CHAPTER 1

Improvement of gluten-free granola production technology in the restaurant segment

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Abstract

Granola is a popular product among supporters of healthy eating due to its high fiber, vitamin, and mineral content.

This study aimed to obtain popular breakfast cereals – granola – using various ingredients. It researched twelve recipe compositions based on rice, buckwheat and amaranth flakes, freeze-dried peach, strawberry, cherry, and fig as well as almond and hazelnut nuts. The granola recipe contained two different sweeteners (Jerusalem artichoke syrup and maple syrup). The sensory properties of the samples were evaluated.

The study confirmed that the energy value of all the proposed granola recipes per 100 g is nearly identical, ranging within 352...389 kcal/100 g, which meets the established nutritional standards. The recipes containing buckwheat flakes exhibited higher energy values, while rice-based granola had a slightly lower energy value. However, this difference was not significant. The developed recipes belong to the category of low-glycemic index products (below 55 units), making them suitable for individuals with diabetes and for use in dietary nutrition.

The developed recipe contributes to increasing nutritional value, improving organoleptic properties, and expanding the range of functional food products, such as granola, that meet modern requirements for healthy eating.

Keywords

Granola, gluten-free, pseudo-cereals, freeze-dried fruits, nuts, Jerusalem artichoke syrup, maple syrup, glycemic index.

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1.1 Gluten-free products: demand, production, and scientific development

The modern food market is experiencing a steady increase in demand for functional and specialized products, particularly gluten-free ones. This trend is driven by the growing number of consumers following a gluten-free diet due to medical conditions such as celiac disease and gluten sensitivity, as well as a conscious choice in favor of a healthy lifestyle [1]. As a result, the restaurant segment is forced to adapt its offerings and implement innovative production technologies.

Granola is a popular product among the supporters of healthy eating due to its high fiber, vitamin, and mineral content. However, traditional granola often contains ingredients that may include gluten, such as oat flakes, wheat, or barley components [2], limiting its accessibility for individuals with gluten intolerance.

Despite the availability of gluten-free alternatives on the market, most of them are produced on an industrial scale and may contain preservatives, stabilizers, and flavor enhancers, which reduce their nutritional value and benefits. At the same time, the restaurant segment has the opportunity to offer fresh, high-quality gluten-free granola, developed using original recipes with natural ingredients.

Recent studies also confirm that the restaurant segment is a leader in implementing innovations in the food industry due to broader technological capabilities, availability of qualified staff, and higher consumer expectations. A significant number of consumers who follow a gluten-free diet report a lack of gluten-free options on restaurant menus, creating barriers to eating out. Moreover, studies indicate a growing demand for healthy and functional products among consumers, highlighting the need to expand the range of gluten-free dishes in restaurants [3]. Unlike cafés or food trucks, restaurants are able to ensure consistent quality and presentation of complex functional meals, such as gluten-free granola, which comply with modern healthy eating trends.

In this regard, the relevance of this study is based on the development of recipes and the improvement of production technology for gluten-free granola. This will expand the product range in the restaurant segment, ensure high quality, and meet modern healthy eating standards.

In 2022, the global market for gluten-free products was estimated at 6.45 billion USD, and it is expected to grow at a compound annual growth rate (CAGR) of 9.8% from 2023 to 2030. The primary factors driving this market expansion include increased awareness of disease prevention, particularly for cardiovascular diseases, diabetes, obesity, chronic lung diseases, and metabolic syndrome. An additional catalyst for market growth was the COVID-19 pandemic, which significantly increased the demand for gluten-free products. This trend is caused by consumers' growing focus on their health and well-being. During the pandemic, interest in highly nutritious food products greatly increased, further contributing to the popularity of gluten-free products [4].

The number of individuals suffering from gluten intolerance is rising worldwide, simultaneously increasing the demand for products suitable for a gluten-free diet. Recent scientific research in the field of gluten-free food products demonstrates significant progress in the development of alternative ingredients and production technologies. This category includes pseudo-cereal crops, which are a valuable source of nutrients. They are characterized by a high protein, fiber, vitamin, and mineral content and are naturally gluten-free. This makes them particularly beneficial for individuals with celiac disease or gluten sensitivity. In addition to high nutritional value, pseudo-cereals have beneficial health properties, in particular, they contribute to a reduction in the risk of developing cancer, diabetes, arterial hypertension, and cardiovascular pathologies. Their antioxidant properties are attributed to the presence of phenolic compounds that can reduce oxidative stress [5].

Due to their unique nutritional and functional properties, underutilized pseudo-cereal crops have significant potential for the development of innovative "smart" food products. The most nutritionally rich representatives of this group include amaranth, buckwheat, and quinoa. The protein content of these crops ranges from 9 to 21%, making them a valuable source of plant protein [6].

Researchers also focus on the use of gluten-free grain crops such as amaranth, quinoa, buckwheat, and corn, which have high nutritional value and improve the texture and taste characteristics of the final product. Buckwheat, associated with bioactive components, provides health and nutraceutical benefits. Bioactive components extracted from buckwheat can be used in the pharmaceutical industry to treat various health-related conditions [7]. Buckwheat is also a rich source of starch, while amaranth seeds contain 8–16% dietary fiber. The lipid content in quinoa and amaranth is 2.3 times higher than in wheat and buckwheat [5]. The protein content in amaranth varies from 12 to 24%, depending on the variety and genotype. Its amino acid profile closely resembles that of an ideal protein, with a notable high content of lysine – an essential amino acid, that is typically deficient in most plant proteins [8].

Granola and breakfast cereal flakes are produced using extrusion technology, which is also widely applied to produce other types of snacks. However, the high-fat content of amaranth complicates its use in the production of extruded products, since fat has a significant lubricating effect, which limits the degree of expansion during extrusion [9].

To improve the technological properties and ensure the quality characteristics of the final product, it is recommended to extrude amaranth with the addition of starch.

In addition, the creation of nutritionally balanced extruded food products requires combining amaranth with other cereals, in particular rice, which provides an optimal macronutrient composition [10].

Studies have shown that pseudo-cereals are promising raw materials for the production of gluten-free breakfast cereals. In vitro predictive glycemic index assessments have confirmed that extruded products containing pseudo-cereal ingredients had a significantly lower content of rapidly and slowly digestible carbohydrates compared to control samples. This indicates the potential for using pseudo-cereal flour to regulate the glycemic response to extruded breakfast cereals [10].

Amaranth-based gluten-free granolas were developed, receiving high sensory evaluations and demonstrating appropriate physicochemical and nutritional characteristics. Additionally, inulin and oligofructose were used to improve the quality of amaranth-based bars, which positively affected their sensory properties [10].

Studies also confirm the importance of a balanced composition of gluten-free products to ensure the appropriate level of proteins, fats, and carbohydrates. The use of natural sweeteners, such as honey, agave syrup or date syrup, allows to increase the nutritional value of gluten-free granola without adding refined sugar. The increasing prevalence of diseases related to excessive sugar consumption poses a serious health risk. Many scientific studies have confirmed the correlation between high sugar consumption and an increased risk of developing cardiovascular diseases, obesity, and type 2 diabetes. In this regard, there is a growing demand for sugar-free alternatives or natural sweeteners such as low-calorie sugar substitutes, honey, grape molasses, and others [11]. However, honey loses its beneficial properties at high temperatures during granola baking.

Maple syrup is a delicacy prepared by boiling the sap obtained from various species of maple trees, mainly the sugar maple. Compared to other natural sweeteners, maple syrup is considered a better alternative to refined sugar due to its high concentration of phenolic compounds and minerals. The presence of organic acids (e.g. malic acid), amino acids and essential amounts of minerals including potassium, calcium, zinc and manganese make maple syrup unique [12].

Helianthus tuberosus L., or Jerusalem artichoke, appears to be a superfood that provides human health benefits at the level of the digestive, gastrointestinal, and dermatological systems. It is suitable for diabetic patients due to its high inulin content and is commonly used in hypocaloric diet due to its low carbohydrate content. In fact, 5–15 g per day is beneficial, with an evident prebiotic effect. Despite the science-based potential, the cultivation and consumption of Jerusalem artichoke remain limited at the global scale due to insufficient awareness among both consumers and producers [13].

Jerusalem artichoke (*Helianthus tuberosus L.*) belongs to the sunflower plant family and originates from North America. It produces high-yielding tubers that store inulin as an energy source. The content of this fructan in the tubers ranges from 8–21% [13]. Due to the β (2 $\rightarrow$ 1) bonds, inulin cannot be digested by intestinal enzymes, so it can be successfully used for the development of functional foods [14]. On the other hand, inulin-rich carbohydrates obtained from Jerusalem artichoke tubers have been shown to promote the growth and probiotic properties of some *Lactobacillus* strains [14].

Fruit drying is an essential step in granola production, as dried fruits retain most of the vitamins, minerals, and antioxidants found in fresh fruits [15]. Freeze-dried fruits and berries are produced by lyophilization, a technology of drying by deep freezing and subsequent removal of moisture under vacuum conditions. This method allows to preserve the maximum amount of nutrients, aroma, color, and structure of the product, which distinguishes it from traditional drying methods [16].

Pre-cooling of fruits is an important post-harvest processing step, which ensures the preservation of quality, slows down spoilage processes, and extends the shelf life of fruits. The choice of the optimal cooling method depends on the physiological characteristics of the fruits, storage conditions and economic feasibility [17, 18].

The production process of freeze-dried fruits and berries consists of several key stages. Firstly, fruits and berries are thoroughly washed, cut if necessary, and then the seeds or cores are removed. Then, prepared fruits and berries are frozen at ultra-low temperatures (–40…–50°C). This contributes to the formation of small ice crystals inside the cells. It minimizes damage to the cell membrane and overall structure. After freezing, the product is dried in a vacuum (freeze-drying). Frozen fruits are placed in a vacuum chamber, where moisture evaporates without turning into a liquid state (sublimation), bypassing the melting stage. This preserves the structure, color, taste, and nutrients of berries and fruits. Then the products are subjected to final drying (removal of residual moisture) at a temperature of +30…+50°C. Additional removal of residual moisture is necessary to ensure long-term storage. The process lasts from 8 to 24 hours, depending on the type of product. The finished product is hermetically packaged to prevent moisture absorption from the air [16].

Freeze-dried fruits and berries have numerous benefits. Thus, up to 95% of vitamins and trace elements are preserved, natural taste and aroma are quickly restored upon contact with water, and they have a long shelf life of up to 1–2 years. Freeze drying has proven to be the most effective and innovative method for preserving antioxidant properties. After the sublimation cycle, the final moisture content of the material is only 2–5% of the initial one, ensuring maximum preservation of beneficial properties and the production of high-quality product. This method is promising for preserving the quality of raw materials during drying and preserving its medicinal properties [19].

Freeze-dried products are widely used in the food industry, sports, and tourist nutrition, as well as in the manufacture of baby food, muesli, desserts, and confectionery.

Considerable attention is paid to studying the impact of various technological approaches on the quality of gluten-free products. Studies show that the use of fermentation improves the organoleptic properties and digestibility of gluten-free products [20].

In addition, natural antioxidant-rich ingredients can extend the shelf life of granola without using synthetic preservatives. Foods rich in natural antioxidants include dried fruits and seeds, e.g. walnuts, almonds, hazelnuts, chia seeds, flax seeds; cocoa and dark chocolate with a high cocoa content; green tea and red tea (rooibos); spices, e.g. turmeric, ginger, oregano, parsley, cinnamon; vegetable oils, e.g. olive oil, flaxseed oil, sunflower oil; and red wine [21].

Thus, modern scientific developments in gluten-free technologies aim to improve the quality, nutritional value, and taste characteristics of products, which is an important aspect when developing new recipes for the restaurant segment.

1.2 Development of a gluten-free granola recipe

This scientific research aimed to develop a recipe and improve the technology for producing gluten-free granola in the restaurant segment. The main research objectives were to develop variants of experimental recipes for gluten-free granola; to produce experimental samples; to conduct a tasting evaluation of the experimental samples; to determine their energy value and glycemic index; based on the results obtained, to select the optimal recipe composition and improve the production technology.

Raw materials selected for the production of gluten-free granola included amaranth, buckwheat, and rice flakes; freeze-dried cherry, peach, fig, and strawberry, as well as almond and hazelnut kernels. All raw materials were of industrial origin, specifically: amaranth flakes produced by AmarantBio (Ukraine), rice and buckwheat flakes – Agricom Group (Ukraine), freeze-dried fruit and berry ingredients – Vitberry (Ukraine), Jerusalem artichoke syrup – Erdapfel (Ukraine), maple syrup – Vertmont (Canada), and nuts – Borges (Spain) and Targroch (Poland). The use of industrially produced raw materials ensured standardized quality and reproducibility of experimental conditions.

The first stage of modelling the gluten-free granola recipe involved the selection of analogue. For this purpose, an analysis of existing samples was conducted, in particular, recipes used in industrial analogues. An analogue chosen for modification contained: oat flakes – 100 g, butter – 20 g, raisins – 30 g, walnuts – 80 g, honey – 20 g.

The specified recipe has excellent organoleptic properties and is in high consumer demand.

During the research, the following changes were introduced to the basic recipe (analogue) in order to improve it:

– oat flakes were replaced with buckwheat, rice, and amaranth flakes;
– raisins were replaced with alternative freeze-dried fruits and berries;
– walnut kernels were replaced with almonds and hazelnuts;
– honey was replaced with maple syrup or Jerusalem artichoke syrup.

The replacement of honey with plant-based syrups was carried out taking into account the need to maintain an equivalent level of sweetness in granola compared to the selected analogue. It is known that the sugar content in 100 g of the product is as follows: honey – 80 g, Jerusalem artichoke syrup – 60.3 g, maple syrup – 68 g. Accordingly, the optimal amount of syrups was calculated to ensure the required level of sweetness.

The amount of sugar equivalent to 20 g of honey in 100 g of granola was determined using the formula (1.1)

$$M_{sug} = \frac{M_{hon} \cdot C_{hon}^{sug}}{100}, \tag{1.1}$$

where M_{sug} – mass of sugar in 100 g of granola provided by honey, g; M_{hon} – mass of honey according to the granola recipe, g; C_{hon}^{sug} – sugar content in 100 g of honey, g

$$M_{sug} = \frac{20 \cdot 80}{100} = 16 g.$$

The required amount of syrups, which will provide 16 g of sugar in granola, was determined using the formula (1.2)

$$M_{syr} = \frac{M_{sug} \cdot 100}{C_{syr}^{sug}}, \tag{1.2}$$

where M_{syr} – mass of syrup, g; C_{syr}^{sug} – sugar content in 100 g of syrup: maple syrup – 68 g, Jerusalem artichoke syrup – 60.3 g, respectively:

$$M_{syr}^{marple} = \frac{16 \cdot 100}{68} = 23.5 g,$$

$$M_{syr}^{Jerusalem\,artichoke} = \frac{16 \cdot 100}{60.3} = 26.5 g.$$

Thus, 23.5 g of maple syrup and 26.5 g of Jerusalem artichoke syrup will be introduced into the experimental recipes.

As part of the scientific experiment, twelve experimental recipes were developed: six recipes based on rice flakes (**Table 1.1**) and six recipes based on buckwheat flakes (**Table 1.2**).

Table 1.1 Recipe composition of experimental granola samples based on rice flake

No.	Name and ingredient content, g							
	Rice flakes	Amaranth flakes	Freeze-dried peach	Freeze-dried strawberry	Almond	Jerusalem artichoke syrup	Maple syrup	Butter
rf1	20	80	20	30	30	26.5	–	20.0
rf2	50	50	20	30	30	26.5	–	20.0
rf3	80	20	20	30	30	26.5	–	20.0
rf4	20	80	20	30	30	–	23.5	20.0
rf5	50	50	20	30	30	–	23.5	20.0
rf6	80	20	20	30	30	–	23.5	20.0

Table 1.2 Recipe composition of experimental granola samples based on buckwheat flakes

No.	Name and ingredient content, g							
	Buckwheat flakes	Amaranth flakes	Freeze-dried cherry	Freeze-dried fig	Hazelnut	Jerusalem artichoke syrup	Maple syrup	Butter
rf7	20	80	30	20	30	26.5	–	20.0
rf8	50	50	30	20	30	26.5	–	20.0
rf9	80	20	30	20	30	26.5	–	20.0
rf10	20	80	30	20	30	–	23.5	20.0
rf11	50	50	30	20	30	–	23.5	20.0
rf12	80	20	30	20	30	–	23.5	20.0

The experimental samples were produced on the basis of the Educational and Research Laboratory of Restaurant Production Technology of the National University of Life and Environmental Sciences of Ukraine (Kyiv) using the following technology: dry gluten-free ingredients were measured in the quantitative ratios specified in the recipe and then thoroughly mixed until fully combined; the nuts were ground in a blender, the husk was removed by sieving and mixed with the dry gluten-free base; the syrups (maple and Jerusalem artichoke) were heated to 45°C and melted butter was added to them to obtain a liquid base. Then the liquid and dry bases were combined and thoroughly mixed until the ingredients began to bind together. The prepared semi-finished product was spread evenly on a baking tray and placed into a steam convection oven preheated to 160°C. Heat treatment lasted 30 minutes. The temperature-time regime of heat treatment was selected based on the technological specifics of granola preparation in restaurant production conditions, in particular to ensure even roasting, prevent sugar caramelization and preserve organoleptic properties. This regime is recommended in literary sources for grain mixtures containing cereals, nuts, dried fruits, and natural syrups [22].

Freeze-dried cherries, peaches, and figs were chopped into 5–6 mm cubes. Freeze-dried strawberry slices were cut into 10–12 mm pieces. After heat treatment, the granola was cooled, broken apart if clumped, and then thoroughly mixed with the prepared freeze-dried ingredients. The finished product was packed in 250 g bags.

The organoleptic properties of the finished product were assessed, and the calorie content and glycemic index were calculated using the methodologies described in the literature.

The energy value of the experimental samples was determined using a formula based on the fact that the main macronutrients (proteins, fats, and carbohydrates) have different calorie content. Fats contain the most energy (9 kcal/g), while proteins and carbohydrates provide 4 kcal and 3.75 kcal per 1 g, respectively. Hence, the formula (1.3) is as follows

$$E = 4\sum P + 9\sum F + 3.75\sum C, \tag{1.3}$$

where E – total energy value (kcal per 100 g of granola); P – protein content (g per 100 g of granola); F – fat content (g per 100 g of granola); C – carbohydrate content (g per 100 g of granola).

1.3 Organoleptic evaluation of granola samples

Organoleptic or tasting evaluation is a key stage in the development of new gluten-free granola recipes, since it is the consumer perception of the product that ultimately determines the product's market success. The primary goal of the tasting is to analyze the organoleptic properties, including taste, aroma, texture, visual appeal, and overall quality assessment.

Taste characteristics play a key role in how consumers perceive the finished product. The expert commission assesses the harmony and balance of taste, paying attention to the level of sweetness, sourness, saltiness, and possible bitter notes.

Aroma is equally important and it should match the natural profile of the ingredients, be pleasant and be free from off-flavors that may appear due to improper storage or the use of low-quality raw materials.

The texture of granola is another important parameter in tasting evaluation. The product should not be too hard or too soft. Typically, granola has a crisp texture that should remain firm even after contact with milk or other liquids. During testing, experts analyze crispness retention and moisture absorption rate.

Visual appeal significantly influences consumer choice. Experts assess the uniformity of shape, color, and particle size of the product. A well-presented product directly affects its attractiveness to the end consumer and determines its competitiveness.

During the development of the recipe, it is necessary to establish the optimal ratio of the main components of the product, such as grain components, nuts, and freeze-dried fruits. Tasting analysis allows to determine the balance of these ingredients, ensuring a harmonious taste profile without the dominance of individual components.

An equally important factor is the ratio of sweeteners to other components of granola. Excessive or insufficient sweetness can significantly affect the final perception of the product.

To conduct a tasting assessment, quality criteria and their characteristics, which the finished product must meet, were developed (**Table 1.3**).

Table 1.3 Organoleptic quality indicators of gluten-free granola

Name of indicator	Its characteristics
Appearance	The shape of elements is without clear contours, their surface is not uniform with air pockets and particles of flakes of the certain crop, pieces of nuts, freeze-dried fruits, and berries
Taste and smell	The smell is pleasant, inherent in nuts, freeze-dried fruits, and berries; the taste is rich in nuts and freeze-dried fruits
Color	The rice-amaranth base is golden-brown. The buckwheat-amaranth base is light brown
Consistency	Dried, with large particles of raw materials mixed and bonded together

The five-point evaluation scale was applied, adhering to the following gradation: "excellent level" – 4.8...5.0 points, "good level" – 4.0...4.7 points, "satisfactory level" – 3.0...3.9 points, "low level" (marginally acceptable) – 2.0...2.9 points, "unacceptable level" – below 2.0 points. Granola samples scoring below 2.0 points were excluded from further research. To unify the evaluation of sensory properties, a detailed characteristic of each score was developed, which is presented in **Table 1.4**.

Table 1.4 Criteria for scoring sensory evaluation of gluten-free granola

Points	Criteria description
4.8...5.0 "excellent level"	Uniform, aesthetically appealing appearance, without burnt or stuck parts; intense, pronounced aroma (nuts, fruits, berries); rich, harmonious taste without off-flavors; ideal crispness and textural uniformity; golden-brown uniform color; components are well distributed
4.0...4.7 "good level"	Minor defects in appearance or color; pleasant but less intense aroma; good taste, with possible slight imbalance; almost crispy texture with minor deviations; slight unevenness in color or distribution of ingredients
3.0...3.9 "satisfactory level"	Noticeable irregularity in shape, partial sticking or burning; weakly expressed or insufficiently typical aroma; mediocre taste with indistinct or foreign notes; the texture is not crispy enough or with hard inclusions; uneven coloring
2.0...2.9 "low level"	Significant defects in appearance (sticking, burnt parts); unclear or weak aroma; undesirable or unbalanced taste; unacceptable texture: too hard or sticky; spotty or uneven color
below 2.0 "unacceptable level"	Pronounced defects in shape, color and structure; absence or unpleasant smell; strongly undesirable taste (bitterness, acidity, foreign flavors); texture is completely unacceptable for consumption; overall characteristics do not meet quality requirements

Average tasting scores are visualized in the form of quality profiles (**Fig. 1.1–1.4**).

In the process of analyzing the results of experimental studies presented in profiles (**Fig. 1.1–1.3**), it was found that all granola samples developed in accordance with the proposed recipe compositions received high tasting scores within the "good level" and "excellent level".

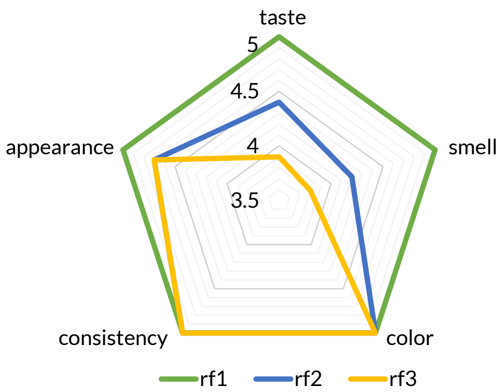

Fig. 1.1 Quality profiles of experimental gluten-free granola recipes based on rice and amaranth flakes and Jerusalem artichoke syrup

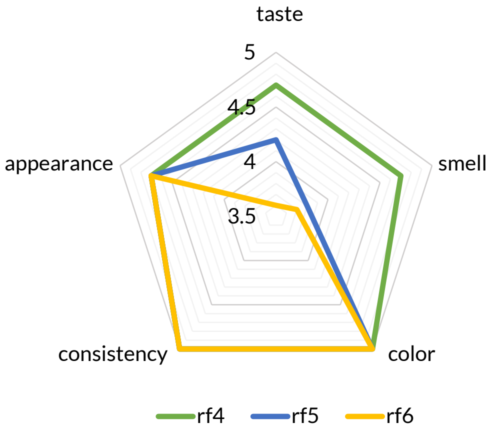

Fig. 1.2 Quality profiles of experimental gluten-free granola recipes based on rice and amaranth flakes and maple syrup

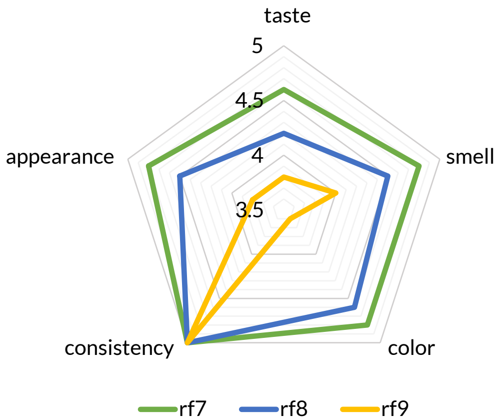

Fig. 1.3 Quality profiles of experimental gluten-free granola recipes based on buckwheat and amaranth flakes and Jerusalem artichoke syrup

The lowest average scores were recorded for granola samples that contained the maximum amount of buckwheat flakes (80%). In particular, the average score for the rf9 recipe composition with Jerusalem artichoke syrup was 4.03 points, and rf12, which contained maple syrup, received 4.08 points.

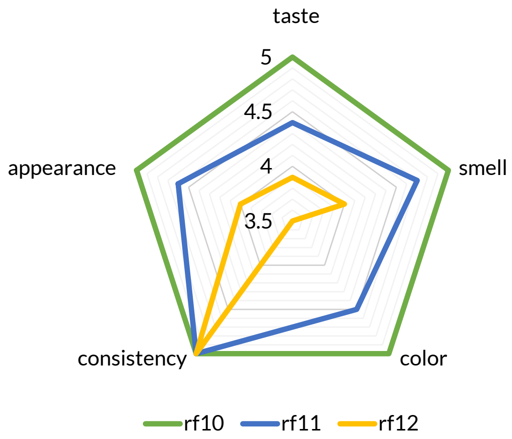

Fig. 1.4 Quality profiles of experimental gluten-free granola recipes based on buckwheat and amaranth flakes and maple syrup

The main criteria that caused the decrease in ratings were the taste and aroma characteristics, color and overall appearance of the product. Most tasters noted an imbalance in taste and aroma in the experimental samples with a high content of buckwheat flakes, which led to an excessive dominance of specific buckwheat notes. In addition, a significant proportion of buckwheat flakes in the composition led to the formation of a dark brown color with a grayish tint, which negatively affected the visual appeal of the product.

The reduction in the proportion of buckwheat flakes, accompanied by an increase in the amaranth content, had a positive effect on organoleptic properties, such as taste, aroma, color, and appearance. Granola samples containing 80% amaranth flakes and 20% buckwheat flakes received the highest tasting scores. Along with this, the use of maple syrup contributed to the harmonization of flavor characteristics, providing the most balanced combination of ingredients. Consequently, rf10 recipe received the highest average score of 5.0 points, while a similar rf7 recipe, but with Jerusalem artichoke syrup, was rated at 4.8 points.

A similar trend was observed in the organoleptic properties of granola produced on the basis of rice and amaranth flakes. The dominant rice taste and aroma in samples containing 80% rice flakes caused a decrease in the tasting scores, regardless of the type of syrup used. Thus, the average score of the rf3 recipe composition was 4.48, and the rf6 – 4.4 points. The decrease in the proportion of rice flakes in the recipe was accompanied by an increase in the overall product rating.

It is worth noting that all granola samples based on rice flakes had excellent color characteristics, as confirmed by consistently high tasting scores (5.0) for all recipes (rf1–rf6). The best result among this group of samples was achieved by granola containing 20% rice flakes and 80% amaranth flakes, with the use of Jerusalem artichoke syrup.

Thus, according to the results of the organoleptic evaluation, the most technologically feasible and sensory acceptable recipe is as follows: rf10, which contains 20% buckwheat flakes, 80% amaranth flakes, freeze-dried cherry and fig, crushed hazelnut kernels, butter, and maple syrup, and rf1, which includes 20% rice flakes, 80% amaranth flakes, freeze-dried peach and strawberry, crushed almond kernels, butter, and Jerusalem artichoke syrup.

The obtained results reveal a significant influence of the recipe composition on the organoleptic properties of granola and confirm the importance of the rational selection of components to achieve the optimal balance of taste, aroma, texture, and appearance of the finished product.

1.4 Energy value of gluten-free granola

The energy value of food products refers to the amount of energy the body receives as a result of their consumption. The body uses this energy to ensure all life processes, including physical activity, metabolism, organ function, and body temperature regulation.

Energy value is a crucial factor for consumers, as it affects the overall health, physical fitness, and prevents the development of various diseases. Knowledge of the energy value of products allows consumers to choose food that best meets their needs and ensures a proper a balance between energy intake and expenditure.

The energy value of food products, including gluten-free granola, is determined per 100 g of the edible potion of the finished dish using formula (1.3).

The initial data for calculating the energy value of the experimental granola recipes are presented in **Table 1.5**.

The total amount of each macronutrient for a certain recipe was determined by formula (1.4)

$$C_{rfi}^{mac} = \sum_{i=1}^{n} mac_i, \tag{1.4}$$

where C_{rfi}^{mac} – the amount of macronutrient in the experimental sample produced according to *i*-th recipe, g; mac_i – the content of macronutrient in a certain ingredient of the recipe, g; *n* – the number of ingredients in the recipe.

The content of each macronutrient in the experimental granola recipes was calculated by formula (1.5)

$$mac_i = \frac{M_i^p \cdot C_{mac}^{100}}{100}, \qquad (1.5)$$

where, M_i^p – the amount of certain ingredient in the recipe, g; C_{mac}^{100} – the content of macronutrient in 100 g of a certain ingredient in the recipe, g.

Results of the calculation of the total content of macronutrients in the experimental granola recipes are given in **Table 1.6**.

The results of determining the energy value (formula (1.3)) of gluten-free granola, which is produced according to the developed experimental recipe compositions, are given in **Table 1.7**.

Table 1.5 Initial data for calculating the energy value of gluten-free granola

Name of ingredient	Content of macronutrients, g per 100 g		
	proteins	fats	carbohydrates
Amaranth flakes	16.00	7.00	65.00
Buckwheat flakes	16.52	2.43	76.61
Rice flakes	6.61	0.50	77.00
Butter	1.00	82.3	0.80
Jerusalem artichoke syrup	0.50	0.00	75.00
Maple syrup	0.20	0.00	68.02
Freeze-dried cherry	1.10	0.51	80.11
Freeze-dried peach	3.04	0.01	68.52
Freeze-dried fig	5.05	1.00	85.19
Freeze-dried strawberry	1.00	0.30	85.00
Almond kernels	18.60	57.70	16.20
Hazelnut kernels	16.10	66.90	9.92
Oat flakes	13.00	6.50	60.00
Raisins	3.10	0.30	79.30
Walnuts	15.20	65.20	13.70
Honey	0.30	0.00	82.40

Table 1.6 Results of calculation of the total macronutrient content in the experimental granola recipes

Recipe number	Granola output, g	Macronutrient content, g per 100 g		
		proteins	fats	carbohydrates
Industrial analogue (control)	250.0	26.35	75.21	57.39
rf1	250.0	21.13	39.47	129.85
rf2	250.0	18.31	37.52	133.45
rf3	250.0	15.49	35.57	137.05
rf4	250.0	21.05	39.47	125.98
rf5	250.0	18.23	37.52	129.58
rf6	250.0	15.41	35.57	133.18
rf7	250.0	22.60	42.91	131.33
rf8	250.0	22.75	41.54	134.81
rf9	250.0	22.91	40.16	138.29
rf10	250.0	22.51	42.91	127.47
rf11	250.0	22.67	41.54	130.95
rf12	250.0	22.82	40.16	134.43

Table 1.7 Results of calculating the energy value of gluten-free granola

Recipe number	Mass of the experimental sample, g	*E*, kcal per mass of the experimental sample	*E*, kcal per 100 g of mass
Industrial analogue (control)	250.0	997.50	399.00
rf1	250.0	926.68	370.67
rf2	250.0	911.35	364.54
rf3	250.0	896.02	358.41
rf4	250.0	911.86	364.74
rf5	250.0	896.53	358.61
rf6	250.0	881.20	352.48
rf7	250.0	969.02	387.61
rf8	250.0	970,36	388.15
rf9	250.0	971.71	388.68
rf10	250.0	954.19	381.68
rf11	250.0	955,54	382.22
rf12	250.0	956.89	382.76

Analysis of the data presented in **Table 1.7** reveals that the energy value of all developed experimental granola variants per 100 g is nearly identical and ranges within 352...389 kcal/100 g.

Recipes containing buckwheat flakes have maximal energy values, while rice-based granola variants have slightly lower values. However, this difference is not significant.

The energy value of the control granola sample (industrial analogue) exceeded the highest value among the experimental variants by 10 kcal and amounted to 399 kcal.

According to nutritional standards, the recommended energy value of breakfast is 300...400 kcal. Therefore, both the control and experimental gluten-free granola recipes comply with these standards.

1.5 Glycemic index of gluten-free granola

One of the key parameters to consider when developing new breakfast cereal recipes is the glycemic index (GI). This index characterizes the rate and extent of blood glucose level increase after consuming a particular food product.

Food products with a high GI (over 70) cause a sharp increase in glucose levels, which may be undesirable for people at risk of developing diabetes or those already diagnosed with the condition. A sharp rise in glucose concentration stimulates active insulin production, which, in turn, may contribute to the development of insulin resistance and overall deterioration of health. Therefore, when creating breakfast cereals, it is advisable to use ingredients with a low or medium GI (below 55), as they help to maintain stable blood glucose levels and are especially beneficial for people with metabolic disorders.

In addition, low-GI food products provide a long-lasting feeling of satiety due to the gradual release of glucose into the bloodstream. This plays a crucial role in appetite control and body weight regulation. Consuming low-GI breakfast cereals helps to prevent sudden fluctuations in glucose levels, which can lead to rapid hunger and excessive snacking. The glycemic index of individual ingredients used in the experimental recipe compositions is given in **Table 1.8**.

Table 1.8 Glycemic index (GI) of gluten-free granola ingredients

Ingredient name	GI of ingredients, r.u. per 100 g
1	2
Amaranth flakes	35.0
Buckwheat flakes	40.0

Continuation of Table 1.8

1	2
Rice flakes	80.0
Butter	15.0
Jerusalem artichoke syrup	13.0
Maple syrup	54.0
Freeze-dried cherries	30.0
Freeze-dried peach	35.0
Freeze-dried fig	50.0
Freeze-dried strawberry	30.0
Almond kernels	25.0
Hazelnut kernels	15.0
Oat flakes	55.0
Raisins	64.0
Walnuts	15.0
Honey	65.0

Calculation results. The results of determining the glycemic index of the developed gluten-free granola recipe compositions are visualized in **Fig. 1.5**.

The glycemic index value for a certain recipe was determined by formula (1.6)

$$GI_{rfi} = \sum_{i=1}^{n} GI_i, \quad (1.6)$$

where GI_{rfi} – glycemic index of the experimental sample, prepared according to the *i*-th recipe, r.u.; GI_i – glycemic index of a specific ingredient in the recipe, r.u.; n – number of ingredients in the recipe.

The glycemic index of each individual ingredient in the experimental granola recipes was calculated according to formula (1.7)

$$GI_i = \frac{M_i^p \cdot GI^{100}}{100}, \quad (1.7)$$

where M_i^p – recipe amount of a specific ingredient, g; GI^{100} – glycemic index of 100 g of a specific ingredient of the recipe, r.u.

Calculation results determining the glycemic index of the developed gluten-free granola recipe compositions are visualized in **Fig. 1.5**.

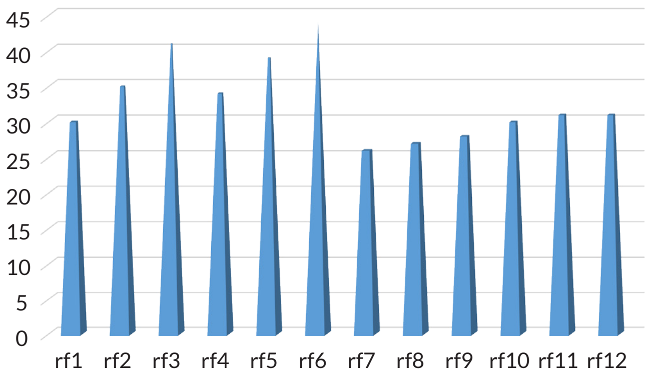

Fig. 1.5 Glycemic index of experimental granola recipe compositions

The control sample (**Fig. 1.5**) is characterized by a glycemic index (GI) of 41, which corresponds to the upper limit of the medium GI range. This value is typical for traditional granola, which includes oat flakes, raisins, and honey – ingredients high in simple carbohydrates, which are quickly absorbed by the body. Analysis of the experimental samples (rf1–rf12) showed a decrease in glycemic index in most variants compared to the control, except for samples rf3 and rf6. In particular, the GI of sample rf6 was 44, which exceeded this indicator in the control variant and was associated with the highest content of rice flakes in the recipe. At the same time, the lowest GI values were observed in samples rf7, rf8, and rf9, indicating the potential advantage of these recipes for dietary nutrition and for developing products with a moderate impact on the body's glycemic response.

1.6 Discussion of results

The research aimed to develop a recipe and improve the production technology of gluten-free granola for the restaurant segment.

The working hypothesis of the research was to develop a granola recipe composition based on gluten-free grain ingredients, freeze-dried fruit and berry raw materials, and nuts. It should also be noted that traditional granola production methods typically use honey as a natural sweetener. However, heat treatment of honey at 160°C or higher temperatures can lead to the formation of harmful compounds, in particular carcinogens, which are associated with an increased risk of cancer. To minimize these negative consequences, let's propose modifying the technological process by replacing honey with alternative sweeteners, in particular, maple syrup and Jerusalem artichoke syrup.

Amaranth flakes, selected as the main ingredient, are considered a valuable product for healthy nutrition. In 100 grams of these flakes, there are 16 g of protein, 3 g of minerals, and 17 mg of vitamins. A significant advantage is their high content of lysine and other essential amino acids, which cereal crops typically lack. Amaranth flakes also contain healthy fats (7 g per 100 g), including polyunsaturated fatty acids. The starch content in amaranth flakes reaches 7 g per 100 g, making them a good source of complex carbohydrates that provide sustained energy. In amaranth, starch is also highly soluble and digestible, which facilitates easier digestion. A fairly high fiber content (8 g per 100 g) helps normalize digestion. A rich mineral composition of amaranth classifies it as an exceptionally nutritious food that supports healthy eating, particularly for individuals with increased micronutrient needs. Squalene (6.1 g), a powerful antioxidant found in amaranth, has anti-inflammatory and immunomodulatory properties. Amaranth flakes are gluten-free, making them suitable for individuals with gluten intolerance.

Buckwheat flakes contain all the essential amino acids, making them an important source of protein. They are a source of complex carbohydrates, which promote long-lasting satiety and help maintain stable blood sugar levels. Their high dietary fiber content helps to improve digestion, normalize bowel function, and promote detoxification. They contain a small amount of fat, including beneficial polyunsaturated fatty acids – linoleic and linolenic – as well as Omega-3 and Omega-6.

The main portion of carbohydrates in rice flakes consists of complex carbohydrates that ensure gradual energy release. Rice flakes contain a small amount of protein, which is less complete, compared to animal proteins, due to the absence of the essential amino acid lysine. The fat content is low, and it mostly consists of unsaturated fatty acids. Rice flakes contain little fiber. They are gluten-free, making them safe for people with celiac disease or gluten intolerance. Due to their high carbohydrate content, rice flakes are an excellent source of quick energy. They are easily digestible, making them suitable for individuals with sensitive digestive systems or during dietary nutrition.

Jerusalem artichoke syrup is known for its beneficial properties thanks to its high inulin content (40 g per 100 g), a natural prebiotic. It is used as a sugar substitute due to its low glycemic index. Maple syrup can be a better alternative to regular sugar due to its more natural composition and beneficial micronutrients, though it should still be consumed in moderation because of its high carbohydrate content.

An important group of granola ingredients consists of non-cereal plant-based components. These include freeze-dried cherry, peach, and fig fruits, as well as strawberry berries. All freeze-dried products retain most of the beneficial nutrients found in fresh fruits.

The results of organoleptic evaluation demonstrated a significant impact of the recipe composition on the consumer properties of the finished product. It was found that a balanced combination of gluten-free flakes (buckwheat, rice, amaranth), freeze-dried fruits and berries, and nuts is crucial for achieving high sensory characteristics. Thus, the samples with a high content of buckwheat flakes received lower ratings due to the dominance of a specific buckwheat flavor and less appealing color. In contrast, increasing the proportion of amaranth flakes had a positive effect on organoleptic qualities, improving the taste, aroma, and visual appeal of the granola.

The replacement of honey with maple syrup and Jerusalem artichoke syrup was a key aspect of the study. The results indicated that the use of maple syrup contributed to better flavor harmony in granola based on buckwheat and amaranth flakes, while Jerusalem artichoke syrup proved to be a suitable sweetener for the recipe with rice and amaranth flakes.

The calculation of energy value showed that all developed recipes fall within the acceptable range for breakfast (352–389 kcal/100 g), which complies with recommended dietary norms. At the same time, granola based on buckwheat flakes had a slightly higher energy value compared to the rice-based one. However, the highest energy value was characteristic of the control sample (commercial analogue).

The results obtained indicate a clear and predictable dependence of the glycemic index (GI) of the experimental granola recipes on the composition of their components.

All ingredients used in the developed recipes belong to the category of low-GI products, except for maple syrup (medium GI) and rice flakes (high GI). Consequently, recipe compositions, which used Jerusalem artichoke syrup as a sweetener, exhibited a lower glycemic index compared to those containing maple syrup. Among the buckwheat-based recipes, the lowest GI was observed in composition rf7, which contained Jerusalem artichoke syrup and a minimal amount of buckwheat flakes.

Rice-based recipe compositions had a higher glycemic index compared to buckwheat-based ones, which is attributed to the high GI of rice flakes. Correlation analysis confirmed a strong direct dependence between the content of rice flakes and the glycemic index of the finished product, with a correlation coefficient of 0.92. The lowest GI value among the recipes of this group was demonstrated by the composition rf1, which contained a minimal amount of rice flakes, Jerusalem artichoke syrup, and other components.

It is important to note that despite some variations in the glycemic index values, all the experimental granola samples fall into the category of low-GI products (below 55 units). This indicates their suitability for inclusion in the diet of individuals with diabetes and those who follow a dietary nutrition plan.

The studies conducted by the authors correlate with those carried out by I. Kaluhina [2], S. Langyan [6] regarding the use of pseudocereal crops, as well as by M. Montenegro [14], and A. Saraiva [12] concerning the use of syrups in granola production.

Summarizing the findings of experimental studies, it can be concluded that in terms of organoleptic properties, energy value, and glycemic index, the most promising granola recipes are as follows: rf10 containing buckwheat and amaranth flakes, freeze-dried cherries and figs, crushed hazelnut kernels and maple syrup, and rf1 containing a minimal amount of rice flakes combined with amaranth flakes, freeze-dried peach, freeze-dried strawberry, almond kernels, and Jerusalem artichoke syrup.

These recipes can be recommended for implementation in production in the restaurant segment.

Technological schemes were developed for the production of gluten-free granola in the restaurant segment based on recipe compositions that were recognized as the best according to the results of experimental studies (**Fig. 1.6, 1.7**).

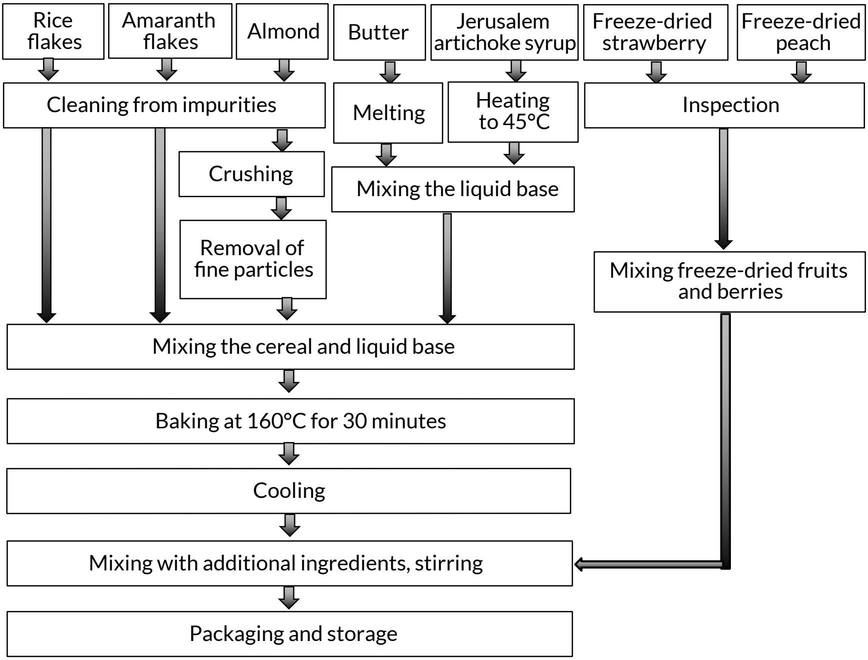

Fig. 1.6 Technological flowchart for the production of gluten-free granola based on the experimental recipe rf1

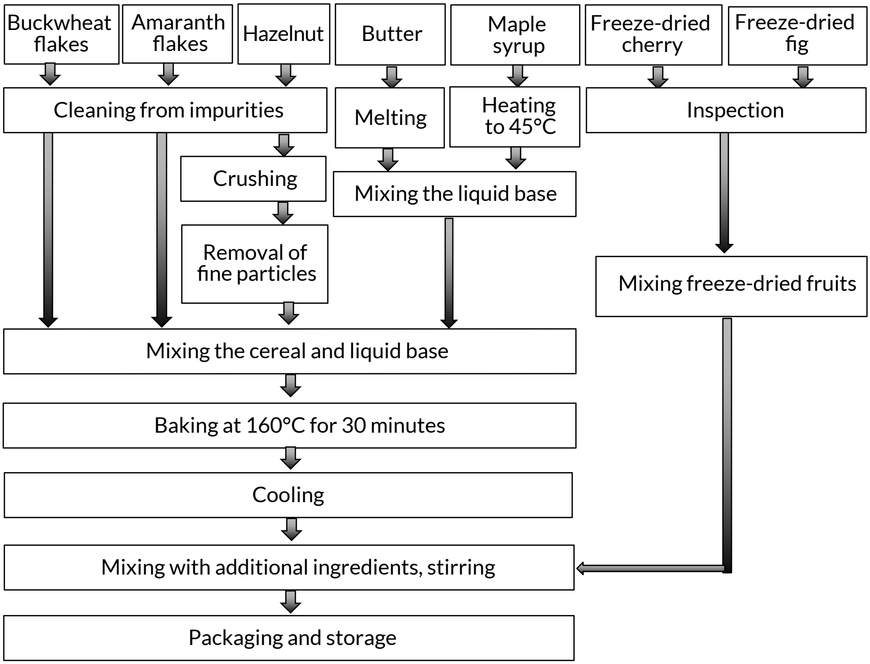

Fig. 1.7 Technological scheme for the production of gluten-free granola based on the experimental recipe rf10

The improved granola production technology differs from the traditional one by incorporating plant-based ingredients with improved functional characteristics into the recipe, as well as implementing additional preparation stages before production.

The production cost of 1 kg of granola using the traditional technology (industrial analog) amounts to 8.81 EUR. In experimental samples, the use of freeze-dried fruits and berries and other high-cost components, such as amaranth flakes, premium nuts, and functional syrups, increases the cost of granola to 15.31 EUR for rf10 recipe and 17.55 EUR for rf1 recipe.

Despite the higher production cost, the experimental granola samples demonstrate economic viability due to the introduction of innovative raw materials and premium product positioning. Specifically, the sale of gluten-free granola produced using buckwheat and amaranth flakes, maple syrup, butter, hazelnut kernels, and freeze-dried cherries and figs (rf10 sample) makes a profit of 3745.61 EUR per ton of product, so that the level of profitability comprises 25%. Meanwhile, the profit from selling granola based on rice and amaranth flakes with Jerusalem artichoke syrup, butter, almond kernels, and freeze-dried peaches and strawberries (rf1 sample) amounts to 1501.86 EUR per ton under 9% profitability.

Future research could focus on studying the impact of different heat treatment regimens on the quality and safety of gluten-free granola using alternative sweeteners, as well as investigating shelf life and packaging materials to preserve the organoleptic and physicochemical properties of the finished product. Additionally, expanding the range of gluten-free granola by incorporating other types of gluten-free flakes, freeze-dried vegetables, and seeds can be an interesting direction.

The research findings significantly contribute to developing innovative food products for the restaurant industry, particularly in the gluten-free nutrition segment. They can also promote expanding a range of healthy and safe breakfast options for consumers.

1.7 Conclusions

Twelve gluten-free granola recipe compositions were developed for scientific research.

The study confirmed that the energy value of all proposed granola recipes per 100 g is nearly identical, ranging within 352...389 kcal/100 g, which aligns with the established nutritional standards. Recipes containing buckwheat flakes exhibited a higher energy value, while rice-based granola had a slightly lower energy value. However, this difference is not significant.

The results confirm a direct and predictable significant dependence of the glycemic index (GI) of the experimental granola recipes on the ingredient composition. According to the research results, despite minor variations in GI values, all developed recipes belong to the group of products with a low glycemic index (below 55 units). This makes them suitable for individuals with diabetes, as well as for inclusion in dietary nutrition.

It was established that from the perspective of organoleptic properties, energy value, and glycemic index, two granola recipes are the most promising: rf10 containing buckwheat and amaranth flakes, freeze-dried cherry and fig, crushed hazelnut kernels, and maple syrup, and rf1 containing a minimal amount of rice flakes combined with amaranth flakes, freeze-dried peach and strawberry, almond kernels, and Jerusalem artichoke syrup.

As a research result, the technology for producing gluten-free granola was improved by incorporating plant-based ingredients with improved functional characteristics into the recipe, as well as implementing additional preparation stages before production. This improvement contributes to increasing nutritional value, improving organoleptic properties, and expanding the range of functional food products that meet modern requirements for healthy nutrition.

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