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Effects of plant powders on the technological and nutritional characteristics of gluten-free breads produced with black chickpea flour

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RESEARCH ARTICLE

Abstract

This study examined the effect of different plant powders on the technological and nutritional qualities of gluten-free bread. As plant powders, fenugreek, okra, and quince seeds were used both separately and in combination. According to technological properties, the greatest increase in the breads' height and specific volume values occurred in the samples coded HD2 (100% okra powder) and HD7 (33.3% fenugreek, 33.3% okra, and 33.3% quince seeds powder) ($P < 0.05$). Scanning electron microscope images revealed that the addition of plant powder increased the porosity of bread samples, particularly in HD2, HD6 (50% okra and 50% quince seed powder), and HD7 samples. All samples enriched with plant powders exhibited higher levels of dietary fiber (DF), ranging from 5.95±0.48% to 6.97±0.4%, compared to the control sample, which had a level of 4.45±0.22% ($P < 0.05$). Incorporation of 100% fenugreek (HD1 sample) resulted in a substantial elevation of the resistant starch value. This feature was considered beneficial for nutrition because it could lower the glycemic potential of bread. Enrichment with okra powder provides nutritious and technologically advantages to gluten-free breads. Panelists provided the least score for fenugreek addition, while the samples containing okra powder received greater acceptance.

Keywords: fenugreek; okra; quince seed; digestible starch; dietary fiber; SEM; FTIR

Introduction

Celiac disease is an autoimmune enteropathy (AIE) of the small intestine triggered by gluten consumption and occurs in genetically susceptible individuals, including children. Currently, the only way to treat celiac disease is to follow strictly a gluten-free diet for life (Difonzo *et al.*, 2022). Gluten is a primary wheat component that influences the quality of baked products. Without gluten, dough exhibits inadequate rheological properties (viscoelasticity) and fails to establish a protein network, compromising the ultimate quality of gluten-free bread (Djeghim *et al.*, 2021). The development of optimally formulated gluten-free products is a prominent research focus in the food industry.

Plant-based materials may serve as effective agents for improving gluten-free bread quality. Recent studies have indicated that several plant-based materials are used in bakery products for the enrichment of these products with vitamins, minerals, proteins, polyphenols, and fibers (Mohammad *et al.*, 2024). Dried fruit pomace added to

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various bakery products as a substitute for flour, sugar, or lipid decreases the amount of calories while increasing dietary fiber (DF) and antioxidant levels (Quiles *et al.*, 2018). Addition of 3%, 6%, and 9% black carrot pomace DF concentrate to the muffins resulted in enhanced water and oil absorption capabilities, compared to rice flour; however, the L* (lightness–darkness) and b* (blue–yellow colors) values, water activity (aw), specific volume, and firmness decreased (Singh *et al.*, 2016). Kırbaş *et al.* (2019) investigated the effect of several fiber sources (apple, orange, and carrot pomace powders) on the rheology of gluten-free batter and the quality attributes of rice flour-based cakes. They discovered that fiber sources improved the rheology and texture of cakes, but decreased the specific volume of cakes. Another investigation indicated that the incorporation of mushroom powder into bakery products enhanced the concentrations of vitamins, minerals (calcium, potassium, magnesium, phosphorus, iron, copper, zinc, and manganese), polyphenols, DF, and protein content in these products. The replacement of wheat flour with mushroom powder influenced crumb color, physicochemical qualities, and textural characteristics of bread, cakes, and biscuits (Salehi, 2019a). Some studies demonstrated that quince seeds (*Cydonia oblonga* Miller) (Górnaś *et al.*, 2013), okra (*Abelmoschus esculentus* L. Moench) (Akcicek *et al.*, 2024; Alamri, 2014; Cumhur *et al.*, 2022; Dantas *et al.*, 2021; Xu *et al.*, 2020; Yang *et al.*, 2020, 2023), and fenugreek (*Trigonella foenum-graecum*) (Shahzad *et al.*, 2020; Shirani and Ganesharanee, 2009) significantly enhanced the nutritional quality of foods, and are a good candidate for mucilage. Okra mucilage is a pectic polysaccharide, composed of L-rhamnose, D-galactose, and L-galacturonic acid (Sinha *et al.*, 2015). It was demonstrated that natural polysaccharides (biopolymers) in okra are safe, biodegradable, and biocompatible, which is advantageous, because of their preferred use over manufactured polymers (Balasubramanian *et al.*, 2016). Fenugreek is a rich source of phytonutrients, including omega fatty acids (ω3, ω6, and ω9), sterols, alkaloids, and saponins (Mohammad *et al.*, 2024). Fenugreek oil's distinct composition confers some health-promoting advantages. It reduces elevated levels of low-density lipoprotein (LDL) cholesterol and triglycerides (Thomas *et al.*, 2011). Quince seeds exhibit exceptional gelling properties. Extract of quince seeds increases the viscosity and shear thinning behavior of solutions (Jouki *et al.*, 2013).

Chickpeas are the third most prevalent legumes cultivated globally, following beans and peas. India is the leading global producer of chickpeas, followed by Pakistan and Turkey (Summo *et al.*, 2019). In contrast to conventional chickpeas, black chickpeas possess a robust seed pericarp with black coloration, small size, and irregular and wrinkled shape. They are rich in proteins, fibers, and bioactive substances (Rachwa-Rosiak *et al.*, 2015). Chickpeas consumption is linked with a number of health benefits, including a decrease in postprandial glucose and associated risks of diabetes mellitus and metabolic syndrome (Aisa *et al.*, 2019; Winham *et al.*, 2017). Moreover, bioactive components of chickpeas have antihypertensive properties (Gupta *et al.*, 2017). Owing to these attributes, they could serve as an excellent choice for enhancing the nutritional value of gluten-free products. In a prior study, black chickpeas were incorporated into functional bread, and the findings showed that bread demonstrated low glycemic index (GI) and rich nutritional content (Yaver, 2022).

Although several studies have explored the use of plant-based ingredients in gluten-free bakery products, no study to date has comprehensively investigated the combined technological and nutritional effects of incorporating black chickpea flour—a nutritionally rich yet underutilized gluten-free flour—with mucilage-forming plant powders. This research addresses this gap by formulating gluten-free breads using black chickpeas flour and supplementing them with okra, fenugreek, and quince seed powders, which were selected for their known functional and mucilage-forming properties. These plant powders were used not only as nutritional enhancers but also as natural alternatives to synthetic additives, which are commonly used to improve dough structure and bread quality in gluten-free formulations. The primary aim of this study was to assess the potential of these natural ingredients to improve both technological properties (such as dough behavior and bread quality) and nutritional characteristics, including digestible and resistant starch levels and GI. The use of these plant powders, both individually and in novel combinations, within a black chickpeas-based gluten-free matrix represents a distinct and innovative approach not previously reported in the literature.

Materials and Methods

Materials

Black chickpeas flour (Cey Natural Foods, Turkiye), gluten-free rice flour (Dr. Oetker, Germany), sunflower oil (Agricultural Credit Cooperative, Turkiye), granulated sugar (Turkşeker, Turkiye), non-iodized salt (Billur salt, Turkiye), gluten-free yeast (Dr. Oetker), milk (Sütaş, Turkiye), fenugreek (Metin Baharat, Sivas, Turkiye), okra, and quince seeds used in the experiments were sourced from the local market in Sivas, Turkey.

Because of the research and preliminary trials, 1% by weight of plant powders was added to dough for producing gluten-free bread.

Table 1. Types of plant powders used in dough and their related proportions based on samples.

Sample code	Types of plant powder (%)		
	Fenugreek	Okra	Quince seed
Control	–	–	–
HD1	100	–	–
HD2	–	100	
HD3	–	–	100
HD4	50	50	–
HD5	50	–	50
HD6	–	50	50
HD7	33.3	33.3	33.3

HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6: 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder.

Table 2. Bread dough ingredients.

Ingredient	Amount (g)	Amount (%, w/w)
Chickpea Flour	160	31.77
Rice flour	80	15.88
Sunflower oil	6	1.19
Sugar	5	0.99
Salt	4	0.79
Dry yeast	4	0.79
Plant powder*	4.5	0.89
Water	220	43.69
Milk	20	4.37
Total	**503.5**	**100**

*The ratio and type of plant powder is used as suggested in Table 1 for each code, excluding the control group.

Methods

Preparation of bread dough

The codes of the bread samples and the detailed composition of plant powders ingredients, including types and ratios, were provided in Table 1. The ingredients and proportions of these ingredients for bread dough were selected based on the recommendations of Angioloni and Collar (2011) (Table 2). All components, except oil, were mixed in a dough mixer (KitchenAid, USA) for 15 min. Then oil was added and mixed for an additional 5 min.

Fermentation was performed using commercial baker's yeast (*Saccharomyces cerevisiae*) at a concentration of 2% (w/w of flour). After mixing, the dough was covered with stretch film and fermented in an incubator (Memmert, Germany) at 28 ± 1°C for 2 h. Subsequently, 500 g of dough was placed in a rectangular loaf pan and second fermentation was performed for 30 min under the same conditions. Finally, the breads were baked at 190°C for 30 min.

Technological properties of gluten-free bread samples

A caliper was used to measure the height of gluten-free breads produced with black chickpeas flour and various plant powder additions. The mean of measurements obtained from three distinct places of bread was considered.

The specific volume (cm^3/g) of the samples was determined using the seed displacement method (rapeseed) in accordance with American Association of Cereal Chemists (AACC, 2000) method 10-05.01. Specific volume of bread sample was determined by the displacement of rapeseed grains. All gluten-free breads were maintained at ambient settings for 6 h post-baking, after which the analyses were conducted. The following equation was used for computation:

$$\text{Specific volume } (\text{cm}^3/\text{g}) = \frac{\text{volume of bread}}{\text{weight of bread}}.$$

The moisture content of the samples was determined using an infrared moisture analyzer (model MOC63u; Shimadzu, Japan).

Color measurements of gluten-free bread crust of the samples were obtained by assessing five different points on bread surface using a colorimeter (CR-400; Konica Minolta, Tokyo, Japan). The colorimeter employs three-dimensional (3D) color measurement, where L* (lightness) on the y-axis denotes lightness–darkness of the sample, ranging from 0 (black) to 100 (white); a* on the x-axis represents green (-a) and red (+a); and b* on the z-axis signifies yellow (+b) and blue (-b) color magnitude or position. The instrument was calibrated using a white tile at an aperture of 8 mm, with an observer angle of 2°, and illuminant D65.

The pore morphology of gluten-free bread samples was evaluated using a scanning electron microscope (SEM) (TESCAN MIRA3 XMU, Brno – Czech Republic). Samples were mounted on circular aluminum stubs using double-sided adhesive carbon tape, sputter-coated with gold for 100 s, and examined at room temperature under an accelerating voltage of 15 kV. The images were captured at a magnification of 20×.

Nutritional values of gluten-free breads

The analysis was conducted in accordance with the Association of Official Analytical Chemists' (AOAC, 1995) guidelines. Ash content was quantified using the gravimetric method (AOAC Official Method 923.03), in which about 2.0–3.0 g of the sample was placed in a ceramic crucible and ashed in a muffle furnace at 550°C until a consistent weight was achieved. The protein level of the samples was quantified using the micro-Kjeldahl method (AOAC Official Method 950.48). A total of 1 g of sample was digested with 2.5 mL of sulfuric acid in the presence of a catalyst. The sample was subsequently prepared on a heating unit in a fume cabinet until the liquid in the tube became transparent and had a bluish-green color. The digest was diluted with 10 mL of distilled water, followed by the addition of 10 mL of 45% sodium hydroxide. The micro-Kjeldahl flask was connected to the distillation apparatus, and the resulting ammonia was collected in a boric acid solution containing indicators methylene blue and methyl red. Protein (%) was determined using the following formula (total N [%] × 6.25). Lipids were quantified using the Soxhelet method (AOAC Official method 948.22). The available carbohydrates were calculated using the difference, according to the following equation:

$$\text{Available carbohydrates} = (100 - [\text{moisture} + \text{ash} + \text{protein} + \text{lipid}]);$$ data were expressed as net weight in g/100 g of sample.

The energy levels (kcal) were determined by multiplying the quantity of macronutrients by their respective conversion factors (4 kcal/g for protein, 9 kcal/g for lipid, and 4 kcal/g for carbohydrates) (Krupa-Kozak *et al.*, 2021).

The total dietary fiber was determined by an enzymatic–gravimetric analysis using a commercial assay kit (K-TDFR-200A, Megazyme International Ireland Limited, Bray, Ireland). The procedure was conducted in accordance with the AOAC's enzymatic-gravimetric method 985.29, as specified in kit instructions. This method involves hydrolyzing 1 g of gluten-free bread samples, which have been dried, crushed, and sieved through a 0.5-mm mesh, using α-amylase, protease, and amyloglucosidase, followed by ethanol precipitation to obtain a residue for protein and ash analysis. The total DF calculations for the samples were conducted using MegaCalc™ Excel®, available for download on the Megazyme website (www.megazyme.com).

The concentrations of rapidly digestible starch (RDS), slowly digestible starch (SDS), total digestible starch (TDS), total starch (TS), and resistant starch (RS) in bread samples were determined using the Megazyme assay kit (K-DSTRS; Megazyme International, Ireland) by following the manufacturer's protocol. Briefly, samples were incubated with pancreatic α-amylase (PAA) and amyloglucosidase (AMG) in sodium maleate buffer (pH 6.0) at 37°C for up to 4 h with constant agitation. To stop enzymatic reactions at specific time points—20 min (RDS), 120 min (SDS), and 240 min (TDS)—1 mL of the reaction mixture was transferred into falcon tubes containing 50-mM acetic acid. For TS, 4 mL of the sample was added to 95% ethanol. The remaining maltose was hydrolyzed with amyloglucosidase (100 U/mL), and glucose concentration was determined using the glucose oxidase-peroxidase method (GOD-POD) method. Absorbance was measured at 510 nm after incubation at 50°C for 20 min. Calculations were performed using the MegaCalc™ Excel® tool. The estimated glycemic index (eGI) and hydrolysis index (HI) were calculated as described by Angioloni and Collar (2011), with HI determined by comparing the area under the hydrolysis curve (0–240 min) of the sample to that of the white bread control.

To calculate eGI according to the equation given by Goñi *et al.* (1997), the content of total starch and the starch hydrolyzed for 90 min were determined.

$$\text{eGI} = 39.21 + 0.803 \times \text{H90},$$

where H90 is the total starch (%) hydrolyzed at 90 min.

Sensory analysis

A ranking test was used for sensory analyses. In all, 40 individuals (20 females and 20 males), aged 18–45 years, who had previously consumed gluten-free products from the student residences of Sivas Cumhuriyet University, were chosen as panelists. The panelists were instructed to assess color, appearance, aroma, flavor, and the overall enjoyment of sliced samples, assigning scores from 1 to 5 (1: very poor, 2: poor, 3: average, 4: good, 5: excellent). The order of sample presentation was randomized for each panelist to prevent order bias. Prior to sensory analyses, ethical approval was obtained from the Ethics Committee of the Scientific Research Proposal Ethics Evaluation Board, Social Sciences Institute, Sivas Cumhuriyet University (Judgment No. 2023/14, dated 25.12.2023).

Fourier-transform infrared spectrometry (FTIR)

The chemical bond structure of gluten-free bread samples was analyzed using an FTIR analyzer (Mode Tensor 27; Bruker, USA). Prior to analysis, the bread samples were prepared by slicing the crumb portion and drying it in a vacuum oven at 40°C for 24 h to remove moisture without altering the chemical structure. The dried samples were then crunched into fine powder using a laboratory mill and passed through a 100-µm sieve to ensure uniform particle size.

Approximately 1–2 mg of the powdered sample was mixed thoroughly with 100 mg of potassium bromide (KBr) and compressed into a thin and transparent disc using a hydraulic press under 10 tons of pressure. The FTIR spectra were recorded in the mid-infrared region (4,000–400 cm^{-1}) at a resolution of 4 cm^{-1}, and 16 scans per sample were averaged to improve signal quality.

Statistical analysis

Differences between the samples were assessed using analysis of variance (ANOVA) using the Minitab 20.0 software (State College, PA). A *post hoc* test (least significant difference test) was applied when significant differences were determined at a 95% confidence level (CL).

Results and Discussion

Technological properties of gluten-free bread samples

Figure 1 shows the appearance of baked gluten-free bread samples. In this study, the technologic properties of the samples were determined after cooking and post-baking of gluten-free breads. The technological properties of the samples were evaluated using height, specific volume, humidity (crumb, crust, and total), color properties (L*, a*, and b*), and SEM images.

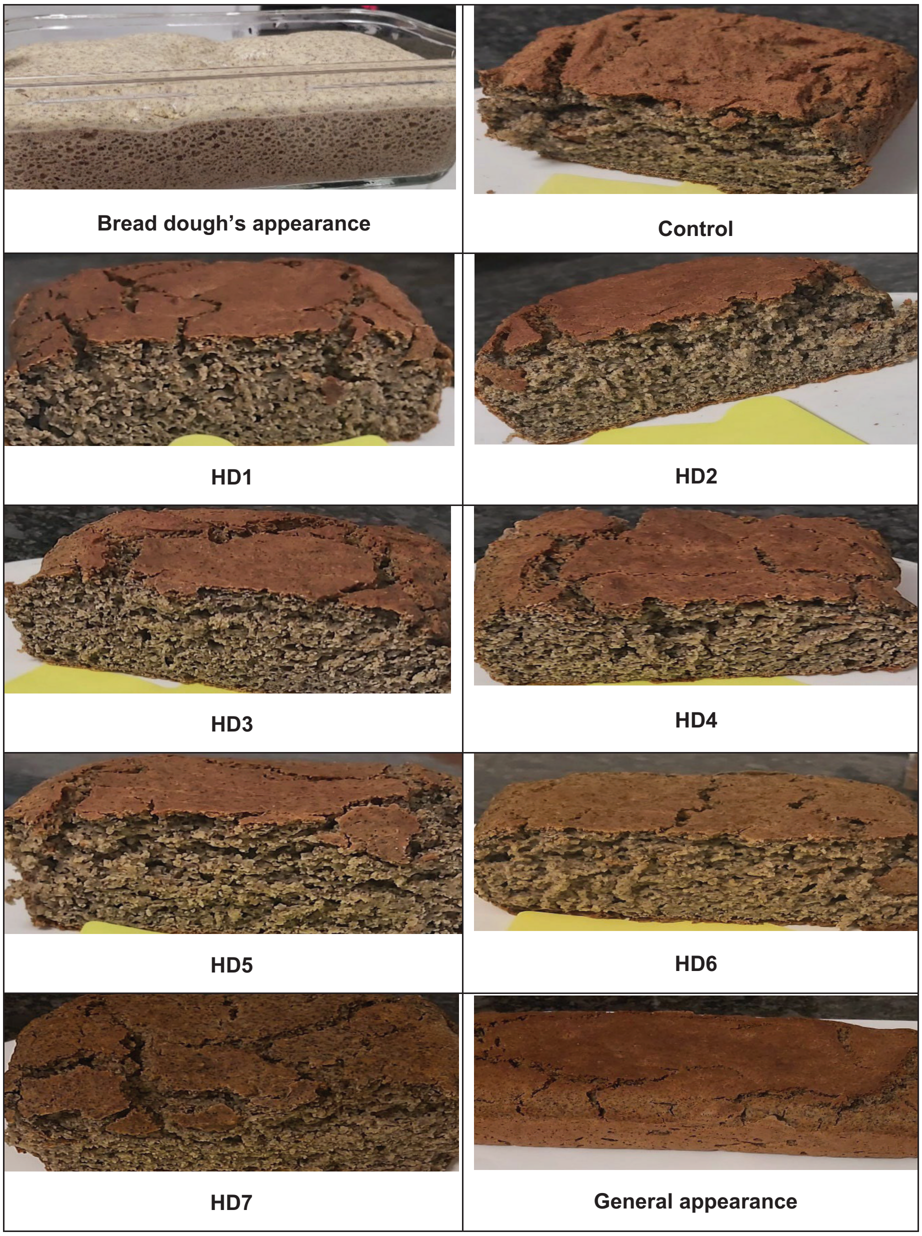
Height and specific volume (volume/unit mass) are visual attributes that substantially influence customer preference. The mean value of height and specific volume of the samples enriched with plant powder ranged from 2.87 cm to 3.11 cm and from 2.36±0.04 cm^3/g to 4.23±0.18 cm^3/g, respectively (Table 3). The mean height and specific volume of the control samples were 2.34 cm and 2.17±0.02 cm^3/g, respectively. The height and specific volume of the samples were significantly increased by the plant powders used ($P < 0.05$) (Table 4). These results strongly suggest that okra powder, whether used alone or in combination with other functional plant-based powders, contributes positively to the technological quality of gluten-free bread. The structural and volumetric improvements observed are consistent with the findings of Tufaro *et al.* (2022), who reported that okra powder if particularly used along with hydroxypropyl methylcellulose (HPMC) enhanced bread structure and increased both height and specific volume. The cited authors' work further supports the notion that okra powder, because of its inherent mucilaginous and water-retention properties, may serve as a natural alternative to synthetic hydrocolloids, offering a cleaner-label solution in gluten-free bakery formulations. Similarly, El-Sayed *et al.* (2014) reported that cakes prepared with wheat flour and okra gum as a fat substitute demonstrated a markedly greater specific volume relative to wheat flour cake controls, with increased concentration of okra gum.

The moisture values of the crumb, crust, and total moisture of gluten-free bread samples with different plant powder additions ranged from 43.96±2.11% to 49.64±2.55%, 17.11±0.41% to 25.11±0.27%, and 32.49±3.24% to 33.71±2.08%, respectively (Table 3). Table 1 shows that the control samples' corresponding measurements were 46.96±2.54%, 20.20±1.80%, and 33.58±1.19%. The ANOVA test indicated statistically significant differences for crust moisture only among moisture measurements ($P < 0.05$) (Table 4). The sample coded HD6 (50% okra powder and 50% quince seed powder) resulted in an approximate 1.24-fold increase in crust moisture, compared to the control bread. Tuluk *et al.* (2018) found that a 1% substitution of okra powder resulted in a higher moisture content in the bread compared with the control, but the impact of increased proportion of substitution on moisture content was negligible. Other studies indicated that moisture content could vary with the incorporation of plant sources (Salehi, 2019b) and that the moisture content of bread increases due to the high water retention capacity of fibers, consequently decreasing the hardness of crumb (Fratelli *et al.*, 2018).

Color also plays a significant role in consumer preferences of bread products. The development of crust coloration is facilitated by moisture evaporation when the crust attains a temperature of 100°C. At temperatures below 150°C, Maillard reactions contribute to color development, whereas temperatures above 150°C involve both Maillard reactions and caramelization processes that lead to browning (Temkov *et al.*, 2024).

Crusts with L*, a*, and b* values of gluten-free breads produced using various plant powders are shown in Table 3. The sample values varied between 32.38±3.92 and 38.09±3.13, 11.14±1.79 and 12.98±1.08, and 19.38±0.36 and 23.15±0.69, respectively. For the same measurements, the control sample values were 38.71±1.91, 11.91±0.60, and 22.97±0.58, respectively. The ANOVA test indicated a significant difference in the b* value of samples ($P < 0.05$) (Table 4).

The incorporation of plant powder did not affect the L* value of samples, as black chickpeas flour, a predominant dark-colored ingredient in bread manufacture, was used. The sample with the highest b* value, coded HD6 (50% okra powder and 50% quince seed powder), had a value of 23.15±0.69. The HD1 (100% fenugreek powder), HD3 (100% quince seed powder), and HD5 (50% fenugreek powder and 50% quince seed powder) samples had lower b* values than other samples (Table 3). In color measurements, a rise in the b* value in a positive direction indicates an increase in yellow color. The incorporation of okra powder resulted in an elevation of b* value in gluten-free bread, indicating a more pronounced yellow color, whereas the inclusion of fenugreek powder led to a decrease in b* value. Chickpea flour, rich in protein, facilitates the Maillard reaction that occurs in crust



Bread dough’s appearance

Control

HD1

HD2

HD3

HD4

HD5

HD6

HD7

General appearance

Figure 1. Baked gluten-free bread samples. Notes. HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6: 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder.

during baking (Kahraman *et al.*, 2022). The darkening of crust can be achieved by incorporating plant powders into gluten-free bread. Gluten-free breads typically have a lighter color, compared with wheat breads (Gallagher *et al.*, 2004). Consistent with our findings, the incorporation of okra gum or okra powder in breads (Xu *et al.*, 2020) and sour cherry seed protein powder enhanced the yellow color of gluten-free cakes (Cingöz, 2023).

SEM is a technique that scans a specific region of the material using a tiny, convergent electron beam produced in condenser lenses (Kwiecińska *et al.*, 2019). For an accurate comparison, images of all samples were displayed at an identical magnification ratio of 20 µm (Figure 1). The images displayed substantial quantities of undamaged and round shaped starch granules, indicated by the white arrows in Figures 2A,B,D. In a similar study, gluten-free breads made with chickpeas demonstrated elevated levels of spherical, undamaged starch granules of considerable size. As they declared, this signified that the starch granules underwent partial gelatinization during the baking process (Kahraman *et al.*, 2022). In addition,

Table 3. Technological properties of gluten-free breads.

Sample code	Height (cm)	Specific volume (cm^3/g)	Moisture (crumb) (%)	Moisture (crust) (%)	Moisture (total) (%)	L*	a*	b*
HD1	2.91±0.20^{b}	2.49±0.12^{c}	47.47±2.06^{a}	17.11±0.41^{c}	33.52±3.10^{a}	34.93±2.18^{a}	12.98±1.08^{a}	19.38±0.36^{c}
HD2	3.48±0.20^{a}	4.23±0.18^{a}	49.64±2.55^{a}	17.79±1.88^{c}	33.71±2.08^{a}	37.79±2.10^{a}	12.61±2.21^{a}	22.98±1.30^{a}
HD3	2.87±0.13^{b}	2.36±0.24^{c}	46.72±1.50^{a}	19.17±0.12^{b,c}	33.48±0.42^{a}	32.38±3.92^{a}	11.14±1.79^{a}	19.92±1.16^{b,c}
HD4	3.03±0.12^{b}	2.55±0.20^{b,c}	43.96±2.11^{a}	21.32±2.51^{b}	32.64±1.30^{a}	35.18±2.74^{a}	12.48±0.75^{a}	21.37±2.44$^{a–c}$
HD5	2.99±0.07^{b}	2.54±0.16^{c}	47.63±4.06^{a}	17.45±0.08^{c}	32.54±2.02^{a}	35.80±1.51^{a}	12.25±0.87^{a}	19.90±1.60^{b,c}
HD6	3.05±0.04^{b}	3.54±0.54^{a,b}	49.27±0.61^{a}	25.11±0.27^{a}	37.19±0.16^{a}	38.09±3.13^{a}	12.96±0.67^{a}	23.15±0.69^{a}
HD7	3.11±0.21^{a,b}	3.86±0.09^{a}	44.78±4.04^{a}	20.21±3.07^{b,c}	32.49±3.24^{a}	37.36±1.32^{a}	12.04±1.38^{a}	22.10±0.74^{a,b}
Control	2.34±0.14^{c}	2.17±0.02^{c}	46.96±2.54^{a}	20.20±1.80^{b,c}	33.58±1.19^{a}	38.71±1.91^{a}	11.91±0.60^{a}	22.97±0.58^{a}

HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6; 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder.
The values in the table show the mean values and ± standard deviation values of analysis results.
Different superscript letters in the same column indicate statistical differences ($P < 0.05$).

Table 4. ANOVA test results of technological properties of gluten-free bread samples.

Analysis	Mean square adj-MS	F	*P*	R^2	R^2-adj
Height	0.16254	8.68	0.002	0.871	0.771
Specific volume	1.04580	12.33	0.014	0.956	0.878
Moisture (crumb)	11.572	1.62	0.200	0.415	0.1587
Moisture (crust)	19.418	6.01	*0.002*	0.750	0.6255
Moisture (total)	6.933	1.75	0.169	0.433	0.185
L*	13.325	2.16	0.096	0.485	0.260
a*	1.117	0.67	0.694	0.227	0
b*	6.206	4.96	0.009	0.759	0.606

P values indicate statistically significant differences ($P < 0.05$). F = F-statistic from ANOVA, used to test overall significance of the model. R^2 = Coefficient of determination, represents the proportion of variance explained by the model. adj-MS = Adjusted mean square, calculated by dividing the sum of squares by the corresponding degrees of freedom. R^2-adj = Adjusted R^2, corrects R^2 for the number of predictors in the model, providing a more accurate measure of model fit.

Aydin *et al.* (2023) reported that inhomogeneous porous structures in gluten-free noodles produced with okra and pumpkin seeds were associated with the inhibition of complete gelatinization of starch by proteins, resulting in a compact and dense network morphology characterized by reduced cooking loss and extended cooking time.

The SEM images indicate that pore sizes, hole densities, and structural integrity of gluten-free bread samples with added plant powder differed from those of the control group (Figure 2). The control bread sample exhibited a less porous and more plate-like structure, which was attributed to the insufficient capture of air bubbles in the bread (Figure 2H). Turkut *et al.* (2016) stated that the plate-like structure resulted from gluten proteins capable of enduring the pressure differential generated during baking, which is unachievable in gluten-free bread dough, leading to the formation of microscopic pores that envelop starch granules at vulnerable places. All bread samples with plant powder exhibited significant porosity, with HD2, HD6, and HD7 samples exhibiting the highest levels of porosity (Figures 2A–G).

Nutritional properties of gluten-free bread samples

Ash is the inorganic that remains after the burning of organic matter at higher temperatures. Higher ash content signifies a substantial presence of mineral materials (Widiastuti *et al.*, 2016). The ash level of gluten-free bread samples with plant powder additives ranged from 0.95±0.01% to 1.74±0.08%, whereas the control sample

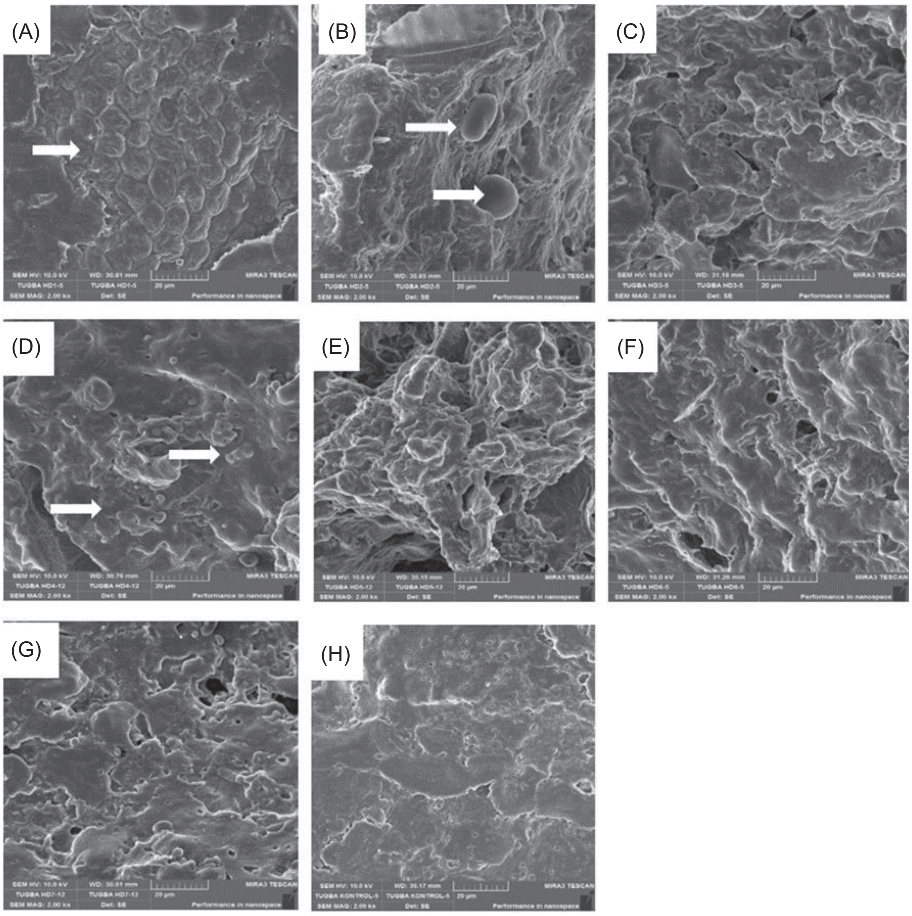


Figure 2. SEM images of gluten-free bread samples (magnification: 20×). (A) HD1: 100% fenugreek powder; (B) HD2: 100% okra powder (C) HD3: 100% quince seed powder; (D) HD4: 50% fenugreek powder and 50% okra powder; (E) HD5: 50% fenugreek powder and 50% quince seed powder; (F) HD6: 50% okra powder and 50% quince seed powder; (G) HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; (H) control sample without plant powder.

had an ash level of 0.78±0.26% (Table 5). The incorporation of plant powder into gluten-free bread samples markedly elevated the ash levels of samples ($P < 0.05$) (Table 6). Similar to our results, the values ranged from 1.93% to 2.45%, depending on the total amount of chickpea flour used to manufacture rice-based, gluten-free bread (Barışık and Tavman, 2018). Natural additions, including plant-based proteins, enhance the texture characteristics of bread and extend its shelf life because of their functional features, such as effective water retention capacity (Wang *et al.*, 2017).

The protein contents of gluten-free breads with addition of plant powder were 9.33±0.38% and 11.57±0.09%, whereas the protein contents of the control samples were 9.76±0.32% (Table 5). Although these values are slightly lower than those reported in other studies (Summo *et al.*, 2019; Yaver, 2022), a significant increase ($P < 0.05$) was observed in HD5, HD6, and HD7 samples. The main feature of these coded samples was that they contained a mixture of plant powders used in the research. These increases are attributable to the high protein content of plant-based additives. Similar findings were reported by Yang *et al.* (2023), who noted that the addition of okra powder improved the protein content and nutritional quality of fresh noodles.

Compared to the control sample, which had an average lipid concentration of 2.49±0.90%, the average fat concentration of gluten-free breads produced with plant powder ranged from 2.37±0.54% to 5.61±0.33% (Table 5). All samples containing fenugreek powder (HD1, HD4, HD5, and HD7) had a significantly higher lipid content than the control sample ($P < 0.05$) (Table 6), indicating that the incorporation of fenugreek powder enhanced lipid concentration in gluten-free breads. Among all gluten-free bread samples, HD3 sample, entirely with quince seeds powder, exhibited the greatest lipid concentration of 5.61±0.33%. Our data corresponded with the studies indicating that quince seed powder is an excellent raw

Table 5. Nutritional values of gluten-free bread samples.

Sample code	Ash (%)	Protein (%)	Lipid (%)	Carbohydrates (%)	Energy (kcal)	Total dietary fiber (%)
HD1	1.23±0.46$^{b–d}$	9.78 ±0.17^{d,e}	2.82±1.43^{b,c}	52.55±2.66^{a}	270.8±27.2 ^{a}	5.95±0.48^{b}
HD2	1.27±0.06^{b,c}	9.98±0.49$^{c–e}$	2.37±0.54^{c}	52.66±2.18^{a}	271.90±7.97^{a}	6.46±0.24^{a,b}
HD3	1.63±0.01^{a,b}	9.33±0.382^{e}	5.61±0.33^{a}	50.11±0.40^{a}	288.23±0.21^{a}	6.21±0.22^{a,b}
HD4	0.95±0.01^{c,d}	10.63±0.46$^{b–d}$	4.05±0.22^{b}	50.62±0.51^{a}	282.29±2.06^{a}	6.35±0.12^{a,b}
HD5	1.80±0.23^{a}	10.72±0.67$^{a–c}$	3.65±0.37^{b,c}	52.30±1.41^{a}	284.91±5.00^{a}	6.17±0.14^{a,b}
HD6	1.69±0.31^{a}	11.57±0.09^{a}	4.00±0.23^{a,b}	45.38±0.08^{b}	263.84±2.75^{a}	6.69±0.85^{a,b}
HD7	1.74±0.08^{a}	11.12±0.52^{a,b}	3.15±0.58^{b,c}	49.70±3.82^{a,b}	274.24±9.55^{a}	6.97±0.4^{a}
Control	0.78±0.26^{d}	9.76±0.32^{d,e}	2.49±0.90^{c}	53.31±0.99^{a}	279.24±3.07^{a}	4.45±0.22^{c}

HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6: 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder.
The values are mean values ± standard deviation of analysis results.
Different superscript letters in the same column indicate statistical differences ($P < 0.05$).

material for producing high-quality cold-pressed oil (Górnaś *et al.*, 2013). Similar lipid ratios (4.63–9.92%) were observed consistent with the research on addition of buckwheat flour, crushed grape seeds, pomegranate seeds, and flax seeds in gluten-free bread formulations (Tümer and Öztürk, 2018).

The average content of carbohydrates in gluten-free bread samples with additional plant powder ranged from 49.70±3.82% to 52.66±2.18% (Table 5). The average content of carbohydrates in control sample was 53.31±0.99%. Comparable results were reported for many chickpea cultivars, ranging from 47.4% to 55% (Khan *et al.*, 1995).

The average energy values of the samples, including the additional plant powder, ranged from 263.84±2.75 kcal to 288.23±0.21 kcal. The control sample exhibited an average energy value of 279.24±3.07 kcal (Table 5). No statistically significant difference was observed in the energy values of samples ($P > 0.05$) (Table 6). The gluten-free bread samples exhibited higher energy levels because of chickpea flour used as a main ingredient in bread samples. Similar to our results, Khan *et al.* (1995) reported the energy levels of various cultivars of chickpeas ranging as 327 kcal/100 g–365 kcal/100 g.

The DF content of gluten-free bread samples with addition of various plant powders ranged from 5.95±0.48% to 6.97±0.4%, and the DF content in the control sample was 4.45±0.22% (Table 5). All plant powder-added samples had larger DF levels than the control sample ($P < 0.05$) (Table 6), with the HD1 sample having the lowest DF value. Similar to our results, because of higher DF content of black chickpea flour, black chickpea flour was a good choice for making bread in a study (Yaver, 2022). In another study, the average DF content of black chickpeas from various areas was 18.0 g/100 g dry matter (DM) (Summo *et al.*, 2019). Shahzad *et al.* (2020) incorporated 5% extracted plant powders (cress, fenugreek, flax, and okra seeds) into a gluten-free flour blend derived from sorghum and Turkish beans. The researchers reported that the average DF content of the control, fenugreek, and okra samples was 1.60%, 1.86%, and 1.74%, respectively.

Table 6. ANOVA test results for the nutritional values of gluten-free bread samples.

Analysis	Mean square Adj-MS	F	*P*	R^2	R^2-adj
Ash	0.328	6.77	0.003	0.812	0.692
Protein	1.244	7.24	0.003	0.835	0.800
Lipid	2.678	4.74	0.008	0.719	0.567

P values indicate statistically significant differences ($P < 0.05$).
F = F-statistic from ANOVA, used to test overall significance of the model. R^2 = Coefficient of determination, represents the proportion of variance explained by the model. adj-MS = Adjusted mean square, calculated by dividing the sum of squares by the corresponding degrees of freedom. R^2-adj = Adjusted R^2, corrects R^2 for the number of predictors in the model, providing a more accurate measure of model fit.

Consistent intake of fiber-rich foods has numerous benefits for the human body, and these are attributable to both soluble and insoluble fibers. Short-chain fatty acids are generated through the fermentation of DF in the intestines, and may lead to reduced triglyceride levels, inhibition of cholesterol synthesis in the liver, and decreased levels of LDL in human blood circulation (Difonzo *et al.*, 2022). Consuming fiber-rich foods eliminates harmful compounds in the colon, enhances feces volume, and reduces constipation issues. It helps to control blood sugar and weight by promoting a feeling of fullness while boosting the number of beneficial bacteria in the stomach (Mao *et al.*, 2021).

Dietary starch is typically categorized into RDS, SDS, and RS based on the rate and degree of enzymatic digestion. From a physiological viewpoint, RDS generates a rapid increase in blood glucose and insulin concentrations, whereas SDS is gradually metabolized in the small intestine, leading to a gradual and sustained release of glucose in the circulation (Englyst *et al.*, 1992). RS primarily consists of amylose, arriving in the colon unaltered, where it is fermented by probiotic bacteria (Giuberti *et al.*, 2015). Short-chain fatty acids, such as butyrate, recognized for their preventive properties against colorectal cancer, are generated (Difonzo *et al.*, 2022).

The average RDS content of the samples with added plant powder ranged from 39.27±1.78 g/100 g DM to 44.54±1.62 g/100 g DM; the SDS content ranged from 18.43±1.23 g/100 g DM to 27.45±1.03 g/100 g DM; the TDS content ranged from 25.92±1.55 g/100 g DM to 59.49±1.24 g/100 g DM; the RS content ranged from 2.65±0.24 g/100 g DM to 6.25±0.89 g/100 g DM; and the TS content ranged from 30.31±1.06 g/100 g DM to 55.31±13.04 g/100 g DM. In the control samples, the average RDS content was 43.66±0.027 g/100 g DM; the SDS content was 18.43±1.23 g/100 g DM–27.45±1.03 g/100 g DM; the TDS content was 47.86±2.67 g/100 g DM; the RS content was 4.36±0.11 g/100 g DM; and the TS content was 54.37±5.59 g/100 g DM (Table 7).

No significant difference was discovered when the RDS content of samples with additional plant powders was compared to the control sample ($P > 0.05$) (Table 8), but the HD4 sample was the only one with a 1.38-fold increase in the SDS content ($P < 0.05$). The application of 50% fenugreek powder and 50% okra powder resulted in a notable increase in the bread's SDS value. The gluten-free bread sample HD2 had the highest TDS value among all samples ($P < 0.05$). The addition of 100% okra powder to gluten-free breads significantly increased the TDS value of breads ($P < 0.05$). The RS value of the samples indicated that the largest increase (1.4-fold) was recorded in HD1 and HD6 samples, compared to the control sample. The incorporation of 100% fenugreek powder resulted in a substantial elevation of RS value ($P < 0.05$).

According to international dietary standards, baked meals heavy in carbohydrates should have at least 14% TS as resistant starch, rather than TDS value (EFSA Panel on Dietetic Products, Nutrition and Allergies [NDA], 2011). The proportion of RS–TS ratios in gluten-free bread enriched with plant powders exceeded 14%, in samples HD6 (14.11%), HD4 (14.48%), and HD1 (15.10%). Among all samples, the HD4 sample had the highest SDS, averaging 27.45 g/100 g DM (Table 7). This feature is considered beneficial for nutrition because it may lower the glycemic potential of bread (EFSA Panel on Dietetic Products, Nutrition and Allergies [NDA], 2011). Wolter *et al.* (2013) reported that parameters, such as the extent of gelatinization, size of starch granules, starch composition, and the interaction of protein and fat content, significantly influence the digestibility of starch in bread. The increased SDS level in HD4 samples could be

Table 7. Digestible starch analysis of gluten-free bread samples.

Sample code	RDS	SDS	TDS	RS	TS	eGI
HD1	44.54±1.62^{a}	18.91±1.30^{b}	35.15±2.89^{c,d}	6.25±0.89^{a}	41.40±3.77^{a,b}	88.34
HD2	43.31±2.46^{a}	21.67±3.57^{b}	59.49±1.24^{a}	5.64±0.86^{a,b}	55.31±13.04^{a}	100.56
HD3	44.02±1.92^{a}	21.89±0.32^{b}	48.83±6.88^{b}	4.64±0.26^{b,c}	53.46±7.13^{a}	96.62
HD4	39.27±1.78^{a}	27.45±1.03^{a}	25.92±1.55^{d}	4.39±0.50^{c}	30.31±1.06^{b}	88.05
HD5	42.99±0.57^{a}	20.09±1.23^{b}	41.33±2.48^{b,c}	5.64±0.21^{a,b}	46.98±2.69^{a}	91.44
HD6	44.07±0.97^{a}	18.43±1.23^{b}	37.5±4.97^{c}	6.16±0.07^{a}	43.66±4.91^{a,b}	88.89
HD7	43.97±1.33^{a}	18.48±0.83^{b}	47.82±5.99^{b}	2.65±0.24^{d}	47.30±1.74^{a}	93.26
Control	43.66±0.027^{a}	19.81±3.02^{b}	47.86±2.67^{b}	4.36±0.11^{c}	54.37±5.59^{a}	94.61

HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6: 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder.

RDS: rapidly digestible starch; SDS: slowly digestible starch; TDS: total digestible starch; RS: resistant starch; TS: total starch; eGI: estimated glycemic index.

The values are mean values ± standard deviation of the analysis. Different superscript letters in the same column indicate statistical differences ($P < 0.05$).

Table 8. ANOVA test results for digestible starch analysis of gluten-free bread samples.

Analysis	Mean square adj-MS	F	*P*	R^2	R^2-adj
RDS	5.575	2.52	0.11	0.688	0.414
SDS	17.762	4.99	*0.019*	0.814	0.651
TDS	211.24	12.81	*0.001*	0.918	0.847
RS	2.897	11.87	*0.001*	0.912	0.835
TS	138.55	3.67	*0.044*	0.763	0.555

RDS: rapidly digestible starch; SDS: slowly digestible starch; TDS: total digestible starch; RS: resistant starch; TS: total starch; eGI: estimated glycemic index.
P values indicate statistically significant differences ($P < 0.05$).
F = F-statistic from ANOVA, used to test overall significance of the model. R^2 = Coefficient of determination, represents the proportion of variance explained by the model. adj-MS = Adjusted mean square, calculated by dividing the sum of squares by the corresponding degrees of freedom. R^2-adj = Adjusted R^2, corrects R^2 for the number of predictors in the model, providing a more accurate measure of model fit.

attributed to the presence of undamaged starch granules in bread.

Results similar to our study were found in studies involving additional plant-based materials for manufacturing gluten-free foods. Menon *et al.* (2016) reported that the most significant increase in SDS value was 1.19-fold and the least increase in RS value was 1.29-fold in noodle samples using starch derived from different plants (banana, cassava, and green mug bean). Another study found that RDS decreased and both SDS and RS increased by 1.05- and 1.87-fold, respectively, comparing the control sample to the samples made with okra seed flour (Hu *et al.*, 2020). Kahraman *et al.* (2022) reported that TS of the samples ranged from 40.53±0.86 g/100 g DM to 48.51 ± 1.0 g/100 g DM in gluten-free bread produced using chickpea flour.

Compared to gluten-containing foods, gluten-free foods exhibit poorer nutritional quality, reduced resistant starch content, and increased GI. The primary factors contributing to this are the type and origin of carbohydrates (starch and DF) and total absence of gluten network (Giuberti *et al.*, 2015; Korus *et al.*, 2009). Foods with a higher GI induce a rapid and significant release of glucose, whereas foods with a lower GI consist of slowly digested carbohydrates, resulting in a prolonged and lesser increase in blood glucose levels (Wolter *et al.*, 2013).

The eGI values of gluten-free breads enriched with plant powders ranged from 88.06 to 100.56 (Table 7). The average eGI value of the control sample was 94.61. Gluten-free cereal-based products typically exhibit worse nutritional quality, reduced resistant starch content, and elevated GI, compared to gluten-containing products (Giuberti *et al.*, 2015). The term GI is utilized to assess the blood glucose response elicited by diets. The GI classifies carbohydrate-dense foods based on their impact on post-prandial blood glucose levels. Foods were categorized as having low (<55), medium (55–69), and high (>70) GI (Foster-Powell *et al.*, 2002). All samples produced in this study were classified as 'high' GI (GI > 70). The eGI value of HD4 sample was the lowest (88.06), compared to the control sample. Furthermore, the eGI values of HD1 (88.34) and HD5 (91.44) samples were inferior to those of the control sample. All these samples had the characteristic of containing fenugreek. A comparable outcome was identified by Shirani and Ganesharanee (2009). Their analysis indicated that incorporating 15% fenugreek polysaccharide into chickpea–rice mixture substantial reduced the GI of samples.

Sensory analysis

The results of the sensory analysis of gluten-free bread samples are shown in the Figure 3. Based on the sensory results, a radar plot was generated to provide a graphic illustration of the aroma profiles and variances among the samples for easy identification (Figure 3). As can be seen in the radar graph, the sample coded HD6 (50% okra, and 50% quince seeds powder) received the highest color score from the panelists; the sample coded HD2 (100% okra powder) received the highest score in terms of appearance, taste, smell, and general appreciation. Generally, for general evaluations, the sample coded HD1 (%100 fenugreek) received the lowest score among all samples. The dominant odor associated with fenugreek limited its consumption, resulting in decreased satisfaction among the panelists. Initial research indicates that this circumstance limits the use of fenugreek in gluten-free products. (Shahzad *et al.*, 2020).

FTIR results

Fourier-transform infrared spectroscopy is a rapid and efficient technique for identifying variations across multiple functional groups and molecule configurations. The FTIR spectra exhibit characteristic peaks corresponding to the chemical bonds and functional groups present in the sample (Tomas *et al.*, 2020). The FTIR spectroscopy revealed that the control bread sample had a distinct spectrum from the gluten-free bread samples enriched with plant powders, with the maximum peak detected at 1,016–1,018 cm^{-1}, 1,742–1,744 cm^{-1}, and 3,272–3,279 cm^{-1} (Figure 4). In the control sample, significant peaks appeared at 1,626 cm^{-1} and 3,276 cm^{-1} (Figure 4).

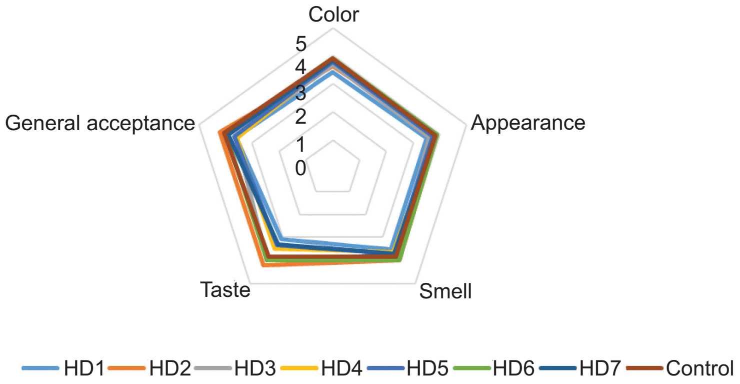


Figure 3. **Sensory analysis of gluten-free breads. Notes: HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6: 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder.**

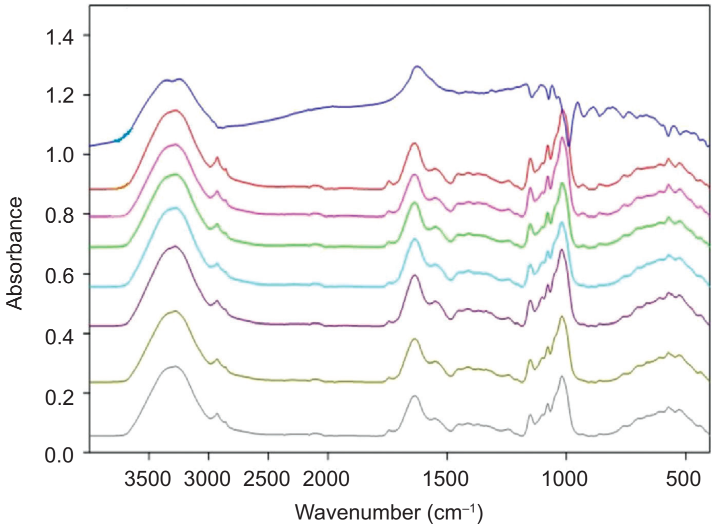


Figure 4. **FTIR spectrum of gluten-free breads. Notes. HD1: 100% fenugreek powder; HD2: 100% okra powder; HD3: 100% quince seed powder; HD4: 50% fenugreek powder and 50% okra powder; HD5: 50% fenugreek powder and 50% quince seed powder; HD6: 50% okra powder and 50% quince seed powder; HD7: 33.3% fenugreek powder, 33.3% okra powder, and 33.3% quince seed powder; control: without plant powder. The lines represent different samples. Dark blue: control; orange: HD1; pink: HD2; green: HD3; turquoise: HD4; purple: HD5; yellow: HD6; gray: HD7.**

The peaks comparable to those identified in gluten-free samples prepared with black chickpea flour were also observed in the research done by Golea *et al.* (2023). The authors stated that the vibration modes of starch, the primary component of wheat flour, and amylose and amylopectin, the primary components of starch, led to the observation of peaks in the following wavelength regions: below 800 cm^{-1}, 800–1,500 cm^{-1} (fingerprint region), 2,800–3,000 cm^{-1} (CH stretching region), and 3,000–3,600 cm^{-1} (OH stretching region). The spectral range of 1,500–900 cm^{-1} is referred to as the 'fingerprint region' due to the distinctive patterns of the analyzed material (Sujka *et al.*, 2017). The peaks observed in the 900–1,100 cm^{-1} region, resulting from the observations, are attributed to distinct vibrational modes of carbohydrates and ketones (Giuberti *et al.*, 2015; Mao *et al.*, 2021). The spectral range of 1,700–1,600 cm^{-1} is related to the vibrational modes associated with carbohydrates and the amide I (C=O stretching) band (Giuberti *et al.*, 2015; Wolter *et al.*, 2013). Amide I and amide II bands are distinctive protein peaks (Lin *et al.*, 2021; Linlaud *et al.*, 2011). The 1,629 cm^{-1} vibration peak was determined to exhibit significant hydrogen bonding. These data substantiate the conclusion that fibers in the bread samples exhibit significant hydrogen bonding and helical configuration. A noticeably wide peak was identified in the FTIR spectra of all samples within the range of 3,500–3,000 cm^{-1}. This peak is attributed to the stretching vibrations of intermolecular O–H and N–H bonds, resulting from potential interactions between water and macromolecules, such as proteins and starches (Tomas *et al.*, 2020). Thinner peak at 2,926 cm^{-1}, observed in all samples (ranging from 2,920 to 2,850 cm^{-1}), was attributed to lipids, resulting from the symmetric stretching vibrations of C–H bonds (Su and Sun, 2018). Lin *et al.* (2021) attributed the signal at 2,925 cm^{-1} to the asymmetric stretching vibrations of methylene-CH_2 group in aliphatic chains.

Conclusions

The addition of 100% and 50% okra powder to gluten-free breads resulted in desirable technological characteristics, such as increased bread height, specific volume, crust moisture, and improved b* color values. During sensory evaluations, these were the most preferred samples by panelists. In contrast, breads containing 100% and 50% fenugreek powder received the lowest scores for color, appearance, aroma, taste, and the overall acceptability, probably because of strong and dominant aroma of fenugreek.

Both fenugreek and okra powders significantly increased the SDS content in breads. This is a nutritionally favorable trait because higher SDS levels are associated with lower glycemic activities. Additionally, SEM images revealed that the inclusion of plant powder improved the morphological structure of gluten-free breads and enhanced their dietary fiber content.

Black chickpea flour, which is used as the main base flour, is a rich source of dietary fiber that may aid in colon health, blood glucose regulation, weight management, and the growth of beneficial gut microbiota. However, it is important to note that its use also increased carbohydrate and energy content of breads and contributed to a higher GI. Therefore, future studies should focus on combining black chickpea flour with other gluten-free flours to balance its nutritional benefits while achieving lower GI values.

Currently, many commercial gluten-free products rely on synthetic hydrocolloids, raising concerns among health-conscious consumers. Replacing these with natural plant-based alternatives not only improves the technological quality of gluten-free products but also contributes to a more nutritionally complete formulation in terms of dietary fiber, protein, and mineral contents.

Competing Interests

The authors had no relevant financial interests to disclose.

Author Contributions

Both authors contributed equally to this article.

Conflicts of Interest

None.

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