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EFFECT OF GRAPE SEED FLOUR ADDITION ON THE TECHNOLOGICAL AND SENSORY PROPERTIES OF BREAD

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Abstract: The present study examines the impact of partially replacing wheat flour (type 480) with grape seed flour on the technological and sensory characteristics of bread. Experimental formulations included substitution levels of 5%, 10%, 15%, 20%, 25%, and 30%, alongside a control sample. Bread quality was assessed through height–to–diameter ratio, specific volume (gravimetric method), crumb porosity, elasticity, and sensory attributes such as crust appearance, crumb structure, color, flavor, and overall acceptability. Results demonstrated that moderate replacement levels (5–20%) enhanced crust color, crumb uniformity, and sensory appeal, while maintaining satisfactory porosity and elasticity. In contrast, higher substitution levels (25–30%) increased crumb moisture and stickiness, reduced loaf volume, and negatively affected overall technological performance. These findings indicate that grape seed flour can be effectively incorporated as a functional ingredient in bread, enriching its nutritional profile with dietary fiber, minerals, and antioxidants. At appropriate levels of substitution, grape seed flour contributes both to product innovation and to the development of bakery goods with improved nutritional value, while preserving desirable technological and sensory properties.
Keywords: bread quality, grape seed flour, technological properties, sensory properties, functional ingredients, antioxidant activity, sustainability

1. INTRODUCTION

Bread is one of the most consumed staple foods worldwide, representing an important source of carbohydrates, proteins, and energy *(Mesta–Corral et al., 2024)*. However, wheat–based products lose a significant proportion of nutrients during the refining process, including vitamins, fibers, and phytochemicals, which limits the health benefits of the final product *(Wysocka et al., 2025)*.

For this reason, the reformulation of bakery products has become a major research direction, driven by consumers' demand for healthier and more functional foods *(Guiné and Florença, 2024)*. One commonly applied strategy is the partial replacement of wheat flour with alternative raw materials rich in bioactive compounds, fibers, and antioxidants, aiming to improve both nutritional and technological properties *(Zestrea, Popescu and Boeștean, n.d.)*.

Globally, the food industry generates considerable amounts of by–products. These materials can be valorized as functional food ingredients, helping to reduce economic losses and contributing to environmental protection. The wine industry is a relevant example: approximately 20–25% of the initial grape mass remains as residues (skins, seeds, pulp, yeast), equivalent to around 200 thousand tons annually. If not properly managed, these residues may cause ecological issues (Boff et al., 2022).

Romania holds an important position in European viticulture, with over 165–167 thousand hectares cultivated and more than 1 million tons of grapes harvested annually, which underlines the significance of sustainable by–product utilization *(Turek–Rahoveanu, 2022)*.

Grape seeds are a valuable by–product, representing between 1% and 6% of berry weight and containing high levels of dietary fiber, proteins, lipids, minerals, and polyphenols (5–8%). Due to this composition, comparable to protein–rich plant products, grape seeds are frequently used as dietary supplements *(Ma and Zhang, 2017)*. Grape seed flour, obtained by drying and milling the seeds after cold oil extraction, has emerged as a promising functional ingredient thanks to its richness in dietary fiber, polyphenols, flavonoids, and resveratrol.

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These bioactive compounds exhibit multiple health–promoting effects, including antioxidant, anti–inflammatory, anticancer, hypolipidemic, and antibacterial activity *(Oprea et al., 2022; Yalcin et al., 2022)*. Grape seed flour has been successfully tested in various food products such as bread, biscuits, noodles, cereal bars, and muffins, with the most favorable results observed at moderate substitution levels of 5–10%, which enhance the nutritional and functional profile without compromising sensory quality *(Antonic et al., 2021)*.

Moreover, grape seed flour is naturally gluten–free, making it suitable for individuals with gluten intolerance or sensitivity. Its incorporation into bakery products improves sensory attributes (color, aroma, texture) and nutritional quality, although higher substitution levels may negatively affect bread structure and consumer acceptability *(Różańska et al., 2021; Muñoz–Bernal et al., 2024)*. Proanthocyanidins, the main bioactive components of grape seeds, have remarkable biological and pharmacological activity.

They interact with gluten proteins in dough, influencing the formation of the gluten network and modifying dough structure and stability through disulfide/thiol exchange and non–covalent interactions, ultimately affecting bread elasticity and quality *(Tong Jiang et al., 2023)*.

Therefore, the use of grape seed flour provides a dual opportunity: the development of bakery products with enhanced nutritional and functional value and the sustainable valorization of wine–making by–products, contributing to circular economy practices and environmental protection.

The present study aims to evaluate the effect of partial substitution of wheat flour with grape seed flour (5–30%) on the technological and sensory properties of bread, with the goal of identifying the optimal replacement level that ensures both improved nutritional value and desirable quality attributes.

2. MATERIALS AND METHODS

Raw Materials

The raw and auxiliary materials used to prepare the flour mixtures included potable water, sunflower oil, salt, sugar, wheat flour type 480 (ash content = 0.48%; Product: S.C. V&G Oil 2002 SRL, Vrancea, Romania), grape seed flour (finely milled, obtained from Romanian grape varieties and supplied by Herbal Sana), and dry yeast (Dr. Oetker, 7 g sachet). Wheat flour and grape seed flour were incorporated in varying proportions according to the experimental design.

Experimental Design

Seven bread variants were formulated to evaluate the effect of grape seed flour substitution on bread quality. The control sample (Sample 1) was prepared exclusively with wheat flour type 480 (100%). In the experimental variants, wheat flour was partially replaced with grape seed flour at incremental levels:

- Sample 1 (Control): bread from 100% wheat flour (type 480);
- Sample 2: bread with 5% substitution of wheat flour by grape seed flour;
- Sample 3: bread with 10% substitution;
- Sample 4: bread with 15% substitution;
- Sample 5: bread with 20% substitution;
- Sample 6: bread with 25% substitution;
- Sample 7: bread with 30% substitution.

The substitution percentages were calculated relative to the total flour mix (325 g). All other ingredients (water, oil, salt, sugar, yeast) were kept constant across formulations.

Breadmaking Process

Each 500 g flour formulation was prepared using the ingredients listed in Table 1.

Table 1. Bread recipe for 500 g flour mix

Ingredient	Amount
Warm water (35 °C)	210 mL
Sunflower oil	3 tsp
Salt	0.5 tsp
Sugar	2 tsp
Wheat flour (Type 480)	325 g
Dry yeast	1.5 tsp

Abbreviations: cc = cubic centimeter = milliliter (1 cc = 1 mL); tsp = teaspoon ≈ 5 mL; tbsp = tablespoon ≈ 15 mL.

The dough was prepared by adding the ingredients into the bread maker pan in the order specified in Table 1. Kneading, fermentation, proofing, and baking were performed automatically by the bread maker, ensuring uniformity across all samples. After baking, loaves were cooled at room temperature for 2 hours prior to analysis.

Table 2. Experimental bread formulations with wheat flour and grape seed flour substitutions (for 500 g flour mix)

Sample	Wheat flour (Type 480) [g]	Grape seed flour [g]
Control (0%)	325	0
5% substitution	308.75	16.25
10% substitution	292.5	32.5
15% substitution	276.25	48.75
20% substitution	260	65
25% substitution	243.75	81.25
30% substitution	227.5	97.5

Substitutions were calculated as percentages of the total flour mix (325 g)

Figure 1 – Tefal Pain Plaisir PF220 bread maker: 1 – cover; 2 – control panel; 3 – kneading bowl; 4 – kneading arm (Munteanu et al., 2019)

Equipment

Bread preparation was carried out using a Tefal Pain Plaisir bread maker, set on the 500 g bread program (program no. 5), a reliable appliance for automated dough mixing, fermentation, proofing, and baking (Figure 1). The leavening agent was Dr. Oetker dry yeast (7 g sachet), commonly used in home and experimental baking. Ingredients were accurately weighed using a digital analytical balance (±0.01 g precision). Liquids and small quantities of ingredients such as oil, salt, sugar, and yeast were measured with the graduated spoon provided with the bread maker (marked in teaspoons, tsp, and cubic centimeters, cc).

3. ANALYTICAL METHODS

Rheological analysis

The rheological properties of dough were determined using a Brabender Farinograph (Brabender GmbH, Germany), which records dough resistance during mixing under controlled conditions. The equipment was connected to specialized software, enabling precise determination of flour quality parameters. The farinographic parameters evaluated included water absorption (%), dough development time (min), stability (min), degree of softening (FU), dough elasticity (FU), and the farinograph quality index (FQN). These provide essential information on dough strength and behavior during kneading, fermentation, and baking.

The experimental setup is shown in Figure 2: (a) Brabender Farinograph connected to computer software for recording farinographic curves, (b) addition of wheat and grape seed flour mixtures into the mixing chamber, (c) dough formation during mixing. The kneading chamber was maintained at 30 °C by circulating water and covered with a transparent glass plate to prevent evaporation. At the end of the 20-minute mixing test, a small amount of flour was added and kneaded for 60 s to facilitate cleaning of the mixing arms.

Figure 2 – Brabender Farinograph and dough mixing process during rheological tests

The determinations were carried out in the specialized laboratory of the Department of Biotechnical Systems, Faculty of Biotechnical Systems Engineering, National University of Science and Technology Politehnica Bucharest.

Physical analysis of bread

— Specific Volume

The specific volume of bread was determined using the rapeseed displacement method, according to SR 91:2007 and the AACC International Approved Methods (10th ed., 2000). This method is based on measuring the volume of rapeseeds displaced by the bread loaf in a calibrated 500 cm^3 graduated cylinder. The cylinder was weighed empty and after filling with rapeseeds to the reference mark in order to calculate rapeseed density (ρ, g/cm^3). Bread samples were then weighed and introduced into the cylinder, and the displaced volume was recorded.

The specific volume (cm^3/100 g product) was calculated using the following equation:

$$V = \frac{(m_4 - m_5)}{m_3 \cdot \rho} \times 100 \quad (1)$$

where: m_3 is the mass of the bread sample (g), m_4 the mass of the cylinder filled with rapeseeds plus the sample placed on top (g), m_5 the mass of the cylinder with rapeseeds after the sample was introduced (g), and ρ the density of rapeseeds (g/cm^3).

This parameter is an important indicator of bread quality, as it reflects the balance between loaf expansion during fermentation and baking and the formation of crumb structure.

— Height/Diameter Ratio (H/D)

The loaf height–to–diameter ratio (H/D) was determined as an indicator of bread development and shape quality. Loaf height (H) was measured as the maximum vertical dimension, or, in the case of scored loaves, as the arithmetic mean of the maximum and minimum values. The loaf diameter (D) was measured as the average of two perpendicular dimensions at the loaf base. The H/D ratio was then calculated to describe loaf geometry. Higher H/D values are generally associated with better loaf development, superior volume, and desirable shape characteristics, whereas lower values may indicate insufficient fermentation, poor flour quality, or over–proofing.

— Crumb Porosity

Crumb porosity reflects the degree of aeration of bread and is an important quality indicator, as it influences digestibility and consumer acceptance. A 60 mm slice was cut from the central part of the loaf, from which a cylindrical crumb sample was extracted using a metal perforator (lightly greased with oil).

The cylinder height was measured with a precision ruler (±1 mm) and its mass with an analytical balance (±0.01 g).

Porosity (P, %) was calculated as:

$$P = \frac{V - \frac{m}{\rho}}{V} \cdot 100 \quad (2)$$

where: V is the cylinder volume (cm^3), m is the crumb mass (g), and ρ is the density of the crumb (g/cm^3).

— Crumb Elasticity

Elasticity was determined by compressing cylindrical crumb samples (6 cm high) to half their initial height for 1 min using a Hounsfield texture analyzer. After release, the samples were allowed to recover for 1 min, and the final height was recorded.

Elasticity (E, %) was calculated as:

$$E = \frac{B}{A} \times 100 \quad (3)$$

where: A is the initial height of the crumb cylinder (mm) and B the height after recovery (mm).

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Sensory evaluation

The sensory evaluation of bread samples focused on external appearance (including perceived loaf volume and shape symmetry), crust color and texture, crumb color, porosity and elasticity, as well as taste, aroma, freshness, and overall acceptability. Crust and crumb attributes were assessed for uniformity and intensity, while crumb porosity and elasticity reflected pore distribution and resilience after compression. Taste was judged based on overall flavor perception and the absence of undesirable bitterness, aroma on pleasantness and intensity, and freshness on the balance between staleness and moistness. Finally, overall acceptability summarized the general impression of each sample. All attributes were rated using a 9–point hedonic scale, where 1 corresponded to "dislike extremely" and 9 to "like extremely."

4. RESULTS

Rheological properties

The farinograph analyses revealed that the addition of grape seed flour (GSF) significantly modified dough behavior compared with the control (100% wheat flour). Dough consistency decreased progressively with higher substitution levels, attributable to the absence of gluten and the dilution of wheat proteins responsible for elasticity and extensibility. This trend is consistent with findings from Antonic et al. (2021) and Yalcin et al. (2022), who reported reduced dough strength in bakery formulations enriched with grape by–products.

The farinographic parameters obtained for wheat, GSF blends are summarized in Table 3. The data show clear differences across substitution levels, particularly in development time, stability, softening degree, and water absorption.

Table 3. Rheological properties of wheat–grape seed flour blends (5–30% substitution)

Parameter	5%	10%	15%	20%	25%	30%
Development time [min]	1.4	1.7	1.5	2.4	6.4	7.2
Stability [min]	2.2	2.5	8.1	10.2	11.4	12.7
Softening degree [FU] (ICC)	74	49	32	43	39	39
Farinograph Quality Number (FQN)	30	28	98	130	133	139
Consistency [FU]	499	493	460	438	440	438
Water absorption capacity [%]	58.5	58.5	58.5	58.5	58.5	58.5
Correction to 500 FU	58.5	59.3	57.5	57.0	57.0	57.0

Development time increased with higher substitution levels, indicating delayed gluten network formation due to fibers and phenolic compounds from GSF. Stability values were higher in samples with moderate substitution (up to 15%), suggesting that grape seed fibers improved water retention and temporarily reinforced dough structure. However, excessive substitution (>20%) led to poorer dough handling properties, as fiber reinforcement could no longer compensate for the lack of gluten.

Softening degree decreased at moderate additions but worsened again at higher levels, with the 20% substitution showing the weakest dough matrix. Elasticity also declined progressively, confirming weakened gluten extensibility.

Interestingly, the 10% substitution level recorded the highest water absorption capacity, reflecting the strong water–binding ability of grape seed fibers. Beyond 25%, absorption values stabilized, indicating limited additional effect. The farinograph quality number (FQN)

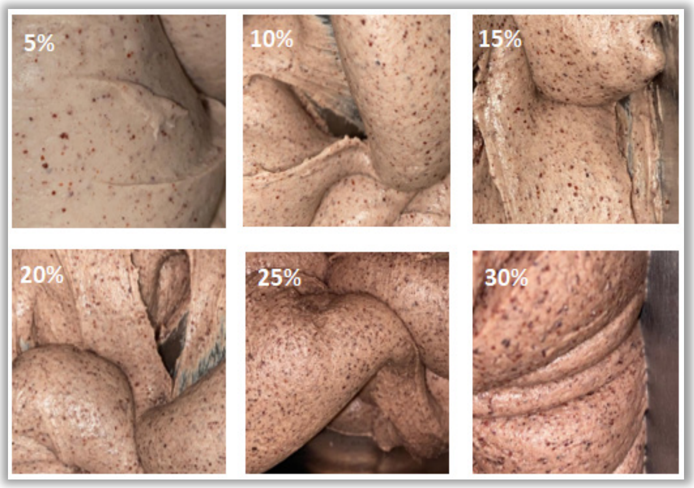

Figure 3 – Color evolution as a function of grape seed flour addition

improved with moderate additions, showing higher resistance to mechanical handling, but values fluctuated inconsistently beyond 20%.

In addition to rheological changes, grape seed flour visibly influenced bread color, as illustrated in Figure 3. Darker crusts were observed with increasing substitution, confirming the contribution of grape seed pigments to bread appearance.

Overall, the results demonstrate that grape seed flour has a significant impact on dough rheology. While small additions (5–10%) improve water absorption and maintain acceptable stability, higher levels (>20%) severely compromise dough quality. These findings highlight the importance of optimizing substitution levels to balance nutritional improvement with technological performance.

Physical properties of bread

The physical characteristics of bread were significantly influenced by the level of wheat flour substitution with grape seed flour.

— Bread volume (specific volume by rapeseed displacement method)

The specific volume of bread is an important quality indicator that reflects loaf expansion and crumb aeration. Measurements were performed using the rapeseed displacement method, based on the relationship between the loaf mass and the density of displaced rapeseeds.

The obtained results are summarized in Table 4, while the trend of volume variation with increasing grape seed flour substitution is illustrated in Figure 4.

Table 4. Specific volume of bread samples (cm^3/100 g product)

Sample	P1 (Control)	P2 (5%)	P3 (10%)	P4 (15%)	P5 (20%)	P6 (25%)	P7 (30%)
Volume (cm^3/100 g)	491.38	475.40	390.75	318.91	295.09	262.52	193.77

The results show a clear and progressive decrease in bread volume as the proportion of grape seed flour increases. The control sample (100% wheat flour) exhibited the highest volume (491.38 cm³/100 g), while the 30% substitution sample recorded the lowest value (193.77 cm³/100 g), indicating very limited loaf expansion.

This decline is mainly attributed to the lack of gluten in grape seed flour, which reduces the dough's ability to retain fermentation gases. Consequently, breads with higher substitution levels are denser, less aerated, and exhibit poorer technological quality.

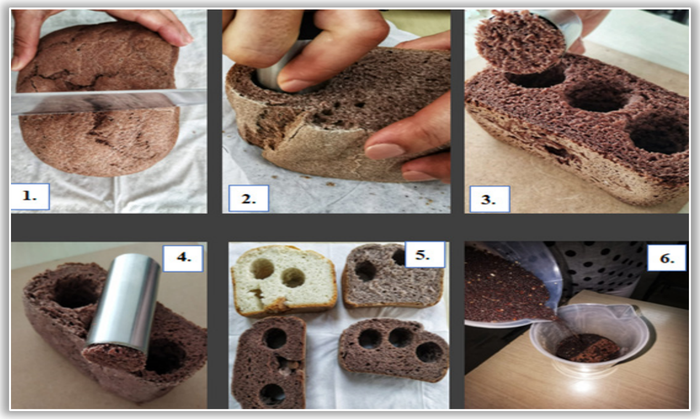

Figure 4 – Bread volume determination by the gravimetric (rapeseed displacement) method for samples with different levels of grape seed flour substitution (0–30%): (1) bread cutting; (2) crumb selection; (3–4) cylinder extraction and removal; (5) crumb comparison; (6) volume measurement

— Height–to–diameter ratio (H/D)

The determination of the H/D ratio was carried out to evaluate the degree of bread loaf development in samples with different levels of grape seed flour substitution. The obtained values are presented in Table 4.

Table 5. Results of H/D ratio determination

Sample	P1 (Control)	P2 (5%)	P3 (10%)	P4 (15%)	P5 (20%)	P6 (25%)	P7 (30%)
H/D	0.595	0.567	0.517	0.500	0.492	0.480	0.437

The results show a progressive decrease in the H/D ratio with increasing levels of grape seed flour. The control bread (100% wheat flour type 480) exhibited the best loaf development (H/D = 0.595), while the 30% substitution sample recorded the lowest value (H/D = 0.437), indicating very poor loaf expansion.

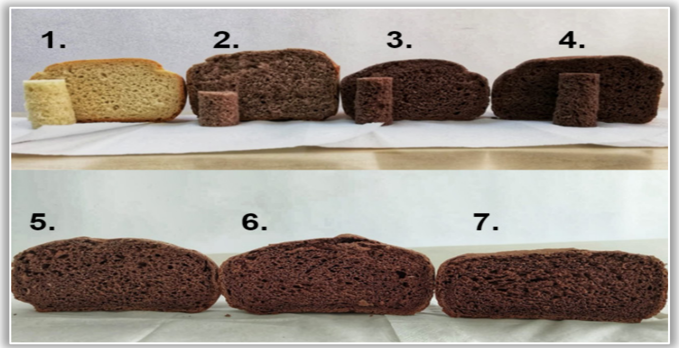

Figure 5 – Visual comparison of bread samples with increasing substitution levels of wheat flour by grape seed flour (0–30%), illustrating differences in loaf height–to–diameter ratio (H/D): 1 – Control (0%), 2 – 5% substitution, 3 – 10% substitution, 4 – 15% substitution, 5 – 20% substitution, 6 – 25% substitution, 7 – 30% substitution

This trend can be explained by the absence of gluten in grape seed flour, which weakens the gluten network responsible for gas retention during fermentation. As a result, at higher substitution levels, the dough becomes less extensible and denser, leading to reduced loaf volume and poorer symmetry.

— Bread crumb porosity

Bread crumb porosity was determined for all samples with different substitution levels of wheat flour by grape seed flour, and the results are presented in Table 6.

Table 6. Bread crumb porosity of samples with different substitution levels of wheat flour by grape seed flour (0–30%)

Sample	P1 (Control, 0%)	P2 (5%)	P3 (10%)	P4 (15%)	P5 (20%)	P6 (25%)	P7 (30%)
Porosity (%)	69.62	59.61	55.27	52.93	51.26	47.26	28.90

The results indicate a steady decline in crumb porosity as the percentage of grape seed flour increased. The control bread (P1) exhibited the highest porosity (69.62%), while the lowest value (28.90%) was recorded for P7 (30% substitution). This trend reflects the reduced gas retention capacity of dough with higher substitution levels, due to the dilution of the gluten network by the gluten–free grape seed flour.

— Elasticity of bread crumb

Bread crumb elasticity was determined for all samples with different substitution levels of wheat flour by grape seed flour. The results are presented in Table 7.

Table 7. Elasticity of bread crumb for samples with different substitution levels of wheat flour by grape seed flour (0–30%)

	P1 (Control, 0%)	P2 (5%)	P3 (10%)	P4 (15%)	P5 (20%)	P6 (25%)	P7 (30%)
	90.00	95.00	88.30	95.00	93.30	84.21	90.00

Although elasticity values remained high overall (84–95%), a noticeable decrease was recorded at 25% substitution, suggesting that excessive addition of grape seed flour weakens dough structure. Overall, moderate substitutions (5–20%) maintained good crumb elasticity, comparable or superior to the control.

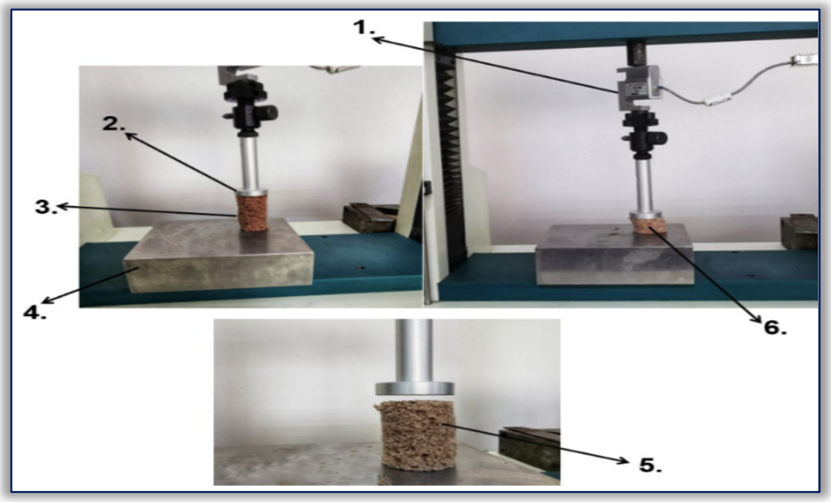

Figure 6 – Determination of bread crumb elasticity using the Hounsfield apparatus

(1) Force cell 1000 N, (2) compression head with movable flat plate, (3) crumb cylinder (6 cm), (4) fixed flat plate, (5) crumb cylinder after release of compression, (6) compression of crumb cylinder

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5. SENSORY EVALUATION

The sensory evaluation of bread samples focused on the external appearance, shape symmetry, loaf volume, crust color and texture, crumb elasticity and porosity, as well as taste and aroma. The addition of grape seed flour significantly influenced these characteristics while also enriching the nutritional value of bread. The dietary fibers in grape seed flour increased water retention, contributing to prolonged freshness and improved crumb texture, particularly at moderate substitution levels.

Samples with 5%, 10%, and 20% grape seed flour showed the best sensory attributes: a crispier and darker crust, a well–developed crumb with uniform porosity, and a pleasant flavor profile with subtle nutty and fruity notes. These samples achieved the highest sensory scores, confirming a high level of consumer acceptability.

At higher substitution levels (25–30%), bread quality declined. The crumb became moister and denser, loaf volume decreased, and the overall structure was less uniform. These changes resulted in lower sensory scores, indicating that excessive substitution compromises bread quality and consumer acceptance.

In conclusion, moderate levels of grape seed flour addition (5–20%) improve bread appearance, texture, and flavor, while higher levels (25–30%) negatively affect sensory properties and reduce overall acceptability.

6. CONCLUSIONS

The experimental results demonstrated that grape seed flour can be effectively incorporated into wheat bread formulations as a functional ingredient. Its addition significantly enriched the nutritional profile of bread by increasing fiber and polyphenol content, while also enhancing antioxidant capacity.

Moderate substitution levels (5–10%) provided the best balance between nutritional improvement and technological quality, yielding breads with acceptable volume, porosity, elasticity, and sensory properties. Substitutions up to 20% were still feasible, although loaf development and crumb porosity gradually declined.

At higher substitution levels (25–30%), bread quality deteriorated markedly, with reduced loaf volume, porosity, and overall acceptability. These effects are mainly due to the absence of gluten in grape seed flour, which weakens the dough structure and limits gas retention during fermentation.

Overall, grape seed flour represents a promising sustainable ingredient for bakery applications, contributing both to improved nutritional value and to the valorization of winemaking by–products within a circular economy framework. Future studies should optimize formulations and further investigate the health benefits of grape seed flour–fortified bakery products.

In practical terms, these findings suggest that grape seed flour can be successfully used in both artisanal and industrial bakery production, offering an accessible way to diversify bread products while promoting sustainability and consumer health.

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