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Development and Sensory Evaluation of Gluten-Free Baked Products: A Comparative Study of Bread, Biscuits, and Pizza

Naji E. Aborus[1]*, Ibrahim Greiby[2], Amal M. Othman[3], and Amina M. Omran[3]

[1] Research, Scientific Consulting and Training Center, Nalut University, Libya
[2] Dep. of Food Science and Technology, Faculty of Agriculture, University of Tripoli, Libya
[3] Department of Public Health, Faculty of Medical Technology, Nalut University, Libya

Abstract

This study aimed to evaluate the sensory acceptance of three gluten-free baked products bread, biscuits, and pizza by assessing a range of sensory attributes related to product quality and consumer acceptance. The study involved 30 assessors, of whom 80.0% were ordinary consumers, 13.3% were academics, and 6.7% were nutrition specialists. The products were evaluated using a five-point sensory scale, with the attributes assessed varying according to product type and including taste, texture, mouthfeel, aroma, color, overall appearance, crispness, elasticity, and moisture. The data were analyzed using descriptive statistics, a one-sample t-test comparing the means with the neutral value (3), Pearson's correlation coefficient, and Cronbach's alpha to assess the internal consistency of the evaluation instrument. The results showed different patterns of sensory acceptance among the three products. For gluten-free bread, the mean texture score was 3.50 and the mean taste score was 3.60; both were significantly higher than the neutral value, whereas the other attributes did not differ significantly from the neutral value. For biscuits, taste had the highest mean score (4.40), followed by color (4.30), crispness (3.93), and aroma (3.83), and all four attributes were significantly higher than the neutral value, whereas mouthfeel did not differ significantly from the neutral value. For pizza, taste had a mean score of 3.50 and it was the only attribute that differed significantly from the neutral value, while the mean scores for structure, mouthfeel, aroma, and overall appearance remained around the neutral level. Correlation analyses also revealed positive relationships among several sensory attributes, most notably between taste and mouthfeel in biscuits, between taste and appearance in pizza, and between texture and taste in bread. The findings indicate that sensory acceptance was not homogeneous across the products and that taste represented one of the most consistent dimensions of acceptance, whereas texture, mouthfeel, and structure remained important areas for improvement in some products. The study provides an initial indication that gluten-free baked products with acceptable sensory characteristics can be developed, while highlighting the need for future studies using larger samples and more detailed experimental designs to verify the effects of formulations and ingredients on sensory attributes.

Keywords: Gluten-free products; sensory evaluation; consumer; bread; biscuits; pizza.

Corresponding*: n.aburas@nu.edu.ly Tel: 218944670021

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Introduction

Gluten-free food products represent an important and growing area of food development, driven by the need to provide suitable alternatives for individuals following gluten-free diets for health reasons, particularly those with celiac disease, as well as by increasing interest in developing gluten-free products with acceptable nutritional, technological, and sensory quality. The quality of these products is not limited to their absence of gluten; it is also associated with their ability to provide acceptable sensory characteristics in terms of taste, texture, mouthfeel, aroma, and appearance, which are directly related to the consumer experience and product acceptance (Alibekova et al., 2026; Lawless and Heymann, 2010; Stone and Sidel, 2004).

Developing gluten-free baked products is a technological challenge because, in conventional wheat-based products, gluten plays a major role in forming an elastic protein network that helps retain fermentation gases and maintain product structure, volume, and texture during baking. Consequently, the absence of this network in gluten-free products may lead to changes in dough and final-product structure, including reduced elasticity, weaker cohesion, and changes in volume, texture, and sensory properties compared with conventional products (Salehi, 2019; Villanueva et al., 2021; Alibekova et al., 2026). Research on gluten-free product development has therefore focused on using combinations of flours, starches, and functional ingredients to compensate for some of the technological functions normally provided by gluten. These strategies include the use of rice and maize flours and different starches, together with hydrocolloids, binders, and other ingredients that may improve dough properties, water retention, structural development, texture, volume, and the sensory characteristics of the final product. The effects of these ingredients depend largely on the raw material, its concentration, and the nature of interactions among the components within the formulation (Capriles and Arêas, 2014; Salehi, 2019; Villanueva et al., 2021).

Hydrocolloids are particularly important in gluten-free product development because some can increase dough viscosity and water-holding capacity and help stabilize the structure and retain gas, potentially improving product volume, softness, and sensory characteristics. Scientific reviews have shown that the effects of hydrocolloids are not consistent across all formulations but depend on the type and concentration of hydrocolloid and on the flour or starch used; excessive use may also produce undesirable properties such as rubbery texture, excessive viscosity, or undesirable sensory effects (Salehi, 2019; Villanueva et al., 2021; Alibekova et al., 2026). Achieving appropriate technological or nutritional properties does not necessarily guarantee consumer acceptance. Sensory evaluation is therefore an essential tool in food product development because it provides a direct means of measuring human perception of product attributes and identifying strengths and weaknesses. Sensory tests cover multiple dimensions, including taste, aroma, color, mouthfeel, texture, and overall acceptance, and can be used to guide product development, improve formulations, and identify attributes most closely associated with consumer acceptance (Lawless and Heymann, 2010; Stone and Sidel, 2004).

Studies focusing on gluten-free products emphasize the importance of combining sensory evaluation with assessment of the physical and technological properties of the product. For example, Pagliarini et al. (2010) showed that sensory evaluation can help

identify appearance, aroma, taste, and texture attributes that distinguish gluten-free breads, and that identifying these attributes can contribute to more effective product development and formulation. Rabie et al. (2024) demonstrated the potential for developing gluten-free biscuits using yellow corn flour and alternative plant ingredients while evaluating their physical and sensory properties. Although studies on gluten-free food product development are increasing, consumer responses may vary according to product type, formulation, and physical structure. Bread, biscuits, and pizza represent different baked-food systems in terms of dough composition, proportions of flour, starch, and fat, auxiliary ingredients, and final product structure; consequently, the sensory attributes most influential in acceptance may differ among products. Studying several products within a comparative framework can therefore provide a more specific understanding of the performance of each formulation rather than treating gluten-free products as a homogeneous category. In this context, the present study developed and evaluated three gluten-free baked-product formulations bread, biscuits, and pizza using formulations based primarily on rice flour, corn starch, and other ingredients that varied according to the product, with Arabic gum incorporated as a functional ingredient.

the current study aimed to identify the sensory attributes that were most accepted and needed for improvement of gluten-free bread, biscuits, and pizza, and to compare the evaluation patterns across the three products, thereby providing an empirical basis for formulation development and improvement of sensory acceptance and strengths. Also, to assess whether the mean sensory scores differed significantly from the neutral scale value, and measure the internal consistency of the sensory evaluation instrument.

2. Materials and Methods

2.1. Study Design

The study followed an experimental approach combining the preparation of three gluten-free baked-product formulations bread, biscuits, and pizza followed by sensory evaluation of the resulting products by a group of assessors. The formulations were prepared using a range of gluten-free flours, starches, and auxiliary ingredients, with Arabic gum incorporated into the bread, pizza, and biscuit formulations as an aid in developing product characteristics .

2.2. Preparation of Gluten-Free Bread

A gluten-free flour blend for bread was prepared on the basis of 1 kg of dry mixture, Table1, The blend consisted of rice flour, corn starch, corn flour, and chickpea flour, together with Arabic gum, sugar, salt, instant yeast, and vegetable oil. The formulation of the gluten-free bread was developed based on

Table 1. Composition of the flour blend used to prepare gluten-free bread (per 1 kg of dry mixture)

Ingredient	(%)	Amount (g)
Rice flour	40	400
Corn starch	25	250
Corn flour	15	150
Chickpea flour	10	100
Arabic gum	1.5	15
Sugar	3	30
Salt	1.5	15
Instant yeast	2	20
Vegetable oil	2	20
Warm water	*80–70	800–700 mL

*The water percentage represents the amount added to the dry mixture according to the specified formulation range and is therefore not included in the total percentage of dry ingredients

the researcher's experience and scientific judgment, taking into consideration the functional and technological properties of the selected ingredients. All laboratory analyses were performed in triplicate (n = 3).

During dough preparation, a semi-fluid consistency was adopted as part of the formulation developed in the present study. Arabic gum was incorporated as a functional ingredient to improve dough cohesion and contribute to the texture of the gluten-free products, compensating, to some extent, for the absence of gluten (Hernández-Figueroa, et. al., 2025). These formulation choices were established by the authors based on the specific requirements of the products under investigation

2.3 Preparation of Gluten-Free Biscuits.

The gluten-free biscuit formulation was prepared using rice flour and corn starch as the main ingredients, together with sugar, butter/margarine, eggs, baking powder, vanilla, and Arabic gum (Abdelshafy et. al., 2026). The biscuit formulation used in this study was developed by the authors, with consideration given to the potential influence of fat content on product texture and crispness. Sesame or chocolate could be incorporated as optional ingredients depending on the intended product type; however, neither ingredient was included in the basic formulation evaluated in this study. The ingredient proportions used in the experimental formulation are presented in Table 2.

2.4. Preparation of Gluten-Free Pizza.

The gluten-free pizza formulation was developed by the authors specifically for the present study. The dough was prepared using a blend of rice flour, corn starch, potato flour, and corn flour, combined with Arabic gum, yeast, olive oil, salt, and water (Pasqualone, et al., 2022). The proportions of the ingredients were established by the authors to develop a suitable gluten-free pizza dough. The complete formulation is presented in Table 3.

Table 2. Composition of the gluten-free biscuit formulation

Ingredient	(%)	Amount (g)
Rice flour	45	450
Corn starch	20	200
Sugar	15	150
Butter/Margarine	15	150
Egg	3	30
Baking powder	1	10
Vanilla	0.5	5
Arabic gum	0.5	5
Total	100	1000

2.5. Sensory Evaluation

After preparation of the three products, sensory evaluation was conducted using a five-point rating form. Thirty assessors evaluated each product. The panel consisted of 24 ordinary consumers (80.0%), 4 academics (13.3%), and 2 nutrition specialists (6.7%). Sensory attributes were selected according to the nature of each product(ISO 11136:2014). For bread, the evaluated attributes included texture, taste, and specify the additional attributes assessed. For biscuits, the attributes included crispness, taste, mouthfeel, aroma, and color. For pizza, the attributes included product structure, taste, mouthfeel, aroma, and overall

Table 3. Composition of the gluten-free pizza dough

Ingredient	**(%)**	**Amount (g)**
Rice flour	40	400
Corn starch	30	300
Mashed potato	10	100
Corn flour	10	100
Arabic gum	1.5	15
Yeast	2	20
Olive oil	3	30
Salt	1.5	15
Water*	70	700mL

*Water was used at a level of 70% according to the specified dough formulation.

appearance. A five-point rating scale was used, with a score of 3 designated as the neutral level. The mean score for each attribute was statistically tested against this value using a one-sample t-test.

2.6.Statistical Analysis

Sensory evaluation data were analyzed using descriptive and inferential statistics. The analysis included frequencies, percentages, and arithmetic means, in addition to a one-sample t-test to compare the mean of each sensory attribute with the neutral value of 3. A result was considered statistically significant at $p \leq .0.05$ Pearson's correlation coefficient was also used to examine relationships among the different sensory attributes, with Pearson correlation coefficients interpreted according to statistical significance levels of 0.05 and 0.01 as reported in the analysis outputs.

2.7. Reliability Testing of the Evaluation Instrument

The internal consistency of the sensory evaluation instrument was assessed separately for each product using Cronbach's alpha coefficient. The analysis was conducted to examine the consistency of the items included in the sensory evaluation questionnaire.

2.8. Presentation of Results

To present the study as a concise scientific article suitable for publication, the detailed frequency Tables generated from the statistical analysis will not all be reproduced. Instead, the main results are presented in focused Tables containing means and standard deviations, t-test results, reliability coefficients, and the most important statistically significant correlation coefficients. The sensory performance of the three products is also compared within a unified framework, allowing the attributes that achieved scores above the neutral level and those requiring further improvement in each product to be identified.

3. Results and discussion

3.1. Sensory Evaluation of Gluten-Free Bread

The sensory evaluation results for bread showed mean scores of 3.50 for texture, 3.60 for taste, 3.43 for aroma, 3.30 for elasticity, 3.10 for moisture and 3.40 for color on the five-point rating scale, with 3 representing the neutral value as shown in Table 4.

Table 4. Attribute's parameters for Gluten-Free Bread, mean and std. deviation

Attribute's	N	Minimum	Maximum	Mean	Std. Deviation
Texture	30	1	5	3.50	0.94
Taste	30	1	5	3.60	1.13
Aroma	30	1	5	3.43	1.19
Elasticity	30	2	5	3.30	0.95
Moisture	30	1	5	3.10	1.13
Color	30	2	5	3.40	1.10
Average				3.88	

One-sample t-tests comparing the observed means with the neutral value indicated statistically significant higher scores for texture ($t = 2.921$, $p = .007$) and taste ($t = 2.902$, $p = .007$). In contrast, aroma, elasticity, moisture, and color did not differ significantly from the neutral value ($p < 0.05$). Cronbach's alpha for the six sensory attributes was 0.762, indicating acceptable

internal consistency which presented in Table 5.

Table 5. One-Sample t-Test Results for the Sensory Attributes of Gluten-Free Bread

Attributes	t	p	Difference from 3
Texture	2.921	0.007	0.500
Taste	2.902	0.007	0.600
Aroma	1.987	0.056	0.433
Elasticity	1.725	0.095	0.300
Moisture	0.487	0.630	0.100
Color	1.989	0.056	0.400

Note: The reference value for the t-test was 3.00, P-values < 0.05

The importance of texture in the present findings is consistent with previous literature indicating that the absence of a gluten network represents a major technological challenge in developing cohesive and elastic structures in gluten-free dough and bread. Gluten-free bread formulations often require careful adjustment of water content and the incorporation of starches, hydrocolloids, and other functional ingredients to improve dough rheological properties and the structural quality of the final product (Salehi, 2019; Lazaridou et al., 2007). This observation is particularly relevant to the present formulation, which was based on rice flour, corn starch, corn flour, chickpea flour, and Arabic gum. However, the present study does not allow the independent effect of Arabic gum to be determined because the formulation was not compared with a control formulation or formulations containing different gum concentrations. Therefore, attributing the observed texture characteristics solely to Arabic gum would constitute a causal inference beyond the experimental design. Lazaridou et al. (2007) reported that hydrocolloids can modify the rheological properties of gluten-free dough by influencing viscosity, viscoelastic behavior, and water retention, thereby helping compensate for some of the structural limitations associated with the absence of gluten. Taste had a mean score of 3.60 and was significantly higher than the neutral value, with 63.3% of assessors rating it as "very good" or "excellent." This result indicates a favorable level of taste acceptance for the present formulation rather than demonstrating its superiority over other formulations. In contrast, the moisture, elasticity, and color results indicated that these attributes did not exceed the neutral value statistically. The importance of water management is supported by previous research showing that water content and batter consistency are closely associated with the technological quality of gluten-free bread. Sciarini et al. (2010) demonstrated that, in gluten-free bread formulations based on rice, corn, and soy flours, water incorporation and hydrocolloid addition influenced batter consistency and several bread-quality characteristics. Similarly, Salehi (2019) highlighted the role of hydrocolloids in modifying the rheological and textural properties of gluten-free bakery products. The absence of a significant difference in elasticity is also consistent with the technological challenge of replacing the structural and viscoelastic functions of gluten. Accordingly, the present findings suggest partial success in achieving favorable texture and taste characteristics, while elasticity, moisture, and certain visual characteristics remain areas for further formulation development. Sciarini et al.

(2010) investigated the effects of different hydrocolloids on gluten-free batter properties and bread quality using formulations based on rice, corn, and soy flours. Their findings demonstrated that hydrocolloid incorporation affected batter consistency, specific bread volume, crumb structure, crust color, and crumb firmness. The authors also reported a strong relationship between batter consistency and bread specific volume, highlighting the importance of formulation composition and water incorporation in determining the technological characteristics of gluten-free bread. These findings support the importance of selecting and combining suitable flour sources and functional ingredients when developing gluten-free bakery products. Moroni et al. (2009) reviewed the potential application of sourdough fermentation in gluten-free bread production. They explained that the absence of gluten presents a substantial technological challenge because gluten contributes to the structural, textural, and gas-retention properties of conventional bread. The review indicated that sourdough fermentation, through the metabolic activities of lactic acid bacteria and yeasts, may improve several quality characteristics of gluten-free bread, including texture, palatability, aroma, shelf life, and nutritional properties. These findings demonstrate the potential of fermentation-based approaches to improve gluten-free bread quality, although sourdough

fermentation was not investigated in the present study. Regarding the reliability of the sensory evaluation instrument, Cronbach's alpha for bread was 0.762 across six items (Table 6), indicating acceptable internal consistency among the evaluated sensory attributes in the present sample. It should be emphasized that Cronbach's alpha reflects the internal consistency of the evaluation instrument rather than the sensory quality or acceptability of the bread itself.

Table 6. Cronbach's Alpha of the Sensory Evaluation Instrument for Bread

Indicator	Value
Cronbach's Alpha	0.76
Number of items	6.00

3.2. Sensory Evaluation of Gluten-Free Biscuits

The reliability analysis revealed a Cronbach's alpha coefficient of 0.735 for the pizza evaluation instrument (seven items), indicating acceptable internal consistency. In contrast, the biscuit evaluation instrument showed a lower alpha coefficient of 0.563 (seven items), suggesting relatively limited internal consistency. This difference indicates that the sensory attributes used to evaluate pizza were more internally consistent than those used for biscuits. Therefore, the biscuit results should be interpreted with some caution, particularly when considering the consistency of the sensory evaluation items.
Biscuits showed relatively high mean scores for several sensory attributes. In Table 7, the mean scores were 4.40 for taste, 4.30 for color, 3.93 for crispness, and 3.83 for aroma, whereas mouthfeel had a mean score of 3.20. The one-sample t-test showed that crispness,

Table 7. Attribute's parameters, mean and std. deviation of Gluten-Free Biscuits

Attribute's	N	Minimum	Maximum	Mean	Std. Deviation
Crispness	30	2	5	3.93	1.08
Taste	30	3	5	4.40	0.72
mouthfeel	30	1	5	3.20	0.99
Aroma	30	2	5	3.83	0.79
Color	30	2	5	4.30	0.79
Average				3.93	

taste, aroma, and color differed significantly from the neutral value, whereas mouthfeel did not significantly differ.

Taste had the highest mean score among the biscuit attributes (M = 4.40), and 86.6% of assessors rated taste as “very good” or “excellent.” This indicates a high descriptive level of taste acceptance in the present sample and is supported by the relatively large statistical difference from the neutral value ($t = 10.592$, $p < 0.001$) as shown in Table 8.

Table 8. One-Sample t-Test Results for the Sensory Attributes of Gluten-Free Biscuits

Attribute	t	p	Difference from 3
Crispness	4.731	<0.001	0.933
Taste	10.592	<0.001	1.400
Mouthfeel	1.099	0.281	0.200
Aroma	5.767	<0.001	0.833
Color	8.963	<0.001	1.300

The mean taste score was 4.40, representing the highest descriptive mean among the evaluated biscuit attributes, and 86.6% of assessors rated taste as "very good" or "excellent." This finding indicates a favorable level of taste acceptance among the assessors. It is consistent with previous research demonstrating that gluten-free biscuits with acceptable sensory characteristics can be developed through the appropriate selection and combination of alternative flour sources and functional ingredients. Rabie et al. (2024), for example, demonstrated the feasibility of producing gluten-free biscuits using yellow corn flour supplemented with sweet lupine and sweet potato powders, and reported favorable sensory responses to selected formulations. Similarly, Di Cairano et al. (2018) emphasized that the selection of suitable alternative flours and ingredients is important for achieving desirable technological and sensory characteristics in gluten-free biscuits. In the present study, the favorable taste scores were accompanied by relatively high ratings for crispness, color, and aroma. However, these associations do not establish that any individual ingredient was responsible for the observed sensory acceptance. The formulation contained rice flour, corn starch, sugar, fat, eggs, baking powder, vanilla, and Arabic gum; therefore, determining the specific contribution of each ingredient would require a separate experimental design involving controlled formulations and different ingredient levels.

Crispness was another favorable characteristic of the biscuits, with a mean score of 3.93, which was significantly higher than the neutral value ($p < 0.001$). The importance of crispness in biscuit evaluation is well established, as texture-related properties, including crispness, firmness, and breaking strength, are among the principal sensory attributes used to assess biscuit quality (Di Cairano et al., 2018). From a functional perspective, the textural requirements of biscuits differ considerably from those of bread. Bread requires a cohesive and elastic structure that supports gas retention and contributes to loaf volume and crumb development. In contrast, particularly in short-dough biscuits, limited gluten network development is desirable because a short, tender, and crisp structure is preferred over an elastic one (Di Cairano et al., 2018). Therefore, the differences observed between bread and biscuits in the present study should not be interpreted simply as differences in overall product quality, but rather in relation to the distinct

technological and sensory requirements of each product. Mouthfeel had a mean score of 3.20 and did not differ significantly from the neutral value ($p = 0.281$). Although this score was slightly above the neutral level, the absence of statistical significance indicates that the assessors did not demonstrate a clear positive or negative response regarding this attribute. Consequently, mouthfeel represents a potential area for further improvement in the biscuit formulation, particularly in terms of achieving a smoother and more desirable oral texture. This interpretation is consistent with Di Cairano et al. (2018), who reported that gluten-free biscuits may exhibit undesirable mouthfeel characteristics, including dryness and a sandy texture, depending on the flour sources and functional ingredients used. Their review emphasized that gluten-free biscuit development requires balancing technological properties, nutritional composition, sensory characteristics, and consumer acceptance. These findings support the importance of considering mouthfeel alongside taste, crispness, aroma, and appearance when developing acceptable gluten-free biscuits.

Regarding the reliability of the sensory evaluation instrument, Cronbach's alpha was 0.563 across five items (Table 9), indicating relatively limited internal consistency among the evaluated sensory attributes in the present sample. This coefficient reflects the degree of consistency among the questionnaire items and should not be interpreted as an indicator of the biscuits' sensory quality or overall acceptability.

Table 9. Cronbach's Alpha of the Sensory Evaluation Instrument for Biscuits

Indicator	Value
Cronbach's Alpha	0.563
Number of items	5.000

3.3. Sensory Evaluation of Gluten-Free Pizza

As presented in Table 10, the sensory evaluation results showed variations in the assessors' responses to the different attributes of the gluten-free pizza. Taste received the highest mean score (3.50), indicating a favorable response from the assessors. In comparison, the mean scores for structure, mouthfeel, aroma, and overall appearance were 3.03, 3.13, 3.20, and 3.03, respectively. These values were close to the neutral reference score of 3.00, suggesting that the assessors' responses to these attributes were generally neutral rather than clearly positive or negative. The one-sample t-test, which compared the mean score of each sensory attribute against the neutral reference value of 3.00, confirmed that taste was the only attribute showing a statistically significant difference from neutrality ($t = 4.349$, $p < 0.001$). The mean difference of 0.50 represents the difference between the observed mean taste score (3.50) and the neutral reference score (3.00). This statistically significant positive difference indicates that the assessors evaluated the taste of the pizza more favorably than the neutral level. In contrast, the differences observed for structure (mean = 3.03), mouthfeel (mean = 3.13), aroma (mean = 3.20), and overall appearance (mean = 3.03) were not statistically significant compared with the neutral reference value ($p > 0.05$). Although aroma had a slightly higher descriptive mean than the other non-significant attributes, this numerical difference does not provide sufficient statistical evidence to conclude that the assessors positively accepted the aroma. Similarly, the scores for structure and overall appearance were almost identical to the neutral value, indicating neither a clearly favorable nor an unfavorable assessment. Overall, these findings suggest that taste was

Table 10. Attribute's parameters for Gluten-Free Pizza, mean and std. deviation

Attribute's	N	Minimum	Maximum	Mean	Std. Deviation
Structure	30	1	5	3.03	1.129
mouthfeel	30	1	5	3.50	0.630
Texture	30	1	5	3.13	1.008
Aroma	30	1	5	3.20	1.186
Appearance	30	1	5	3.03	1.273
Average				3.18	

the strongest sensory attribute of the developed gluten-free pizza, whereas structure, mouthfeel, aroma, and overall appearance did not demonstrate statistically significant positive acceptance. Therefore, further formulation development may be needed to improve these characteristics and achieve a more balanced sensory profile. These results should be interpreted in relation to the specific formulation and the assessors involved in the present study, rather than as evidence of superiority over other gluten-free pizza formulations.

Accordingly, the clearest positive sensory finding for the gluten-free pizza was related to taste, whereas structure, mouthfeel, aroma, and overall appearance remained close to the neutral reference value. Importantly, the absence of statistically significant differences from the neutral value does not necessarily indicate that these attributes were unacceptable or poorly evaluated. Rather, it means that the available data did not provide sufficient statistical evidence to establish that their mean scores were either significantly higher or lower than the neutral score of 3.00. Therefore, the statistical test used in the present study determines whether the mean score differs significantly from the predefined neutral reference value; it does not independently classify the product as good or poor. The relatively modest scores for some sensory attributes may be considered in light of the technological challenges associated with gluten-free product development (Table 11). Previous studies have highlighted that the absence of gluten, which normally provides a cohesive and viscoelastic protein network, can adversely affect the structural integrity, texture, and overall quality of gluten-free doughs and baked products (Cappelli et al., 2020; Salehi, 2019). Furthermore, reviews have emphasized that

Table 11. One-Sample t-Test Results for the Sensory Attributes of Gluten-Free Pizza

Attribute	t	p	Difference from 3
Structure	0.162	8730.	0.033
Taste	4.349	0.001>	0.500
Mouthfeel	0.724	4750.	0.133
Aroma	0.924	3630.	0.200
Appearance	0.143	8870.	0.033

appropriate management of water content, starch selection, hydrocolloids, and other functional ingredients is essential for modifying dough viscosity, improving water retention, and developing a more stable structure in gluten-free formulations (Cappelli et al., 2020; Bender & Schönlechner, 2020; Salehi, 2019). These factors are particularly relevant to the development of gluten-free pizza, where the dough must maintain sufficient structural integrity and desirable textural properties during preparation and baking. In the present study, the lower mean scores for structure, mouthfeel, and overall appearance relative to taste identify these characteristics as potential targets for further formulation improvement.

However, the sensory results alone cannot establish which ingredient or technological factor was responsible for these differences. To investigate the underlying causes, future studies should compare different formulations, including control formulations and varying concentrations of functional ingredients, while simultaneously assessing relevant physical, textural, and rheological properties alongside sensory responses. Such an approach would help identify the contribution of individual ingredients and determine which formulation adjustments could improve the overall sensory profile of gluten-free pizza.

In Table 12 Cronbach's alpha for pizza was 0.735 across seven items, indicating relatively acceptable internal consistency in the present sample, while emphasizing the need to distinguish measurement reliability from judgments about product quality.

Table 12. Cronbach's Alpha of the Sensory Evaluation Instrument for Pizza

Indicator	Value
Cronbach's Alpha	0.735
Number of items	5.00

3.4. Relationships among Sensory Attributes

Pearson analysis showed several statistically significant positive correlations among sensory attributes as presented in Table 13. In biscuits, the correlation between taste and mouthfeel was relatively strong ($r = 0.650$, $p \leq 0.01$) while crispness was correlated with taste ($r = 0.432$, $p \leq 0.05$) and color with aroma ($r = 0.411$, $p \leq 0.05$). In pizza, taste was correlated with overall appearance ($r = 0.624$, $p \geq 0.01$) and mouthfeel ($r = 0.598$, $p \leq 0.01$), while structure was correlated with overall appearance ($r = 0.551$, $p \leq 0.01$) These findings suggest that sensory attributes may be interrelated in assessors' perceptions; assessors do not evaluate each attribute as completely independent of the others. However, the correlational nature of the data does not permit causal inference. Statements such as "improving mouthfeel leads to improved taste" should therefore be avoided unless tested using an appropriate experimental design. This interpretation is consistent with sensory evaluation principles, which view acceptance as the result of interactions among multiple sensory dimensions rather than a single attribute (Lawless and Heymann, 2010). Mancebo et al. (2015) demonstrated that controlling the proportions of rice flour and starches in gluten-free mixtures is an important factor in improving bread quality, particularly its technological and physical properties, emphasizing the importance of formulation design in achieving a balanced gluten-free bread formulation.

Table 13. Pearson Correlation Coefficients among the Sensory Attributes of Biscuits

Relationship	r	Significance
Taste × Mouthfeel	0.650	≤0.01
Crispness × Taste	0.432	≤0.05
Color × Aroma	0.411	≤0.05

These results indicate interrelationships among some sensory dimensions in assessors' perceptions, but they do not establish causal relationships. For example, the correlation between taste and mouthfeel does not justify concluding that improving mouthfeel will necessarily improve taste; the present data demonstrate only a statistical relationship within the sample as shown in Table 14.

3.5. Integrated Interpretation of Sensory Evaluation Results

Overall, the results indicate the possibility of achieving acceptable to good sensory acceptance in gluten-free baked products using the formulations studied, with clear

Table 14. Pearson Correlation Coefficients among the Sensory Attributes of Pizza

Relationship	r	Significance
Taste × Overall appearance	0.624	≤0.01
Taste × Mouthfeel	0.598	≤0.01
Structure × Overall appearance	0.551	≤0.01

differences in the attributes representing strengths and areas for improvement. In bread, texture and taste were prominent, whereas further development is needed for elasticity, moisture, and some visual characteristics. In biscuits, relatively high scores were observed for taste, color, crispness, and aroma, while mouthfeel remained close to the neutral level. In pizza, taste was the only attribute that differed significantly from the neutral value, indicating a need for further work on structure, mouthfeel, and overall appearance. The comparison should also be interpreted in light of the different technological requirements of bread, biscuits, and pizza. Each product has specific sensory and structural characteristics, and the attributes assessed were not identical across all three products. Therefore, the results should not be used to rank the products in terms of overall quality or superiority. Instead, they identify product-specific sensory attributes that may warrant further investigation and formulation development. Future studies using standardized assessment of common sensory attributes and an appropriate statistical design would be required to determine whether differences among the products are statistically significant.

3.6. Visual Comparison Using the Spider Chart

Figure 1 provides a visual comparison of the sensory profiles of the three gluten-free products (bread, biscuits, and pizza), highlighting differences in the distribution of mean scores across the evaluated sensory attributes. The observed patterns are generally consistent with previous studies demonstrating that the sensory characteristics and consumer acceptance of gluten-free bakery products depend on product type, flour composition, and the functional properties of the ingredients used. For gluten-free bread, the spider chart shows relatively higher scores for taste and texture, while the other sensory attributes exhibited a more closely grouped distribution. This pattern is consistent with Pagliarini et al. (2010), who identified taste, aroma, color, and texture as important sensory descriptors for differentiating commercial gluten-free breads. Similarly, Laureati et al. (2012) reported that consumer preference for gluten-free bread was positively associated with sweetness, porosity, and softness, emphasizing the importance of taste and textural characteristics in determining bread acceptability. These findings support the relevance of taste and texture as important dimensions of the sensory profile observed in the present bread formulation. Regarding biscuits, the spider chart revealed relatively higher mean scores for taste, color, crispness, and aroma, indicating a more favorable sensory profile across these attributes compared with the other evaluated products. This observation is supported by Silva-Paz et al. (2024), who evaluated the physicochemical and sensory characteristics of gluten-free cookies prepared using different alternative flour sources. Their study demonstrated that ingredient composition influenced sensory perception, and that corn- and chickpea-based cookies achieved relatively favorable consumer acceptance. The researchers also considered texture-related attributes, including crunchiness and brittleness, together with

taste, color, and aroma, highlighting the importance of these characteristics in gluten-free biscuit evaluation. Therefore, the relatively favorable biscuit profile observed in Figure 1 is consistent with previous findings emphasizing the contribution of flour selection and formulation composition to the sensory quality of gluten-free biscuits.

For pizza, the spider chart showed that most sensory attributes, including structure, corn-based formulations supplemented with different lentil flours. Their results demonstrated that changes in flour composition influenced several sensory characteristics, particularly color, consistency, and pliability, while the consumer responses also varied among the formulations. The authors further reported that gluten-free pizza quality could be affected by textural characteristics and

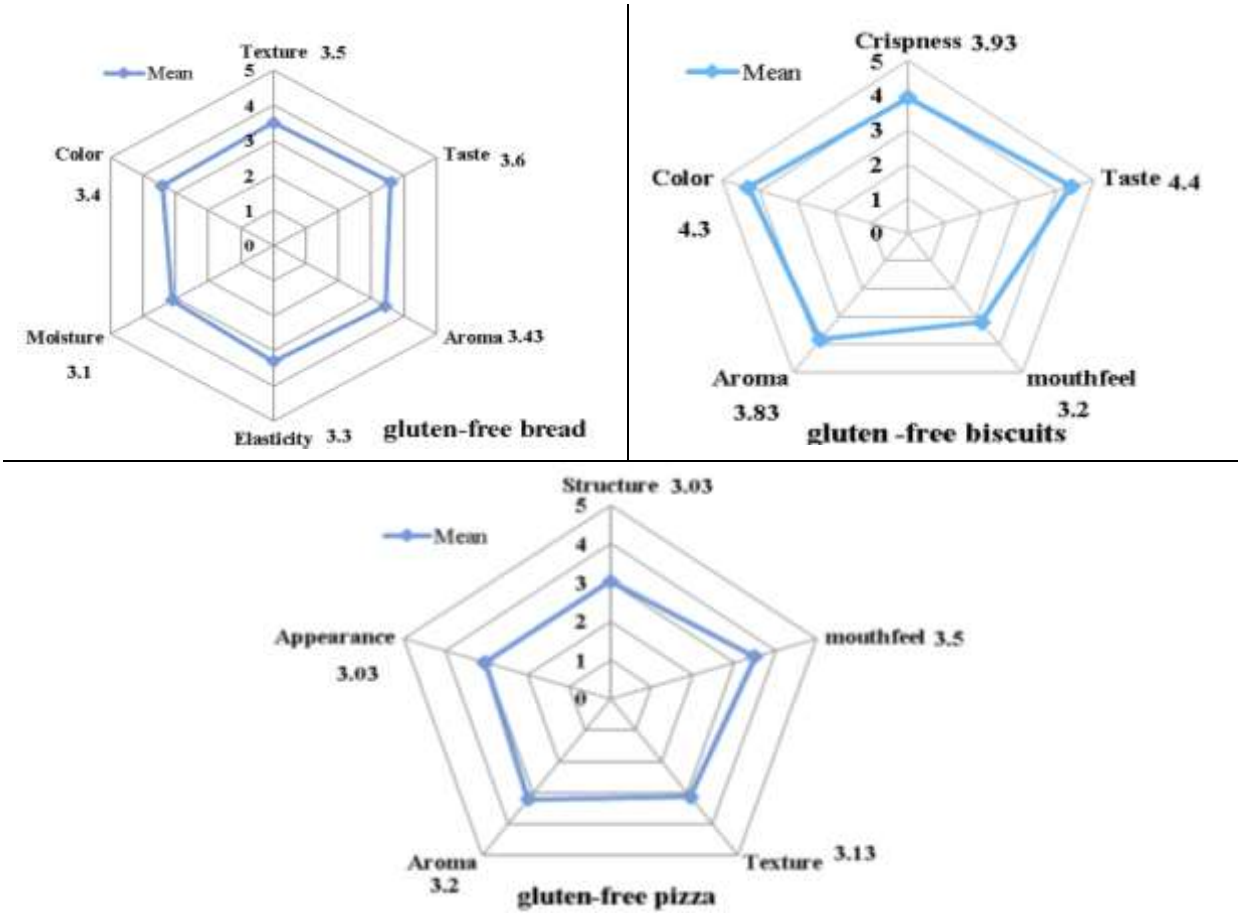


Figure 1. Spider chart of mean sensory evaluation scores for Atributes parameters for gluten –free of bread, biscuits, and pizza

mouthfeel, aroma, and overall appearance, remained close to the neutral level, whereas taste achieved a relatively higher mean score of 3.50. This pattern can be discussed in relation to the findings of Pasqualone et al. (2022), who investigated the sensory characteristics and consumer acceptance of gluten-free pizza prepared using rice- and mouthfeel. These findings highlight the importance of formulation composition in determining the sensory profile of gluten-free pizza and provide a relevant basis for interpreting the differences observed in the present study. When the three products are considered together, taste appears to be a relatively consistent favorable attribute, as its

mean score was significantly higher than the neutral reference value in all three products. However, the remaining sensory attributes showed different patterns according to product type. Biscuits exhibited relatively favorable scores for several attributes, bread showed a comparatively balanced sensory profile with favorable taste and texture scores, whereas pizza showed more limited positive responses beyond taste. These differences may reflect the distinct technological and sensory requirements of each product, as well as the different ingredient combinations used in their preparation. It is important to emphasize that the spider chart provides a descriptive visualization of the mean sensory scores and does not independently establish statistically significant differences among the three products. Furthermore, direct numerical comparisons with previous studies should be interpreted cautiously because of differences in sensory scales, panel composition, formulations, and evaluation procedures. Therefore, Figure 1. should be considered a complementary visual representation of the findings, while the statistical results presented in the corresponding tables provide the basis for interpreting the significance of the observed sensory responses. Overall, the spider chart highlights the different sensory profiles of the three developed gluten-free products and identifies the attributes that may require further improvement during subsequent formulation development.

3.7. Sensory Acceptance Patterns and Formulation Considerations

The differences in sensory acceptance observed among the three products may reflect their distinct formulations and technological requirements. Bread and yeast-leavened pizza require sufficient dough cohesion and structural stability to support expansion during fermentation and maintain an appropriate structure during baking. In gluten-free formulations, the absence of the gluten network makes gas retention and structural development more challenging. Consequently, flour and starch composition, water content, and the use of hydrocolloids are important considerations in developing gluten-free baked products (Capriles and Arêas, 2014; Lazaridou et al., 2007; Salehi, 2019). Research on gluten-free pizza bases has also demonstrated the importance of flour composition and processing properties in determining the physical and sensory characteristics of the final product (Kumar et al., 2022). In contrast, gluten-free biscuits are generally formulated to achieve a short, crisp texture, and their technological and sensory properties depend on appropriate ingredient selection and formulation (Di Cairano et al., 2018). These differences provide a technological context for interpreting the sensory patterns observed in the present study. However, because only one formulation of each product was evaluated, the observed results cannot be attributed to any single ingredient, nor can they establish a statistically significant ranking among the three products.

4. Study Limitations

Despite the importance of the findings, they should be interpreted in light of several methodological limitations:

- The sample size was relatively limited, with only 30 assessors evaluating each product, which restricts the ability to generalize the findings to the Libyan population as a whole.
- .The sample composition was weighted toward ordinary consumers: ordinary consumers represented 80% of the assessors, compared with 13.3% academics and 6.7% nutrition specialists. This is

suitable for assessing consumer acceptance but does not provide adequate representation of specialist groups or people who follow gluten-free diets for medical reasons.

- No dedicated sample of patients with celiac disease or individuals with gluten sensitivity/non-celiac gluten sensitivity was included; therefore, the results cannot be considered direct evidence of product acceptance among these groups.
- The use of a one-sample t-test against the neutral value of 3 means that the study tested whether the mean of each attribute differed from the neutral level and did not directly test differences among bread, biscuits, and pizza. Therefore, the products should not be statistically ranked on the basis of the means alone.
- The reliance on sensory evaluation without sufficient support from objective measurements such as hardness, volume, moisture, water activity, and rheological properties limits the ability to explain the technical causes underlying the sensory findings.
- A large number of alternative formulations were not tested for each product. The study focused on a specific formulation, and therefore the optimal formulation cannot be identified through broad experimental testing.
- Information concerning manufacturing and sensory-evaluation conditions was limited in the available data, including details of exact baking conditions, temperature and time, order of sample presentation, and coding procedures. These factors may affect sensory evaluation results if they are not standardized.

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تطوير وتقييم حسي لمنتجات المخبوزات الخالية من الجلوتين: دراسة مقارنة للخبز والبسكويت والبيتزا

ناجي أبوراس[1]، إبراهيم غريبي[2]، أمال م. عثمان[3]، وأمينة م. عمران[3]

[1] مركز البحوث والاستشارات العلمية والتدريب، جامعة نالوت، ليبيا
[2] قسم علوم وتقنية الأغذية، كلية الزراعة، جامعة طرابلس، ليبيا
[3] قسم الصحة العامة، كلية التقنية الطبية، جامعة نالوت، ليبيا

المستخلص

هدفت هذه الدراسة إلى تقييم القبول الحسي لثلاثة منتجات مخبوزة خالية من الجلوتين، هي الخبز والبسكويت والبيتزا، من خلال تقييم مجموعة من الخصائص الحسية المرتبطة بجودة المنتج وقبول المستهلك. شملت الدراسة 30 مقيّمًا، كان 80.0% منهم من المستهلكين العاديين، و13.3% من الأكاديميين، و6.7% من أخصائيي التغذية. جرى تقييم المنتجات باستخدام مقياس حسي خماسي الدرجات، مع اختلاف الخصائص المقاسة وفقًا لنوع المنتج، وشملت: الطعم، والقوام، والملمس الفموي، والرائحة، واللون، والمظهر العام، والهشاشة، والمرونة، والرطوبة. وحُللت البيانات باستخدام الإحصاء الوصفي، واختبار t لعينة واحدة لمقارنة المتوسطات بالقيمة المحايدة (3)، ومعامل ارتباط بيرسون، ومعامل ألفا كرونباخ لتقييم الاتساق الداخلي لأداة التقييم. أظهرت النتائج اختلافًا في أنماط القبول الحسي بين المنتجات الثلاثة. ففي الخبز الخالي من الجلوتين، بلغ متوسط تقييم القوام 3.50 ومتوسط تقييم الطعم 3.60، وكان كلاهما أعلى بصورة دالة إحصائيًا من القيمة المحايدة، في حين لم تختلف الخصائص الأخرى اختلافًا دالًا عن القيمة المحايدة. أما البسكويت، فقد سجل الطعم أعلى متوسط (4.40)، يليه اللون (4.30)، والهشاشة (3.93)، والرائحة (3.83)، وكانت الخصائص الأربع جميعها أعلى بصورة دالة إحصائيًا من القيمة المحايدة، بينما لم يختلف الملمس الفموي عنها بصورة دالة إحصائيًا. وبالنسبة للبيتزا، بلغ متوسط تقييم الطعم 3.50، وكان الخاصية الوحيدة التي اختلفت بصورة دالة إحصائيًا عن القيمة المحايدة، في حين ظلت متوسطات البنية والملمس الفموي والرائحة والمظهر العام حول المستوى المحايد. كما كشفت تحليلات الارتباط عن علاقات موجبة بين عدد من الخصائص الحسية، أبرزها العلاقة بين الطعم والملمس الفموي في البسكويت، وبين الطعم والمظهر في البيتزا، وبين القوام والطعم في الخبز. وتشير النتائج إلى أن القبول الحسي لم يكن متجانسًا بين المنتجات، وأن الطعم مثّل أحد أكثر أبعاد القبول اتساقًا، في حين ظلت خصائص القوام والملمس والبنية مجالات مهمة للتحسين في بعض المنتجات. وتوفر الدراسة مؤشرًا أوليًا على إمكانية تطوير منتجات مخبوزة خالية من الجلوتين ذات خصائص حسية مقبولة، مع التأكيد على الحاجة إلى إجراء دراسات مستقبلية باستخدام عينات أكبر وتصميمات تجريبية أكثر تفصيلًا للتحقق من تأثير التركيبات والمكونات في الخصائص الحسية.

الكلمات المفتاحية: منتجات خالية من الجلوتين؛ التقييم الحسي؛ المستهلك؛ الخبز ؛ البسكويت؛ البيتزا.

للمراسلة: n.aburas@nu.edu.ly +218944670021

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