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Investigation of the physicochemical and sensory properties of functional cake enriched with malted barley flour and red grape pomace powder

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ABSTRACT

In this study the physicochemical, sensory and microbial properties of cakes enriched with malted barley flour (0.5 and 1%) and grape pomace powder (3 and 6%) and 1% malted barley flour and 6% grape pomace powder was investigated. Results showed that incorporating these compounds increased the moisture, ash, and fiber content of the cakes with no significant effect on fat content and pH. The addition of both compounds significantly increased the total phenolic content and antioxidant capacity, with the highest activity observed in samples containing GP ($P < 0.05$). Compared to the control, cakes with 6% GP had less firmness, and the combination of 1% MB and 3% GP had higher firmness. Adding GP also resulted in a darker color in cakes. The lowest porosity was observed in cakes enriched with GP, while MB improved porosity. Additionally, the highest cake volume was observed in the treatment containing 1% MB and 3% GP, while higher levels of GP led to a decrease in volume. No bacterial and mold and yeast growth were observed on the production day and the seventh day of storage, respectively. The highest and lowest total counts were observed in treatments enriched with 3% GP (2.50 log CFU/g) and 1% MB (1.75 log CFU/g), respectively ($P < 0.05$). Sensory analysis also showed that the cake containing 1% MB and 3% GP was the best according to the panelists and received the highest score. The findings of this study confirmed that malted barley flour and red grape pomace powder are suitable components for enriching cakes in terms of bioactive compounds. Given the positive effects of these ingredients on textural, sensory, microbial quality, and antioxidant properties of cakes, they can be effectively utilized to fortify bakery products in the industry.

1. Introduction

The bakery industry is one of the largest food sectors worldwide, producing highly popular products such as biscuits, cookies, and cakes due to their convenience and long shelf life. Given their widespread consumption across various age groups, cakes are an ideal candidate for fortification with essential nutrients to develop functional food products [1]. Functional foods are defined as products that offer health benefits beyond basic nutrition. Essentially, they resemble conventional foods and are consumed as part of a normal diet but are modified to provide physiological benefits beyond meeting basic dietary requirements [2].

Many functional foods are developed by incorporating plant-based bioactive compounds or extracting biologically active substances from natural sources. Notable examples include antioxidants, polyphenols, and dietary fibers, which play a crucial role in inhibiting oxidative reactions in biological systems, thereby preventing or delaying oxidative damage to essential biomolecules such as carbohydrates, proteins, and lipids [3]. Antioxidants used in food products can be either synthetic or naturally occurring. Naturally derived phenolic compounds, flavonoids, and other plant-based antioxidants not only slow oxidative deterioration in food matrices but also provide protective effects against chronic conditions such as coronary heart disease, cancer, and age-related neurodegenerative disorders [4].

Dietary fiber is another essential component in functional food development. It consists of indigestible plant cell wall components such as cellulose, hemicellulose, and lignin. Since dietary fiber is not absorbed by the human body, it provides no calories [5]. The consumption of fiber-rich whole grains has been linked to various health benefits, including improved cardiovascular and digestive health, weight management, reduced serum cholesterol levels, blood pressure regulation, glycemic control, and enhanced bowel regularity, thereby preventing constipation [6].

Barley is one of the four major cereal crops worldwide and is a valuable source of dietary fiber [7]. Sprouted barley flour, derived from germinated, dried, and milled barley grains, is a highly nutritious ingredient in functional food formulations. Compared to non-sprouted grains, sprouted barley has an enhanced nutritional profile, including higher protein, soluble sugar, lipid, mineral, and vitamin content [8]. Moreover, germination has been shown to increase crude fiber, protein, and lipid levels while enhancing the antioxidant and antimicrobial properties of grains [9].

Red grapes are among the most economically significant horticultural crops, valued for their well-established nutritional benefits. Grape pomace, a byproduct of grape processing, is rich in bioactive compounds but poses environmental disposal challenges. During the grape harvest season, large volumes of pomace are generated in a short period, contributing to environmental concerns due to its high phenolic content, which lowers pH levels and slows biodegradation. Consequently, improper disposal of grape pomace can lead to environmental issues such as surface and groundwater contamination, unpleasant odors, insect and pest infestations, disease spread, and oxygen depletion in soil and water bodies [10].

Grape pomace is a rich source of essential bioactive compounds, including citric acid, tartaric acid, dietary fiber (lignocellulosic components), phenolic compounds, anthocyanins (malvidin, peonidin), flavonols (quercetin, myricetin), stilbenes, and phenolic acids. Incorporating grape pomace into food products provides a dual benefit: reducing environmental impact while enhancing the nutritional value of fortified foods [11].

With the growing global interest in functional and health-promoting foods, this study evaluates the effects of incorporating sprouted barley flour and red grape pomace powder into cake formulations on their physicochemical and sensory properties.

2. **Materials and Methods**

Raw Materials

The essential ingredients for cake preparation included food-grade oil, sugar, eggs, white flour, baking powder, and vanilla, all of which were procured from local grocery stores. For the purposes of this study, sprouted barley grains (malt) were supplied by the Giah Essence Phytopharm Company. Additionally, seedless red grapes of the Shahrud 'Rish Baba' variety were obtained from the local market. This specific variety, indigenous to the region and classified under *Vitis vinifera L.*, is registered with the code 3.4.2.6, as documented by the Seed and Plant Certification and Registration Institute. Furthermore, the chemical reagents and solvents utilized in this research included petroleum ether (Kian Kaveh Azma, highly pure), sulfuric acid (98%), hydrochloric acid (37%), sodium hydroxide, boric acid (99.5%), and Kjeldahl catalyst, all of which were laboratory-grade and acquired from Merck.

Preparation of malted Barley Flour

This product was obtained by milling germinated barley seeds (malt). To produce light-colored malt flour, high-diastatic-activity malt was milled and sieved through a fine mesh for uniformity.

Preparation of Grape Pomace Flour

Seedless red grapes of the Shahroud 'Rish Baba' variety were purchased from the local market. After juice extraction, the pomace was dried in an oven at 40°C until a constant weight was achieved. The dried pomace was ground using an electric grinder, sieved through an 80-mesh sieve (pore size: 177 microns), and stored at 20°C until further analysis.

Cake Preparation

The eggs were separated into yolks and whites. The egg whites (100 g) were beaten at speed 3 for 1 minute using a mixer. Sugar (100 g) and egg yolks (70 g) were added and mixed at speed 2 for 1 minute. Wheat flour (100 g) and baking powder (2 g) were sifted together and added to the mixture, then mixed for 50 seconds. The cake gel, consisting of an emulsifier and refined sunflower oil (1.5 g), was added and mixed at low speed for 1 minute. The cake batter was transferred into circular baking molds and baked at 200°C for 30 minutes. After cooling to room temperature, the cakes were wrapped in plastic film and prepared for testing (control sample). For the production of functional cakes, germinated barley flour was substituted at three levels (0, 0.5, and 1%), and red grape pomace powder was substituted at three levels (0, 3, and 6%) in the flour composition. All samples were prepared in triplicate. Shelf-life evaluations were conducted on days 1, 7, and 14 of storage [12].

Proximate analysis of cakes

The moisture content of the cakes was determined following the Iranian National Standard No. 213 [13], while the ash content was measured based on the Iranian National Standard No. 37 [14]. The protein percentage was assessed according to the Iranian National Standard No. 19052 [15], and the fat percentage of the samples adhered to the Iranian National Standard No. 11691 [16]. Additionally, pH values were evaluated in accordance with the Iranian National Standard No. 37 [14].

Fiber Content Measurement

To determine the fiber content in the cake, the standard raw fiber test method was used. In this method, a specific amount of the cake sample was weighed accurately and subjected to successive digestions with 1.25% sulfuric acid and 1.25% sodium hydroxide. This digestion process removed proteins, fats, and water-soluble carbohydrates. After digestion, the solid residue containing raw fiber was washed with water and dried. The dried residue weight represented the raw fiber content of the cake, which was reported as a weight percentage relative to the initial sample weight. This method, widely used in food analysis, measures raw fiber, including cellulose and lignin [17].

Total Phenolic Content Measurement

The total phenolic content was measured using the Folin-Ciocalteu reagent. Absorbance was recorded at 760 nm using a UV-Visible spectrophotometer. Results were expressed as milligrams of gallic acid per 100 grams of the sample (mg GAE/100g) [18].

Total Antioxidant Capacity Measurement

An aliquot of each sample was added to a 0.1 mM DPPH solution. The resulting mixture was thoroughly stirred and left for 15 minutes in a dark room. Absorbance was measured at 517 nm. Ascorbic acid solution and solvent + (sample without DPPH) were used as the positive and negative controls, respectively. These steps were also performed with BHA, which served as a standard antioxidant [19]. The DPPH radical scavenging activity, also known as radical inhibition activity, was calculated using the following formula:

$$Radical\ scavenging\ activity = \left[\left(\frac{A_{control} - A_{sample}}{A_{control}}\right)\right] \times 100$$

In this formula, A_control represents the absorbance of the control sample, and A_sample represents the absorbance of the test sample.

a. **Cake Volume Measurement**

Cake volume was measured using the rapeseed displacement method. The box was filled with rapeseed, and its top was leveled. The rapeseeds were then poured into a graduated cylinder to determine the volume of the box. The cake sample was placed inside the box, and rapeseeds were added again, leveling the top. The rapeseeds were poured into the graduated cylinder once more to determine the volume of the box in the second state. The difference between these two values provided the cake's volume [20].

Texture Properties Measurement

Cake texture firmness was considered as the highest resistance to deformation. To this end, the firmness of the cake samples was measured using a texture analyzer. A 2.5 cm cubic piece from the cake's core (without the crust) was removed, and the device probe compressed 1 cm (40%) of the texture. The force rate before and during the test was set at 1 millimeter per second, and after the test, it was increased to 10 millimeters per second. The highest force applied to the sample at the end of the compression process was recorded in N [21].

Cake Porosity Measurement

A cross-sectional slice of the cake was prepared using a serrated knife, and its image was captured with a scanner. Porosity was measured using ImageJ software by calculating the ratio of light to dark points, which served as an indicator of porosity [22].

Cake Color Measurement

Color properties such as b*, L*, and a* of the cake samples were evaluated using image processing techniques with an image processing device. L* represents lightness, where 100 corresponds to a completely white sample and 0 to a completely black sample. a* indicates the red-green quality, with positive values indicating redness and negative values indicating greenness. b* represents the yellow-blue quality, with positive values indicating yellowness and negative values indicating blueness [23].

Sensory Evaluation

After preliminary training on sensory testing, 10 evaluators (men and women aged 20-40 years) were selected. A 5-point hedonic scale was used for the sensory evaluation of the cake samples. In this stage, each evaluator was provided with a coded sample, a glass of water, and a scoring form. The judges evaluated all samples randomly, drinking water between each sample. Factors such as texture, porosity, aroma, taste, and overall acceptance were assessed [24].

Total Viable Microorganism Count

A serial dilution of each sample was prepared to evaluate the total viable count. The first dilution was a 0.1 dilution, represented as 1:10. To prepare the 0.1 dilution, 10 grams of the sample were weighed and ground, then 90 milliliters of peptone water diluent were added, resulting in a uniform mixture. To further dilute the sample, test tubes containing 9 milliliters of diluent were used, labeled as 0.01, 0.001, 0.0001, and 0.00001. A 1-milliliter sterile pipette was used to transfer 1 milliliter from the 0.1 dilution to the first tube labeled 0.01, and the dilution process continued. All operations were performed under sterile conditions near a flame. The sample was then cultured using the PCA method. Petri dishes were inverted and incubated at 32°C for 48 hours, after which counting was performed. The total count was expressed as log cfu/g [25].

Mold and Yeast

To measure mold and yeast, peptone water broth was used. A 0.1 dilution of the sample in peptone water was prepared, then 0.1 milliliters was transferred to a DRBC culture plate and spread using spreaders. The cultured plates were incubated aerobically with the lid facing up in an incubator at 25°C for 5 days. The prepared plates were immediately used and should not be exposed to light [25].

3. Statistical Analysis

All experiments were conducted in a completely randomized design. The results were analyzed using analysis of variance (ANOVA), and means were compared using Duncan's test at a 5% significance level. Data analysis was performed using SPSS software, and graphs were plotted using Excel 2010. All experiments were repeated three times

4.1. Chemical Composition of Wheat Flour and Grape Pomace

"The moisture, ash, fat, protein, and fiber content of grape pomace, white flour, and sprouted barley flour are presented in Table 1. The results show that sprouted barley flour has a higher protein content by weight compared to white flour, and its fiber content (9.88%) is significantly higher than that of white flour. In contrast, grape pomace contains relatively high fiber (27.61%) and protein (22.66%) levels. The presence of these two components in both sprouted barley flour and grape pomace makes them suitable enrichment sources. In addition to boosting protein content, the higher fiber content can enhance digestive performance [6, 26, 27]. Furthermore, a study by Abdullah et al. (2022) confirmed that sprouted barley flour contains significant amounts of fiber and protein, which aligns with the findings of this study [7].

Table 1. The chemical composition of grape pomace (GP), white flour (WF), and malted barley flour (MB) (%wet weight basis).

treatment	Fat	Protein	Moisture	Ash	Fiber	Carbohydrate
Grape pomace powder	3.81±0.001	22.66±0.33	5.38±0.42	8.57±1	27.61±0.87	31.97±0.44
Wheat flour	0.86±0.35	8.22±0.72	13.07±0.79	0.43±0.92	1.23±0.1	77.32±0.69
malted barley flour	0.75±0.15	31.4±0.21	9.88±0.33	4.66±0.17	0.56±0.05	52.8±0.49

4.2. Chemical Characteristics of Cake

4.2.1. Moisture

Moisture content of the cake is a critical criterion for determining the quality and shelf life of the final product. Excess moisture can reduce shelf life and increase the likelihood of microbial spoilage, while lower moisture content can lead to dryness and reduced consumer acceptance. The moisture content of the control cake was approximately 17.5%. Adding sprouted barley flour and grape pomace to the cake formulation at the beginning of the storage period resulted in an increase in moisture, which further increased as the percentage of these ingredients rose (Table 2) ($P < 0.05$). The increase in moisture with the addition of barley flour may be attributed to its high water absorption properties. This is due to changes in the gluten structure and the higher fiber content in sprouted barley, which give it a greater ability to absorb and retain moisture compared to regular wheat flour. Additionally, the combination of sprouted barley flour with other ingredients can affect the physical and chemical properties of the cake, ultimately resulting in higher moisture content.

Similarly, the addition of grape pomace powder also increased the moisture content, which could be attributed to its high fiber and phenolic content, both of which have strong water-absorbing properties. Previous studies have shown that adding sprouted flour to cakes increases moisture content, with cakes made from sprouted flour generally having moisture levels in the range of 18% to 20% [28]. Furthermore, prior research has demonstrated that incorporating fruit pomace powders, such as apple and orange pomace, can increase the moisture content of cakes to a range of 17% to 19% [29]. Overall, the moisture content results in this study are consistent with the findings of similar studies.

On the other hand, as the storage period progressed, the moisture content significantly decreased compared to the first day, with the lowest moisture observed after 14 days of storage (Table 2). In general, over time, moisture in the cake is transferred to the surrounding environment, particularly if the cake is not stored under proper conditions, such as without airtight packaging [30]. This moisture transfer can lead to a reduction in the cake's internal moisture. Additionally, changes in the cake's texture structure during storage may reduce its moisture retention capacity, contributing to the decrease in moisture [31]. However, the formulation containing grape pomace and sprouted barley flour still maintained higher moisture after 14 days of storage compared to the control sample. This can be attributed to the higher fiber and water-absorbing compounds present in this treatment (Table 1).

4.2.1 - Protein

According to the data in Figure 4-2, the highest protein content was observed in the 1% sprouted barley flour treatment, which had 12%, while the lowest protein content was found in the 6% grape pomace powder treatment, with 8.5% (Table 2). The protein content in the control treatment was 10.21%. The increase in protein percentage in formulations containing sprouted barley flour can be attributed to the higher protein content of this flour compared to white flour. Conversely, the protein content in the 3% and 6% grape pomace powder treatments decreased to 9.07% and 8.52%, respectively, due to the replacement of a portion of the flour with grape pomace. Additionally, the fibrous compounds in grape pomace may influence the availability and measurement of proteins, affecting water distribution and interactions with other ingredients in the cake, which could contribute to a relative decrease in protein content compared to the control sample [32].

In general, the protein content in cakes typically ranges from 8% to 13%. The proteins in flour, particularly gluten, combine with water to form a network that contributes to the cake's structure and volume [33]. Variations in protein content can affect the product's characteristics; higher protein content may lead to a firmer texture and increased volume, while lower protein content may result in a softer texture and reduced volume [34]. Previous studies suggest that the inclusion of additives with higher protein content can improve cake texture and increase volume, while additives with lower protein content may have a negative impact on cake quality. Yaqoob et al. (2018) reported that cakes made with sprouted wheat flour had higher protein content and improved texture [6]. Similarly, Aksu et al. (2024) reviewed studies on cakes made with various flours, including sprouted flours, and found that cakes made with sprouted flour exhibited higher protein content [35]. The protein content results from the storage evaluation on days seven and fourteen showed no significant differences between storage days in any of the treatments.

4.2.2 - Fat

"The results indicate that the addition of sprouted barley flour and grape pomace powder to the cake formulation did not significantly affect the fat content of the cake. In the control treatment, the fat content was 46.22%, which increased to 45.93% in the 1% sprouted barley flour treatment and to 47.07% and 46.50% in the 3% and 6% grape pomace powder treatments, respectively. No significant differences in fat content were observed during storage on the seventh and fourteenth days. The slightly higher values in samples containing grape pomace could be attributed to the higher fat content in grape pomace, which contributes to the increased fat in the final cake formulation (Table 1).

Fat is a crucial ingredient in cake making, influencing texture, flavor, and sensory properties. During the baking process, fat acts as a tenderizer, helping to soften and smooth the cake's texture. It also plays a role in the even distribution of heat during baking and contributes to the formation of a proper internal structure. Typically, fat content in cakes ranges from 40% to 50% based on wet weight. This fat content helps maintain moisture and reduces hardness, resulting in a cake with the desired softness and smoothness [36].

Table 2. The chemical composition (wet weight basis), total phenolic content (TPC), and antioxidant activity (AA) of cakes enriched with different levels of GP and MB

		treatments					
parameter	Storage day	Control	0.5% MB	1% MB	3% GP	6% GP	1% MB+3%GP
moisture	0	17.57±0.2^{aA}	18.06±0.4^{bA}	18.53±0.3^{cA}	18.27±0.7^{bcA}	18.81±0.1^{dA}	18.32±0.4^{cdA}
	7	15.94±0.5^{aB}	15.89±0.4^{bB}	15.55±0.2^{cB}	15.65±0.5^{cB}	15.33±0.4^{dB}	15.35±0.5^{cdB}
	14	13.57±0.2^{aC}	14.06±0.4^{bC}	14.53±0.3^{cC}	14.28±0.7^{bcC}	14.81±0.1^{dC}	14.32±0.4^{cdC}
Protein	0	10.41±0.2^{aA}	11.32±0.1^{bA}	12.03±0.1^{bA}	9.33±0.1^{cA}	8.52±0.04^{dA}	10.23±0.2^{aA}
	7	10.48±0.2^{aA}	11.37±0.1^{bA}	11.97±0.2^{bA}	9.20±0.3^{cA}	8.50±0.03^{dA}	10.23±0.11^{aA}
	14	10.41±0.2^{aA}	11.32±0.1^{bA}	12.02±0.1^{bA}	9.31±0.1^{cA}	8.49±0.05^{dA}	10.23±0.2^{aA}
Fat	0	46.49±0.3^{aA}	45.86±0.1^{bA}	46.03±0.1^{bA}	47.21±0.1^{cA}	46.65±0.1^{dA}	46.93±0.1^{aA}
	7	46.51±0.3^{aA}	45.91±0.2^{bA}	46.06±0.1^{bA}	47.23±0.1^{cA}	46.70±0.2^{dA}	46.92±0.1^{aA}
	14	46.46±0.3^{aA}	45.84±0.2^{bA}	46.02±0.1^{bA}	47.18±0.1^{cA}	46.64±0.2^{dA}	46.94±0.2^{aA}
pH	0	6.85±0.05^{aA}	6.75±0.05^{bA}	6.82±0.1^{bA}	6.90±0.05^{cA}	6.90±0.05^{dA}	6.85±0.05^{aA}
	7	6.78±0.1^{aA}	6.75±0.05^{bA}	6.83±0.1^{bA}	6.90±0.1^{cA}	6.90±0.05^{dA}	6.87±0.05^{aA}
	14	6.84±0.1^{aA}	6.76±0.1^{bA}	6.80±0.1^{bA}	6.91±0.04^{cA}	6.90±0.05^{dA}	6.86±0.04^{aA}
Ash	0	3.2±0.05^{aA}	3.15±0.05^{bA}	3.25±0.05^{bA}	2.8±0.05^{cA}	3.05±0.05^{dA}	3.35±0.05^{aA}
	7	3.19±0.1^{aA}	3.18±0.04^{bA}	3.25±0.04^{bA}	2.79±0.1^{cA}	3.08±0.1^{dA}	3.34±0.1^{aA}
	14	3.20±0.1^{aA}	3.15±0.05^{bA}	3.25±0.05^{bA}	2.80±0.04^{cA}	3.07±0.1^{dA}	3.33±0.1^{aA}
Fiber	0	0.87±0.3^{aA}	1.11±0.4^{bA}	1.42±0.9^{bA}	2.57±1.1^{cA}	3.05±0.05^{dA}	3.90±0.8^{dA}
	7	0.87±0.3^{aA}	1.12±0.5^{bA}	1.40±0.9^{bA}	2.55±1^{cA}	3.13±0.2^{dA}	3.21±1.6^{dA}
	14	0.86±0.3^{aA}	1.13±0.4^{bA}	1.41±0.9^{bA}	2.58±1^{cA}	3.12±0.1^{dA}	3.25±1.6^{dA}
TPC	0	12.5±0.3^{aA}	14.3±0.4^{bA}	17.2±0.5^{bA}	22.6±0.5^{cA}	25.3±0.6^{dA}	27.1±0.7^{dA}
	7	12.37±0.5^{aA}	13.87±0.3^{bA}	17.00±0.1^{bA}	22.73±0.6^{cA}	25.54±0.5^{dA}	26.80±0.6^{dA}
	14	12.35±0.5^{aA}	13.71±0.5^{bA}	16.94±0.08^{bA}	22.69±0.6^{cA}	25.34±0.5^{dA}	26.94±0.1^{dA}
AA	0	12.54±1^{aA}	14.29±0.8^{abA}	15.64±1.5^{abA}	16.76±0.4^{bcA}	18.77±0.4^{cdA}	20.58±0.5^{eA}
	7	12.42±1^{aA}	14.26±0.8^{abA}	15.60±1.5^{abA}	16.73±0.4^{bcA}	18.71±0.4^{cdA}	20.51±0.6^{eA}
	14	12.49±1.1^{aA}	14.25±0.8^{abA}	15.64±1.5^{abA}	16.74±0.4^{bcA}	18.75±0.4^{cdA}	20.58±0.6^{eA}

Different lowercase letters indicate significant differences between treatments and different uppercase letters indicate significant differences in storage days at the significant level of 0.05%.

4.2.3 - pH

The pH level in cakes typically ranges from 6.5 to 6.98. Maintaining an appropriate pH is crucial as it can significantly influence enzyme activity, the performance of raw materials, and the sensory characteristics of the final product. For example, a higher pH can enhance cake volume but may compromise texture quality, while a lower pH can result in stickiness and reduced cake volume. Therefore, controlling pH within the ideal range is essential for achieving a cake with optimal quality [7].

The analysis results from this study revealed no significant changes in pH across the different treatments. In the control treatment, the pH was 6.85, with the maximum change due to the addition of sprouted barley flour or grape pomace being less than 0.1 to 0.2 pH units. Previous studies have shown that pH values in cakes typically fall within a similar range, and variations in pH can have notable effects on the quality of the final product. While other research indicates that the use of various additives can influence the pH of cakes, this study observed no significant pH changes, likely due to the relatively small quantities of additives used in the formulation.

4.2.4 – Ash

"The ash content in a cake reflects the level of insoluble minerals transferred from the raw materials to the final product. This characteristic can be influenced by factors such as the type and amount of additives, the quality of flour, and the baking process. The results showed significant differences in ash content across the different treatments ($P < 0.05$). In the control treatment, the ash content was 3.20%, which increased to 3.50% and 3.70% with the addition of 0.5% and 1% sprouted barley flour, respectively. In contrast, the ash content in the 3% and 6% grape pomace treatments decreased to 2.90% and 3.0%, with the lowest value observed in the 3% pomace treatment. However, no significant differences in ash content were observed during storage.

The increase in ash content with the addition of sprouted barley flour may be attributed to its higher mineral content. Previous studies have shown that adding enriching flours, such as sprouted flour, to cakes typically increases ash content due to their higher mineral content [28]. Conversely, the decrease in ash content with grape pomace may be due to its higher organic compound content and lower mineral content. Aydın et al. (2023) found that adding fruit pomace powder generally increased the ash content of cakes, but the increase was less pronounced compared to enriching flours [38].

4.2.5- Fiber

"Fiber is an essential component in nutrition, exerting significant effects on both health and the quality of food products. In cakes, fiber contributes to enhanced nutritional and structural properties by increasing volume, improving texture, and aiding moisture retention. The fiber content in cakes typically varies depending on the use of various additives, such as whole flours or fiber-enriched ingredients. An appropriate level of fiber in cakes helps improve satiety, reduce the glycemic index, and generally enhances the nutritional profile of the final product. However, it is important to note that excessive fiber can negatively affect the cake's texture and flavor, resulting in a denser texture and altered taste [39].

In this study, the fiber content in the cakes showed significant differences ($P < 0.05$). The control treatment had a fiber content of 0.87%, which increased to 1.11% and 1.14% with the addition of 0.5% and 1% sprouted barley flour, respectively. When 3% and 6% grape pomace were added, the fiber content increased to 2.57% and 3.05%, respectively. Additionally, the combination of barley flour and grape pomace yielded the highest ash content (3.9%), which was significantly higher than that of all other treatments ($P < 0.05$).

The increase in fiber content in the treatments containing grape pomace can be attributed to the high fiber content of grape pomace, which contributed to the elevated fiber levels in the cakes. In contrast, the treatments containing barley flour showed a more moderate increase in fiber content, as barley flour has a lower fiber content compared to grape pomace (Table 1). Previous studies have indicated that the addition of fiber to bakery products can improve their nutritional and structural properties. However, the amount and type of fiber must be carefully controlled to avoid adverse effects on product quality. The results of this study align with previous findings that highlight the beneficial impact of fiber on the nutritional properties of bakery products [40].

4.2.6- Total Phenols

Phenols are a group of antioxidant compounds that are highly valued in food products due to their health benefits and antioxidant properties. These compounds help reduce oxidative damage and prevent chronic diseases. The total phenol content in cakes was significantly influenced by various additives, including sprouted barley flour and grape pomace ($P < 0.05$). The control treatment contained the lowest amount of phenolic compounds (12.5 mg gallic acid equivalents per gram). In contrast, adding grape pomace resulted in a greater increase in phenolic content compared to barley flour. The highest phenol content was observed in the treatment containing both sprouted barley flour and grape pomace ($P < 0.05$).

Red grape pomace powder is rich in phenolic compounds, such as resveratrol, flavonoids, polyphenols, tannins, and coumarins. Resveratrol, one of the most well-known phenolic compounds in red grapes, is notable for its antioxidant and anti-inflammatory properties. Flavonoids, including anthocyanins, catechins, and epicatechins, contribute to the red grape's color and exhibit strong antioxidant and anti-inflammatory effects [41]. Tannins, known for their astringent and antimicrobial properties, can help reduce bacterial growth and improve the shelf life of food products. Coumarins, which possess anti-inflammatory and antioxidant properties, are beneficial in reducing the risk of chronic diseases such as diabetes and cancer. The phenolic compounds in red grape pomace not only improve the nutritional quality of food but also contribute to enhancing flavor, increasing shelf life, and improving the health benefits of food products [42, 43].

Several studies have examined the effect of adding red grape pomace on the phenolic content of cereal-based products. For example, Rainero et al. (2022) investigated the impact of enriching bread with red grape pomace. Their results showed that replacing wheat flour with 5 and 10 grams of grape pomace powder (GPP) per 100 grams increased the total phenolic compounds and antioxidant capacity in the enriched bread compared to the control sample [44]. Similarly, Tolve et al. (2021) also explored enriching wheat bread with GPP and found that adding GPP enhanced the total phenolic compounds and antioxidant capacity [26]. These findings align with the results of this study. Additionally, sprouted barley flour is a rich source of phenolic compounds, such as phenolic acids, flavonoids, and tannins [45]. Studies have identified phenolic acids as some of the most important phenolic compounds in sprouted barley flour [46].

In this study, the total phenol content slightly decreased over the 7th and 14th days of storage, although the decrease was not significant, indicating that storage time did not significantly affect the degradation of phenolic compounds. The reduction in phenolic compounds during storage may be attributed to various factors, including oxidation, interactions with proteins, fats, and sugars in the cake, and the high storage temperature, which accelerates oxidation [47, 48]. Despite these potentially destructive factors, the phenolic compounds in the samples of this study did not decrease significantly, which can be attributed to the proper storage conditions over time.

Another key feature of cakes enriched with natural additives is their total antioxidant activity, which is closely linked to the phenolic content. The results of the total antioxidant activity in the various cake treatments demonstrated that increasing the amounts of sprouted barley flour and grape pomace significantly enhanced the total antioxidant activity, which was consistent with the total phenolic content results ($P < 0.05$). As with the total phenolic content, adding grape pomace resulted in higher antioxidant activity compared to barley flour, with the combination of both ingredients showing the highest antioxidant activity among all samples (20.5 mg). Furthermore, similar to the total phenolic compounds, the antioxidant activity of the samples did not show a significant decrease during storage. These findings confirm previous research highlighting the positive effect of natural compounds on antioxidant activity [49-51].

4.2.7- Cake Volume

Cake volume is a key characteristic in determining the final quality of the product. A larger volume is typically associated with a softer and more desirable texture, reflecting good dough performance during the baking process. Several factors, including the type of flour, fat and sugar content, and the type of leavening agent, influence the final volume of the cake. This parameter can also serve as an indicator for evaluating the impact of additives such as fiber, protein, or fruit pomace on the structure and physical properties of the product [52].

The results indicated that the amount and type of additives significantly influenced the cake volume. The control (reference) treatment and treatments containing 0.5% sprouted barley flour or 3% grape pomace powder did not show significant differences in volume. However, the treatment with 1% sprouted barley flour exhibited a slight but significant increase in volume compared to the previous two treatments, likely due to a balanced composition and improvements in the rheological properties of the dough. In contrast, the treatment with 6% grape pomace powder showed the lowest volume. The highest cake volume was observed in the combined treatment containing 1% sprouted barley flour and 3% grape pomace powder, with a volume of 107 cubic centimeters. This increase can be attributed to the high fiber content in the pomace, which influences the dough structure and potentially reduces its ability to retain gases during baking.

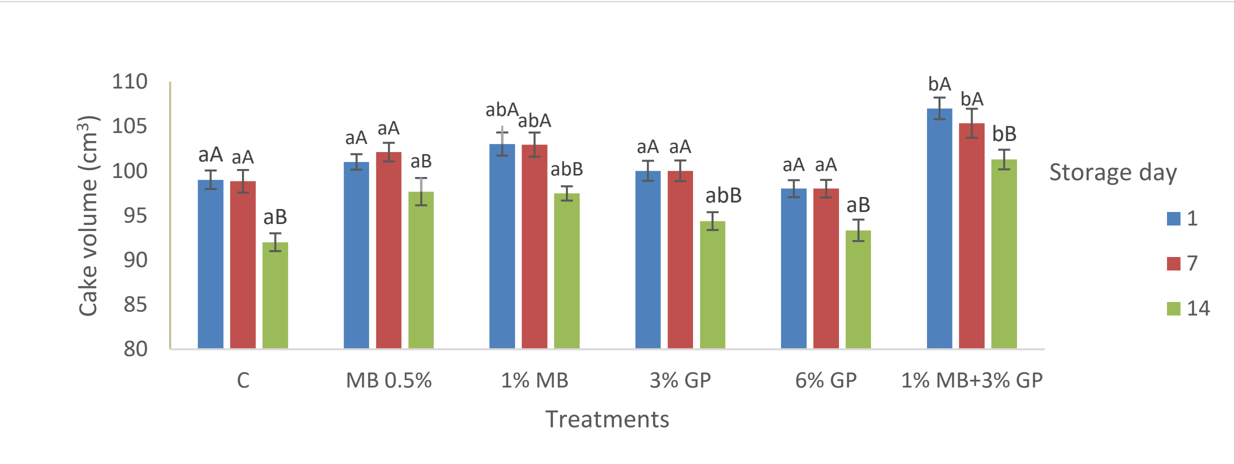

Figure 1. Volume of cakes enriched with different levels of GP and MB during the storage period

Similar studies have shown that adding fiber to cake dough can reduce volume due to its effects on the gluten network. These results align with previous studies that indicate the negative impact of high fiber content on cake volume. However, more balanced combinations of sprouted barley flour and grape pomace, as seen in the combined treatment of this study, can contribute to increased cake volume.

Furthermore, the results showed a decrease in cake volume during storage over a 14-day period. One of the primary factors contributing to this change is moisture loss. As moisture decreases, the cake may shrink slightly, resulting in reduced volume. Additionally, during storage, the cake's texture may become firmer, or changes may occur in the distribution of air and gases within the structure, further affecting its overall volume [53].

4.2.8- Cake Texture

Texture firmness is another key parameter that directly influences the final quality of the cake. As one of the primary indicators of texture evaluation, firmness refers to the cake's ability to maintain its shape and structure under pressure or mechanical changes. This characteristic is assessed based on the cake's resistance to deformation over time and under storage conditions [54]. The firmness of a cake should be balanced with other qualities, such as moisture, softness, and fermentation. It serves as an indicator of the product's durability and shelf life, which can affect its storage and warehouse longevity [53].

Generally, the firmness of the cake's texture increased as the storage period progressed (1st, 7th, and 14th days), which is expected due to processes like texture drying and the chemical and physical changes that occur during storage. On the first day of storage, the combined treatment and the treatment with 1% sprouted barley flour exhibited the highest firmness (26.55 and 28, respectively), significantly higher than the other treatments. The lowest firmness was observed in the treatment with 6% grape pomace powder, with a firmness of 23.99. This trend remained consistent throughout the storage period, with significant differences observed between treatments at various storage days.

Previous studies have shown that the addition of grains and dietary fibers can significantly impact cake texture [52, 55]. Specifically, the inclusion of barley flour, which is rich in protein and fiber, positively influences the cake structure and increases texture firmness. In contrast, adding grape pomace, which contains fiber and moisture, may result in a softer texture, thereby reducing the cake's firmness.

A study by Sempio et al. (2024) demonstrated that adding fiber-rich flours can increase cake firmness and reduce moisture, which aligns with the findings of the barley flour treatments in this study [56]. Additionally, research by Salehi et al. (2020) on the use of natural additives in cakes highlighted that these additives can have varied effects on the textural properties of cakes, a result also supported by this study [57].

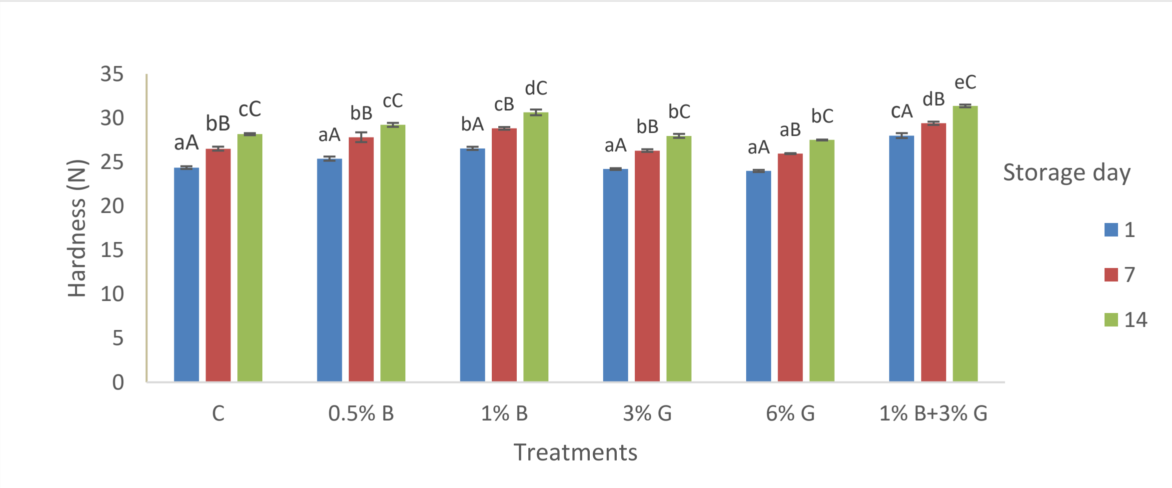

Figure 2. Hardness of cakes enriched with different levels of GP and MB during the storage period

4.2.9- Cake Porosity

Cake porosity refers to the amount of empty space within the cake's structure, which influences various factors such as volume, softness, and texture. Proper porosity is essential for achieving a uniform and soft texture, generally improving the sensory acceptability of the final product. Excessive porosity can lead to a brittle and dry texture, while lower porosity may result in a dense and undesirable texture. The results from the different treatments revealed significant differences in porosity: the treatment with 1% sprouted barley flour and the combined treatment of barley flour and grape pomace exhibited the highest porosity (40.83% and 40.7%, respectively), while the treatment with 6% grape pomace powder had the lowest porosity (36.60%). These differences suggest that the addition of sprouted barley flour enhances the cake's textural structure, while higher amounts of grape pomace, likely due to increased texture density, reduce cake porosity [58].

In this context, Nazari et al. (2021) found that in the production of gluten-free bread using mung bean sprouted flour, the resulting bread exhibited higher porosity compared to the control [59]. Similarly, Ruan et al. (2019) observed increased porosity in chiffon cakes made with sprouted wheat flour [60]. Previous studies have consistently shown that various additives can significantly influence cake porosity. For instance, Salamon et al. (2024) reported that ingredients such as sprouted barley flour and other fiber-rich materials can enhance the cake's porosity structure [61]. The results of this study align with these findings, suggesting that the use of sprouted barley flour increases porosity, while the inclusion of grape pomace powder reduces the cake's porosity.

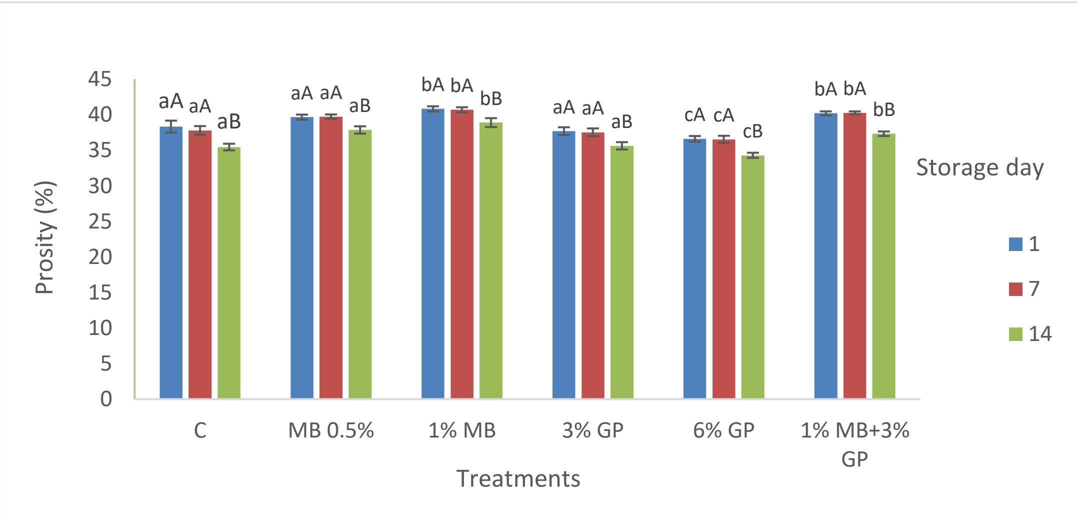

Figure 3. Porosity of cakes enriched with different levels of GP and MB during the storage period

Regarding storage time, no significant differences were observed between the day of production and the seventh day of storage. However, by the 14th day, porosity had significantly decreased across all treatments ($P<0.05$). This reduction is likely attributed to moisture loss over time, which can lead to a drier and firmer texture. Such changes in texture may result in a reduction in porosity, particularly if the air spaces within the cake become smaller or compressed. Additionally, the cake's structure may be affected by gravitational forces or temperature fluctuations during storage, causing alterations in the distribution and size of the air pockets within the cake [62, 63].

4.2.10- Color measurement

Cake color is one of the key parameters influencing consumer perception, thereby increasing the market demand for baked products such as cakes. The color index **L*** represents the brightness of the cake, where higher L* values correspond to a lighter color. In this study, the control treatment, the 1% sprouted barley flour treatment, and the combination of 1% sprouted barley flour with 3% grape pomace powder exhibited higher L* values, indicating lighter colors. In contrast, cakes containing 3% and 6% grape pomace powder displayed lower L* values, resulting in darker colors. This decrease in brightness is attributed to the higher concentration of natural pigments in grape pomace, which imparts a darker hue to the cake.

The highest **a*** color index (redness-greenness) was observed in the 1% sprouted barley flour treatment, with a value of 2.70, indicating the greatest redness. Conversely, the lowest a* value (2.12) was found in the 6% grape pomace powder treatment, which displayed the least redness and a tendency towards greenness. These variations in the a* index are primarily due to differences in the pigment composition of the additives used.

The **b*** color index, representing yellowness, showed significant differences across all treatments (P<0.05). The highest b* value (21.45) was recorded in the control sample, and this value gradually decreased with the increase in the percentage of sprouted barley flour and grape pomace powder in the cake formulations. The lowest b* value (17.89) was observed in the treatment containing 6% grape pomace powder, indicating the least yellowness in this sample. The reduction in yellowness with the addition of sprouted barley flour may be linked to its phenolic content, which can impact the color of the cake.

Table 3. Color parameters of cakes enriched with different levels of GP and MB

parameter	Storage day	treatments					
		Control	0.5% MB	1% MB	3% GP	6% GP	1% MB+3%GP
L^*	0	$77.18±3.1^{aA}$	$78.05±5.02^{aA}$	$78.53±4.2^{aA}$	$76.43±3.25^{bA}$	$76.45±8.1^{bA}$	$75.85±9^{bA}$
	7	$77.17±4.02^{aA}$	$78.05±4.31^{aA}$	$78.52±3.12^{aA}$	$76.42±2.89^{bA}$	$76.43±5.2^{bA}$	$75.88±5.6^{bA}$
	14	$74.8±2.1^{aB}$	$73.74±3.22^{aB}$	$72.7±2.8^{aB}$	$70.53±6.4^{bB}$	$70.53±4.2^{bB}$	$70.27±5.48^{bB}$
a^*	0	$2.46±0.05^{aA}$	$2.59±0.07^{aA}$	$2.68±0.1^{aA}$	$2.34±0.03^{abA}$	$2.14±0.01^{bA}$	$2.57±6.24^{bA}$
	7	$2.48±0.01^{aA}$	$2.54±0.06^{aA}$	$2.5±0.02^{aA}$	$2.53±0.1^{abA}$	$2.33±0.002^{bA}$	$2.57±0.15^{bA}$
	14	$2.47±0.05^{aA}$	$2.44±0.1^{aA}$	$2.54±0.09^{aA}$	$2.53±0.8^{abA}$	$2.36±0.03^{bA}$	$2.54±0.34^{bA}$
b^*	0	$21.5±0.6^{aA}$	$20.8±0.9^{bA}$	$19.93±1.3^{cA}$	$18.7±3.1^{dA}$	$17.92±1.8^{eA}$	$19.22±4.12^{cA}$
	7	$21.09±0.3^{aA}$	$20.46±0.21^{bA}$	$19.79±2.1^{cA}$	$17.53±1.8^{dA}$	$16.53±0.8^{eA}$	$19.27±5.3^{cA}$
	14	$20.14±0.4^{aA}$	$21.37±0.34^{bA}$	$19.7±0.9^{cA}$	$17.24±3.2^{dA}$	$16.33±0.79^{eA}$	$19.16±1.38^{cA}$

Different lowercase letters indicate significant differences between treatments and different uppercase letters indicate significant differences in storage days at the significant level of 0.05.

During storage, significant differences in color change were only observed in the **L*** (brightness) index, while no significant changes were recorded in the a* and b* color indices after 7 and 14 days. The brightness index significantly decreased in all treatments by the 7th and 14th days of storage, with the combined treatment of grape pomace and sprouted barley flour showing the lowest brightness on the 14th day (P<0.05). This reduction in brightness over time is likely due to the exposure of the cake to air, resulting in the oxidation of surface compounds and leading to a darker color. Additionally, the loss of moisture during storage can dry out the surface, contributing to color darkening and a decrease in the L* value. Furthermore, storage temperature plays a role in color changes, as higher temperatures can accelerate non-enzymatic browning reactions, such as the Maillard reaction, which darkens the cake [64].

4.2.11- Sensory Evaluation

Sensory evaluation is a vital tool in assessing the quality of food products, including cakes. It provides valuable insights into consumer perception, focusing on sensory attributes such as appearance, color, aroma, taste, texture, and overall acceptance. This evaluation is essential in the development of new products or the enhancement of existing ones, as it helps optimize formulations and production processes.

In this study, sensory evaluation was conducted by 10 trained evaluators who assessed various attributes, including product appearance, porosity, aroma, flavor, color, texture, and overall acceptance. The results indicated that different treatments had a significant impact on the sensory quality of the cakes. The control treatment and the combination of 1% sprouted barley flour with 3% grape pomace powder received the highest scores in most attributes, particularly in overall acceptance, aroma, flavor, and texture, suggesting that these treatments performed best in terms of sensory appeal.

One possible reason for the higher scores in these two treatments could be the inclusion of ingredients that positively influenced the texture and flavor of the cakes. Specifically, the moisture-rich or appropriately fatty components in these treatments likely contributed to a softer, more flavorful texture, enhancing overall consumer acceptance. Conversely, the lowest scores were observed in the treatments with 3% and 6% grape pomace powder, which may be attributed to the lower moisture and fat content of these ingredients, or their higher proportion of dry matter, which could have negatively impacted the sensory quality.

Table 4. Sensory analysis of cakes enriched with different levels of GP and MB

		treatments					
Sensory parameter	Storage day	Control	0.5% MB	1% MB	3% GP	6% GP	1% MB+3%GP
Appearance	0	4	3	4	3	3	4.1
	14	2	1	3	2	2	3
Porosity	0	4	3	4	3.1	3	4
	14	2	1	2	2	2	4
Flavor	0	4	3	4	3	3	4
	14	2	1	3	2	2	3
Color	0	4	3	4	3	3.1	4
	14	2	1	4	3	2	3
Texture	0	4	3	4	3.1	3	4.1
	14	2	1	2	1	2	3
Overall acceptance	0	4	3	4	3.1	3	4.1
	14	1	1	2	1	2	3

The findings of this study align with previous research indicating that the composition and proportions of ingredients can significantly influence the sensory properties of cakes. For instance, Nakov et al. (2020) explored the production of functional cakes with dried grape pomace powder and found that adding up to 4% grape pomace powder did not negatively affect any sensory attributes, but rather improved the technological characteristics of the cakes [65].

4.2.12- Total Microorganism Count

In all samples, increased storage time resulted in an increase in microbial load, with samples that exhibited no microbial growth on the production day showing the highest microbial counts on the fourteenth day of storage. Comparing the treatments, the 3% grape pomace powder treatment exhibited the highest total microorganism count at 3.70 log CFU/g, significantly higher than the other treatments ($P < 0.05$). The total bacterial count in the control treatment and the 6% grape pomace powder treatment was 3.45 log CFU/g and 3.55 log CFU/g, respectively. This increase could be attributed to the high fiber and nutrient content in the grape pomace powder, which may provide a conducive environment for microbial growth. Previous research has demonstrated that fiber-rich materials can enhance microbial activity, which likely contributed to the observed increase in microorganism counts.

In contrast, the 1% sprouted barley flour treatment exhibited the lowest total microorganism count at 3 log CFU/g. This reduction could be attributed to the antimicrobial properties of sprouted barley flour, as documented in various studies. Sprouted barley flour contains bioactive compounds with antimicrobial effects, which can reduce microbial presence. For example, Gorjanović et al. (2007) reported that the antimicrobial effect of sprouted barley is due to two tomato-like proteins that inhibit both bacterial and fungal growth [67].

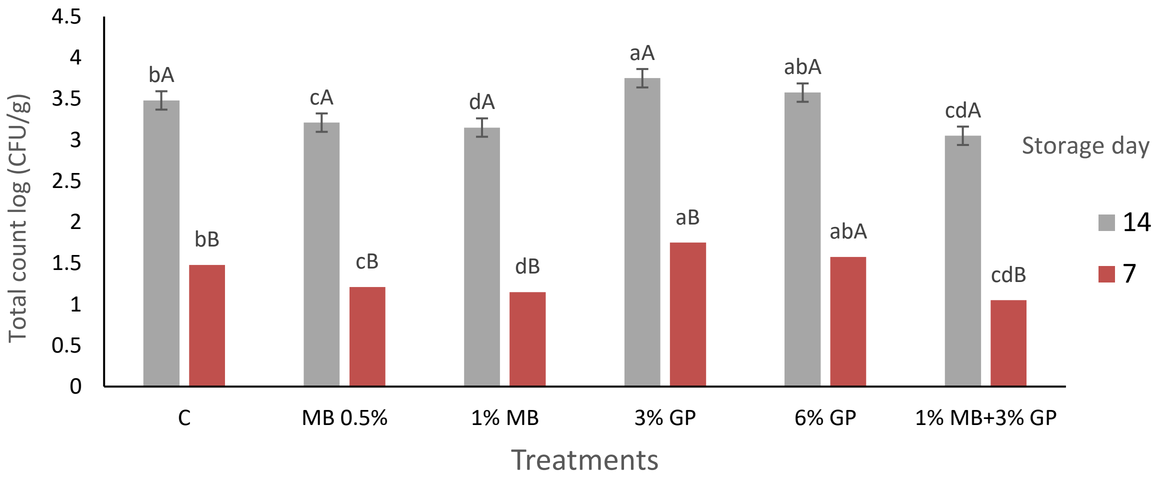

Figure 4. Total count of cake enriched with different levels of GP and MB during the storage period

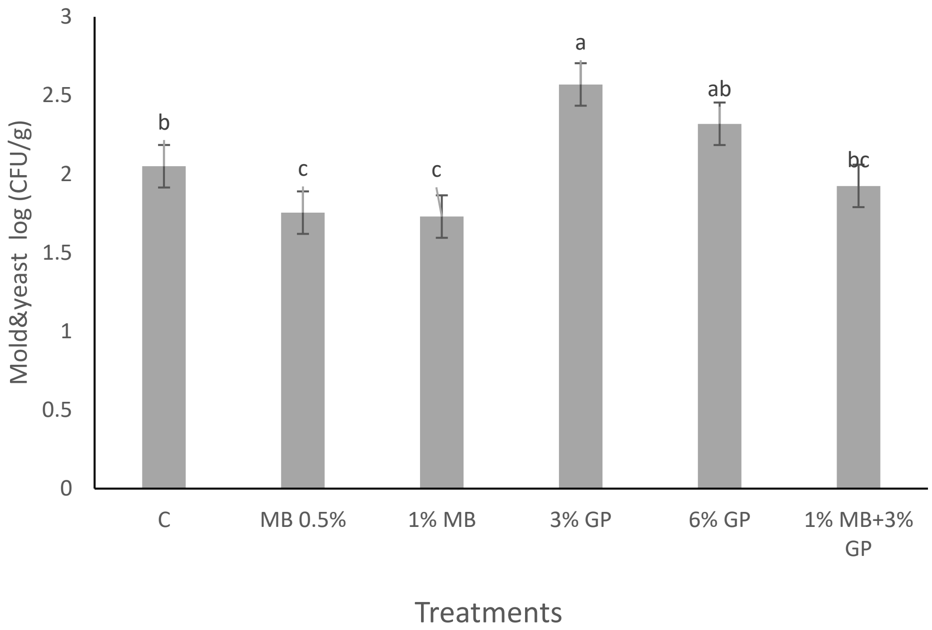

Figure 5. Total mold and yeast count of cake enriched with different levels of GP and MB during the storage period

The mold and yeast counts followed a similar trend to the total microorganism count, with the mold and yeast load being zero until the seventh day of storage and only appearing on the fourteenth day. This delay can be attributed to the longer growth requirements of molds and yeasts compared to bacteria. The highest mold and yeast count was observed in the 3% grape pomace powder treatment, with 2.50 log CFU/g, which was statistically higher than the other treatments ($P < 0.05$). As mentioned earlier, the nutrient and fiber content in the grape pomace powder likely provides favorable conditions for microbial growth. In contrast, the 1% sprouted barley flour treatment exhibited the lowest mold and yeast count, at 1.75 log CFU/g, likely due to the antimicrobial properties of the sprouted barley flour.

4.Conclusion

This study investigated the effect of adding sprouted barley flour and grape pomace powder on the physicochemical, microbial, and sensory properties of cake. The results demonstrated that the inclusion of these ingredients significantly impacted the parameters under consideration. In terms of texture firmness, the treatment containing 1% sprouted barley flour and 3% grape pomace powder exhibited the highest firmness, while the 6% grape pomace powder treatment showed the lowest firmness. Additionally, the treatments with 0.5% and 1% sprouted barley flour exhibited higher porosity compared to those with grape pomace powder, resulting in a softer and lighter cake. The incorporation of grape pomace powder caused a noticeable darkening and increased yellowness of the cakes, while sprouted barley flour induced fewer changes in these color parameters. Sensory evaluation revealed that the cake with 1% sprouted barley flour and 3% grape pomace powder received the highest scores, particularly for texture and overall acceptance.

Regarding microbial growth, no growth was observed in the total microorganism count on the first day of storage or in the mold and yeast counts up to the seventh day. However, at the end of the storage period, the cake containing 3% grape pomace powder exhibited the highest microbial growth, whereas the 1% sprouted barley flour treatment showed the lowest microbial growth. These differences may be attributed to the antimicrobial properties of sprouted barley flour and the nutrient-rich content of grape pomace powder. Based on these findings, the treatment containing 1% sprouted barley flour and 3% grape pomace powder emerged as the most optimal formulation, performing best across multiple evaluations, including firmness, texture, and overall acceptance. This combination could be considered a promising option for enhancing the quality of baked cakes. Overall, the results suggest that adding sprouted barley flour and grape pomace powder can significantly improve the properties of cakes, offering potential opportunities for enhancing the quality of baked products.

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بررسی ویژگی های فیزیکوشیمیایی و حسی کیک فراسودمند غنی شده با آرد جو جوانه‌زده و پودر تفاله انگور قرمز

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چکیده

در این تحقیق ویژگی‌های فیزیکوشیمیایی، حسی و میکروبی کیک‌های غنی‌شده با آرد جو جوانه‌زده(۰/۵ و ۱ درصد)و پودر تفاله انگور(۳ و ٦ درصد)و ترکیب ۱٪ آرد جو جوانه زده و ٦ ٪ پودر تفاله انگور مورد بررسی قرار گرفت. نتایج نشان داد که افزودن این ترکیبات سبب افزایش رطوبت، خاکستر و فیبر کیک ها می شود درحالی که تاثیر معنی داری بر میزان چربی و pH نداشت. با افزودن هر دو ترکیب به کیک، میزان ترکیبات فنلی کل و ظرفیت آنتی اکسیدانی آنها به صورت معنی داری افزایش یافت و این افزایش در نمونه های حاوی تفاله انگور بالاتر بود (P <۰/۰۵). ترکیب ۱٪ آرد جو جوانه‌زده با ۳٪ پودر تفاله انگور ، سفتی بالاتری داشته وافزودن پودر تفاله انگور به نمونه ها سبب تیره تر شدن کیک ها شد. کمترین میزان تخلخل در کیک‌های تهیه شده با پودر تفاله انگور مشاهده شد و بالاترین حجم کیک نیز در تیمار ترکیبی مشاهده شد. تعداد کل میکروارگانیسم‌ها در روز اول نگهداری و کپک و مخمر تا روز ۷ نگهداری صفر بود با این حال با افزایش زمان نگهداری، رشد باکتری و کپک و مخمر در تمامی نمونه ها مشاهده شد که بالاترین مقدار آن در تیمار ۳٪ پودر تفاله انگور با ۲/۵۰ log CFU/g وکمترین مقدار آن در تیمار ۱٪ آرد جو جوانه‌زده با ۱/۷۵ log CFU/g بود (P <۰/۰۵). آنالیز حسی نیز نشان داد که تیمار ۱٪ آرد جو جوانه‌زده + ۳٪ پودر تفاله انگور از نظر ارزیابان بهترین تیمار بوده و بالاترین امتیاز را دریافت کرد.نتایج این مطالعه تأیید کرد که آرد جو جوانه‌زده و پودر تفاله انگور ترکیباتی مناسب برای غنی‌سازی کیک‌ها از نظر ترکیبات زیست‌فعال هستند. با توجه به تأثیر مثبت این ترکیبات بر ویژگی‌های بافتی، حسی، کیفیت میکروبی و آنتی‌اکسیدانی کیک‌ها، می‌توان از آن‌ها برای غنی‌سازی محصولات نانوایی در صنعت بهره‌برداری کرد.