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Research Article

SENSORY ANALYSIS OF GLUTEN-FREE BREAD AND TRADITIONAL BREAD TYPES: A COMPARISON OF CONSUMER PREFERENCES AND ACCEPTANCE LEVELS*

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Abstract

This study evaluates the sensory properties (taste, texture, aroma and overall acceptability) of gluten-free bread, white bread, and whole wheat bread through a panel of 20 participants. Assessments were conducted using a 9-point hedonic scale, and statistical analyses were performed using the Wilcoxon and Friedman tests. The findings reveal that gluten-free bread received lower scores in sensory attributes compared to traditional bread types. In particular, gluten-free bread was found to be insufficient in meeting consumer expectations, especially in terms of taste, texture, and aroma. Whole wheat bread received the highest scores across all criteria, making it the most preferred bread type. White bread was moderately accepted, while gluten-free bread emerged as a product requiring improvement, especially regarding its texture and aroma.

Keywords: Gastronomy, Gluten-Free Bread, Sensory Analysis, Consumer Acceptance, Bread Varieties

Introduction

Gluten is a protein complex naturally present in cereals such as wheat, barley, and rye, playing a critical role in the development of the viscoelastic properties of dough (Shewry and Halford, 2002). In particular, gluten contributes to gas retention during fermentation in breadmaking, facilitating volume expansion and the development of the characteristic structure of bread. However, for certain individuals, gluten consumption presents significant health risks. Disorders such as coeliac disease, gluten intolerance, and wheat allergy necessitate strict dietary restrictions on gluten-containing foods. Coeliac disease, an autoimmune disorder triggered by an abnormal immune response to gluten, leads to villous atrophy in the small intestine and impaired nutrient absorption. Globally, the prevalence of coeliac disease is estimated at approximately 1% (Catassi and Fasano, 2008; Halmos and Gibson, 2019).

In recent years, demand for gluten-free products has increased not only due to medical necessity but also as a result of broader healthy eating trends (Prada et al., 2019). Gluten-free products have gained popularity among a wider consumer base seeking alternative diets which are believed to enhance digestive health. This shift has accelerated efforts to develop gluten-free alternatives to staple food products, notably bread. Nonetheless, the absence of gluten introduces significant technological and sensory challenges in bread production. Gluten-free breads commonly suffer from reduced gas retention capacity, resulting in decreased loaf volume, and are often characterized by a dry, crumbly texture with diminished elasticity (Hager et al., 2012). Furthermore, the use of alternative flours, such as rice, maize, and quinoa, in combination with additives like xanthan gum and guar gum, produces sensory profiles that differ markedly from those of traditional wheat-based breads (Capriles and Arêas, 2014).

Against this backdrop, evaluating the extent to which gluten-free breads meet consumer sensory expectations has emerged as an important research focus within the food industry and product development domains. Sensory analysis methods provide a systematic framework for assessing attributes such as taste, aroma, texture, and appearance, offering valuable insights into consumer preferences (Stone and Sidel, 2004).

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Although various strategies including protein enrichment, enzymatic modifications, and controlled fermentation techniques have been developed to enhance the sensory qualities of gluten-free breads, there remains a limited number of studies directly comparing the sensory attributes of gluten-free and conventional breads (O'Shea et al., 2014; Tümer and Özer, 2018). Furthermore, systematic investigations into consumer perceptions and preferences regarding gluten-free versus traditional breads are still needed.

This study aims to address this gap by conducting a comparative sensory evaluation of gluten-free bread alongside white bread and whole wheat bread, focusing on key sensory parameters such as taste, texture, aroma, and overall acceptability. Sensory assessments were performed by a panel of 20 participants using a nine-point hedonic scale. Data were analysed using non-parametric statistical methods, specifically the Wilcoxon and Friedman tests.

The results revealed that gluten-free bread received significantly lower scores, particularly in terms of texture and aroma, compared to conventional breads. In contrast, whole wheat bread consistently achieved the highest preference scores across all evaluated parameters, indicating a strong consumer preference.

The findings of this study offer practical implications for formulation development aimed at enhancing the sensory quality of gluten-free breads. Additionally, they provide important insights for consumers who follow a gluten-free diet either for medical reasons or as part of a healthy lifestyle, supporting the development of more satisfying gluten-free products.

Conceptual Framework

Gluten-Free Bread and Nutritional Trends

In recent years, the growing importance of healthy eating has led to significant shifts in individuals' food consumption preferences. Nutrition is a fundamental requirement for maintaining human life and ensuring a healthy standard of living. Improvements in dietary quality contribute positively to both physical and mental health. In this context, establishing a healthy dietary regimen requires the conscious and balanced intake of essential nutrients and energy in quantities appropriate to the body's needs (Sayın, 2025).

As a consequence of these developments, gluten-free breads have become a necessity, particularly for individuals diagnosed with coeliac disease or gluten intolerance. Initially adopted solely for medical reasons, gluten-free breads have increasingly gained popularity among a broader consumer base influenced by the rising trend toward healthy eating (Prada et al., 2019). This trend has been further accelerated by perceived benefits of gluten-free diets on digestive health and metabolic functioning (Graça et al., 2021). However, the sensory and textural properties of gluten-free breads differ markedly from those of traditional wheat-based breads, directly impacting consumer preferences (Graça et al., 2021).

In Turkey, bread constitutes a staple food item and holds significant influence over consumer habits. Interviews conducted with 12 bakeries in the central districts of Mersin Province revealed that among traditional bread types, white bread and whole wheat bread are the most preferred varieties. Based on these findings, this study undertakes a comprehensive comparison among gluten-free bread, white bread, and whole wheat bread.

White bread, produced using refined wheat flour, is characterized by a soft crumb structure and a neutral flavor profile, making it highly popular among a wide range of consumers (Gallagher et al., 2003). Nevertheless, the lower nutritional value of refined flour compared to whole wheat flour has led to increasing criticism of white bread from a health perspective (Marti et al., 2017). In alignment with current healthy eating trends, interest in whole wheat bread has subsequently grown. Due to its high fiber content and richer nutrient profile, whole wheat bread has emerged as a prominent choice for health-conscious consumers (Mezaize et al., 2010). However, compared to white bread, its more intense aroma and firmer texture can have negative effects on consumer acceptance.

Gluten-free breads, utilizing alternative grains, display distinct differences in both sensory and nutritional attributes relative to traditional breads. The absence of gluten results in a firmer and more brittle texture, while factors such as shelf life, moisture retention, and flavor profile further influence consumer acceptance. Research has emphasized the importance of carefully evaluating the nutritional content of gluten-free breads and has highlighted the need for formulation improvements to better meet consumer sensory expectations in line with the rising demand (Gani et al., 2012; Heiniö et al., 2016).

Furthermore, since consumers often exhibit limited appreciation for the sensory properties of unrefined bakery products, various scientific studies have aimed to improve their acceptability by focusing on enhancing sensory profiles.

In this context, the present study aims to explore consumer perceptions toward gluten-free bread and to examine how this product is positioned in comparison to traditional breads. The field research conducted in Mersin Province seeks to identify the advantages and disadvantages of gluten-free bread and to contribute to the development of improved formulations in future product innovations.

Conceptual Background on Gluten-Free Bread

In recent years, the growing interest in gluten-free products has been attributed not only to health-related concerns but also to individual dietary preferences and the pursuit of a healthier lifestyle. In this context, gluten-free bread has become a focal point of various scientific investigations, both in terms of production techniques and consumer perceptions. Studies in the literature emphasize that the evaluation of gluten-free breads involves not only their physical and chemical properties but also cognitive, emotional, and symbolic dimensions of consumer attitudes.

In a study conducted by Pontual et al. (2017), consumer perceptions of gluten-free pizza dough were analyzed using the word association method. The research specifically examined the associations evoked by dough thickness and the raw materials used (e.g., cassava and rice flour) in consumers' minds. The findings revealed that consumers evaluated not only the sensory attributes such as taste and texture but also the symbolic meanings attributed to the term "gluten-free."

Similarly, another study by Hager et al. (2012) compared the sensory properties and overall quality of gluten-free breads prepared with flours of different botanical origins to those of traditional wheat bread. Evaluations conducted with trained panelists indicated that only breads made with oat flour exhibited sensory qualities comparable to wheat bread. In contrast, breads made with flours such as buckwheat, maize, quinoa, sorghum, and teff received significantly lower sensory scores. This study, supported by scanning electron microscopy and image analysis, highlighted the critical role of ingredient selection in determining product quality.

De Kock et al. (2020) emphasized the crucial role of sensory analysis in the development of gluten-free bakery products. Their research pointed out that sensory characteristics such as appearance, aroma, taste, and texture are fundamental determinants of consumer acceptance. The authors underlined that employing various sensory evaluation methods provides a scientific foundation for the product development process, leading to the formulation of more successful consumer-oriented products. Furthermore, they suggested that further studies are needed to investigate how gluten-free products are perceived by different age groups and consumer profiles.

Beyond rice flour, which is commonly used in gluten-free bread formulations, additives such as gums, enzymes, and dietary fibers are often incorporated to enhance product quality. McCarthy et al. (2005) optimized a gluten-free formulation containing rice flour, potato starch, skimmed milk powder, and hydroxypropyl methylcellulose (HPMC) using response surface methodology. Ahlborn et al. (2005) conducted sensory analyses of gluten-free breads enriched with milk and egg proteins. Moore et al. (2006) and Lopez et al. (2004) demonstrated the potential of various starch-gum combinations to improve texture and flavor attributes. In addition, Lazaridou et al. (2007) investigated the effects of components such as pectin and sodium caseinate on dough rheology and final product quality.

In a study by Yılmaz and Doğan (2015), eight different gluten-free bread formulations were developed by incorporating emulsifiers and thickeners into various flour and starch blends. These products were evaluated in terms of sensory attributes, staling behavior, protein content, and volume. The results indicated that gluten-free breads staled more rapidly, exhibited lower protein content and volume, and were less favored in sensory evaluations compared to wheat-based bread. The study concluded that the inclusion of rice flour was essential in formulations and that enhancing protein content could improve the nutritional value of the final product.

Another study by Hatta et al. (2015) involved the addition of enzymes such as bacillolysin, papain, and subtilisin to gluten-free breads produced with rice flour. These enzymatic additions led to a 30–60% increase in loaf volume and a 10–30% reduction in crumb firmness. Furthermore, the use of flaxseed extract as a structural improver, in place of pectin and guar gum, enhanced the sensory acceptability of the breads, although its effects on staling and textural properties were found to be limited.

Collectively, these findings demonstrate that in the production of gluten-free bread, it is essential to consider not only the selection of ingredients and technological processes but also consumer perceptions, sensory acceptance, and marketing strategies. Integrating sensory analysis into the production process facilitates the development of scientifically robust, consumer-friendly products.

In conclusion, the systematic and holistic application of sensory analyses in the development of gluten-free breads not only enhances consumer satisfaction but also supports the sustainability and success of such products in the marketplace. Scientific research in this domain provides valuable insights that contribute to the strategic planning and advancement of the gluten-free food industry.

Materials and Methods

In the present study, gluten-free bread, white bread, and whole wheat bread were subjected to various preliminary treatments and subsequently evaluated through sensory analysis to assess consumer acceptability. Sensory attributes were assessed based on the criteria described by Meilgaard et al. (2007), focusing on taste, texture, aroma, and overall acceptability. A nine-point hedonic scale, ranging from 1 ("dislike extremely") to 9 ("like extremely"), was employed for the evaluations. *The necessary ethics committee approval for data collection in this research was obtained from the Mersin University Ethics Committee on 04/04/2025 with decision number 83.*

For the statistical analysis, the Wilcoxon signed-rank test and the Friedman test were applied. The Wilcoxon test was utilized to determine differences between two related samples, whereas the Friedman test was employed to analyze differences across multiple related samples. All statistical analyses were performed using SPSS software, and a significance level of $p<0.05$ was adopted.

Sensory evaluations are instrumental in assessing not only the visual and taste-related properties of food products but also in measuring consumer perceptions. Specifically, sensory factors such as taste, aroma, texture, and appearance are recognised as critical determinants of consumer preferences (Stone and Sidel, 2004; Lawless and Heymann, 2010). Accordingly, the present study compared gluten-free bread with white and whole wheat breads to evaluate the impact of ingredient variations on sensory characteristics.

The sensory tests were conducted with panelists who had received formal training in pastry and bakery products through the Continuing Education Centre (SEM) at Mersin University. All three types of bread were prepared in uniform shapes and weights, with environmental variables carefully controlled to minimise external influences. The bread samples used in the study were procured from a local company in Mersin, Türkiye, specialising in pastry and bakery production.

Figure 1. Different Types of Bread

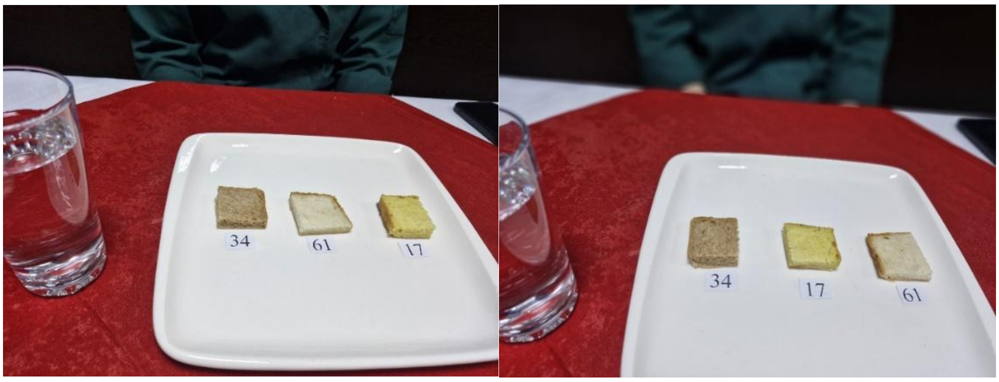
Table 1. Bread Formulations and Production Parameters

Bread Type	Formulation Components	Baking Conditions
White Bread	500 g bread wheat flour, 10 g fresh yeast, 8 g salt, 300 g water	220 °C for 35 minutes
Whole Wheat Bread	500 g whole wheat flour, 10 g fresh yeast, 8 g salt, 300 g water	220 °C for 40 minutes
Gluten-Free Bread	500 g corn flour, 100 g vegetable oil, 10 g granulated sugar, 6 g salt, 10 g fresh yeast, 220 g warm water	180 °C for 55 minutes

This study investigates the effects of breads prepared with different ingredients and methods on consumers' perceptions of taste and acceptability. A panel of 20 semi-trained participants evaluated the bread types based on taste, texture, aroma, and overall acceptability. The primary question posed to the panelists was to assess how the variations in ingredients and methods influenced the taste, texture, aroma, and overall acceptability of the bread samples.

Sensory analyses were conducted during the optimal time period, between 11:30 and 13:30, when participants' sensory responses are most accurate. The test samples were arranged as shown in Figure 2 and were evaluated by the panelists.

Figure 2. Product Evaluation, Blind Tasting, and Reverse Coding



Blind tasting and reverse coding strategies were employed to ensure the reliable and impartial collection of data. Blind tasting requires evaluators to assess the products based solely on their sensory characteristics without knowing the identity of the products. This methodology helps prevent bias in evaluations and ensures that the products are assessed objectively (Stolzenbach et al., 2013). Reverse coding, on the other hand, is a technique that ensures the application of the coding system free from misinterpretations or external influences. These methods enhanced the reliability of the data and reinforced the scientific validity of the study.

The preferred testing method for the sensory analysis was the hedonic test. This test is commonly used to evaluate the sensory attributes of products as perceived by consumers, including taste, aroma, texture, and overall acceptability. Table 1 presents the analysis conditions based on the test format and the number of panelists.

Table 2. Sensory Analysis Protocol and Demographic Characteristics of Panelists

Test No	Type of Test Administered	Panel Type and Number of Panelists	Number of Samples Evaluated	Data Analysis Method Employed
1	Hedonic Test	Semi-trained panelists (n = 8–25) Untrained panelists (n ≥ 80)	1–18	Analysis of Variance (ANOVA) or Rank Analysis (Rank Test)

Source: Altuğ Onoğur and Elmacı, 2019

Results

The frequency analysis results presented in Table 3 reveal the socio-demographic profile of the study participants. Examination of the findings shows that the proportion of female participants (70%) was higher than that of male participants (30%), indicating that the sample was predominantly composed of women.

In terms of marital status, 65% of the participants were single, while 35% were married. This suggests that the majority of the sample group consisted of single individuals.

Regarding age distribution, the majority of participants (65%) fell within the 21–30 age range. Participants aged 31–40 accounted for 20% of the sample, whereas those aged 20 years and under, 41–50 years, and 51–60 years each represented 5%. Notably, there were no participants aged 61 years and above, indicating that the sample largely consisted of younger individuals.

In terms of educational attainment, 45% of the participants held a bachelor's degree. Individuals with an associate degree and those with a secondary education each accounted for 25% of the sample, while 5% of the participants had attained a postgraduate degree. There were no participants with only a primary school education. These results suggest that the study sample predominantly consisted of individuals with higher education qualifications.

Overall, the sample primarily comprised young, highly educated, female, and single individuals. This demographic composition is an important factor to consider when interpreting the study findings

Table 3. Frequency Analysis Results of Participants' Demographic Profile (n = 20)

Socio-Demographic Characteristic	n	Percentage (%)
Gender		
Female	14	70.0
Male	6	30.0
Marital Status		
Single	13	65.0
Married	7	35.0
Age		
20 and under	1	5.0
21–30	13	65.0
31–40	4	20.0
41–50	1	5.0
51–60	1	5.0
61 and over	0	0.0
Education Level		
Primary Education	0	0.0
Secondary Education	5	25.0
Associate Degree	5	25.0
Bachelor's Degree	9	45.0
Postgraduate Degree	1	5.0

Table 4 presents the frequency analysis results of the sensory evaluation criteria for different types of bread. The sensory panel group, consisting of 20 participants, evaluated the different bread types based on taste, aroma, texture, and overall acceptability criteria.

For white bread, the evaluations yielded average scores of 5.80 for taste, aroma, and overall acceptability, and 5.70 for texture. The standard deviation values ranged between 0.76 and 0.83, while the minimum and maximum values varied between 4 and 8. These findings indicate that white bread was generally perceived at a moderate level of acceptability and that the panelists' evaluations were relatively consistent.

In the sensory evaluations of gluten-free bread, slightly lower scores were obtained compared to white bread, with average scores of 5.60 for taste, 5.45 for aroma, 5.25 for texture, and 5.65 for overall acceptability. Notably, a relatively high standard deviation of 1.11 was observed for the texture criterion, suggesting greater variability among individual evaluations. An examination of the minimum and maximum values revealed that panelists' scores for gluten-free bread ranged between 3 and 8.

The sensory evaluations for whole wheat bread revealed significantly higher scores, with averages of 8.50 for taste, 8.45 for aroma, 8.75 for texture, and 8.65 for overall acceptability. Considering that the minimum and maximum scores ranged between 7 and 9, it can be stated that the panelists' sensory evaluations of whole wheat bread were both highly consistent and favorable. The low standard deviation values (ranging from 0.44 to 0.68) further support this observation.

The sensory analysis results demonstrate that panelists rated whole wheat bread the highest across all criteria, including taste, aroma, texture, and overall acceptability. Although white bread received higher sensory scores than gluten-free bread, a significant gap was observed between white bread and whole wheat bread. Gluten-free bread, in particular, received the lowest average scores for texture and aroma, and greater variability among panelists' evaluations was noted, indicating a wider distribution in individual assessments.

These findings reveal that whole wheat bread was the most preferred bread type in terms of sensory attributes, while suggesting that gluten-free bread requires improvements, particularly in terms of taste and texture. Overall, the study provides valuable insights into the effects of different bread types on consumer preferences.

Table 4. Sensory Evaluation Results for Bread Types (n = 20 participants)

Bread Type	Sensory Criteria	Mean	Std. Dev.	Minimum	Maximum
White Bread	Taste	5.80	0.83	4	7
	Aroma	5.80	0.76	4	7
	Texture	5.70	0.80	4	7
	Overall Acceptability	5.80	0.83	4	8
Gluten-Free Bread	Taste	5.60	0.82	3	7
	Aroma	5.45	0.99	3	7
	Texture	5.25	1.11	3	7
	Overall Acceptability	5.65	1.03	3	8
Whole Wheat Bread	Taste	8.50	0.51	8	9
	Aroma	8.45	0.68	7	9
	Texture	8.75	0.44	8	9
	Overall Acceptability	8.65	0.48	8	9

The findings presented in Table 5 encompass the statistical analysis of taste evaluations for three different types of bread. Initially, the Friedman test was applied to examine the overall differences regarding the taste parameter, followed by pairwise comparisons using the Wilcoxon signed-rank test where significant differences were identified.

The Friedman test is a non-parametric test used to analyse whether there are differences in median values among dependent groups. In this study, the test was employed to determine differences in the taste evaluations of white bread (61), gluten-free bread (34), and whole wheat bread (17) presented to the participants. According to the results, the Friedman test yielded a chi-square value of 35.043 with 2 degrees of freedom (Df) and a p-value of 0.000. This finding indicates that there is a statistically significant difference in taste among the bread types ($p<0.05$).

An examination of the mean ranks of the bread types reveals that whole wheat bread (3.00) had the highest rank, followed by white bread (1.58) and gluten-free bread (1.43). Similarly, regarding the mean taste scores, whole wheat bread (8.50) achieved the highest value, whereas white bread (5.80) and gluten-free bread (5.60) received lower scores. These findings suggest that participants evaluated whole wheat bread more favourably in terms of taste compared to the other two bread types.

Since the Friedman test only indicates the presence of overall differences among groups, the Wilcoxon signed-rank test was conducted to identify between which groups the significant differences occurred. The Wilcoxon test is a non-parametric test used to assess median differences between two related groups.

Upon examining the Wilcoxon test results, it was found that in the comparison between whole wheat bread and white bread, all 20 rankings were positive, with no negative rankings, indicating that whole wheat bread was rated significantly higher in taste than white bread ($Z=-3.972$, $p=0.000$). Similarly, the comparison between whole wheat bread and gluten-free bread also showed all 20 positive rankings, confirming that whole wheat bread was rated significantly higher than gluten-free bread ($Z=-4.030$, $p=0.000$). These results demonstrate a distinct superiority of whole wheat bread over the other two types in terms of taste.

On the other hand, the taste difference between gluten-free bread and white bread was not found to be statistically significant ($Z=-0.921$, $p=0.357$). The small difference between negative and positive ranks and the high number of ties suggest that participants' taste perceptions for these two types of bread were very similar.

In conclusion, the study findings reveal that participants rated whole wheat bread significantly more favourably in terms of taste, while no significant difference was perceived between gluten-free and white bread. This indicates that the sensory characteristics of whole wheat bread are superior concerning taste, whereas gluten-free and white bread are perceived similarly in this regard.

Table 5. Friedman and Wilcoxon Test Results for Taste Parameter Evaluations (n=20)

Test Type	Comparison	Mean Rank	Mean	Std. Dev.	N	Chi-Square / Z	Df	p
Friedman	61 White Bread	1.58	5.80	0.83	20	35.043	2	0.000

	34 Gluten-Free Bread	1.43	5.60	0.82				
	17 Whole Wheat Bread	3.00	8.50	0.51				
Wilcoxon	Taste_34 - Taste_61				20	-0.921		0.357
	Negative Ranks: 6 / Positive Ranks: 3 / Ties: 11							
	Taste_17 - Taste_61				20	-3.972		0.000
	Negative Ranks: 0 / Positive Ranks: 20 / Ties: 0							
	Taste_17 - Taste_34				20	-4.030		0.000
	Negative Ranks: 0 / Positive Ranks: 20 / Ties: 0							

The findings presented in Table 6 comprise the statistical analysis of aroma evaluations across three different bread types, based on the results of the Friedman and Wilcoxon tests. The Friedman test revealed a statistically significant difference among the bread types with respect to aroma (Chi-square=32.250, df=2, p=0.000). An examination of the mean ranks indicated that whole wheat bread had the highest mean rank, whereas white bread and gluten-free bread demonstrated lower mean ranks. Similarly, in terms of mean aroma scores, whole wheat bread received the highest rating, while white and gluten-free breads were rated lower. These results suggest that participants evaluated the aroma of whole wheat bread more positively compared to the other two bread types.

Pairwise comparisons conducted using the Wilcoxon signed-rank test showed no statistically significant difference between gluten-free bread and white bread in terms of aroma (Z=-1.615, p=0.106). This finding indicates that participants perceived the aromatic characteristics of these two bread types similarly. Conversely, the comparison between whole wheat bread and white bread revealed that whole wheat bread was rated significantly higher in aroma (Z=-3.982, p=0.000). Likewise, the comparison between whole wheat bread and gluten-free bread demonstrated a statistically significant preference for the aroma of whole wheat bread (Z=-3.852, p=0.000). These results clearly indicate that participants evaluated the aroma of whole wheat bread more favourably, and that its aromatic properties were distinctly preferred over those of the other two bread types.

In conclusion, the findings indicate that whole wheat bread possesses a significant superiority in terms of aroma compared to the other bread types. No significant difference was observed between gluten-free bread and white bread regarding aroma, suggesting that both breads were perceived similarly in aromatic terms.

Table 6. Friedman and Wilcoxon Test Results for Aroma Parameter Evaluations (n=20)

Test Type	Comparison	Mean Rank	Mean	Std. Dev.	N	Chi-square / Z	df	p
Friedman	61 White Bread	1.63	5.80	0.76	20	32.250	2	.000
	34 Gluten-Free Bread	1.40	5.45	0.99				
	17 Whole Wheat Bread	2.98	8.45	0.68				
Wilcoxon	Aroma_34 - Aroma_61				20	-1.615		.106
	Negative Ranks: 9 / Positive: 4 / Ties: 7							
	Aroma_17 - Aroma_61				20	-3.982		.000
	Negative Ranks: 0 / Positive: 20 / Ties: 0							
	Aroma_17 - Aroma_34				20	-3.852		.000
	Negative Ranks: 0 / Positive: 19 / Ties: 1							

The results presented in Table 7 encompass the statistical analysis of texture evaluations for three different types of bread. According to the Friedman test results, a statistically significant difference was identified among the bread types in terms of texture (Chi-square=35.314, df=2, p=0.000). An examination of the mean ranks indicates that whole wheat bread received the highest rank, followed by white bread and gluten-free bread, respectively. The mean texture scores corroborate this ranking, with whole wheat bread obtaining the highest average score, while white bread and gluten-free bread received lower scores. These findings suggest that participants evaluated whole wheat bread more favourably in terms of texture compared to the other bread types.

Pairwise comparisons conducted using the Wilcoxon signed-rank test revealed no statistically significant difference between gluten-free bread and white bread (Z=-1.727, p=0.084), indicating that these two bread types were perceived as similar in texture. In contrast, the comparison between whole wheat bread and white bread demonstrated that whole wheat bread was rated significantly higher in terms of texture (Z=-4.052, p=0.000). Similarly, the comparison between whole wheat bread and gluten-free bread also showed a statistically significant difference in favour of whole wheat bread (Z=-3.970, p=0.000). The absence of negative ranks in both comparisons indicates that all participants consistently evaluated whole wheat bread more positively regarding its texture.

Overall, these findings demonstrate that whole wheat bread is perceived significantly more favourably than the other bread types in terms of texture. The lack of a significant difference between white bread and gluten-free bread suggests that these two types share similar textural characteristics. These results highlight that the textural properties of whole wheat bread are more appealing to consumers and suggest that textural differences may play a critical role in bread preference.

Table 7. Friedman and Wilcoxon Test Results for Texture Parameter Evaluations (n=20)

Test Type	Comparison	Mean Rank	Mean	Std. Dev.	N	Chi-square / Z	df	p
Friedman	61 White Bread	1.65	5.70	0.83	20	35.314	2	0.000
	34 Gluten-Free Bread	1.35	5.25	1.11				
	17 Whole Wheat Bread	3.00	8.75	0.44				
Wilcoxon	Texture_34 - Texture_61				20	-1.727		0.084
	Negative Ranks: 8 / Positive Ranks: 2 / Ties: 10							
	Texture_17 - Texture_61				20	-4.052		0.000
	Negative Ranks: 0 / Positive Ranks: 20 / Ties: 0							
	Texture_17 - Texture_34				20	-3.970		0.000
	Negative Ranks: 0 / Positive Ranks: 20 / Ties: 0							

Table 8 presents the Friedman and Wilcoxon test results conducted for the overall acceptability parameter. The Friedman test indicated a statistically significant difference in terms of overall acceptability among the three types of bread (Chi-square=34.812, df=2, p=0.000). While the mean ranks for white bread and gluten-free bread were quite close to each other, whole wheat bread exhibited a notably higher mean rank. These findings suggest that participants evaluated whole wheat bread as having a higher level of overall acceptability compared to the other bread types.

An examination of the pairwise comparisons conducted through the Wilcoxon signed-rank test revealed that the difference between gluten-free bread and white bread was not statistically significant (Z=-0.812, p=0.417). This result suggests that participants perceived these two types of bread similarly in terms of overall acceptability. However, the comparison between whole wheat bread and white bread revealed a statistically significant difference (Z=-3.962, p=0.000), with whole wheat bread receiving significantly higher ratings for overall acceptability. Similarly, a significant difference was observed in the comparison between whole wheat bread and gluten-free bread (Z=-3.959, p=0.000), again favouring whole wheat bread.

These results demonstrate that participants evaluated whole wheat bread more positively than both white and gluten-free bread regarding overall acceptability. Particularly, the findings indicate that white bread and gluten-free bread were perceived similarly in terms of general acceptability, whereas whole wheat bread was distinctly preferred over both alternatives.

Table 8. Friedman and Wilcoxon Test Results for Overall Acceptability Parameter Evaluations (n=20)

Test Type	Comparison	Mean Rank	Mean	Std. Dev.	N	Chi-square / Z	df	p
Friedman	61 White Bread	1.53	5.80	0.83	20	34.812	2	0.000
	34 Gluten-Free Bread	1.48	5.65	1.03				
	17 Whole Wheat Bread	3.00	8.65	0.48				

Wilcoxon	Overall Acceptability_34 - Overall Acceptability_61	20	-0.812	0.417
	Negative Ranks: 5 / Positive Ranks: 4 / Ties: 11			
	Overall Acceptability_17 - Overall Acceptability_61	20	-3.962	0.000
	Negative Ranks: 0 / Positive Ranks: 20 / Ties: 0			
	Overall Acceptability_17 - Overall Acceptability_34	20	-3.959	0.000
	Negative Ranks: 0 / Positive Ranks: 20 / Ties: 0			

Main Research Question

The primary objective of this study is to investigate the effects of different bread formulations, prepared using varying ingredients and methods, on consumers' sensory evaluations in terms of taste, texture, aroma, and overall acceptability.

Answers to the Research Question

The findings of the study revealed that gluten-free bread demonstrated significant differences in consumers' sensory evaluations compared to traditional breads, namely white bread and whole wheat bread.

In terms of taste, gluten-free bread received considerably lower scores than both white and whole wheat bread. This suggests that consumers found the flavour of gluten-free bread less appealing. The lower ratings are attributed to the absence of cereal-based components and the distinct flavour profiles introduced by alternative flours, such as rice or corn flour, which differ from the traditional taste characteristics of wheat-based breads.

Regarding texture, gluten-free bread again scored lower compared to its traditional counterparts. This result is primarily due to the firmer, more brittle, and denser structure typical of gluten-free bread. The absence of gluten, which contributes to the elastic and cohesive structure in conventional breads, led to a noticeable limitation in meeting consumers' textural expectations.

When evaluating aroma, gluten-free bread obtained the lowest average score. Consumers found the aroma of gluten-free bread less pleasant, likely due to the presence of alternative grains and starches that introduce different aromatic compounds not typically associated with traditional wheat-based fermentation. The familiar, characteristic aroma of fermented wheat flour, which was positively evaluated in traditional breads, was largely absent in gluten-free formulations.

In terms of overall acceptability, gluten-free bread scored significantly lower compared to white and whole wheat breads. The differences observed in taste, texture, and aroma collectively contributed to a reduced preference for gluten-free bread among the general consumer group. Nevertheless, it was observed that a specific consumer segment, particularly those adhering to health-conscious diets or with special dietary requirements (e.g., coeliac disease, gluten sensitivity), demonstrated a higher acceptance of gluten-free bread.

Overall, the study highlighted that the sensory attributes of gluten-free bread were generally less aligned with consumer expectations when compared to traditional breads. However, it was evident that gluten-free bread remains a viable option for niche consumer groups seeking alternatives due to health or dietary considerations. These findings suggest that targeted improvements in the taste, texture, and aroma of gluten-free bread could significantly enhance consumer acceptance.

To further explore the impact of formulation adjustments, a comparative analysis was conducted between two gluten-free bread formulations, labelled as Formulation No. 25 and Formulation No. 45. Table 9 presents a detailed comparison of their ingredient compositions.

Formulation No. 25 was initially tested alongside traditional breads and was associated with several negative sensory evaluations, particularly in terms of texture, moisture retention, and flavour. Based on this feedback, Formulation No. 45 was developed with modifications including the addition of alternative flours such as einkorn wheat flour and rice flour, and structural stabilisers such as milk, vegetable oil, and eggs. These adjustments aimed to enhance the moisture retention capacity and the internal structural stability of the gluten-free bread.

Subsequent sensory testing with the same panel group (n=20) demonstrated that these improvements positively influenced consumer evaluations. The systematic comparison between the two formulations clearly indicated that ingredient optimisation plays a crucial role in enhancing product quality in gluten-free bread production.

Thus, Table 9 effectively illustrates the direct impact of formulation changes on the sensory attributes of the final product and underscores the importance of carefully selecting and balancing ingredients in gluten-free bread development.

Table 9. Comparative Evaluation of Ingredient Compositions Between Gluten-Free Bread Formulations (n=20)

Ingredient	Gluten-Free Bread 45 (g/ml/unit)	Gluten-Free Bread 25 (g/ml)
Corn flour	90 g	500 g
Einkorn wheat flour	90 g	–
Rice flour	90 g	–
Sugar	25 g	10 g
Baking powder	10 g	–
Milk	100 ml	–
Vegetable oil	100 ml	100 g
Egg	2 units	–
Salt	–	6 g
Fresh yeast	–	10 g
Warm water	–	220 g

These results provide valuable insights for future gluten-free bread development and suggest that strategic ingredient modifications can significantly contribute to achieving greater sensory acceptance among consumers.

In Table 10, the sensory evaluation results of the gluten-free bread formulations No. 25 and No. 45, as assessed by the same panel group, are presented comparatively. The data obtained indicate that formulation No. 45 received significantly higher scores across all sensory parameters (appearance, aroma, texture, taste, freshness, and overall acceptability) compared to sample No. 25 ($p < 0.05$). Particularly notable differences were observed in terms of texture and taste, with the improved formulation demonstrating a more effective alignment with consumer expectations.

Statistical analyses were conducted using the independent samples t-test, with a significance level set at $p < 0.05$ within a 95% confidence interval. The findings suggest that the formulation modification represents an effective strategy for enhancing the sensory quality of gluten-free breads.

These results are consistent with previous studies in the literature reporting that the diversification of flour types and the inclusion of moisture-retaining auxiliary ingredients contribute to improvements in the quality characteristics of gluten-free products (Houben and Becker, 2012; Jnawali et al., 2016; Conte et al., 2018). Prior research has frequently highlighted common challenges associated with gluten-free breads, including irregular surface structure, pale crust coloration, insufficient mouthfeel, low flavor quality, and limited shelf life (Houben et al., 2012; Jnawali et al., 2016; Conte et al., 2018).

The concept of visual texture encompasses the external appearance, crust color, loaf volume, and crumb grain structure of the product. Particularly, crust and crumb color play a critical role in consumer preferences (Gallagher et al., 2003; Conte et al., 2018). Gluten-free breads are generally characterized by a paler color and less appealing appearance compared to their wheat flour counterparts, which is attributed to the natural color properties of the raw materials used, as supported by findings in the literature (Gallagher et al., 2003; Różyło et al., 2015). Furthermore, the lower protein content and higher moisture levels typical of gluten-free products tend to limit caramelization reactions responsible for brown pigment formation, thereby hindering the development of the desired browned crust color (Mohammadi et al., 2014).

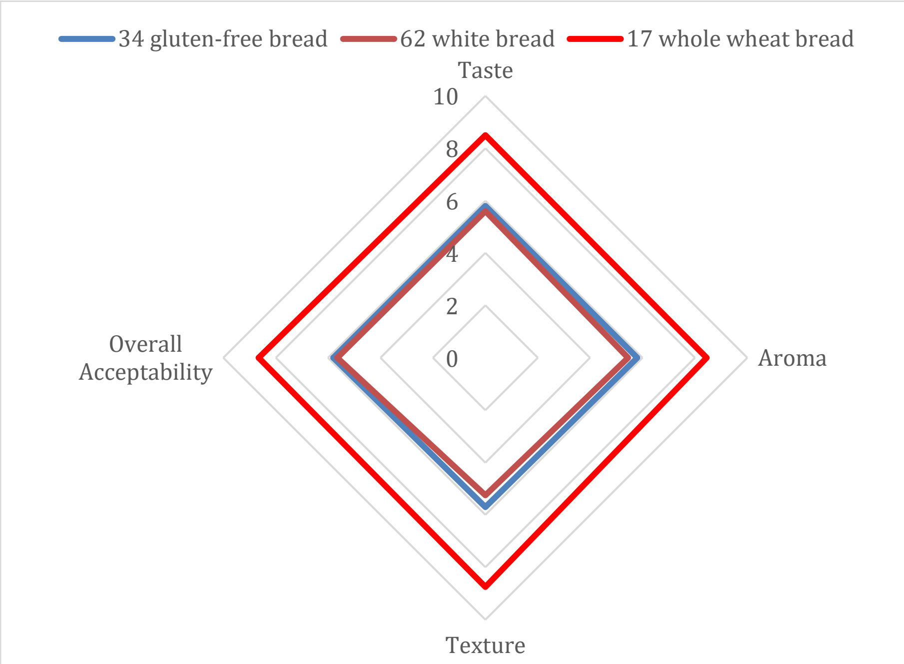
Table 10. Sensory Evaluation Results of Gluten-Free Bread Formulations No. 25 and No. 45

Sensory Attribute	Bread No. 25 (Mean ± SD)	Bread No. 45 (Mean ± SD)	p-value
Appearance	6.2 ± 1.1	7.8 ± 0.9	,000
Aroma	5.9 ± 1.3	7.5 ± 1.0	,001
Texture	5.6 ± 1.4	8.0 ± 0.8	,000
Taste	5.4 ± 1.5	7.7 ± 0.9	,000
Overall Acceptability	5.5 ± 1.3	7.9 ± 0.8	,000

Conclusion

In this study, the sensory attributes (taste, texture, aroma, and overall acceptability) of gluten-free bread were comparatively evaluated alongside traditional bread types, namely white bread and whole wheat bread.

Figure 1. Sensory Characteristics



Sensory analyses were conducted by a panel group consisting of twenty participants, using a 9-point hedonic scale, and statistical analyses were performed using the Wilcoxon and Friedman tests. The findings revealed that gluten-free bread received significantly lower scores across all sensory parameters compared to traditional breads. In particular, it was found to be insufficient in meeting consumer expectations in terms of taste, texture, and aroma. Conversely, whole wheat bread achieved the highest scores across all criteria and emerged as the most preferred bread type. White bread was moderately accepted, while gluten-free bread was identified as a product requiring improvement, particularly regarding its texture and aroma.

The study's results indicate that there is a need for formulation optimisation to enhance consumer acceptance of gluten-free breads. Specifically, the use of alternative flour blends (such as einkorn wheat flour and rice flour) and moisture-retaining ingredients (such as milk, eggs, and vegetable oils) could significantly improve the sensory quality of gluten-free breads. Indeed, the developed gluten-free bread formulation No. 45 demonstrated significant improvements across all sensory parameters compared to the standard gluten-free bread. These results underline the critical role of ingredient optimisation in tailoring gluten-free products to consumer preferences.

The contribution of this research to the literature lies in providing strategies for enhancing the sensory acceptability of gluten-free breads and enabling direct comparisons with traditional bread types. A key practical outcome of this study is the potential development of more flavourful and texturally acceptable gluten-free products, particularly for individuals with coeliac disease and those adhering to gluten-free diets.

For future research, it is recommended to investigate the effects of different gluten-free flour combinations (such as quinoa, buckwheat, and chickpea flours) and functional additives (such as pectin, guar gum, and probiotics). Additionally, conducting studies with larger consumer panels would offer a more detailed evaluation of gluten-free bread acceptance across diverse demographic groups.

In conclusion, this study has demonstrated the necessity for improving the sensory quality of gluten-free breads and has provided evidence for the impact of formulation modifications. It serves as an important guide for the food industry and researchers in enhancing gluten-free products to better meet consumer expectations.

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