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Exploring gluten-free cake: a comprehensive investigation of development, functionality, and structure

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RESEARCH PAPER

Abstract

This study aimed to develop a cost-effective and nutritious gluten-free cake enriched with rice bran for introduction. Gluten-free cakes were prepared using rice flour (RF), maize flour (MF), and chickpea flour (CF) in different proportions. Following organoleptic evaluation, the T3 combination (40% RF, 40% MF, and 20% CF) was selected to incorporate varying percentages of rice bran (RB), namely 5%, 10%, and 15%. Chemical analysis revealed that the treatments caused a significant change in fiber (0.87–2.84%), fat (23.43–24.45%), and ash (0.16–1.52%) content with the addition of rice bran. Storage had a considerable impact on gluten-free, high-fiber cakes. The gluten-free cake formulated with 10% RF was the most acceptable. SEM analysis showed that porosity increased with higher concentrations of rice bran in the cakes. The results indicated that the functional properties of the gluten-free cake improved with the addition of 10% rice bran to the composite flour used in cake preparation.

Keywords: celiac disease, gluten-free products, rice bran, SEM, storage

Introduction

Interest in gluten-free (GF) foods is growing worldwide, along with intense competition among the health sectors. However, creating high-quality gluten-free bread (GFB) remains challenging (Bogue and Sorenson, 2008). In 2016, global sales of GF foods rose by 12.6%, compared to a growth rate of just over 4% for packaged food products

(Terazono, 2017; Xhakollari *et al.*, 2019). Gluten refers to a protein found in grains such as wheat, barley, and rye (Šmídová and Rysová, 2022; Toth *et al.*, 2020). Gliadin and glutenin combine to form gluten, which provides the necessary elasticity for good texture in bakery products (Anderson *et al.*, 1990; Arendt *et al.*, 2002). Gluten intake can cause a variety of issues in gluten-intolerant individuals, including celiac disease (a condition in which the mucosa of the small intestine is damaged), gluten ataxia, and non-celiac gluten sensitivity (Al-Toma et al., 2019; Ahmed *et al.*, 2012; Banureka & Mahendran, 2009).

Wheat is one of the significant food crops from Poaceae family, and is produced, consumed, and stored globally (Anwar *et al.*, 2023; Shahzad, 2023). However, due to soluble non-starch polysaccharides (NSPs) content its nutritive value is low (Anwar *et al.*, 2023a; Anwar *et al.*, 2023b). A persistent intolerance to wheat gluten results in autoimmune enteropathy, also known as celiac disease, and the only effective treatment for this condition is considered to be adhering to a strict gluten-free diet (Niewinski, 2008). Despite the fact that the GF products sector now offers a wide variety of items that can be consumed by individuals with gluten intolerance without any risk, challenges regarding the ideal formulation—such as perceptible texture, flavor, and adequate nutritional properties—still exist (Šmídová and Rysová, 2022). Scientists have recently started to focus more on legumes as a means of producing good structures and textures, as well as a source of nutrients and bioactive substances, and as a low-glycemic index component in the production of GF goods (Melini *et al.*, 2017). Chickpea, a widely grown and consumed pulse in Pakistan and India from the legume family, has flour that is the richest source of lysine, along with a high amount of protein (24-28%), potassium (K), and phosphorus (P), in addition to a low glycemic index (GI) (Arab *et al.*, 2010; Azizah *et al.*, 2007). Due to its high lysine content, chickpea flour is typically combined with other types of flour (e.g., rice flour) to produce a balanced GF product. The production of gluten-free bakery products typically uses around 30-50% chickpea flour (Bhaduri, 2013).

Two of the most commonly used raw ingredients are maize starch and rice flour (Mancebo *et al.*, 2015). The hypoallergenic properties, low sodium (Na) level, mild flavor, and pale color of rice flour make it one of the best flours for baking gluten-free goods (Muhimbula *et al.*, 2011; Torbica *et al.*, 2012). When preparing gluten-free bread, the particle size of the rice flour is equally important. Rice flour contributes a good texture to the batter, providing consistency and springiness to the dough, which results in a better texture and a pleasant mouthfeel in baked products, due to its higher pore distribution (Giwa & Abiodun, 2010; Ergin & Herken, 2012). Flours with larger particle sizes give bread a higher specific volume and softer texture (de la Hera *et al.*, 2013). Maize is a high-yielding and important cereal crop of the world (Akram *et al.*, 2023). Maize flour, which contains a high amount of fat-soluble vitamins (A and E), is also considered an alternative source in the preparation of gluten-free (GF) products. Corn starch, which contains 77% carbohydrates, 11% water, 7% fiber, 7% proteins, 4% lipids, and 1.8% ash, can be used along with other ingredients in the manufacturing of GF products (Dhingra, 2012). The inclusion of maize starch by Mancebo *et al.* (2016) in the preparation of GF cookies reduced hydration and resulted in cookies with better texture. A comparison of the effects of egg albumin and rice bran protein concentrate (RBPC) on the characteristics of gluten-free bread, conducted by Phongthai *et al.* (2016), showed a significant impact on the rheological properties, as well as the porosity and sensorial characteristics of the crumb. Moreover, RBPC was more effective in preventing bread aging than egg albumin. Rice serves as a fundamental grain crop and a staple food for nearly half of the global population (Iftikhar *et al.*, 2023). The use of rice bran in the manufacture of GF cakes enhances nutritional properties, such as protein and dietary fiber content (Phimolsiripol *et al.*, 2012). Since gluten-free (GF) breads are primarily starch-based and contain low levels of vitamins, minerals, and particularly dietary fiber, they are often characterized by low nutritional quality. The current research involves the use of various flour mixtures along with varying concentrations of rice bran to enhance the functional and sensorial properties of GF cakes, increasing their fiber content while ensuring they are economical and nutritious for people with gluten intolerance or those seeking a balanced, nutrition-rich diet.

Materials and Methods

Sampling

Raw materials were purchased from a local market. In preliminary trials, different flours were analyzed, and rice flour (RF), maize flour (MF), and chickpea flour (CF) were selected for the preparation of gluten-free cakes. In test trials, gluten-free cakes were formulated using various ratios of rice flour (RF), maize flour (MF), and chickpea flour (CF). Well-suited combinations were chosen based on organoleptic evaluation. In the main experiment, the selected treatment was supplemented with varying quantities of rice bran to prepare gluten-free cakes enriched with rice bran.

Production of gluten-free cake

To identify the optimal combination of ingredients for producing gluten-free cakes, different flours were

Table 1. Combination of flours mix/s to formulate the cake samples.

Treatments	Wheat (%)	Rice (%)	Maize (%)	Chick Pea (%)
T_0 (control)	100	–	–	–
T_1	–	50	50	–
T_2	–	45	45	10
T^3	–	40	40	20
T_4	–	35	35	30

combined at various ratios to form composite flours, with wheat flour used as a control sample (Table 1). Gluten-free cakes were baked following the AACC method 10-90 C and prepared by adding 250 g sugar, 175 g flour, 200 ml milk, 100 g egg, 120 ml oil, and 10 g baking powder (AACC, 2000). All ingredients, except for the flour, were mixed until a semi-firm foam formed, after which the flour was added. The cake batter (150 g) was then poured into a mold and baked at 190°C for 15 minutes in an electric oven. After baking, the gluten-free cakes were allowed to cool to room temperature. Cake samples were packed in polyethylene bags and stored for further analysis.

Supplementation of stabilized rice bran

Based on sensory analysis, the best flour combination (40% RF, 40% MF, and 20% CF) was selected and subjected to supplementation with stabilized rice bran (5%, 10%, and 15%) to prepare high-fiber, nutritious cakes. A microwave dryer (Model no. WMO-926-GBP-G, 900 W, operating at 900 W) was used to stabilize the rice bran (Table 2). A 100-gram sample was roasted in the microwave oven at 120°C for five minutes. The rice bran was then cooled, and polyethylene bags were used for storage.

Chemical analysis

Different combinations of flour and gluten-free cakes were analyzed for ash (method 923.03), fat (method 203.06), and fiber (method 926.09), following the AOAC (2005) method.

Organoleptic evaluation

To select the best flour mixture, organoleptic evaluations were conducted by 12 panelists (six males and six females) from the Department of Food Science and Technology, UOS, Pakistan. Judges were randomly assigned to three cake samples for sensory assessment, including color, taste, texture, and overall acceptability.

Table 2. levels of Stabilized rice bran in gluten-free cakes.

Treatments	Composite flour (g)	Rice bran (g)
T_1 (control)	100	–
T_2	95	5
T_3	90	10
T_4	85	15

The evaluation was performed using a 9-point hedonic scale. The tests were conducted in isolated booths, and the panelists were asked to cleanse their mouths by consuming water after each assessment. Similarly, the sensory characteristics of rice bran-supplemented cake samples were evaluated by 25 judges using a 9-point hedonic scale (Larmond, 1977).

Physical analysis

The volume of the gluten-free cakes was measured using the rapeseed displacement method. The weight of the cake was recorded using a weighing balance, and the density was calculated by dividing the weight of the cake by its "volume".

Image analysis

Samples supplemented with varying ratios of rice bran were examined using SEM (Company) after eight days of storage. The samples were attached to a sample holder with double-sided tape and coated with approximately 135 Ångström Au/Pd (device coating speed: 3 Å/s) using an SC 7620 mini sputter coater (gold or angstrom). The SEM images were analyzed using Image Pro Plus 6.0, and the porosity of the samples was examined (Hayta & Hendek Ertop, 2018).

Statistical analysis

A Completely Randomized Design (CRD) was applied, and the data obtained for each parameter were subjected to statistical analysis to determine the level of significance using the Analysis of Variance (ANOVA) technique, as described by Steel *et al.* (1997).

Results and Discussion

Chemical analysis of raw material

The contents of fiber, ash, and fat in wheat flour (WF), rice flour (RF), maize flour (MF), chickpea flour (CF), and rice bran (RB) are depicted in Figure 1. The proximate compositions of the raw materials were significantly different from one another. Chemical analysis showed that RB had the highest fiber, ash, and fat content among all the raw materials. When only the flours were considered, maize flour (MF) had the highest fiber content (2.01±0.07%), whereas chickpea flour had the highest ash (2.60±0.09%) and fat (5.01±0.17%) content. These results were further confirmed by the graph shown in Figure 1 and were used in selecting flour combinations for the preparation of gluten-free cakes.

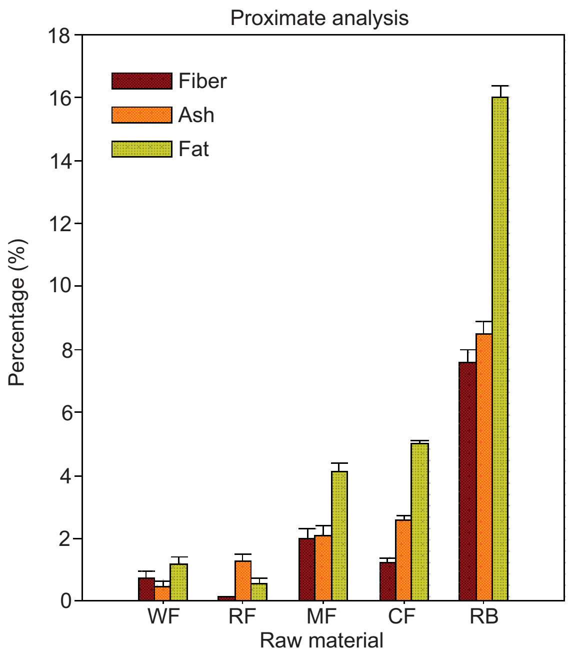

Figure 1. Fiber, ash, and fat content (%) of wheat flour (WF), rice flour (RF), maize flour (MF), chickpea flour (CF), and rice bran (RB).

Organoleptic evaluation of gluten-free cake samples

Figure 2 shows the analysis of gluten-free cakes based on color, taste, texture, and overall acceptability. For all the mentioned parameters, all samples received a score greater than 7, indicating that all combinations of mixed flour were satisfactory to consumers (Table 3). Paesani *et al.* (2021) presented similar results, where all evaluated parameters of gluten-free layer cakes stabilized with wholegrain maize flours received a value greater than 5. Among all treatments, T3 (40% RF + 40% MF + 20% CF) was found to be the most acceptable based on sensory analysis and was selected for further studies. The selection of T3 can be attributed to its more suitable content of fiber, ash, and fat, as the overall appearance of the cake is greatly influenced by the proximate composition of the flour. Regarding individual organoleptic parameters, T1, T2, and the control sample (T0) showed no significant difference; however, T3 and T4 were found to be significantly different from each other and from the other three samples, except for the "Taste" attribute of T3 (Table 4). Thus, based on sensory analysis, T3 was chosen for the addition of bran (10%, 15%, 20%) and further analysis. The sensory characteristics were statistically analyzed using LSD (P ≤ 0.01).

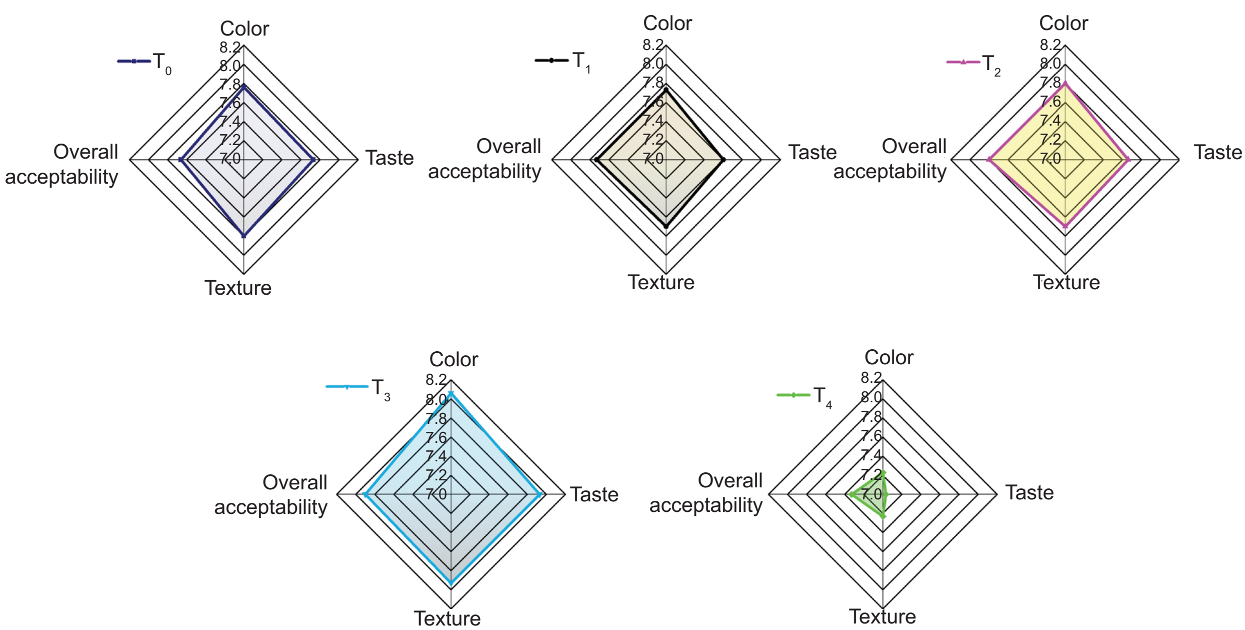

Figure 2. Organoleptic radar chart showing color, Taste, Texture, and overall acceptability of gluten-free cakes substituted with various combination of flours (T_0 [control sample], T_1, T_2, T_3, T_4).

Physical analysis

Figure 3 illustrates the physical attributes of T1 (control), T2, T3, and T4 with 0%, 5%, 10%, and 15% levels of rice bran. It was observed that the density of the cake samples significantly increased with an increase in rice bran in the cake batter. The lowest cake density was recorded for T1 (0.35±0.01 g/cm^3), where rice bran was not added, while the highest cake density (0.46±0.02 g/cm^3) was found for T4 (15% RB), followed by 0.43±0.01 g/cm^3 in T3 (10% RB) and 0.40±0.01 g/cm^3 in T2 (5% RB). The results of this study align with the findings of previous studies, where a similar increase in cake density was observed with the incorporation of fiber into cake recipes extracted from different sources (Ayadi *et al.*, 2009; Sudha *et al.*, 2007; Lu *et al.*, 2010). Similarly, the weight of the cake samples increased with an increase in the percentage of rice bran. The maximum weight was found in T4 (124.27±4.23 g), followed by 123.01±4.18 g in T3 and 122.37±4.16 g in T2. These results were supported by a study by Wilder *et al.* (2010), who demonstrated a positive correlation between bran level and cake weight. The lighter weight of the control samples might be attributed to the large air-water contact area. However, the water-absorbing properties of bran can contribute to the formation of heavier cakes, as an increase in water retention corresponds to an increase in weight.

Table 3. Organoleptic evaluation of gluten-free cake samples.

Treatments	Color	Taste	Texture	Overall acceptability
T_0	7.76^{ab}	7.73^{a}	7.80^{ab}	7.66^{ab}
T_1	7.73^{ab}	7.60^{ab}	7.70^{ab}	7.73^{ab}
T_2	7.80^{ab}	7.66^{a}	7.70^{ab}	7.80^{ab}
T_3	8.06^{a}	7.93^{a}	7.93^{a}	7.90^{a}
T_4	7.23^{b}	7.03^{b}	7.23^{b}	7.33^{b}
LSD ($P \leq 0.01$)	0.57	0.15	0.14	0.47

*Values with the same letter in the same column do not present significant differences.

The minimum cake volume (289.0±9.83 cm^3) was observed in T4, while the maximum cake volume (335.50±11.41 cm^3) was found in T1 (Control), followed by T2 (310.10±10.54 cm^3) and T3 (294.8±10.02 cm^3). These results were similar to those reported by Gomez *et al.* (2010), who stated that the density and volume of the cake are influenced by various factors. The specific volume of the baked cake reflects the amount of air retained in the final product. The most important factors are the consistency of the cake batter and the amount of air remaining in the final product. Higher gas retention results in greater expansion of the product.

Chemical analysis of cake supplemented with rice bran (RB)

Figure 4 shows the effect of storage time (days) on ash, fiber, and fat content (%). The results indicated

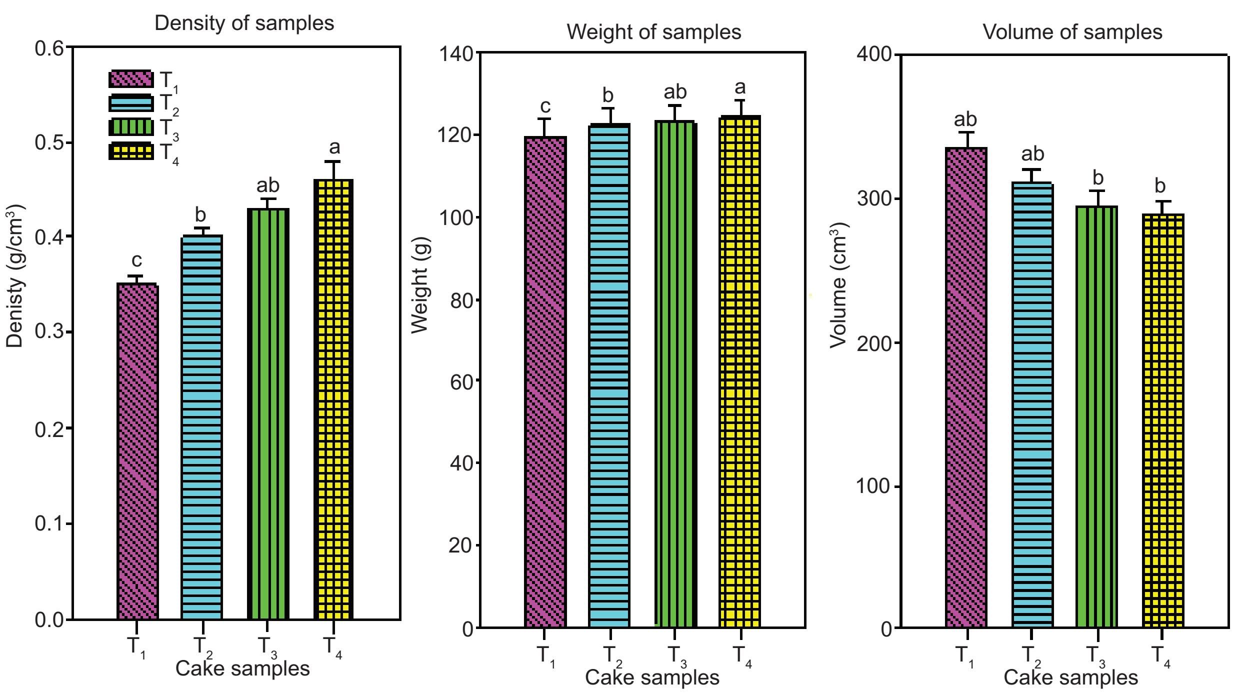

Figure 3. Density (g/cm^3), weight (g), and volume (cm^3) of T_1 (0% RB), T_2 (5% RB), T_3 (10% RB), T_4 (15% RB) cake samples. Means lacking common subscript in the same physical attribute indicates significant difference between cake samples.

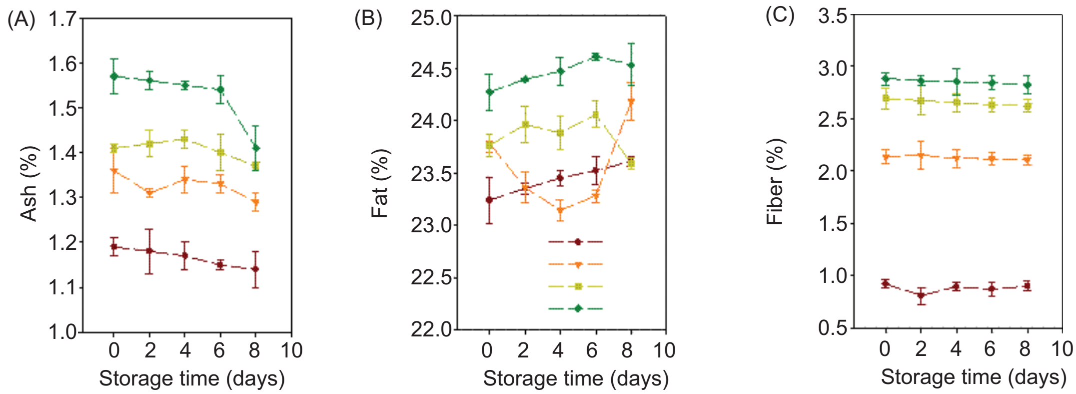

Figure 4. Changes in the Ash (%), Fat (%), and Fiber (%) of T_1, T_2, T_3, T_4 cake samples supplemented with 0%, 5%, 10%, and 15% rice bran, respectively with storage time. Means lacking common subscript in the same physical attribute indicates significant difference between cake samples.

a significant difference between the treated samples in terms of ash content (%). The ash content increased as rice bran content increased. After eight days of storage, a non-significant variation in ash content was observed. A slight, non-significant decline in ash (%) was observed for all samples with increasing storage time. For instance, immediately after baking, the ash content in T2 was 1.36±0.05%, whereas on the 8th day, the ash content declined to 1.3±0%. Sharif *et al.* (2009) observed a similar trend in the ash content of cookies.

Figure 4B shows the fat (%) of different samples plotted against storage time (days). The highest value was recorded for T4 (24.53±0.20%), followed by T2 (24.18±0.18%), T1 (23.61±0.05%), and T3 (23.59±0.05%). Rice bran contains a high quantity of fat, so as the rice bran content increased, the fat content of the final product also increased. Neha and Chandra (2012) reported similar results. It was also observed that the fat content decreased with storage time. At the start of storage, the fat content was 24.12%, whereas after 8 days of storage, it decreased to 23.55%. Sharif *et al.* (2009) reported a similar trend. These results are consistent with those of Kumarasiri *et al.* (2018), who suggested that the slight reduction in fat content was due to the oxidation of unsaturated fatty acids, which occurred due to the presence of atmospheric oxygen and moisture uptake.

The results showed that rice bran concentration had a significant effect on the fiber content (Figure 4C). It was observed that the highest fiber content was recorded in T3 (2.82±0.09%), while the lowest fiber content was found in T0 (0.90±0.05%). The increase in fiber content was attributed to the rise in rice bran concentration. These results are consistent with those of Sharif *et al.* (2009). The data related to storage duration showed a slight decrease in the fiber content of the cake samples. However, this decrease was not statistically significant. These results are supported by Younas *et al.* (2011).

Organoleptic evaluation of gluten free cake during storage

A graph was plotted between the mean scores of the sensory attributes and the storage period (Figure 5). Figure 5A shows the crumb color scores versus storage time (days). The maximum score was given to T0 (8.13), and the minimum score was attained by the T4 sample (6.83), where 15% rice bran was integrated. The crumb color of the samples became progressively darker with increasing supplementation, resulting in a lower level of acceptance (7.12 to 6.83). Neha and Chandra (2012) report similar results. During storage, the color score exhibited a decreasing trend. For instance, the score of T4, which received the lowest score, decreased to 7.9, 6.86, 6.6, and 4.93 after 2, 4, 6, and 8 days, respectively. Similarly, the color of the crust increased with an increase in bran concentration, thereby decreasing the acceptance level. The highest mean score for crust color was recorded for T1 (6.89), and the lowest mean score was obtained for T4 (6.78). However, this change was not statistically significant. Moreover, the crust color also declined with the passage of time, as shown in Figure 5B. During storage, a decrease in the likeness of crust color might be due to moisture assimilation, oxidation of fat, caramelization, and the Maillard reaction (Sharif *et al.*, 2009).

The textural scores of the gluten-free cakes plotted against storage time (days) are shown in Figure 5C. The judges placed T1 (6.98) in the first position, followed by T2 (6.81), T3 (6.53), and T4 (6.20). Rice bran provides a prominent mouthfeel. Hence, as the concentration

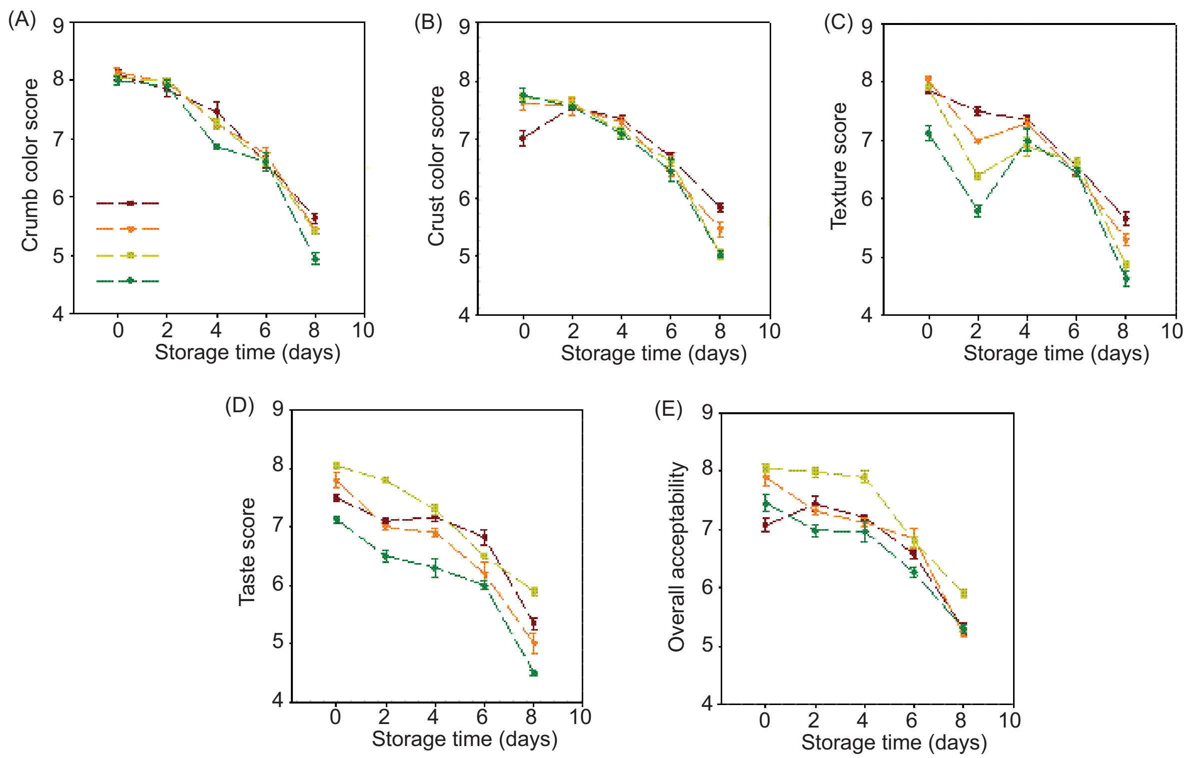

Figure 5. Changes in organoleptic attributes of T_1, T_2, T_3, T_4 cake samples supplemented with 0%, 5%, 10%, and 15% rice bran, respectively with days (storage time). Means lacking common subscript in the same physical attribute indicates significant difference between cake samples.

increased, the texture score decreased. Figure 5C indicates a decline in the texture score with an increase in storage time. On the 8th day, the highest and lowest scores were recorded for T4 (4.63) and T1 (5.66), respectively. This decline can be attributed to the rancidity of the fat and moisture absorption from the surroundings. These results are consistent with those of Sudha *et al.* (2007).

The taste scores for gluten-free cakes with added rice bran are shown in Figure 5D. The highest taste score (6.81) was observed in T0 (control), whereas the minimum taste score (6.20) was recorded for T4 (15% rice bran). These results are supported by those of Younas *et al.* (2011). The taste of cake samples was affected by storage. The taste ranged from 7.73 to 5.11. The samples were stored at room temperature for eight days. Neha and Chandra (2012) reported similar trends.

Figure 5E depicts the overall acceptability of all treatments versus storage time. The OA score (7.2) was recorded for the control sample. However, as the RB concentration increased, the OA score decreased. Neha and Chandra (2012) report similar results. Overall acceptability decreased with storage. The highest overall acceptability score was recorded at the beginning of the study. The minimum score of 5.43 was recorded after eight days of storage. Sharma and Chauhan (2002) reported a similar trend.

SEM analysis

In Figure 6, the gray images show the SEM results of the T1, T2, T3, and T4 samples. The images depict a significant difference in the porosity levels of all treatments. This difference might be due to the increase in bran and moisture content, which leads to a decrease in the "rupture force," resulting in non-uniformity and decompression as the bran percentage increases in cake samples. SEM results showed that fragments, irregular in shape, were caused by the incorporation of ingredients, especially rice bran. The holes observed in the texture of the cakes may be related to the "interaction of proteins" with other ingredients. The results of the image analysis were consistent with those reported by Bruna *et al.* (2016). These studies suggested that fiber, being less aerated than traditional wheat flour, does not trap air as effectively, leading to a denser texture. Additionally, the hygroscopic nature of rice bran could have contributed to the observed increase in density by absorbing moisture from the batter, further compacting the structure. Moreover, the consistency of the batter and the interactions between rice bran and other ingredients are critical factors in

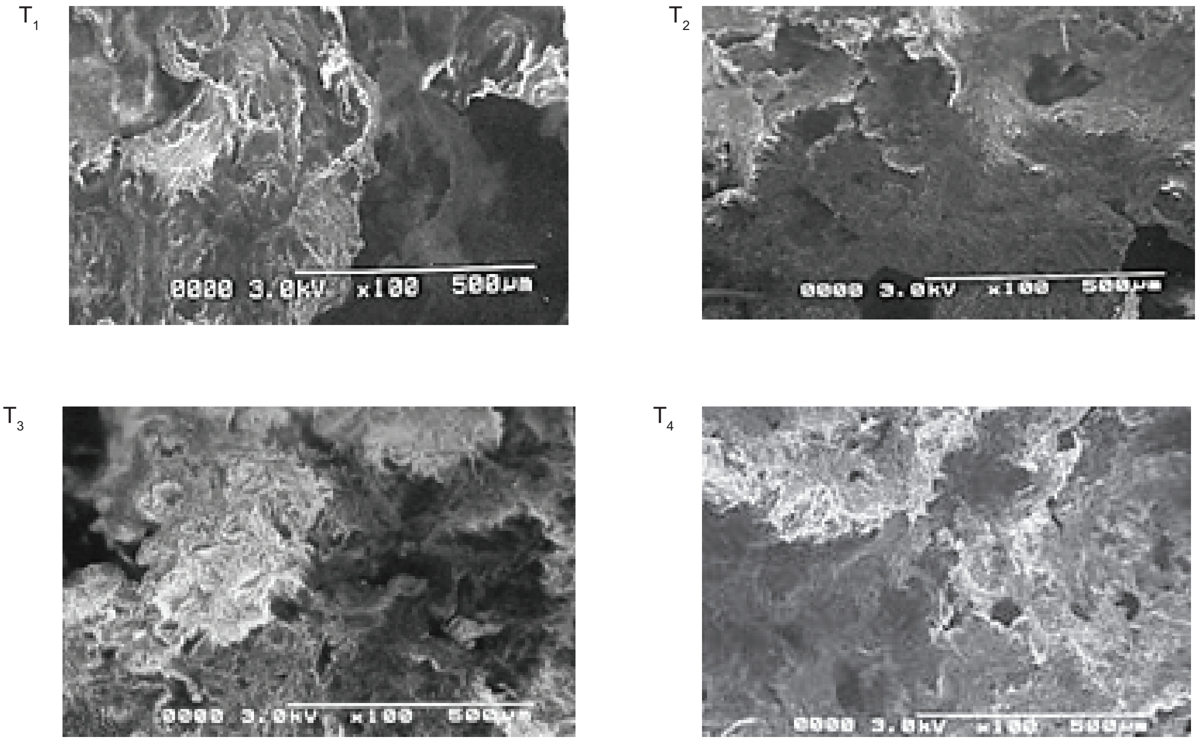

Figure 6. Changes in the pattern of porosity in gluten free cake samples supplemented with 5,10 and 15% rice bran where T_1 (control), T_2 (5% rice bran), T_3 (10% rice bran) and T_4 (15% rice bran).

the development of the structure during baking. In this study, the addition of rice bran affected the density and texture, making the product more compact, especially with higher fiber content (Maggio and Orecchio, 2018). These changes might be associated with compositional or moisture changes over time but do not compromise the functional benefits of dietary fiber in rice bran-enriched products.

Conclusion

In this study, a cost-effective and nutritious gluten-free cake was developed using composite flour enriched with rice bran. Gluten-free cakes were prepared using rice flour (RF), maize flour (MF), and chickpea flour (CF) in different proportions. Following organoleptic evaluation, the T3 combination (40% RF, 40% MF, and 20% CF) was selected to add varying percentages of rice bran (RB), namely 5%, 10%, and 15%. Among the physical attributes, the density and weight of the cake increased, while the cake volume decreased with an increase in the percentage of rice bran. Chemical analysis revealed that the treatments caused a significant shift in fiber, fat, and ash content, with an increase in rice bran. SEM analysis showed that porosity increased with higher concentrations of rice bran in the cakes. The functional properties of the gluten-free cake improved with the addition of 10% rice bran to the composite flour for cake preparation.

Data Availability

All the data generated or analyzed during this study are available in the manuscript.

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Author Contributions

The experiment was designed by S.J., M.N., M.A., and W.K, and conducted by Q.Q., S.J., M.A., H.N., and A.N. The recording, data analysis, and interpretation of results were carried out by W.K., M.Z.K., and F.K.M., while M.Z.K. and W.K. wrote the draft. F.K.M. and E.M. made significant revisions to the text. Validation, visualization, funding acquisition, reviewing, and editing were done by F.K.M., A.M.S., and M.Z.K. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare no conflict of interests.

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