appearance of the crust, the condition and color of the crumb from gluten-free flour will correspond to the lowest score of existing scales. In addition, when determining the condition of the crust surface, it is not always clear whether the cracks are short, small, or large, similar shortcomings apply to determining the characteristics of taste and smell.

Therefore, an approach to organoleptic assessment of gluten-free bread quality has been devised to more objectively determine the properties of bread made from gluten-free flour cultures.

The devised approach to assessing the quality of gluten-free bread provides for an assessment scale (Table 2), which contains the following indicators: appearance (shape, surface, color of the crust); crumb condition (consistency, structure, color); taste; smell. The highest score for an indicator is 5 points, the lowest is 1 point. Weighting coefficients have also been devised: 0.4 is assigned to taste indicators, 0.3 to crumb condition, 0.2 to appearance, and 0.1 to smell.

As a result of multiplying the obtained score by the corresponding weighting coefficient and the sum of the products, a total score is obtained. By the number of points, the product is assessed as: "excellent (5)" – not less than 4.6 points; "good (4)" – from 4 to 4.5 points; "satisfactory (3)" – from 3 to 3.9 points; "unsatisfactory (0)" – 2.9 and less points.

The devised technique for assessing the quality of bread takes into account the smaller volume and porosity of products from gluten-free raw materials compared to wheat bread.

Thus, the use of the proposed organoleptic assessment of gluten-free bread will provide a more objective determination of the properties of bread from gluten-free flour.

Table 2

Scale of organoleptic evaluation of gluten-free bread quality

Qualitative characteristic	Weighting factor	Points	Bread quality characteristics
Appearance (shape, surface, crust color)	0.2	5	The shape is correct, corresponding to the given shape of the product (or the shape in which the bread was baked), without lateral leaks. The surface is smooth, without contamination, without large cracks and defects, glossy. The color is uniform, corresponding to bread from this type of raw material, without burning
		4	The shape is regular with a slightly convex surface. The surface is quite smooth, with a few small bubbles, and barely noticeable small cracks and tears. The sides are slightly rough. The color is quite uniform
		3	The shape is regular with a slightly flattened surface. The surface is bumpy, rough, the upper and lateral crusts are shiny, not burnt; there are obvious (not large) cracks and tears. The surface color is quite uniform
		2	The shape is irregular with a flattened surface, flat, has obvious blisters, bumps, wrinkled. Small cracks up to 1/3 of the surface of the side of the product. The surface color is uneven
		1	The surface is torn, concave, blistered. Large pores throughout, cracks longer than 1/3 of the surface of the side of the product. The surface color is uneven, burnt, not typical of bread made from this type of raw material
Condition of the crumb (consistency, structure, color)	0.3	5	The consistency is very soft, tender, elastic, and quickly restores its shape. The crumb is baked with uniform porosity, not sticky and not wet, without «hardening» (a non-porous dense strip of crumb along the lower crust, which occurs when baking bread in an insufficiently heated oven) and «unmixed» (a lump of flour or pieces of old bread in the thickness of the crumb). Large pores, voids, and compaction are allowed. The color is uniform, characteristic
		4	Quite soft, quite elastic, slightly moist to the touch; quite porous (the non-porous part of the crumb occupies up to 25% of the bread cross-section); does not return to its original shape well after pressing
		3	Satisfactorily soft (slightly dense), moderately elastic; uneven porosity (the non-porous part of the crumb occupies 25–50% of the bread cross-section); slightly rough, dry or slightly moist when chewed, slightly clumpy
		2	Noticeably compacted, not very elastic crumb; uneven porosity (non-porous part of crumb occupies more than 50% of bread cross-section); rough, dry or moist when chewed, crumbles or noticeably clumps
		1	Strongly wrinkled, moist and soft to the touch, inelastic, brittle; non-porous; strongly clumps when chewed, rough; «hardness» or «lumps» present
Smell	0.1	5	The aroma is characteristic of this raw material from well-fermented dough, strongly pronounced, characteristic of this type of product (raw material)
		4	Pleasant, less pronounced, characteristic of bread made from this type of flour
		3	Typical of bread, weakly expressed, yeasty, doughy
		2	Unexpressed, foreign, sour, alcoholic
		1	The smell of unleavened dough, strongly sour, moldy, musty, foreign, unpleasant, pungent
Taste	0.4	5	Typical for this type of product (raw material), pleasant, without foreign taste; pronounced; without crunch on the teeth; easy to chew
		4	Less pronounced, typical for this type of product (raw material), specific, when chewed, it causes a rather pleasant feeling, slightly dry in taste, chews well
		3	Weakly pronounced, characteristic, without a specific taste, bland, dry
		2	Unsweetened, sour, doughy, slightly bitter, not pronounced; does not correspond to this type of product (raw material)
		1	Unsweetened, yeasty, strongly acidic, oversalted, bitter, not typical for this type of product (raw material), foreign, unpleasant; noticeable crunch on the teeth; difficult to chew

5. 2. Results of studying the organoleptic quality indicators of bread of new recipes

Of all the sensations perceived by the senses during the organoleptic evaluation of food products, the most complex is the perception through the smell of the product. The organoleptic properties of bread, in particular its taste and smell, are considered by modern physiology as an essential element of the nutritional value of food products, which affects their digestibility.

The bread was subjected to organoleptic evaluation in accordance with the devised methodology (Table 2), by trained tasting participants. The results of the evaluation of the organoleptic properties of bread are given in Tables 3–6 and Fig. 2–5: in total, the best organoleptic characteristics were demonstrated by samples 7 and VII[1-3] (quinoa flour, corn/buckwheat flour, and starch in equal proportions).

Sample 6 (a mixture of quinoa flour and potato starch) (Fig. 2, *f*) resembled a "sponge" with large voids in appearance. Samples 5 and 7 (Table 3) had a rough crust, and samples 6 and 7 had cracks, which may be a feature of the type of starch used.

The control sample had a white-orange-brown crust, there were single cracks on the surface, the crumb was baked, brittle. The taste and smell were characteristic of this product, with a light nutty flavor. In general, samples with quinoa flour were distinguished by increased dough viscosity and a dense crumb.

Considering the uneven porosity and the detection of voids in sample 6 Fig. 2 (Table 3), corn starch was selected for further study.

a b c d e f g

Fig. 2. Images of quinoa flour bread: *a* – *Chenopōdium quīnoa* (*Control*); *b* – *Chenopōdium quīnoa* / *Psyllium* 0.75%; *c* – *Chenopōdium quīnoa* / *Psyllium* 1.00%; *d* – *Chenopōdium quīnoa* / *Psyllium* 1.25%; *e* – *Chenopōdium quīnoa* 50% / *Frumentum amylum* 50%; *f* – *Chenopōdium quīnoa* 50% / *Annuum amulum* 50%; *g* – *Chenopōdium quīnoa* 33.3% / *Frumentum amylum* 33.3% / *Annuum amulum* 33.3%

a b c d e f g

Fig. 3. Images of bread made from quinoa and buckwheat flour No. 1 (green grain): *a* – *Chenopōdium quīnoa* (*Control*); *b* – *Fagopyrum esculentum*-**I**; *c* – *Frumentum amylum*; *d* – *Chenopōdium quīnoa* 50% / *Fagopyrum esculentum*-**I** 50%; *e* – *Chenopōdium quīnoa* 50% / *Frumentum amylum* 50%; *f* – *Fagopyrum esculentum*-**I** 50% / *Frumentum amylum* 50%; *g* – *Chenopōdium quīnoa* 33.3% / *Fagopyrum esculentum*-**I** 33.3% / *Frumentum amylum* 33.3%

a b c d e f g

Fig. 4. Images of bread made from quinoa and buckwheat flour No. 2 (grain subjected to HTT): *a* – *Chenopōdium quīnoa* (*Control*); *b* – *Fagopyrum esculentum*-**II**; *c* – *Frumentum amylum*; *d* – *Chenopōdium quīnoa* 50% / *Fagopyrum esculentum*- **II** 50%; *e* – *Chenopōdium quīnoa* 50% / *Frumentum amylum* 50%; *f* – *Fagopyrum esculentum*-**II** 50% / *Frumentum amylum* 50%; *g* – *Chenopōdium quīnoa* 33.3% / *Fagopyrum esculentum*-**II** 33.3% / *Frumentum amylum* 33.3%

a b c d e f g

Fig. 5. Images of bread made from quinoa and corn flour: *a* – *Chenopōdium quīnoa* (*Control*); *b* – *Frumentum*; *c* – *Frumentum amylum*; *d* – *Chenopōdium quīnoa* 50% / *Frumentum* 50%; *e* – *Chenopōdium quīnoa* 50% / *Frumentum amylum* 50%; *f* – *Frumentum* 50% / *Frumentum amylum* 50%; *g* – *Chenopōdium quīnoa* 33.3% / *Frumentum* 33.3% / *Frumentum amylum* 33.3%

Table 3

Organoleptic quality indicators of bread made from quinoa flour

Variant	Appearance		Condition of the crumb		Smell	Taste	Organoleptic evaluation, points
	Shape, surface	Crust color	Consistency, structure	Color			
1 (Control)	Typical bread shape, smooth crust, with small cracks, no ruptures	light brown	Baked, without lumps, voids, not sticky	Light gray	bread	Characteristic, with a nutty flavor	4.4
2	Typical bread shape, smooth crust, with small cracks, no ruptures	light brown	Baked, without lumps, voids, not sticky	Gray	bread	Characteristic, with a nutty flavor	4.5
3	Typical bread shape, smooth crust, with small cracks, no ruptures	brown	Baked, without lumps, voids, not sticky	Gray	bread	Characteristic, with a nutty flavor	4.7
4	Typical bread shape, smooth crust, with small cracks, no ruptures	brown	Baked, without lumps, voids, not sticky	Gray	bread	Characteristic, with a nutty flavor barely bitter	4.0
5	Typical bread shape, not smooth crust, with small cracks and irregularities, no ruptures	light brown	Baked, without lumps, voids, not sticky	Dark yellow	bread	Inherent in this crop	4.7
6	Typical bread shape, smooth crust, with small cracks, with ruptures	dark yellow	Baked, without lumps, voids, not sticky	Dark yellow	bread	Inherent in this crop	4.0
7	Typical bread shape, slightly rough, with small cracks, with ruptures	yellow	Baked, without lumps, voids, not sticky	Yellow	bread	Characteristic, pleasant	4.9

Table 4

Organoleptic quality indicators of bread made from quinoa and buckwheat flour No. 1 (green buckwheat)[1]

Variant	Appearance		Condition of the crumb		Smell	Taste	Organoleptic evaluation, points
	Shape, surface	Crust color	Consistency, structure	Color			
1 (Control)	Typical bread shape, smooth crust, with small cracks, no ruptures	Light brown	Baked, without lumps, voids, not sticky	Light gray	Bread, spicy	Characteristic, with a nutty flavor	4.4
II[1]	Typical bread shape, smooth crust, with small cracks, no ruptures	Pale yellow	Baked, without lumps, voids, not sticky, dense	Gray	Buckwheat	Buckwheat	4.3
III	Typical bread shape, smooth crust, no cracks, with large dents	White	Baked, without, voids, not sticky, brittle, hardens quickly	White	Milky	Milky	3.8
IV[1]	Typical shape for bread, smooth crust, with large cracks, no ruptures	Light brown	Baked, without lumps, voids, not sticky	Dark yellow	Milky	Milky	4.5
5	Typical bread shape, not smooth crust, with small cracks and irregularities, no ruptures	Light brown	Baked, without lumps, voids, not sticky	Dark yellow	Bread	Inherent in this crop	4.7
VI[1]	Typical bread shape, smooth crust, no cracks, no ruptures	Pale yellow	Floury, without lumps, voids, not sticky	Gray, with traces of lumps	Bread	Inherent in this crop	3.9
VII[1]	Typical bread shape, smooth crust, with small cracks, with large dents	Light brown	Baked, without lumps, voids, not sticky	Gray	Bread	Inherent in this crop	4.3

Table 5

Organoleptic quality indicators of bread made from quinoa and buckwheat flour No. 2 (grain subjected to HTT)[2]

Variant	Appearance		Condition of the crumb		Smell	Taste	Organoleptic evaluation, points
	Shape, surface	Crust color	Consistency, structure	Color			
1 (Control)	Typical bread shape, smooth crust, with small cracks, no ruptures	Light brown	Baked, without lumps, voids, not sticky	Light gray	Bread, spicy	Characteristic, with a nutty flavor	4.4
II[2]	Typical bread shape, smooth crust, with small cracks, no ruptures	Brown	Not baked, sticky	Brown, dense	Buckwheat	Inherent in this crop	2.0
III	Typical bread shape, smooth crust, no cracks, with large dents	White	Baked, without, voids, not sticky, brittle, hardens quickly	White	Milky	Milky	3.8
IV[2]	Typical bread shape, smooth crust, with small cracks, no ruptures	Dark brown	Baked, without lumps, voids, not sticky	Light brown	Milky	Milky	3.9
5	Typical bread shape, not smooth crust, with small cracks and irregularities, no ruptures	Light brown	Baked, without lumps, voids, not sticky	Dark yellow	Bread	Inherent in this crop	4.7
VI[2]	Typical bread shape, smooth crust, no cracks, no ruptures	Pale yellow	Not baked, sticky	Brown, dense	Bread	Inherent in this crop	2.1
VII[2]	Typical bread shape, smooth crust, with small cracks, with large dents	Dark brown	Rather well-baked, without lumps, voids, not sticky	Gray	Almost buckwheat	Buckwheat, pleasant	4.0

Table 6

Organoleptic quality indicators of bread made from quinoa and corn flour[3]

Variant	Appearance		Condition of the crumb		Smell	Taste	Organoleptic evaluation, points
	Shape, surface	Crust color	Consistency, structure	Color			
1 (Control)	Typical bread shape, smooth crust, with small cracks, no blowouts	Light brown	Baked, without lumps, voids, not sticky	Light gray	Bready, spicy	Characteristic, with a nutty flavor	4.4
II[3]	Typical bread shape, smooth crust, with small cracks, no blowouts	Yellow	Baked, without lumps, voids, not sticky, brittle and crumbly	Yellow	Bread	Inherent in this crop	4.0
III	Typical bread shape, smooth crust, without cracks, with large blowouts	White	Baked, without, voids, not sticky, brittle, hardens quickly	White	Milky	Milky	3.8
IV[3]	Typical bread shape, not smooth crust, with small cracks, no blowouts	Light yellow	Baked, compacted consistency, fine porosity, without «tempering»	Yellow	Milky	Milky	3.8
5	Typical bread shape, not smooth crust, with small cracks and irregularities, no blowouts	Light brown	Baked, without lumps, voids, not sticky	Dark yellow	Bread	Inherent in this crop	4.7
VI[3]	Typical bread shape, smooth crust, with small cracks, no blowouts	Pale yellow	Baked, elastic, uniform porosity, without «hardening»	Yellow	Bread	Inherent in this crop	4.7
VII[3]	Typical bread shape, smooth crust, with cracks, no blowouts	Light brown	Baked, without lumps, voids, not sticky, dense	Gray	Bread	Inherent in this crop	4.9

In the control sample and in products made from green buckwheat flour (Fig. 3, sample IV[1]) and corn flour (Fig. 5, sample IV[3]), some fragility and looseness of the products were observed, the crust thickening is associated with rapid hydration.

In the samples, starch gelatinization is one of the determining indicators in the formation of the quality of bread. In sample III (corn starch 100%) – the crumb is dry, hard, and brittle (Tables 4–6). Sample III (Fig. 3–5) was distinguished by a large volume but the surface of the product was with cracks and uneven and after 6 hours it acquired hardness, becoming stale. The fragility in products made from corn starch and flour (samples III and II[3]) may be due to an insufficient amount of structuring agents that would provide better crumb viscosity. Rapid hardening of the crumb indicates poor water retention.

Sample VI[1] (a mixture of green buckwheat flour and corn starch) had a mealy crumb and traces of unmixed flour, which may be a consequence of the short duration of kneading (Fig. 3, Table 4). However, in sample VI[2] (a mixture of HTT buckwheat flour and corn starch), the surface of the product is smooth, without ruptures (Fig. 4, Table 5).

It should be noted that in sample II[2] (Fig. 4, Table 5) with 100% buckwheat flour from HTT buckwheat and VI[2] – from a mixture of such flour with corn starch, the bread crumb was sticky, unbaked.

With the addition of corn flour (Fig. 5, Table 6), an improvement in the bread crust was observed. The samples had a yellow crust, a smooth surface, without cracks or defects, a baked crumb, elastic, not brittle, not sufficiently fluffy. The taste and smell were typical of the product, with a light aftertaste and aroma of raw materials with a nutty aftertaste.

6. Results based on devising gluten-free bread recipes and studying the criteria for their sensory evaluation: results and summary

In works [13, 15, 20], methodologies for preparing and evaluating the quality of bread using gluten-free flour in the recipe of wheat products are proposed. Unlike [13, 15], our approach to assessing the quality of bread from gluten-free raw materials is unified.

The proposed approach to sensory evaluation of gluten-free bread refers to the food industry and could be applied during laboratory baking of bread. Our methodology does not contradict the well-known 5-point scale for evaluating bread, which makes it possible to compare the results obtained with bread from other cereal crops. The devised gradation provides a more objective determination of the properties of bread from gluten-free flour.

Our data indicate that the addition of any concentration of psyllium powder contributes to the improvement of the physicochemical parameters of bread, primarily – an increase in the volume of finished products. The best organoleptic parameters were the sample with the addition of 1% psyllium (yellow-brown color, smooth surface). However, the addition of more than 1% psyllium to the flour mass leads to a deterioration in the physical properties of the dough – it acquires a rubbery structure, and for organoleptic parameters – the color darkens, which is not positive from the consumer's point of view.

The control sample of bread made from quinoa flour had a typical shape, a smooth crust, with small cracks, without ruptures, the crumb – baked, without lumps, voids, not sticky. According to the organoleptic analysis, it received 4.4 points. A slightly higher score (4.5–4.7 points) was determined in samples 2, IV[1] and 3, 5 and VI[3] with the addition of structure-forming agents (0.75–1.0% psyllium, 50% corn starch) to quinoa flour, as well as corn and buckwheat flour from green buckwheat.

The best organoleptic score (4.9 points) was obtained by bread products prepared from quinoa flour with a mixture of starches (sample 7) and from a mixture of quinoa and corn flour with corn starch – sample VII[3].

Bread samples II[2] and VI[2] (Fig. 4, Table 5), made from buckwheat flour subjected to HTT and a mixture of such flour with corn starch in equal proportions, received an unsatisfactory rating, since they had an unbaked, sticky crumb.

It can be argued that the use of additives intensifies the process of dough fermentation. Development of innovative technologies for gluten-free bakery products based on flour mixtures using starch and pectin as a structure-forming agent is promising [21].

Psyllium can absorb water and turn into a thick, viscous gel that is not digested in the small intestine (Fig. 1) [22].

Potato and corn starches are characterized by high water resistance and viscosity [8]. This contributes to the formation of a stable dough consistency, which helps ensure uniform rising of bread during proofing and baking.

When using quinoa flour in a mixture with green buckwheat flour, using 0.75 and 1.0% psyllium husk powder and 50 and 33.3% corn starch as structure-forming agents, the organoleptic properties of the products were superior to the control sample. The literature describes a wide range of effective doses of psyllium – from minimal to significantly increased (up to 15–17%) [14], which usually lead to an increase in dough viscosity, compaction of the structure or undesirable changes in taste. Therefore, the effect we established, where a small amount (1%) provides the most favorable sensory profile, can be considered a novelty of the study. This indicates that for gluten-free systems with a high content of starches, the optimal structure-forming effect of psyllium is achieved at minimal dosages. Our result indicates a synergistic interaction between the high-protein quinoa fraction and the starch matrix, which provides an optimal balance between gas retention (crumb porosity), elasticity, and pleasant taste characteristics.

The search for ingredients and development of technology for enriched gluten-free bread is one of the promising directions for providing the consumer market with healthy and balanced food products [23]. At the same time, the use of new types of raw materials in product formulations is justified by the acquisition of specific properties by the developed products – improved composition, organoleptic characteristics or functional effect.

As a result of the organoleptic evaluation of bread of new formulations, the addition of up to 1% psyllium and up to 50% corn starch as a structural component of gluten-free bread is recommended. The basis of the dough recipe for gluten-free bread is recommended to be quinoa flour and, in a smaller proportion, green buckwheat and corn flour. Given the lower availability of quinoa flour on the market, it is advisable to industrially use corn and green buckwheat flour in the manufacture of other groups of grain flour food products.

The proposed composite mixture based on quinoa, buckwheat, and corn flour, supplemented with optimal dosages of structure-forming agents (xanthan gum, psyllium, starch), ensures the formation of a stable structure, improved porosity and increased overall sensory appeal of bread without the use of wheat gluten.

Thus, the results of the study can serve as a scientific and practical basis for the implementation of innovative approaches in the production of gluten-free bread and contribute to improving the quality of products focused on modern consumer needs. Our data allow us to recommend to manufacturers the use of psyllium and corn starch in the manufacture of gluten-free bread.

The practical significance relates to the fact that the devised approach to laboratory assessment of bread quality could increase the objectivity and reproducibility of gluten-free bread analysis. The proposed scoring system taking into account weighting factors makes it possible to standardize the approach to quality determination, ensures reproducibility of results, and could be used at technological laboratories, educational institutions, and enterprises for internal production control.

The study was conducted only on composite mixtures of quinoa, buckwheat, corn flour and structuring agents: xanthan gum, psyllium, starch; therefore, the results cannot be fully extrapolated to other types of gluten-free mixtures.

Further research areas may include studying the influence of other recipe mixtures, as well as external technological factors, on the sensory and physicochemical parameters of gluten-free bread quality, as well as the economic efficiency of the production process.

7. Conclusions

1. The devised technique for organoleptic assessment of gluten-free bread provides for a five-point assessment scale containing the following indicators: appearance (shape, surface, color of the crust); crumb condition (consistency, structure, color); taste; smell. The developed weighting factors take into account the smaller volume and porosity of products made from gluten-free raw materials compared to wheat bread.

2. The positive effect of leavening agents such as corn starch, psyllium, and xanthan gum as a stabilizer of the fermentation process on the organoleptic indicators of gluten-free bread has been established. The sample with the addition of 1% psyllium stood out in terms of organoleptic indicators (yellow-brown color, smooth surface). However, adding more than 1% psyllium to the flour mass contributes to the deterioration of organoleptic indicators – the color darkens, which is not positive from the consumer's point of view. It has been proven that samples with quinoa flour, corn (buckwheat) flour, and corn starch in equal proportions have the best organoleptic characteristics.

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

The data will be provided upon reasonable request.

Use of artificial intelligence

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

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Authors' contributions

Nina Osokina: Project administration, Methodology; **Kateryna Kostetska:** Methodology, Investigation, Resources, Supervision, Writing – original draft; Andrii **Kysil:** Investigation, Writing; Olesia Priss: Validation, Writing – review and editing.

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