









Evaluation of the Effect of Grape Seed Powder on the Nutritional Value, Antioxidant Activity, Color, and Sensory Quality Characteristics of Functional Cake Production

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ABSTRACT

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cake, grape seed powder, antioxidant activity, polyphenols, dietary fiber, functional foods, phenolic compounds, organoleptic indicators, biological activity, statistical analysis

The objects of the study were grape seed powder (GSP), wheat flour, and cake samples prepared on their basis, auxiliary materials, technological methods, and means. The problem is that the effect of adding GSP to functional cake formulations on the nutritional value, antioxidant activity, physicochemical, and sensory quality characteristics of the product, as well as the optimal level of addition, has not been determined. In the cake formulation, 4, 8, 12, 16, and 20% of wheat flour was replaced with GSP. Comparative analysis of the raw materials showed that the total dietary fiber content in GSP was 35.15 g/100 g, whereas this indicator was 2.86 g/100 g in wheat flour. The amount of phenolic compounds in GSP was determined as 8386 mg GAE/100 g, while antioxidant activity was 4735 $\mu\text{mol TE}/100\text{ g}$. The physicochemical, antioxidant, color, and sensory characteristics of the cake samples were evaluated. It was determined that as the amount of GSP increased, dietary fiber, phenolic compounds, and antioxidant activity values also increased. The amount of insoluble dietary fiber increased from 1.61% to 8.22%, while soluble fiber increased from 1.23% to 2.13%. The total phenolic compound content increased from 83.51 mg GAE/100 g to 211.88 mg GAE/100 g, and antioxidant activity increased from 2.01 to 51.92 $\mu\text{mol TE}/100\text{ g}$. Color analyses showed a decrease in the L value from 45.60 to 33.25, indicating darkening of the product. According to the results of sensory evaluation and analysis of variance, the sample containing 8% GSP had the highest overall acceptability score (8.9 points; $p < 0.05$). Therefore, the 8% supplementation level was evaluated as the most favorable compromise between functional properties and sensory quality within the tested range.

1. INTRODUCTION

The application of circular economy principles in the food industry has increased interest in the valorization of agro-industrial by-products. Grape processing generates large amounts of pomace, including grape seeds, which are rich in dietary fiber, polyphenols, flavonoids, antioxidants, and valuable fatty acids. These properties make grape seeds a promising ingredient for the development of functional foods while supporting sustainable resource utilization and waste reduction.

The relevance of this study is associated with the growing demand for healthier food products and the efficient use of local raw materials. However, the effects of grape seed powder

(GSP) incorporation on the quality characteristics, nutritional value, and sensory properties of cakes have not been fully investigated. Therefore, this study evaluates the potential of grape seed powder as a functional ingredient in cake production.

A review on the valorization of grape pomace [1] highlighted its composition, green extraction approaches, industrial applications, and relevant regulatory and sustainability aspects. However, no specific extraction method was identified as superior.

It has also been reported that incorporating grape pomace into food products enhances antioxidant activity and may improve shelf life through microbiological and physicochemical effects [2]. Nevertheless, further research is

needed on efficient and food-compatible green extraction methods for obtaining bioactive compounds from grape pomace.

Physicochemical analyses of gluten-free baked products prepared from mixtures containing grape pomace flour demonstrated that increasing the amount of pomace flour improved the nutritional value and composition of the products [3]. However, the optimal level of incorporation in formulations was not determined in this study.

Research focusing on vermicomposting as an environmentally safe approach for the management and valorization of winery by-products, particularly grape pomace, reported that vermicompost enhances soil fertility and has potential as an organic fertilizer for maintaining soil health [4]. Nevertheless, the use of pomace in food production was not investigated.

The obtained results indicated that grape seed waste is rich in bioactive substances and antioxidant components and has significant potential as a valuable raw material for both the food and pharmaceutical industries [5]. However, the dosage and application method for specific food products were not examined.

The investigated grape seed extracts were found to possess high antioxidant and antimicrobial properties, demonstrating their potential use as natural bioactive additives in food, pharmaceutical, and functional products [6]. However, the optimal amount to be used, depending on the product type, was not investigated.

In this study, the chemical composition, bioactive compounds, minerals, and fatty acid profiles of grape pomaces obtained from ten different grape varieties containing both seed and skin fractions were examined [7]. However, no studies regarding the use of grape pomace as a food ingredient were included.

Samples containing 7% and 9% grape seed flour were found to be unsatisfactory in terms of rheological and sensory characteristics. Nevertheless, the sample containing 3% grape seed flour could be considered a source of dietary fiber, while the sample with 5% grape seed flour could be regarded as a source of copper (Cu), and both samples were rich in zinc (Zn) [8]. However, the effect of grape seed flour on the quality characteristics of confectionery products was not determined.

The effect of 15–25% GSP on the quality characteristics and nutritional value of shortbread cookies was investigated [9]. The results showed that the incorporation of 20% GSP into the formulation was appropriate for obtaining nutritionally enhanced cookies rich in bioactive compounds. However, the use of such additions in cake formulations was not considered.

In a study recommending the replacement of up to 10% of wheat flour with GSP for the production of fortified baladi bread with satisfactory physical and sensory properties, as well as high total polyphenol content and antioxidant activity [10], the effect of GSP on the composition and quality of confectionery products was not investigated.

A study highlighting grape pomace as a promising ingredient in bakery products [11] pointed out that the additional technological and nutritional benefits of bioprocessing have not yet been fully quantified.

A review [12] summarized bioactive compounds in grape pomace, recent green extraction methods, and integrated recovery approaches based on studies from the last five years. However, it did not report specific applications of these compounds in the food industry.

To minimize adverse effects, the use of grape seed flour

with an average particle size of 209 μm at a maximum level of 5% in cookie production was recommended [13]. However, this study did not focus on the use of GSP in cake production.

The utilization of grape pomace in the production of cocoa-based spread products was evaluated [14]. The results showed that the volume-weighted mean particle size was 19.17 μm in Cg, 19.71 μm in Cg10, and 21.04 μm in Cg15 samples. However, GSP was not used, and its dosage was not investigated.

The influence of grape seed extract on the quality characteristics of medium-gluten wheat flour and fresh noodles for the development of functional noodle products was investigated [15]. Increasing levels of grape seed extract enrichment significantly enhanced the total phenolic content and antioxidant capacity of noodles ($p < 0.05$). However, no studies related to confectionery products, particularly cakes, were included.

A study [16] evaluated the effects of grape variety and extraction methods on the composition and antioxidant activity of berry components. The selection of appropriate varieties, raw material preparation, and advanced techniques such as CO₂ extraction were identified as beneficial.

In a study emphasizing the versatility and sustainability of grape seeds in the development of innovative and health-oriented products [17], grape seeds were described as a promising raw material for functional food and nutraceutical formulations, contributing to health, sustainability, and resource efficiency.

It was shown that the use of grape pomace as a food additive/raw material contributes to the development of new functional products and helps address waste management issues in the wine industry. Existing knowledge regarding the bioactivity and health effects of polyphenol-rich extracts obtained from grape pomace was summarized, and the incorporation of grape pomace into food formulations, including improvements in physicochemical, sensory, and nutritional quality, as well as intellectual property information related to food industry applications, was discussed [18].

Research on the nutritional value of grape pomace, the conditions required for its fermentation by lactic acid bacteria, and the chemical changes occurring during fermentation was presented [19]. Furthermore, prospects for developing new functional food products based on the interactions between phytochemical compounds in grape pomace and bacterial strains were highlighted.

Studies on fortified pizza dough in which 15%, 20%, and 25% of wheat flour were replaced with grape skin flour (GS) and a mixture of grape skin and grape seed flour (GM) were incorporated into the cake formulations [20]. The use of grape skin flour and skin-seed mixtures increased anthocyanin and phenolic compound contents as well as antioxidant activity, with the skin-seed mixture showing greater effectiveness.

Recent advances concerning grape seeds, including their polyphenol profile, antioxidant, biological, and antimicrobial effects, as well as their stability in foods, were investigated [21].

The potential of grape seeds as α -amylase and α -glucosidase inhibitors was highlighted, with polyphenols and dietary fiber identified as the main contributors to this bioactivity [22].

The study [23] examined factors affecting anthocyanin extraction, stability, and composition, as well as their application in food products and the role of grape pomace in sustainable winemaking. It also highlighted their influence on product quality and consumer preference.

Defatted GSP was shown to possess different particle forms and a broad size distribution. The resulting emulsion gel exhibited semi-solid elastic properties and demonstrated potential as a vegetable oil substitute [24].

Replacing a portion of flour with grape seeds in bakery products increased fiber, mineral, and protein contents; however, alterations in sensory characteristics were noted. Alternatively, the use of polyphenol extracts may produce more functional products, although requiring more complex technological processes [25].

Bread was produced by incorporating grape seed proanthocyanidins into wheat flour. Improvements in texture characteristics, including hardness, cohesiveness, adhesiveness, and chewiness, were reported [26].

Roasting, one of the first processing methods applied to grape seeds, was investigated. Based on grape variety and roasting conditions, the degree of polymerization of condensed tannins, cyclic proanthocyanidin profiles, and total polyphenol content were analyzed. Roasting significantly influenced proanthocyanidin distribution, increasing the levels of almost all classes, although the effect depended on grape variety [27].

The addition of grape pomace powder improved both the nutritional value and sensory properties of the product. As the amount of grape pomace powder increased, the contents of ash, dietary fiber, phenolic compounds, and flavonoids increased significantly [28].

The study reported that high-purity grape seed extract should contain at least 95% polyphenols and at least 10% monomers, whereas standard-quality extract should contain at least 95% procyanidolic value and at least 6% monomers [29].

A study was conducted to identify the main technological factors affecting the intensification of the wine clarification process. The influence of these factors on clarification efficiency was evaluated, and optimal conditions for improving the process were determined [30].

The study [31] noted that green extraction technologies enhance the efficiency of grape seed extract utilization and emphasized the importance of converting winery waste into valuable products within the framework of circular economy and environmental sustainability.

Products derived from food industry by-products (fruits, vegetables, oil production residues, etc.) and incorporated into functional foods were shown to improve resource efficiency and support zero-waste principles [32].

The effects of certain cake ingredients, namely fat, leavening agent, and inulin, on batter structure and physicochemical properties were investigated using four different formulations [33]. It was reported that replacing fat with inulin reduced batter stability and resulted in the formation of larger air bubbles.

The sensory characteristics of bread, particularly color and texture, were evaluated. The studies demonstrated successful strategies for the incorporation of functional ingredients into baked products and highlighted their contribution to healthier nutrition [34].

Sponge cake samples were prepared using blood powder and compared with conventional formulations. Blood powders increased cake hardness, chewiness, and breaking force, enabling greater filling capacity and the production of specialized shapes [35].

A functional milk-walnut beverage was produced by blending and infusing walnuts with skim milk, resulting in both liquid and solid fractions (dried milk-walnut paste). The

solid fraction accounted for approximately 20% of the raw material. The use of milk-walnut paste enabled product diversification without additional costs and was recommended for industrial application [36].

The physicochemical composition of berries from the indigenous Bayan Shira grape variety at different growth stages was investigated [37]. It was determined that the applied technological processing methods had a significant effect on the extraction of compounds.

A study was conducted on the use of rosehip pomace powder in cake production [38]. It was found that the optimal formulation was achieved by incorporating 2.5% rosehip pomace powder into functional cakes and 3% rosehip pomace extract into yogurt production.

Grape pomace and other secondary raw material-derived powders and fiber-rich additives were used in the production of bakery and confectionery products [39]. The physicochemical composition, structural-mechanical properties, and organoleptic characteristics of the functional products were evaluated. The application of these additives enhanced nutritional value, particularly through enrichment with dietary fiber and phenolic compounds.

The production of functional beverages using extracts prepared from grape pomace was investigated [40]. The results demonstrated that the added extracts significantly enhanced the antioxidant properties and free radical scavenging capacity of the beverages.

Research on the use of components obtained from pomace waste as enriching agents led to the development of functional yogurt, and optimal parameters for drying the pomace and utilizing the resulting pomace powder were established [41, 42].

Modern studies indicate that by-products of the grape processing industry, particularly grape seed and grape pomace, are considered promising raw materials for the development of functional food products due to their high content of polyphenols, flavonoids, dietary fiber, and other bioactive compounds. Numerous studies have reported the application of grape seed and grape pomace in bread, pizza, yogurt, and various other food products. However, the comprehensive effects of different substitution levels of GSP on the nutritional value, antioxidant properties, color characteristics, and consumer acceptance of functional cakes have not been sufficiently investigated. In particular, determining the optimal balance between functional properties and sensory quality remains an important scientific challenge. In this context, the present study was aimed at evaluating the effects of different incorporation levels of GSP on the quality characteristics of functional cakes and determining the optimal supplementation level.

The objective of this research was to evaluate the effects of different substitution levels (4–20%) of GSP on the nutritional value, antioxidant properties, color parameters, and sensory quality of functional cakes. To achieve the research objective, the following tasks were envisaged:

1. Comparative evaluation of the raw materials used for cake production;
2. Investigation of the effect of GSP on the physicochemical and organoleptic properties of the product.

2. MATERIALS AND METHODS

The research objects included GSP, wheat flour, and cake

samples prepared on their basis, auxiliary materials, technological methods, and processing techniques. The study was conducted to determine the effect of GSP application in functional cake production on the quality characteristics of the final product. During the research, cake samples with different formulations were prepared under laboratory conditions, and their physicochemical, technological, and organoleptic characteristics were comparatively evaluated. The ingredients used in the study included wheat flour (premium grade), powdered sugar, eggs, vegetable oil, milk, baking powder, vanillin, and GSP.

The production and analysis stages of the functional cake were carried out according to the following technological scheme (Figure 1).

The grape seeds used in the study were obtained from viticulture farms and wine production enterprises located in Ganja and its surrounding areas. The raw material was mainly separated from the pomace obtained after the processing of Bayanshira, Rkatsiteli, Aligote, and other technical grape varieties. After being washed with running water, the seeds were dried under shaded and well-ventilated conditions at a temperature of 25 ± 2 °C for 8 hours, or in a hot-air circulation drying cabinet at 50–60 °C until a constant weight was

achieved. The final moisture content of the dried material was $8.5 \pm 0.3\%$. Subsequently, the seeds were ground using a laboratory-scale grinder and passed through a 500 µm sieve. The obtained powder was stored in double polyethylene packaging at –18 °C for a maximum period of 30 days until further analyses were conducted. In order to minimize possible losses of phenolic compounds during powder preparation and storage, the samples were utilized within the shortest possible storage period.

Cake samples were prepared in three independent replicates for each formulation. The batter was placed into standard cylindrical molds (60 mm in diameter and 40 mm in height) and baked at 180 °C for 28 minutes. After baking, the samples were cooled at room temperature for 2 hours. Samples for physicochemical and instrumental analyses were taken from the central portion of the cakes.

The experiments for cake production were carried out according to the following variants: In the study, control (without additives) and experimental samples were prepared by adding GSP to flour in five different proportions (4%, 8%, 12%, 16%, 20%), and in total, experiments were conducted in 6 variants (Table 1).

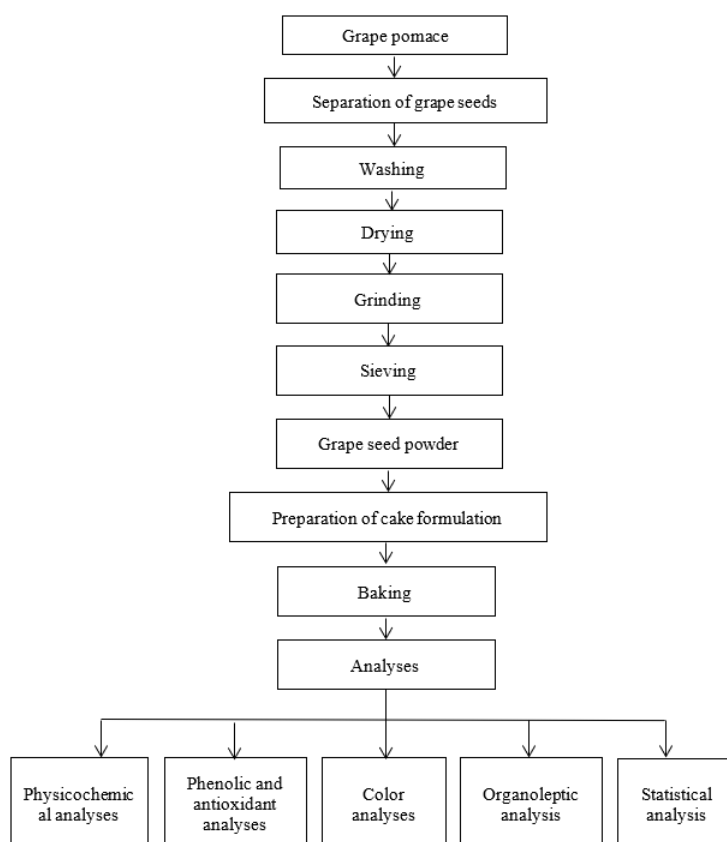


Figure 1. Stages of functional cake production and analysis

Table 1. Amounts of raw materials and auxiliary materials according to variants

Experimental Variants	Raw Materials and Auxiliary Materials, g/100 g						
	Flour	Egg	Sugar	Vegetable Oil	Milk	Baking Powder	GSP
Control	31.5	24.6	21	14.8	6.3	1.8	-
4% addition	30.24	24.6	21	14.8	6.3	1.8	1.260
8% addition	28.98	24.6	21	14.8	6.3	1.8	2.520
12% addition	27.72	24.6	21	14.8	6.3	1.8	3.780
16% addition	26.46	24.6	21	14.8	6.3	1.8	5.040
20% addition	25.20	24.6	21	14.8	6.3	1.8	6.300

Note: GSP: grape seed powder.

As shown in the table, the formulation of the control sample consists of 31.5 g flour, 24.6 g eggs, 21 g sugar, 14.8 g vegetable oil, 6.3 g milk, and 1.8 g baking powder, according to the traditional cake technology. In the other variants, the amount of flour was gradually reduced and replaced with GSP at corresponding percentages. For example, in the 4% addition variant, 1.26 g of flour was replaced, while in the 20% variant, this value amounted to 6.3 g. This principle ensured the maintenance of a constant total formulation mass.

All samples were prepared and baked under the same technological conditions. During cake batter preparation, eggs and sugar were first whipped until a homogeneous mass was obtained, after which vegetable oil and milk were added. Dry components - wheat flour, baking powder, and GSP-were mixed separately and then incorporated into the main mass. The prepared batter was poured into molds and baked at 180 °C for 25–30 minutes. After baking, the samples were cooled at room temperature and subjected to analysis. The protein content was determined using the Kjeldahl method (AOAC 979.09), the fat content was determined by the Soxhlet extraction method (AOAC 920.39), and the ash content was determined according to AOAC 923.03. Total, soluble, and insoluble dietary fiber contents were determined based on AOAC 991.43. The total phenolic content was measured using the Folin–Ciocalteu method and expressed as gallic acid equivalents (GAE). Antioxidant activity was evaluated using the DPPH radical scavenging method, and the results were expressed as Trolox equivalents (TE). Color parameters were measured using a colorimeter in the CIELab system. All analyses were performed in triplicate, and the results were presented as mean ± standard deviation.

The determination of crude ash content was carried out as follows: The crucibles used for ashing were kept in a muffle furnace at 550 ± 25 °C for at least 30 minutes, then cooled in a desiccator and weighed with an accuracy of 0.001 g. Alternatively, after washing, the crucibles were dried in a muffle furnace at 550 ± 25 °C for at least 30 minutes and kept in a drying oven at a minimum temperature of 100 °C.

During the analysis, approximately 5 ± 0.001 g of the sample was first weighed and placed into the crucible, after which it was pre-heated on a heater until carbonization occurred. Subsequently, the sample was transferred to a preheated muffle furnace (at least 30 minutes preheating) and incinerated at 550 ± 25 °C for 3.0 hours. After ashing, the crucible was transferred to a desiccator and cooled to room temperature. The cooled crucible containing the residue was then weighed with an accuracy of 0.001 g.

The ash content (W, %) of the sample was calculated using the following formula:

$$W = \frac{m_2 - m_0}{m_1 - m_0} \times 100\%$$

where, m_2 – weight of the crucible with ash, g; m_0 – weight of the empty crucible, g; m_1 – weight of the crucible with the initial sample, g.

Crude protein determination: 1 g of the powdered sample was placed into a Kjeldahl tube, and 12 mL of sulfuric acid (H₂SO₄) and two Kjeldahl tablets (containing 3.5 g K₂SO₄ and 0.4 g CuSO₄) were added. The mixture was then placed in a digestion unit preheated to 420 °C for 1 hour. After the digestion process was completed, the tubes were cooled, and 80 mL of distilled water was added to a 250 mL flask.

Subsequently, 25 mL of 4% boric acid (H₃BO₃) and 50 mL

of 40% NaOH were introduced into the Kjeldahl distillation unit. The distillation process was carried out for 5 minutes. The resulting solution was titrated with 0.1 M hydrochloric acid (HCl) until a pink color endpoint was reached.

Sensory evaluation was conducted by a panel consisting of 18 members (15 females and 3 males, aged 25–73 years). The panelists received brief prior training on the evaluation of confectionery products and were familiarized with the applied assessment criteria. Samples were coded with random three-digit numbers, and the order of presentation was randomized.

The evaluation was carried out in individual booths under white lighting at a temperature of 22 ± 2 °C. Between samples, the panelists rinsed their mouths with neutral-tasting drinking water.

A 9-point hedonic scale was used for evaluation, where 9 indicated “liked extremely,” 8 “liked very much,” 7 “moderately liked,” 5 “neither liked nor disliked,” and 1 “disliked extremely.” Color, aroma, taste, texture, and overall acceptability were evaluated separately.

Participants took part voluntarily and provided informed consent. All collected data were processed anonymously.

All experiments were conducted in three independent replicates (n = 3), and data are presented as mean values of the measurements. Statistical analysis was performed using IBM SPSS Statistics 26 software. Differences between variants were evaluated using one-way analysis of variance (One-way ANOVA). Tukey’s HSD multiple comparison test was applied to determine significant differences among means. Differences were considered statistically significant at $p < 0.05$.

3. RESULTS AND DISCUSSIONS

3.1 Comparative evaluation of raw materials used for cake production

Based on the conducted studies and the analysis of the chemical composition indicators of additives obtained from grape pomace, it was determined that grape processing wastes are promising food raw materials with high biological and technological potential. It was established that the seed, skin, and stem fractions of pomace are rich in various amounts of sugars, pectins, organic acids, and phenolic compounds (Table 2).

As can be seen from the table, it was found that the peel fraction contains higher amounts of pectin substances, while the seed fraction contains higher levels of phenolic compounds. This indicates that additives obtained from grape pomace possess both structure-forming and antioxidant properties. In particular, the identification of high pectin values in the Sauvignon and Bayan Shira varieties makes the use of these additives appropriate for improving texture and consistency in confectionery products. The high content of phenolic compounds increases the antioxidant activity of grape seeds and enables the enhancement of the biological value of functional products. These substances reduce oxidation processes, thereby positively affecting the preservation of product quality characteristics. Thus, the use of additives obtained from grape pomace in the production of enriched flour confectionery products is considered scientifically and practically appropriate and represents a promising direction for the creation of functional food products.

Table 2. Some composition indicators of additives obtained from grape pomace

Varieties	Mass Concentration							
	Sugars, %		Pectin Substances, %		Acids, %		Phenol Compounds, %	
	Seed	Peel	Seed	Peel	Seed	Peel	Seed	Peel
Bayanshira	7.7	7.2	11.5	18.4	3.08	7.94	0.78	0.62
Aligote	4.2	2.9	6.78	10.34	5.09	8.43	1.47	0.96
Silvaner	7.3	4.6	12.42	15.64	1.96	6.86	1.2	0.66
Sauvignon	6.5	4.2	8.28	15.18	2.08	4.29	0.33	0.29
Rkatsiteli	9.3	7.7	6.44	13.34	12.16	13.0	0.83	0.04
Grape stem (varietal mixture)	5.3		13.8		6.1		2.23	

As can be seen from the table, the mass fraction of sugars differed between the seed and peel fractions. The highest sugar content was observed in the seed of the Rkatsiteli variety (9.3%). This indicates that this variety is richer in carbohydrates. The highest sugar content in the peel was observed in Rkatsiteli (7.7%), whereas Bayan Shira contained 7.2% sugar.

Pectin substances are important structure-forming components in food technology. The analyses show that the amount of pectin substances in the peel fraction was higher than in the seed. The highest pectin content (18.4%) was detected in the berry skin of the Bayan Shira grape variety.

The amount of organic acids was particularly high in the Rkatsiteli variety. In the seed fraction, it was 12.16%, while in the peel fraction, it was 13.0%. Phenolic compounds are biologically active substances characterized by antioxidant properties. According to the results of the study, the highest amount of phenolic compounds was determined in the seed of the Aligote variety (1.47%). The lowest value (0.04%) was observed in the peel of the Rkatsiteli grape variety. In a mixed grape stem sample, sugars accounted for 5.3%, pectin substances for 13.8%, and acids for 6.1%. These indicators show that stems are also rich in biologically active components. The high phenolic content makes their use as antioxidant additives promising. In particular, grape peel is a source of pectin, while grape seed is a source of phenolic and antioxidant substances, and both have high technological and biological significance. The flour, milk, eggs, vegetable oil

(sunflower oil), sugar, and baking powder used in cake production were obtained from local retail markets.

Wheat flour with a moisture content of 12%, ash content of 0.47%, and protein content of 11.02% was used. Semi-skimmed milk was used as the milk component. The grape seeds used in the study were obtained from vineyards and wineries in Ganja and the surrounding areas. After harvesting, the grapes were cleaned of diseased and damaged parts, then separated from the stems, after which juice and pomace were obtained by pressing. The pomace was immediately collected into containers filled with water. The floating seeds were separated using sieves, while the seeds that settled at the bottom were separated from stems and grape skins by filtration. The obtained fraction was allowed to drain for 10 minutes. At this stage, some grape skins remained with the seeds. For drying, the material was spread in a single layer on fabric sheets and dried under natural shaded conditions. The mixture of seeds and skins was mixed every 1 hour, and complete drying was achieved after 8 hours. After separation of grape skins from the dried material, the seeds were placed in double-layer polyethylene bags and stored at $-18\text{ }^{\circ}\text{C}$ in a freezer for use in the research process. During product preparation, the seeds were ground into powder in a grinder in 50 g batches for 12 minutes.

The comparative analysis of the chemical composition indicators (on a dry matter basis) of the raw materials used for cake production, namely wheat flour and GSP, was carried out (Table 3).

Table 3. Comparative analysis of the chemical composition indicators of the raw materials used, g/100 g

Raw Material	Protein	Fat	Soluble Dietary Fiber	Insoluble Dietary Fiber	Total Dietary Fiber	Ash
Flour	11.02	1.45	1.32	1.54	2.86	0.47
GSP	6.45	11.31	3.17	31.98	35.15	2.17

Note: GSP: grape seed powder.

As can be seen from the table, the data characterize the chemical composition indicators of wheat flour and GSP and allow a scientific evaluation of the functional significance of these raw materials in cake formulations. The comparison shows that GSP has a different and more enriched biochemical composition compared to traditional wheat flour. These differences directly affect the nutritional and technological properties of the product. As observed, the protein content in the flour sample is significantly higher than in GSP. However, when other indicators are considered, it becomes clear that GSP has several times higher values than flour. If the fat content in flour was 1.45 g/100 g, in GSP it was approximately 7 times higher, amounting to 11.31 g/100 g. Wheat flour mainly acts as a structure-forming component, and its protein content is 11.02 g/100 g. Proteins, especially gluten fractions, ensure dough elasticity and gas retention capacity, thereby contributing to the formation of a voluminous and soft cake

structure. The fat content of flour is low (1.45 g/100 g), indicating that it is not primarily an energy source but rather a structural component. At the same time, the total dietary fiber content is relatively low at 2.86 g/100 g. Therefore, traditional cake products are not considered rich in fiber.

In GSP, a completely different chemical profile is observed. Although its protein content (6.45 g/100 g) is lower than that of flour, its fat content is significantly higher (11.31 g/100 g). Since grape seed oil is rich in unsaturated fatty acids, particularly linoleic acid, this component increases the biological value of the product. The most significant difference is observed in dietary fiber content. In GSP, the total dietary fiber content is 35.15 g/100 g, which is approximately 12 times higher than in flour. In particular, insoluble dietary fiber predominates (31.98 g/100 g). Insoluble fibers improve digestive system function, accelerate intestinal peristalsis, and help eliminate toxic substances from the body.

Soluble fibers (3.17 g/100 g), on the other hand, swell in water to form a gel, slow glucose absorption, and have a positive effect on reducing cholesterol. For this reason, GSP is of great importance as a functional food additive.

The high ash content in GSP (2.17 g/100 g) indicates that it is richer in minerals. This indicator characterizes the presence of macro- and microelements in the product, especially calcium, magnesium, potassium, and iron. The low ash content of flour indicates that it is a relatively poor raw material in terms of mineral composition.

The comparison of chemical composition indicators shows that the addition of GSP to cake formulations leads to the enrichment of the product with dietary fibers, minerals, and biologically active components. As a result, the functional and preventive properties of the product are enhanced. However, the high fiber content may increase water absorption of the dough, weaken the gluten network, and cause certain changes in the product structure. Therefore, the selection of an optimal addition level is of great importance for maintaining technological and organoleptic quality.

Table 4. Antioxidant properties and color values of raw materials

Physicochemical Parameters	Raw Material	
	Flour	GSP
Phenolic compounds, mg GAE/100 g	96.7	8386
Antioxidant activity, $\mu\text{mol TE}/100\text{ g}$	2.2	4735
Color values		
L	94.26	45.86
A	0.46	9.71
B	9.09	20.02

Note: GSP: grape seed powder.

Below, the antioxidant properties and color indicators of flour and GSP are presented comparatively (Table 4). The obtained results show that GSP is a functionally rich raw material with a high content of biologically active substances and has a higher antioxidant potential compared to traditional wheat flour.

The amount of phenolic compounds in GSP was 8386 mg GAE/100 g, whereas in flour this indicator was only 96.7 mg GAE/100 g. This difference is explained by the fact that GSP is rich in polyphenolic substances, especially flavonoids, catechins, epicatechins, proanthocyanidins, and phenolic acids. Phenolic compounds exhibit high antioxidant activity due to their ability to neutralize free radicals. These substances reduce lipid oxidation, protect cells from oxidative stress, and play an important role in the prevention of cardiovascular, inflammatory, and degenerative diseases in the human body.

A significant difference was also observed in antioxidant activity indicators. In GSP, antioxidant activity was 4735 $\mu\text{mol TE}/100\text{ g}$, whereas in flour it was only 2.2 $\mu\text{mol TE}/100$

g. This result is directly related to the high content of phenolic compounds. High antioxidant activity indicates the ability of GSP to slow down oxidation processes. This property is important both for extending the shelf life of the product and for the preparation of functional food products. The use of such raw material in cake formulations increases the antioxidant value of the product and enhances its biological functionality.

Color indicators also show significant differences between the raw materials. Color parameters were evaluated using the CIELab system (L, a, and b coordinates).

The L value characterizes lightness–darkness. For flour, the L value of 94.26 indicates a very light-colored raw material. In GSP, this value was 45.86, indicating a much darker color. This is due to the high content of phenolic compounds and pigments in grape seeds.

The a value characterizes red–green tones. For flour, this value was 0.46, indicating a neutral color tendency. In GSP, the value of 9.71 shows the dominance of reddish-brown tones. This feature is associated with the presence of polyphenols and natural pigments.

The b value indicates yellow–blue tones. The b value of flour (9.09) reflects a light yellow shade. In GSP, the b value of 20.02 indicates a more intense yellow-brown coloration.

These results show that GSP affects the quality of cake products not only through its antioxidant properties but also through its color-forming characteristics. Its addition to the formulation may darken the product and lead to the formation of brown-golden tones. At the same time, its high antioxidant potential increases the functional value of the product, enhancing its importance for healthy nutrition.

3.2 Investigation of the effect of grape seed powder on the physicochemical and organoleptic properties of the product

The physicochemical composition indicators of cake samples prepared with the addition of GSP are presented below. The results show that increasing the amount of GSP in the formulation had a significant effect on the nutritional value and chemical characteristics of the product. In particular, noticeable changes were observed in dietary fiber, ash content, and pH values (Table 5).

The protein content in the control sample was 6.09%, whereas with an increase in the amount of GSP, it gradually decreased, reaching 5.63% in the sample with 20% addition. This change can be explained by the fact that wheat flour is rich in gluten-forming proteins, while GSP contains a relatively lower protein content. The replacement of a portion of flour with GSP led to a decrease in the total protein content. At the same time, the reduction of gluten proteins may also affect the structural-forming properties of the dough.

Table 5. Physicochemical composition indicators of cake prepared with grape seed powder (GSP)

Experimental Variants	Composition Indicators, Content (%)					
	Proteins	Fat	Ash	Soluble Dietary Fiber	Insoluble Dietary Fiber	pH
Control	6.09	25.48	1.73	1.23	1.61	7.16
4% addition	6.00	25.32	1.80	1.38	2.77	7.05
8% addition	5.91	25.86	1.89	1.51	4.81	6.91
12% addition	5.73	26.00	2.01	1.69	6.92	6.83
16% addition	5.64	25.26	2.14	1.77	7.15	6.69
20% addition	5.63	24.90	2.19	2.13	8.22	6.56

Table 6. Phenolic compounds and antioxidant properties of cakes with grape seed powder (GSP) addition

Experimental Variants	Total Phenolic Compounds, mg GAE/100 g	Antioxidant Activity, $\mu\text{mol TE}/100\text{ g}$
Control	83.51	2.01
4% addition	107.15	11.10
8% addition	135.06	25.36
12% addition	143.58	33.45
16% addition	184.46	42.63
20% addition	211.88	51.92

Although the fat content did not change significantly among the samples, certain differences were observed. In the control sample, the fat content was 25.48%, while in the 12% addition variant, it reached a maximum of 26.00%. This increase is associated with the lipid components of GSP, particularly unsaturated fatty acids. However, at higher addition levels (20%), the fat content decreased to 24.90%, which can be explained by the high water- and fat-binding capacity of dietary fibers.

Ash content increased in all enriched samples. In the control sample, ash content was 1.73%, while in the 20% addition sample, it reached 2.19%. The increase in ash content is related to the richness of GSP in mineral substances. This result indicates enrichment of the product with calcium, magnesium, potassium, and other mineral components.

The content of soluble dietary fiber increased progressively with the addition of GSP, from 1.23% in the control sample to 2.13% in the 20% addition sample. The increase in soluble fiber improves the functional properties of the product, as these fibers support the growth of intestinal microflora, slow glucose absorption, and help reduce cholesterol levels.

A more significant change was observed in insoluble dietary fiber. In the control sample, this value was 1.61%, while in the 20% addition sample, it increased to 8.22%. This increase is associated with the high fiber content of GSP. Insoluble fibers stimulate digestive system activity, improve intestinal peristalsis, and enhance the physiological value of the product. Thus, the addition of GSP increased the functional significance of the cake as a functional food product.

A decrease was observed in pH values. In the control sample, pH was 7.16, while in the 20% addition sample, it decreased to 6.56. This change is associated with organic acids and phenolic compounds present in GSP. The decrease in pH may positively affect microbiological stability and contribute to extending shelf life. At the same time, increased acidity may influence sensory properties, leading to a slightly sour taste note.

Thus, the results presented in the table show that the incorporation of GSP into cake formulations leads to enrichment with dietary fiber and mineral substances, improvement of functional properties, and enhancement of antioxidant potential. However, as the level of addition increases, the reduction in protein content and possible changes in product structure make it necessary to determine the optimal dosage. The increase in GSP content also affects the rheological properties of the dough. Due to its high fiber content, water absorption increases, gluten network formation is partially weakened, and consequently, changes may occur in cake volume, porosity, and softness. While low levels of addition (4–8%) can have a positive effect on product quality, higher levels (16–20%) may result in firmer texture, darker color, and a more pronounced specific taste. Therefore, from a technological and organoleptic point of view, medium levels of addition can be considered more appropriate.

Below are presented the total phenolic compounds and antioxidant activity of cake samples prepared with GSP additions. The results clearly show that the incorporation of GSP significantly increases the biological value of the product and enhances its antioxidant properties (Table 6).

As shown in the table, the total phenolic compounds in the control sample were 83.51 mg GAE/100 g. With the addition of GSP, this indicator increased steadily, reaching 211.88 mg GAE/100 g in the 20% addition sample. This increase is explained by the fact that GSP is rich in polyphenolic substances. Grape seeds contain high amounts of phenolic compounds such as catechins, epicatechins, flavonoids, and proanthocyanidins. These compounds play an important role in neutralizing free radicals and enhancing the functional properties of the product.

The increase in phenolic content was also reflected in antioxidant activity indicators. In the control sample, antioxidant activity was only 2.01 $\mu\text{mol TE}/100\text{ g}$, while in the 4% addition sample, this value increased to 11.10 $\mu\text{mol TE}/100\text{ g}$. With increasing levels of addition, antioxidant activity continued to rise, reaching 51.92 $\mu\text{mol TE}/100\text{ g}$ in the 20% addition variant. This result indicates a direct positive correlation between phenolic compounds and antioxidant activity. The high phenolic content and antioxidant potential of GSP indicate that it is a promising raw material for the development of functional food products. Although the obtained results demonstrate an increase in the antioxidant properties of the product, bioavailability and storage stability require further investigation in separate studies.

The results presented in the table show that increasing the amount of GSP improves the functional value of the product. In particular, the 16% and 20% addition samples exhibited higher levels of phenolic compounds and antioxidant activity, indicating greater biological value. However, it should be taken into account that high levels of addition may affect the color, taste, and texture of the product. Therefore, when selecting the optimal level of addition, both biological activity and organoleptic quality indicators must be evaluated together. Thus, the results confirm that GSP is a promising functional additive for enriching cake products with phenolic compounds and increasing their antioxidant potential. Its application makes it possible to obtain functional flour-based confectionery products with higher biological value that meet the requirements of healthy nutrition.

Cake samples prepared with GSP were evaluated for external and internal color parameters using the CIELab color system (Table 7). Color parameters are important quality indicators influencing consumer acceptance and allow the assessment of the effect of additives on the visual properties of the product. In the CIELab system, the L value characterizes lightness-darkness, the a value characterizes red-green tones, and the b value characterizes yellow-blue tones. The external and internal color values of cakes with GSP addition are presented.

Table 7. External and internal color values of cake samples

Experimental Variants	Color Values					
	L		a		b	
	External	Internal	External	Internal	External	Internal
Control	45.60	72.05	18.22	4.50	23.01	24.86
4% addition	44.72	52.31	14.75	8.12	18.86	16.24
8% addition	41.08	45.80	12.30	9.05	15.45	15.46
12% addition	39.51	40.56	11.95	9.20	14.63	14.19
16% addition	36.40	37.29	11.67	9.11	13.94	12.07
20% addition	33.25	33.15	11.05	9.00	12.18	11.65

As can be seen from the table, as the amount of GSP increased, a decrease was observed in both external and internal L values. In the control sample, the external L value was 45.60, while the internal L value was 72.05. In the 20% addition sample, these values decreased to 33.25 and 33.15, respectively. The decrease in the L value indicates darkening of the product color. This change is associated with the high content of phenolic compounds and natural pigments in GSP. At the same time, the Maillard reaction and caramelization processes during baking also contributed to the formation of a darker color.

Changes were also observed in the a values. In the control sample, the external a value was 18.22, while the internal a value was 4.50. With the addition of GSP, the external value decreased, reaching 11.05 in the 20% addition sample. In contrast, in the internal part, a certain increase was recorded compared to the control, reaching 9.00. This result indicates a more intensive formation of reddish-brown tones inside the product. The main reason for this is the participation of polyphenols and natural colorants present in GSP in thermal color reactions.

A general decreasing trend was observed in the b values. In the control sample, the external b value was 23.01, while the internal b value was 24.86. In the 20% addition sample, these values decreased to 12.18 and 11.65, respectively. This result indicates a reduction in yellow color intensity and the dominance of darker brown tones. The decrease in yellow tones is explained by the reduction in flour content and the dominance of dark pigments from GSP.

The results in the table show that the addition of GSP significantly affected both the external and internal color properties of cakes. As the addition level increased, the product color became darker with brown and reddish tones. These changes are associated with enrichment in antioxidant compounds and can be considered characteristic features of functional products.

At the same time, since color changes directly affect consumer acceptance, the selection of an optimal addition level is of great importance. At medium addition levels (8–12%), the product may show more balanced results in terms of both functional properties and acceptable color characteristics. Thus, the application of GSP not only changes the color properties of cakes but also contributes to improving their biological and functional value.

Cake samples prepared with the addition of GSP were evaluated for their organoleptic properties using a 9-point hedonic scale (Table 8).

The results showed that the sample with 8% GSP addition demonstrated the highest performance across all sensory indicators. This variant achieved an overall acceptability score of 8.9 points and surpassed the control sample. According to the panelists, the color, taste, and texture of this sample were more harmonious and balanced. In particular, mild nutty and

fruity notes formed in the product were positively evaluated.

Table 8. Sensory evaluation of cake samples with grape seed powder (GSP) addition

Variants	Color	Aroma	Taste	Texture	Overall Acceptability
Control	8.2	8.1	8.0	8.1	8.1
4% addition	8.4	8.3	8.4	8.3	8.4
8% addition	8.9	8.8	9.0	8.8	8.9
12% addition	8.6	8.5	8.4	8.3	8.5
16% addition	7.6	7.4	7.2	7.0	7.3
20% addition	6.9	6.8	6.5	6.4	6.6

The 12% addition sample was also highly rated and showed a balanced relationship between functional properties and organoleptic quality. However, compared to the 8% variant, its overall acceptability was slightly lower due to a somewhat denser texture and a more pronounced specific taste. In the 4% addition sample, the product characteristics were close to the control variant, but the effect of GSP was not fully expressed. Therefore, in terms of the optimal balance between functional and sensory properties, this variant was inferior to the 8% addition sample.

Increasing the addition level to 16–20% led to a decline in sensory properties. In these samples, excessive darkening of color, increased firmness of texture, and a more pronounced astringent and bitter taste associated with high phenolic content were observed. The weakening of the gluten network due to high fiber content resulted in reduced porosity and softness of the product. Thus, based on the sensory evaluation results, it was determined that the addition of 8% GSP to the cake formulation can be considered the optimal variant. This sample was characterized by both high organoleptic quality and enhanced antioxidant and functional properties. Although the 12% variant also showed satisfactory results, the 8% addition sample was superior in terms of consumer acceptance.

In order to determine the statistical reliability of the 9-point hedonic evaluation results of cake samples with GSP addition, analysis of variance (ANOVA) was applied. During the analysis, the statistical significance of differences between the overall acceptability scores of the samples was evaluated. Statistical calculations were performed at a 95% confidence level ($p < 0.05$). The results of the ANOVA analysis showed that the level of GSP addition had a statistically significant effect on the overall sensory acceptability of the cake samples ($p < 0.05$). The highest acceptability score was recorded in the 8% addition sample (8.9 points), and this variant was statistically superior to the control and high-addition samples (Table 9).

The 8% addition variant was assigned to the “a” statistical group and was evaluated as the sample with the highest consumer acceptability. This result indicates that the

application of GSP at this concentration optimally improved the color, taste, aroma, and texture characteristics of the product. The control sample was placed in the “b” group and showed statistically lower results compared to the 8% addition sample.

Table 9. Statistical evaluation of the final sensory indicators of cake samples with grape seed powder (GSP) addition

Variants	Overall Acceptability, Score	Standard Deviation (SD)	Statistical Group
Control	8.1 ± 0.12	0.12	B
4% addition	8.4 ± 0.10	0.10	Ab
8% addition	8.9 ± 0.08	0.08	A
12% addition	8.5 ± 0.11	0.11	Ab
16% addition	7.3 ± 0.14	0.14	C
20% addition	6.6 ± 0.16	0.16	D

Note: Statistically significant differences between indicators marked with different letters in the same column are present ($p < 0.05$).

The 12% addition sample demonstrated high acceptability but was placed in the “ab” statistical group, showing results close to both the 8% and 4% addition variants. Although this variant was considered favorable in terms of enhanced functional properties, it lagged behind the 8% addition sample due to a slightly denser texture and a more pronounced specific taste.

In the 16% and 20% addition samples, a statistically significant decrease in overall acceptability was observed ($p < 0.05$). This decrease was associated with excessive darkening of the product color, the formation of a firmer texture, and a more pronounced bitter taste resulting from the high concentration of phenolic compounds. Thus, the results of ANOVA and multiple comparison tests confirmed that the addition of 8% GSP to the cake formulation is the most optimal variant both statistically and sensorially. This sample demonstrated the highest overall acceptability compared to the control and other enriched variants and achieved the best balance between functional properties and organoleptic quality.

3.3 Justification of optimal formulation selection

The results showed that increasing the amount of GSP led to an improvement in dietary fiber content, phenolic compounds, and antioxidant activity of the product. In this regard, the highest functional indicators were observed in the sample with 20% substitution. However, in the development of functional foods, not only the maximum level of bioactive components but also consumer acceptability must be considered.

In the 20% substitution sample, the phenolic content reached 211.88 mg GAE/100 g, and antioxidant activity was 51.92 $\mu\text{mol TE}/100\text{ g}$. However, the overall acceptability score of this sample was 6.6 points. In contrast, the 8% substitution sample showed a phenolic content of 135.06 mg GAE/100 g and antioxidant activity of 25.36 $\mu\text{mol TE}/100\text{ g}$, while achieving the highest sensory score (8.9 points).

The quality changes observed at higher levels of substitution are associated with the chemical composition of GSP. The high content of insoluble dietary fiber strongly

adsorbs water and limits the formation of the gluten network, resulting in reduced gas-holding capacity of the dough and a denser, firmer texture of the product. On the other hand, tannins and other phenolic compounds interact with proteins in the oral cavity, creating an astringent and slightly bitter taste. The darkening of color is related to natural pigments in grape seeds, polyphenols, and Maillard reactions, as well as caramelization processes occurring during baking. As the level of addition increases, the L^* value decreases, leading to a darker brown appearance of the product. Therefore, although the 16–20% substitution samples exhibited higher functional properties, their organoleptic characteristics were significantly reduced.

Thus, the optimal formulation was selected based on the principle of achieving a balance between functional properties and organoleptic quality rather than maximizing functional indicators alone. Accordingly, the 8% substitution level was considered the most appropriate formulation within the scope of this study.

4. CONCLUSION

1. It was determined that the total dietary fiber content in GSP was 35.15 g/100 g, whereas this value in flour was only 2.86 g/100 g. At the same time, the fat content in GSP was 11.31 g/100 g, which was approximately 7.8 times higher than in flour. The phenolic compound content in GSP was 8386 mg GAE/100 g, while in flour it was only 96.7 mg GAE/100 g. Antioxidant activity also showed a significant difference, being 4735 $\mu\text{mol TE}/100\text{ g}$ in GSP and 2.2 $\mu\text{mol TE}/100\text{ g}$ in flour. During the study, pectin substances in grape skin reached 18.4% while phenolic compounds in the seed fraction reached up to 1.47%. The obtained results confirmed that GSP is a promising, enriching additive for functional cake production.

2. The addition of GSP to the cake formulation significantly affected the physicochemical, antioxidant, and color properties of the product. It was determined that with increasing addition level, insoluble dietary fiber increased from 1.61% to 8.22%, while soluble dietary fiber increased from 1.23% to 2.13%. At the same time, ash content increased from 1.73% to 2.19%, while pH decreased from 7.16 to 6.56, indicating enrichment with minerals and organic acids. The phenolic compound content increased from 83.51 mg GAE/100 g in the control sample to 211.88 mg GAE/100 g in the 20% addition sample, while antioxidant activity increased from 2.01 $\mu\text{mol TE}/100\text{ g}$ to 51.92 $\mu\text{mol TE}/100\text{ g}$. These results confirmed that GSP is a functional ingredient with high antioxidant potential. Color analysis showed that the decrease in L values from 45.60 to 33.25 led to a darker product appearance.

The results of the study demonstrated that increasing the amount of GSP led to a consistent rise in phenolic compounds, dietary fiber, and antioxidant activity of the product, with the highest values observed in the sample containing 20% supplementation. However, higher levels of incorporation caused excessive darkening of the product color and a reduction in sensory acceptability.

Based on sensory evaluation and ANOVA analysis, the sample containing 8% GSP provided the most favorable balance between functional properties and organoleptic quality within the tested range. Therefore, the 8% substitution level can be considered the optimal formulation for practical

application in functional cake production.

The obtained results are significant not only for the development of functional food products but also for the efficient utilization of secondary raw materials generated in the grape processing industry. The application of grape seeds as a functional food ingredient contributes to waste reduction, more efficient use of resources, and the implementation of circular economy principles in the food industry.

AUTHOR CONTRIBUTIONS

H.K. Fataliyev – research concept, methodology, and manuscript preparation; G.V. Hajiyeva – conducting experimental work and data collection; S.H. Fataliyeva – laboratory analyses and statistical processing; U. Majnunlu – organization of sensory evaluation and data analysis; K.V. Baloglanova – interpretation of results and literature review; A.T. Taghiyev – scientific editing and final approval.

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