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DEVELOPMENT OF GLUTEN-FREE PASTA PRODUCTS BASED ON MULTIVARIATE ANALYSIS

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The object of the study is the development of the formulation of gluten-free pasta using multivariate analysis. Celiac disease is a chronic disease characterized by damage to the small intestine mucosa by gluten, a plant protein found in cereals. Due to the growing incidence of celiac disease, it became necessary to provide patients with gluten-free products for life. One of the basic gluten-free products for people is pasta. Therefore, there is a need to expand the range of gluten-free pasta.

This development of gluten-free pasta provides for the use of combined flour mixtures from cereals.

According to the results of the study, comparison and analysis of 8 gluten-free pasta formulations developed and optimized using multivariate analysis, it was found that the sample G has the best organoleptic indicators. Based on the results of the "recipe-price" optimization of the sample G, the optimal ratios of pasta components in terms of the competitiveness of the final product were determined. It was found that the most balanced in organoleptic characteristics is gluten-free pasta (sample G) consisting of: corn flour – 33.51 %; rice flour – 22.24 %; xanthan gum – 2.94 %, water – 41.15 %, table salt – 0.09 %.

The results of the study can be useful in the development of pasta, taking into account the characteristics of the raw materials used, for consumers focused on food without allergenic proteins

Keywords: celiac disease, gluten-free pasta, rice flour, corn flour, recipe mathematical modeling, simplex-lattice design

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1. Introduction

Due to the growing incidence of celiac disease and increasing consumption of gluten-free products, comprehensive studies of the features of gluten-free diets are being conducted. In [1], the authors developed gluten-free bread made from red rice flour, microbial transglutaminase and prebiotic (inulin). The authors of [2] argue that the medical community will face problems of people who depend on a gluten-free diet, as well as complications arising in consumers of a gluten-free diet without medical reasons. The paper [3] describes alternative treatments for celiac disease using such strategies as genetically modified wheat, intraintestinal gluten cleavage using glutenases. The authors of the study [4] suggest using flour from white and blue corn, chickpeas and unripe plantain for the production of gluten-free pasta [5, 6]. Researchers say there may be complications in consumers of a gluten-free diet without medical reasons. Experimental works have studied the effect of gluten-free, combined and normal gluten diets on the digestive tract (on the length of small intestine villi) [7–9]. The authors believe that gut microbiota contributes to the cure of celiac disease. Gut microbiota is a complex microbial ecosystem that is closely related to the development of the human immune system. However, these opinions are preliminary to the current situation in this area, and only future experiments and research can confirm their correctness.

Celiac disease is one of the most common autoimmune diseases that affect more than 1 percent of the world's population and cause inflammation in the small intestine. In people with celiac disease, the immune system responds abnormally to gluten (a protein found in wheat, rye, barley and oats), causing damage to the small intestine.

Since there is no cure, it can be managed solely through a gluten-free diet and lifestyle. People with celiac disease remain gluten sensitive throughout their lives, so in this sense, they are never cured. However, a strict gluten-free diet helps effectively control the condition.

A strict lifelong gluten-free diet is the only recognized treatment for celiac disease. By addressing the cause of the disease, a gluten-free diet promotes the healing of the small intestine mucosa and elimination of symptoms. As long as a gluten-free diet is strictly followed, the problems associated with celiac disease will not return. Relapse occurs when gluten is reintroduced into the diet. To prevent relapse, it is necessary to eat gluten-free food. The growing demand for gluten-free products is driven by the growing number of diagnosed celiac patients and the trend to exclude allergenic proteins from the diet. To meet the increased needs of people diagnosed with celiac disease, it is necessary to expand the range of gluten-free products and dishes. Therefore, research on the development of gluten-free pasta formulations is relevant.

2. Literature review and problem statement

In [10], the authors proposed to use raw and roasted buckwheat flour in an amount of 20 % in the production of gluten-free pasta. The addition of buckwheat made it possible to increase the fiber content. Besides, it did not affect cooking losses. However, issues related to the effect on organoleptic parameters when combining buckwheat with other crops remained unresolved. In [11, 12], red rice, chickpea flour and buckwheat were included in the formulation in different percentages. However, the inclusion of plant crops was reflected in the reduction of the structure and development of the dough. In [13], the inclusion of amaranth flour in the formula resulted in a decrease in antioxidant activity. In [14], the inclusion of rice flour and quinoa flour made it possible to obtain products with high biological value. However, the issues of evaluating the organoleptic indicators of finished products remained unresolved. For example, the use of quinoa flour gave a herbal and bitter taste.

The results of authors' research [15, 16] show that the inclusion of green banana, sorghum, and safflower flour in the composition of gluten-free products increases the biological and nutritional value, but affects the moisture content of the dough due to the high moisture content in the products. The humidity of the dough affects the shaping process and negatively affects the shape of the product.

Also in [15, 16], there are no data on the optimization of the developed formulations.

To ensure the quality indicators of gluten-free products, not only raw materials, rheological properties and characteristics were studied, but also the influence of various additives. For example, studies have been conducted [17] on the production of gluten-free breadsticks enriched with olive leaves and olive plant wastewater, and in other studies, the main parameter was gluten-free products enriched with inulin. In [18], there are no data to ensure control over the content of other protein-containing components.

It is shown that in order to increase the biological and nutritional indicators of gluten-free products, it is recommended to include different types of plant crops in the formulation. The authors of [19] studied the combination of buckwheat flour with rice and corn flour at different levels in gluten-free biscuit formulations. The estimated quality parameters were the degree of spreading, color and texture parameters (hardness and brittleness). The disadvantage of this formulation was an increase in moisture content, spreading coefficient and crack resistance with a decrease in the hardness of the product.

Buckwheat, rice and corn are among the most valuable pseudo-cereals in terms of their nutritional composition, and are suitable for celiac patients due to the absence of gluten. However, gluten is the main structural protein responsible for the development of pasta structure. Therefore, the production of high-quality gluten-free products is challenging. One way to solve the issue of structure formation in gluten-free products is to use hydrocolloids in the formulation. Hydrocolloids (gums) are known to have good functional characteristics, such as emulsification, gelling, solubility and texture improvement. In pasta and bakery products, hydrocolloids are used to improve dough characteristics, finished product characteristics, sensory qualities and prolong the shelf life of the products. The following hydrocolloids are used as texture improvers: carrageenan, karaya, alginate, gum arabic, methylcellulose, carboxymethylcellulose, hydroxypropylmethylcellulose, carob, balangu seeds, wild sage seeds, basil seeds and cress seed gum, which improve the rheological, physicochemical, textural and qualitative characteristics of bakery products.

In [18], the effect of hydrocolloids on the rheological, physicochemical, textural and qualitative characteristics of bakery products was investigated. It was found that gums affect gelatinization and reduce starch retrogradation, which helps to improve mixing and increase the shelf life of products due to moisture retention.

The paper [20] presents the results of developing a gluten-free waffle technology using corn, rice and buckwheat flour, as well as a mixture of xanthan and guar gum as structure-forming components in the amount of 0.1 % guar and 0.5 % xanthan gum in buckwheat flour. In this work, the quality indicators were determined by the strength of the wafer sheet and the texture properties of the finished products.

The analysis showed that the consumption of gluten-free products, despite the expansion of the range, tends to increase. For example, in the USA, it is projected to increase by 8.3 % or $10.96 billion from 2022 to 2029 [21]. Major factors driving the gluten-free products market include the increasing incidence of celiac disease and other food allergies, as well as the growing prevalence of irritable bowel syndrome.

In view of the above, the development of gluten-free pasta formulations from combined flour is promising.

3. The aim and objectives of the study

The aim of the study is to develop formulations for gluten-free pasta from combined flour with specified characteristics, which allows the use of various raw materials to expand the range of traditional gluten-free products.

To achieve the aim, the following objectives were set:

– to select components for the gluten-free pasta formulation based on various raw materials;

– to carry out optimization and assessment of pasta formulations according to the quantitative composition of the pasta mixture ingredients.

4. Materials and methods

4. 1. Object of the study

The object of the study is the technology of production of gluten-free pasta from the combined flour of grain crops (corn, rice, buckwheat) conforming to the requirements of Codex Alimentarius 118.

4. 2. Production of pasta in the laboratory

Gluten-free pasta was prepared from a combined pasta mixture. Mixtures were prepared from corn, rice, buckwheat flour in different ratios and combinations. In the formulation, corn starch, xanthan gum and egg white were used as structurants and stabilizers (Table 1).

Table 1

Formulation of combined mixtures for gluten-free pasta

Composition, %	Samples							
	A	B	C	D	E	F	G	H
Corn flour	30–45	–	–	–	–	30–45	30–45	30–45
Rice flour	–	–	–	20–45	20–45	20–45	20–45	–
Buckwheat flour	–	25–40	25–40	–	–	–	–	–
Corn starch	10–25	10–25	10–25	10–25	10–25	–	–	10–25
Egg white	2.5–5	2.5–5	2.5–5	2.5–5	2.5–5	–	–	–
Xanthan gum	1–3	1–3	1–3	1–3	1–3	–	1–3	1–3
Water	41.15	41.15	41.15	41.15	41.15	41.15	41.15	41.15
Salt	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

As can be seen from Table 1, in the formulation A, the basis of the pasta mixture was corn flour, and corn starch, egg white and xanthan gum were used as structure-forming agents. In the formulation G, the pasta mixture included corn flour and rice flour, and xanthan gum as a structurant. The ratio of the mixture components varied within the following range (as a percentage): corn flour – (30–45) %; rice flour – (20–45) %; buckwheat flour – (25–40) %, corn starch – (10–25) %; egg white – (2.5–5) %, xanthan gum – (1–3) %.

Gluten-free pasta was prepared by cold kneading. When kneading, water and salt were constants: 700 g and 1 g, respectively. The pasta was extruded using a barrel-shaped screw with a length-to-diameter ratio L/D=180/40 mm. The dough was formed into tagliolini, using a 3.5 mm round hole die and cut into 30 mm pieces. After pre-drying for 5 minutes at room temperature, additional drying was carried out in a drying oven.

4. 3. Pasta drying

To dry gluten-free pasta, a Memmert UF30 drying oven (Germany) was used. Drying was carried out in an air dryer at 40 °C for 4 hours. Dried pasta (moisture content less than 12 %) was cooled and packed in sealed plastic bags of 250 g.

4. 4. Cooking time

In a small pan, 300 ml of water was heated to a boil. 25±0.5 g pasta was cooked in boiling water and washed with 25–26 °C water for 15 seconds using a plastic sieve to remove excess water.

4. 5. Software implementation of gluten-free pasta parameters optimization

The software of the study included a program for simplex-lattice design and processing the results of the simplex experiment, to optimize the formulation – the Solver tool in Microsoft Excel. Such mathematical processing was also used in the development of formulations for the ratio of ingredients of various pasta products.

4. 6. Optimization of gluten-free pasta parameters

Optimization of the gluten-free pasta components was carried out using Scheffe's simplex-lattice designs over the initial data: x_1, x_2 – mixture components: corn and rice flour, x_3 – additive (xanthan gum), Y – general organoleptic evaluation of pasta. Intervals of variation of input variables: x_1=(30–45) %; x_2=(10–45) %; x_3=(1–3) %.

4. 7. Pasta shaping

After selecting the optimal sample, tagliolini, a type of pasta, 30 mm long and 3.5 mm wide in the form of a tube, were shaped in laboratory conditions (Fig. 1).

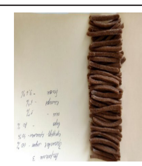
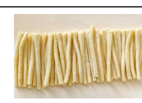
a *b*

Fig. 1. Tagliolini shaping process: *a* – extrusion of pasta; *b* – finished product

Table 2 shows photographs of experimental samples.

Table 2

Photos of experimental samples

Sample	Photo
A	
B	
B	
D	
E	
F	
G	
H	

The shaping process was carried out by a Concerto 5 pasta machine for making taglionili with a special Sirman No. 32 shaping head.

5. Results of organoleptic evaluation and optimization of gluten-free pasta formulations from combined raw materials

5. 1. Selection of gluten-free pasta ingredients based on sensory evaluation

The prepared finished samples (Table 2) were evaluated on a 10-point scale during tasting. The evaluation took into account the following parameters: appearance, color, smell, cooking quality, strength, taste and cooking time. The results of the tasting evaluation are presented in Table 3.

Table 3

Tasting evaluation results

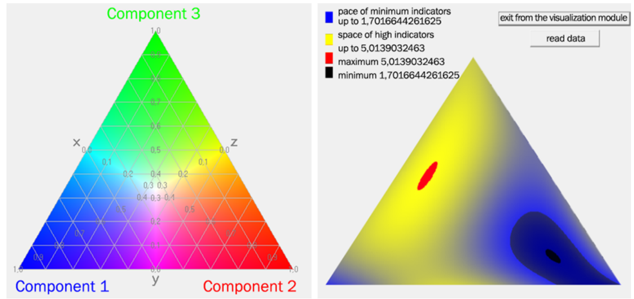
Samples/Parameters	A	B	C	D	E	F	G	H
Appearance	8	7	8	3	3	4	9	5
Color	8	3	8	5	6	8	9	5
Smell	8	7	8	8	8	8	8	8
Cooking quality	9	6	5	4	5	4	9	6
Strength	8	6	7	5	6	5	9	6
Taste	7	6	5	6	7	6	9	7
Cooking time	8	7	7	4	3	3	8	8

Sensory evaluation based on the organoleptic analysis of pasta allowed us to draw the following conclusions: in terms of appearance, the best indicators were in options A, B, C, G. The worst indicators were in options D, E, F, in the first two due to the one-component nature (41.15 and 35.27 % rice flour), and in the latter – the lack of binders such as gum or protein. In terms of color, options A, C, G were in the lead. The presence of corn flour (A – 41.15 %, G – 32.31 %) and buckwheat (29.39 %) in the composition gives a pleasant color. In terms of cooking quality and strength, A and G received the highest scores. The synthesis of corn flour and xanthan gum gives a pleasant to the touch elasticity and pliability during processing. When evaluating the taste, on the example of the absence of aftertaste, bitterness and pleasant taste, option G was in the lead. During the cooking period, some experimental samples boiled soft for 2–3 minutes (options D, E, F), which is explained by the one-component nature of the first two and the absence of a binder. The remaining samples were prepared within 5–9 minutes. As a result of comparison and analysis of characteristics, the sample G has the best organoleptic characteristics.

5. 2. Optimization of the sample G formulation and determining the competitiveness of the final product

The graphical interpretation of the results of the numerical experiment to optimize the formulation of the gluten-free pasta sample G is shown in Fig. 2.

Based on data processing, the following gluten-free pasta formulation was obtained (Table 4).



a *b*

Fig. 2. Graphical interpretation of the results of simplex-lattice design: *a* – effect of the mixture composition on the overall sensory evaluation of pasta; *b* – extremum region

Table 4

Optimized gluten-free pasta formulation

Composition, %	G
Corn flour	32.31
Rice flour	23.40
Buckwheat flour	–
Corn starch	–
Egg white	–
Xanthan gum	2.98
Salt	0.09
Water	41.15

6. Discussion of the results of modeling gluten-free pasta formulations

The analysis of the data obtained (Table 1) allows us to conclude that a decrease in the share of rice flour, with an increase in the share of corn flour and the presence of xanthan gum, provides quality indicators of gluten-free pasta. A comprehensive quality assessment (Table 2) showed that the gluten-free pasta sample G, including corn and rice flour, xanthan gum, as well as water and table salt, is the most balanced in terms of organoleptic characteristics. Optimization of this formulation allowed us to determine the quantitative composition: corn flour – 32.31 %; rice flour – 23.40 %; xanthan gum – 2.98 %, water – 41.15 %, table salt – 0.09 % (sample G).

In this formulation, the presence of xanthan gum provides high overcooking resistance, as well as elasticity and pliability during processing. Corn flour gives a pleasant color.

The data obtained indicate that optimization of the quantitative composition of allergenic proteins in pasta using modeling makes it possible to obtain a finished product that meets the requirements of Codex Alimentarius 118. Simplex-lattice design [22] provides accelerated execution of a large amount of calculations and obtaining a recipe mixture using various raw materials.

The results of the study showed that modeling gluten-free pasta recipes allows optimizing the process of selecting quantitative indicators of gluten-free product components. However, these recommendations apply to the recipe of gluten-free pasta made from corn and rice flour and xanthan gum. At the same time, quantitative reduction of allergenic proteins based on modeling does not always provide acceptable physicochemical and organoleptic characteristics of the final product. Therefore, optimization using simplex-lattice design is recommended. The use of effective modeling and instrumental analysis in combination with organoleptic methods yielded promising results on the characteristics of gluten-free pasta.

7. Conclusions

1. A comprehensive quality assessment showed that the most balanced in organoleptic characteristics is gluten-free pasta produced according to the formulation including corn and rice flour, xanthan gum, as well as water and table salt (sample G). It was found that pasta prepared by this recipe has a pleasant appearance, color, smell, taste and no aftertaste. It was also found that the synthesis of corn flour and xanthan gum gives a pleasant to the touch elasticity and pliability during processing.

2. According to the results of optimization, pasta produced according to the formulation (sample G): corn flour – 32.31 %; rice flour – 23.40 %; xanthan gum – 2.98 %, water – 41.15 %, table salt – 0.09 %, have high organoleptic quality indicators.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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