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Evaluation of the Impact of Fig (*Ficus carica L.*) Seed Flour on the Physicochemical, Textural and Sensory Attributes of Gluten-free Muffins

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RESEARCH ARTICLE

Abstract

This study examined the impact of substituting fig (*Ficus carica L.*) seed flour (FSF) with a gluten-free flour mixture (GFFM; 7% corn starch, 40% rice flour, 8% corn flour, and 45% potato starch) at various ratios (0-10-20-30%) on the some physicochemical, textural, and sensory characteristics of gluten-free muffins (GFM). Total dietary fiber, lipid, and ash content were determined as 75.6%, 13.47%, and 3.1%, respectively. As the proportion of FSF replacement increased, the GFM volume, specific volume, moisture, ash, dietary fiber, and a* significantly ($p < 0.05$) increased, while its top and bottom shrinkage values, hardness, L*, and b* declined. In terms of adhesiveness, cohesiveness, and resilience, there was no significant difference ($p > 0.05$) between the GFM with 10% FSF replaced and the control GFM (without FSF). Moreover, the results also showed that the substitution of FSF caused an improvement in both gumminess and chewiness of GFM relative to the control ($p < 0.05$). The sensory qualities of GFM were enhanced when GFFM were substituted with varying amounts of FSF compared to the control. Consequently, it is possible to obtain high-quality GFM when replacing up to 20% of FSF with GFFM for individuals with gluten-related disorders or those who prefer a gluten-free diet.

Keywords: Gluten intolerance; gluten-free diet; dietary fiber; celiac; texture profile analyses.

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INTRODUCTION

In recent years, there has been a significant increase in the demand for gluten-free products due to the increasing prevalence of gluten-related diseases, including celiac disease and non-celiac gluten sensitivity, as well as the widespread belief that gluten-free foods are healthier (Raju et al., 2023). Gluten-free products have become one of the top 10 food trends of today, with a 16 percent growth in demand worldwide between 2018 and 2022 (Hassan et al., 2024). Despite the continuous expansion of the gluten-free food market, they still lack texture, flavor, and nutritional content compared to their traditional gluten-containing counterparts. As a result, researchers and food technologists are constantly searching for innovative ingredients to improve the quality of gluten-free formulations and meet consumers' increasing demand (Singla et al., 2024). Current approaches utilise nutrient-dense alternatives and by-products to enhance gluten-free products' organoleptic properties and health benefits (Gül et al., 2021; Baldan et al., 2023; Gül et al., 2024).

Several cultures have used figs (*Ficus carica L.),* a member of the Moraceae family, for nutritional and therapeutic purposes, making them a globally significant agricultural product. *Ficus carica* has potential components with deep therapeutic and traditional applications, and the whole plant is thought to be medicinally valuable (Fayyaz et al., 2024). *Ficus carica* polysaccharides exhibit antioxidative, immunomodulatory, anti-inflammatory, and antitumor effects. The composition includes monosaccharides like glucose, galactose, and rhamnose, contributing to their therapeutic potential in health, food, and medical applications (Zhang et al., 2024). The plant contains phenolics, flavonoids, saponins, and triterpenoids linked to various biological activities such as antioxidant, antimicrobial, and anti-inflammatory effects (Faramayuda et al., 2022; Elish et al., 2023). Specific compounds like Cyanidin-3,5-diglucoside and Kaempferol-7-O-rutinoside have the potential to inhibit inflammatory mediators like IL-6 (Mansoor et al., 2023). Traditionally, *Ficus carica* has been utilized for its antidiabetic, hepatoprotective, and anticancer properties, with applications in treating conditions like dysentery and rheumatic diseases (Faramayuda et al., 2022; Dogara et al., 2024). At the same time, the seeds of *Ficus carica* possess significant medicinal value and have remarkable anti-hyperlipidemic properties (Fayyaz et al., 2023). Research indicates that extracts from these seeds can effectively inhibit pancreatic lipase, a key enzyme in lipid digestion, thereby reducing blood lipid levels and potentially aiding obesity management. The presence of bioactive compounds such as Quercetin, Catechin, and Epicatechin has been linked to these effects, showcasing their potential as natural alternatives to conventional anti-obesity medications (Fayyaz et al., 2024). The oil from *Ficus carica* seeds has shown protective effects against kidney damage, indicating broader health implications beyond lipid management (Şirinyıldız, 2024).

Figs, which generally grow in places where the Mediterranean climate prevails, have a significant fresh and dried market share (Akin et al., 2021). Fig production worldwide remains increasingly important due to increasing health trends and demand for natural products. Figs originated in Turkey and then spread to Syria, Palestine, the Middle East, China, and India. Turkey is a leading nation in global fig production and trade because of its favorable environment and sophisticated farming methods. Current statistics indicate that global fig production amounts to 1,242,449 metric tonnes. Turkey leads global fig output with 350,000 metric tonnes, Egypt with 187,000 metric tonnes, and Algeria with 112,000 metric tonnes (FAO, 2024).

Figs consist of leaves, fruits, seeds, and latex. These parts contain various components rich in antioxidants, carbohydrates, amino acids, phenolic compounds, polyunsaturated fatty acids, phytosterols, and bioactive substances such as vitamins, minerals, and phytochemicals (Nadeem and Zeb, 2018; Rasool et al., 2023). The elevated content of these bioactive compounds in *Ficus carica L.* suggests its potential for producing functional products with antioxidant and anticancer attributes (Amessis-Ouchemoukh et al., 2017; Yang et al., 2024). Moreover, fresh and dried figs serve as an excellent source of fiberfiber (Badgujar et al., 2014).

Fig seeds contribute to the nutritional properties and health benefits of figs, and there are 30-1600 of them in one fruit in various sizes, including large, medium, small, and tiny (Badgujar et al., 2014). The proximate composition of fig seeds reveals important nutritional information that highlights their value as a food source. Fig seeds are notably rich in protein and oil. Their oil content ranges from 20.32% to 23.67%, while the protein content is between 14.32% and 15.07% (Nakilcioğlu-Taş, 2019; Bölek, 2021). Fig seed powder contains approximately 56.6% fiberfiber, which can enhance the dietary fiberfiber content of baked goods, such as biscuits and cookies (Gül and Ulutürk, 2019; Bölek, 2021). Fig seeds have a notable oil yield, comparable to other fruit seeds like pumpkin, honeydew, durian, and guava (Irchad et al., 2023). The fig seed oil predominantly comprises unsaturated fatty acids, with a total unsaturated fatty acid content averaging 88.12%. The major unsaturated fatty acids include linolenic acid, which is the most abundant, followed by linoleic acid. There are also monounsaturated fatty acids in the oil, like oleic, eicosanoic, heptadecenoic, and palmitoleic acids (Hssaini et al., 2020). Nakilcioğlu-Taş and Ötleş (2021) reported significant correlations among total polyphenol concentration, total flavonoid content, antioxidant capabilities, and individual polyphenols in fig seed extracts. The fig seed oil contains significant amounts of total phenolics, ranging from 69.83 to 100.99 mg GAE/100 g, contributing to its high antioxidant potency (Hssaini et al., 2020). Fig seed oil has been reported to ameliorate intestinal damage caused by 5-FU-induced mucositis in rats (Alan et al., 2024). Fayyaz et al. (2024) suggest that F. carica seeds possess anti-hyperlipidaemic properties and show promise in reducing obesity. Furthermore, fig seeds contain various essential minerals, including nitrogen, phosphorus, potassium, calcium, sodium, iron, zinc, manganese, copper, and magnesium (Muhammad and Oluwaniyi, 2022; Irchad et al., 2023). Fig seeds are a rich source of minerals, proteins, and oils, with significant potential for nutritional and industrial applications. These components make fig seeds a promising ingredient for enhancing the nutritional quality of food products, particularly in bakery items like biscuits, where they can increase fiber content and reduce caloric density while adding beneficial proteins and fats (Bölek, 2021). Compared to other fig varieties such as *Ficus hispida* and *Ficus racemosa*, all parts of *Ficus carica*, including the seed, exhibited lower concentrations of phytate and oxalate. This suggests that for individuals concerned about their intake of antinutrients, *Ficus carica* may be a more favourable option. *Ficus carica*, nonetheless, contains a significant amount of beneficial compounds despite the presence of antinutrients. The drying procedure can affect phytate and oxalate levels; sun drying is generally more effective in reducing antinutrients (Nigar et al., 2025).

Fig production and processing yield a substantial quantity of by-products, including leaves, pulp, skins, seeds, and latex. These by-products have been generated from fresh figs regarded as undesirable due to spoilage, size, texture, inferior quality as table fruit, insufficient ripeness, and overripeness. Their commercial application is restricted, and they adversely affect the environment. As previously noted, each by-product of the fig industry is abundant in bioactive compounds. Reintegrating these wastes into the economy is crucial for enhancing the economic performance of the Mediterranean region and creating a circular economy that aligns with contemporary consumer desires for sustainability. Nonetheless, these by-products serve as significant sources of high-value-added ingredients for the food sector as useful additives (Ayuso et al., 2022; Rasool et al., 2023). Although fig seeds provide various advantages, their complete potential, particularly in industrial applications and health research, remains insufficiently investigated. Our study brings innovation in improving understanding and utilization of this resource. This research seeks to enhance the value of fig seeds and contribute to sustainable practices in the food industry.

On the other hand, the increasing prevalence of gluten intolerance and celiac disease has spurred a growing demand for gluten-free products. In response to this demand, innovative approaches to gluten-free baking have emerged, including the incorporation of FSF. This novel ingredient not only serves as an alternative to conventional gluten-free flours but also enriches the nutritional profile of GFM. FSF is known for its high fiber content and unique flavor characteristics, which can significantly enhance both the texture and taste of GFM. To the best of our knowledge, we have not found a study on the use of FSF in the production of GFM and its effects on GFM quality. Therefore, the objective of this study was to investigate the usability of FSF in the production of GFM, evaluate its impact on the specific chemical, physical, textural, and sensory quality attributes of GFM, and create a high-quality, nutritious functional product for individuals with coeliac disease, non-coeliac gluten sensitivity, or those opting for a gluten-free diet. FSF was utilized to enhance the nutritious composition of GFM, particularly for dietary fiberfiber and ash content, which refers to mineral matter.

MATERIALS AND METHODS

Materials

A formulation including 7% corn starch, 40% rice flour, 8% corn flour, and 45% potato starch was utilized as GFFM (Hayıt and Gül, 2019). Sugar, margarine, skim milk powder, pasteurized eggs, baking powder, salt, and milk were sourced from the local markets of Isparta, Turkey. FSF was obtained from Bir Numaralı Bitkisel Ürünler (Aydın/Turkey) and stored in hermetically sealed packages in the refrigerator at -4 °C until use. The chemicals were of analytical grade and acquired from Merck Co. (Darmstadt, Germany).

Production of gluten-free muffins

The formula presented in Table 1 was employed in GFM manufacturing following the methodology established by İpek and Dizlek (2018). Muffins prepared with only GFFM (without FSF) were considered control samples. FSF was used in 0%, 10%, 20%, and 30% proportions according to the principle of substitution with GFFM. All muffin production was carried out in three replicates. During the preparation of GFM batters, firstly, pasteurized eggs were beaten using a hand mixer (Tefal Smart, Turkey) at low speed for 2 minutes, then water and sugar were added and beaten at low speed for 1 minute. Margarine was added and beaten at low speed for 1.5 minutes. Then the remaining ingredients were added and beaten at low speed for 1 minute and then at medium speed for 1 minute. The batter weighed 35 grams on muffin baking papers and then placed in muffin molds. They were baked in the middle layer of a conventional oven (Siemens, Turkey) at 200 °C for 20 minutes. After removal from the oven, they were allowed to cool in the muffin cups for 20 minutes and outside the cups for 40 minutes. These cooled GFM were then subjected to the following analyses.

Table 1. Formulation of gluten free muffins

Ingredients	Quantity (g)
GFFM†	100
Sugar	80
Pasteurised eggs	60
Margarine	60
Water	35
Skim milk powder	7.5

Salt	3
FSF‡	0-10-20-30% replaced with GFFM

Note: †GFFM: Gluten free flour mixture, ‡FSF: Fig seed flour.

Proximate composition analysis of flours and gluten-free muffins

The proximal composition of the flours (FSF and GFFM ingredients) and GFMs were analyzed using standard ACCC methods (AACC, 2010). Moisture of samples were determined by triplicate after drying in an oven (Nüve, FN 120, Türkiye) at 130 °C up to constant weight (AACC Method, 44 01.01). The ash content of samples was determined by incinerating at a muffle furnace (Nüve MF 110, Türkiye) at 550 °C until light gray ash is obtained (AACC Method, 08-01.01). Protein content was determined according to Kjeldahl method (AACC Method, 46-12.01) by using boric acid in the indicator solution and digestion of samples in H_2SO_4. The factor utilized for conversion of nitrogen to protein was 5.70. Briefly, total dietary fiber analysis (AACC Method 32-07.01) was performed by subjecting 1 g of fat-free and dried samples to sequential enzymatic hydrolysis by heat-stable alpha-amylase, protease, and amyloglucosidase (Megazyme Kit, K-TDRF, Megazyme, Wicklow, Ireland). Total lipid was measured according to the Soxhlet method (AAAC Method 30-25.01). The water activity (aw) of the GFM was measured using the Testo 650 equipment.

Color analysis of flours and gluten-free muffins

The colors of FSF, GFFM ingredients, and the crust and crumb colors of GFM were examined using a Minolta Tristimulus Colorimeter (Minolta CR410 Tokyo, Japan). Three indicators were used in order to evaluate the color of the raw materials and GFM. The L* index indicated the sample's brightness, the a* index denoted its redness, and the b* index signified its yellowness. The color scale employed the L* value [(0) Black - (100) White], the a* value [(+) red, (-) green], and the b* value [(+) yellow, (-) blue].

Physical analysis of gluten-free muffins

Volume, volume index, symmetry and uniformity index, top shrinkage value, bottom shrinkage value and total volume index of GFM were determined according to AACC Method 10-91.01; (AACC, 2010). The cake measurement template (AACC Method 10-91.01; AACC, 2010) was used to determine the structural properties of the GFM, modified according to the dimensions of the GFM mold. These values were then used to calculate the indices that give insight into the structural properties of the GFM. Volumes of the GFM were determined according to the rapeseed replacement method (Uluöz, 1965). Specific volumes of GFM were calculated as the ratio between the cake volume and its weight (mL/g) according to Madadi et al. (2024). In addition, the baking losses (Dizlek and Gül, 2009) of the GFM were determined.

Texture analysis of gluten-free muffins

The texture profile analysis (TPA), including hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience of GFM with and without FSF, was evaluated using a texture analyzer (TA-XT2, Stable Micro Systems, Surrey, UK). The analysis employed a 36 mm cylinder probe with the following test settings: pre-test speed 1.0 mm/s, test speed 1.0 mm/s, post-test speed 1.0 mm/s, a 5 kg load cell, and a distance equal to half the height of the muffin. GFM was horizontally sliced using an electric knife, the top layer was discarded, and measurements were taken from the base. The muffin samples underwent a double compression test, with measurements taken in three parallel examples and three repetitions. All measurements were performed two hours after baking at 25°C in a controlled environment.

Sensory evaluation of gluten-free muffins

Ten male and ten female panelists who are experts in the area of Food Engineering, aged between 18 and 45 years, who were semi-trained (consumers who received 1 hour of training on the definition and scaling of attributes before sensory testing), conducted a sensory evaluation of GFM using the hedonic scale method. Samples, assigned a random three-digit code, were delivered to the panelists individually, who were provided with drinking water while transitioning between muffin samples. A five-point hedonic scale ranging from 1 (extreme dislike) to 5 (extreme like) was employed to evaluate crust and crumb color, crumb pore structure, textural attributes, chewiness, mouthfeel, sandy/dry structure, odor, aroma, taste/flavor, and overall appreciation (Gül and Ulutürk, 2019).

Statistical analysis

The data obtained for all properties of GFM were firstly subjected to analysis of variance (ANOVA) using the "SPSS" package program (SPSS, 2019). Then the significant values were subjected to Duncan's multiple comparison test. Differences were determined, revealing a significant level at $p < 0.05$. All the experiments were carried out at least three times with three replications.

RESULTS AND DISCUSSIONS

Proximate composition and colors of flour

Proximate composition and color properties of FSF and ingredients (corn and rice flour, corn and potato starch) of GFFM are given in Table 2. Moisture, ash, protein, total dietary fiber, and total lipid content of FSF were determined as 6.13%, 3.1%, 17%, 75.6%, and 15.17%, respectively. Potato starch had the highest moisture content (14.19%) among the raw materials used to produce GFM, while FSF had the lowest (6.13%). The moisture content of FSF is a critical factor influencing its physical properties and processing characteristics. In the present study, the moisture content of FSF (6.13%) was found to be slightly more than that of fig seeds (5.54 to 5.64%) as reported by Nakilcioğlu-Taş (2019).

On the other hand, the moisture content of FSF is slightly lower than that of fig fruit powder, which contains seeds and typically ranges from 6.5% to 8.5% on a wet basis (Poovai et al., 2023). The variations in moisture content of fig seeds may be attributed to differences in drying methods and genotypes. Conversely, compared to the whole fig, the lower moisture content of FSF is an expected result due to the higher moisture content of the whole fresh fig fruit.

Ash content is an important parameter as it provides an estimate of the total mineral content of the seeds. The ash content of FSF (3.10) was determined slightly higher than the ash content (2.99%) of fig (*Ficus carica L.*) seeds collected from three different locations in Aydın (Türkiye) analyzed by Nakilcioğlu-Taş (2019). Furthermore, Bölek (2021) revealed that the ash content of FSF at 3.50%, which is comparable to the 3.1% ash content found in our study. While specific studies on fig seed ash content are limited, research indicates that fig seeds, particularly from *Ficus thonningii*, *Ficus sycomorus*, and *Ficus carica*, are rich in essential minerals, making them valuable dietary components. High levels of calcium (2067.50 mg/100 g), phosphorus (1985.40 mg/100 g), magnesium (1184.10 mg/100 g), and iron (434.10 mg/100 g) were reported by Muhammad and Oluwaniyi (2022) for *Ficus thonningii* seeds. Likewise, Tafere and Teshager (2023) concluded that *Ficus sycomorus* seeds have notable amounts of calcium (31 mg/kg), potassium (122 mg/kg), and magnesium (333 mg/kg), alongside trace elements, including iron (4.19 mg/kg) and zinc (2.06 mg/kg).

Compared to corn flour, rice flour, corn starch, and potato starch used as a gluten-free flour blend, the ash content in FSF was relatively high. The findings align with Ciesarová et al. (2016), who observed that gluten-free maize flour has a much lower ash content (1.1 g/kg). Similarly, Miranda-Villa et al. (2019) noted that ash (0.14%) and lipids (0.44%) are almost nonexistent in rice flour due to substantial reduction during the refining process. Ash content refers to the overall mineral content found in foods, and it is a component of the proximate analysis of foods used to assess their nutritional value (Marshall, 2010). Gluten-free products are usually based on rice flour, corn flour, or starch. As can be seen from the results of this study, the ash and, therefore, mineral matter contents of these components are quite low. One of the essential deficiencies in gluten-free products is that they have less protein, fiber, and minerals and a higher glycaemic index than foods that include gluten (Stantiall and Serventi, 2018). Thus, FSF is a potential source that can be used to increase the nutritional value of GFM and other gluten-free foods with its high mineral content.

Table 2. Proximate composition and colors of flour (FSF† and GFFM† ingredients)

Properties	FSF	Corn flour	Rice flour	Corn starch	Potato starch
Moisture (%)‡	6.13^{d}	7.54^{c}	7.86^{c}	8.30^{b}	14.19^{a}
Ash (%)‡	3.10^{a}	1.02^{b}	0.55^{c}	0.51^{c}	0.61^{c}
Protein (%)‡	1.70^{b}	7.14^{a}	7.70^{a}	0.25^{c}	0.19^{c}
TDF (%)‡	75.60^{a}	2.74^{b}	0.98^{c}	0.01^{d}	0.04^{d}
Total Lipid (%)‡	13.47^{a}	5.15^{b}	1.25^{c}	0.82^{d}	0.50^{e}
Hunter color values					

L*	47.80[d]	73.63[b]	82.57[a]	73.58[b]	87.68[a]
a*	7.64[a]	0.05[b]	-0.04[c]	0.08[b]	-0.09[c]
b*	12.85[c]	23.44[a]	6.44[d]	17.62[b]	2.42[e]

Note: There is no statistical difference (Duncan test, $p > 0.05$) between the data shown with the same letter in the same row.

‡ FSF: Fig Seed Flour, GFFM: Gluten free flour mixture.

† In a dry basis.

The protein content of corn and rice flour is higher than that of corn and potato starch, as indicated in Table 2. Our study's results are consistent with other research on the protein ratio of maize (Martinez and Gomez, 2017) and rice flour (Singh et al., 2016; Miranda-Villa et al., 2019). On the other hand, the protein content of FSF is lower than that of corn and rice flour but higher than that of corn and potato starch. Based on these findings, using corn and rice flour, or even FSF, instead of starch in gluten-free products may be more beneficial regarding nutritional value. The protein content of FSF (1.70%) was found to be significantly lower than the results of FSF (14.82%, 14.74%, and 15.07%) indicated by Bölek (2021) and Nakilcioğlu-Taş (2019), respectively. It is also lower than the protein content of the three *Ficus carica* dried fruits varieties, reported between 2.64 and 3.33 g/100 g (Benali et al., 2024). Conversely, the protein content of FSF is slightly higher compared to the protein content reported for fresh figs, which ranges from 0.70% to 1.3% (Morton, 1987; Kim et al., 1992). The protein content in *Ficus carica* varies significantly across different cultivars and environmental conditions, influenced by factors such as growth stage, nutrient availability, and cultivation methods. (Nazua et al., 2020).

Our research has demonstrated that FSF contains up to 75% dietary fiberfiber, which is the most remarkable result. In our previous studies, grape pomace and grape seed flour (Gül et al., 2013) and pomegranate seeds (Gül and Şen, 2017a) showed less fiberfiber content, while rosehip seeds (Gül and Şen, 2017b) had almost the same fiberfiber content as that of FSF. The dietary fiberfiber content of FSF (75.60%) was determined to be significantly higher than the 56.6% fiber content reported by Bölek (2021). The dietary fiber of fig seed primarily consists of pectin, which is a type of soluble fiber. Pectin contributes to the health benefits of figs, including digestive health and potential cholesterol-lowering effects, enhancing the overall nutritional value of the fruit (Alzahrani et al., 2024). Fig seeds are likely a good source of dietary fiber, contributing to the overall nutritional value of figs. This makes them a potential candidate for use in functional foods and other health-related applications (Manousi et al., 2023). Dietary fiber level is substantially more than that of corn and rice flour, maize, and potato starch. While rice flour, rice starch, and maize starch are the three most common ingredients found in gluten-free products, the amount of nutritional fiber they contain is negligible. It has been observed that patients adhering to a gluten-free diet may not always consume adequate quantities of fiber, which is considered essential for a balanced diet (Vici et al., 2016). Consequently, in recent years, a diverse range of ingredients such as wheatgrass and mung bean microgreens powder (Kaur et al., 2022), breadfruit and plantain (Kemski et al., 2022), and sugar beet fiber (Saeidy et al., 2023) have been implemented to enhance the dietary fiber composition of GFM. In this context, FSF can be considered as a potential additive that can be used to increase the dietary fiber content of gluten-free products with its high fiber content. Fig seeds are a rich source of dietary fiber, offering numerous health benefits and potential applications in food products. Research indicates that fig seed powder can significantly enhance the nutritional profile of baked goods, such as biscuits and cookies (Gül and Ulutürk, 2019; Bölek, 2021), by increasing their fiber content and antioxidant properties. The incorporation of fig seed flour not only improves the dietary fiber levels but also positively affects the sensory attributes of the final products.

The total lipid content of the FSF was found to be 13.47%, which is significantly higher than the total lipid contents of the other constituents—corn flour, rice flour, corn starch, and potato starch of GFFM. Higher oil contents in fig seeds (21.54% to 28.52%) was reported by Hssaini et al., (2020) across the four fig cultivars examined. They indicate a significant variation in oil yield depending on the cultivar. In line with this study, Şirinyıldız et al. (2023) stated that fig seeds contain an oil content of 22.18% based on wet weight. The lower results may be attributed to the calculation on a dry matter basis, as well as variations in cultivar and environmental conditions, similar to the differences observed in other chemical components.

The results indicated that (Table 2) the L* and a* of FSF were substantially greater than those of the other ingredients—corn flour, rice flour, corn starch, and potato starch—in the production of gluten-free muffin flour. Regarding b*, notable distinctions were identified among the constituents employed in the formulation. As expected, corn flour and corn starch had greater b* values, while FSF came in behind. Conversely, rice flour and potato starch exhibited the lowest b*ratings.

Proximate composition of gluten-free muffins

Table 3 provides some chemical properties of the GMF. The moisture content of the GMF increased steadily from the control sample to those with a 30% FSF addition. The progressive increase can be attributed to the rise in dietary fiber content as the FSF level in the formulation increases. As mentioned before, dietary fibers can absorb about ten times their weight in water. A similar pattern was found in studies conducted by Ho et al. (2019) and Palacio et al. (2018), wherein an increase in the amount of pumpkin flour and squash seed dietary fiber, respectively, in the GFM led to a corresponding rise in the muffins moisture content.

Table 3. Chemical properties of gluten-free muffins

FSF† substitution level (%)	Moisture (%)	Ash (%)	Protein (%)	Total Lipid (%)	Total dietary fiber (%)	Water activity (a_w)
0	14.65^{d}	1.22^{c}	6.51^{a}	32.86^{c}	3.20^{d}	0.71^{b}
10	15.90^{c}	1.30^{b}	4.76^{b}	34.22^{b}	7.45^{c}	0.74^{a}
20	16.77^{b}	1.32^{b}	4.81^{b}	34.87^{b}	10.69^{b}	0.75^{a}
30	17.04^{a}	1.40^{a}	4.18^{c}	36.45^{a}	13.13^{a}	0.76^{a}

Note:† FSF: Fig Seed Flour Note: There is no statistical difference (Duncan test, $p > 0.05$) between the data shown with the same letter in the same column.

Similar to moisture values, ash values also rose with the incorporation of FSF. Table 3 illustrates that the ash level of FSF is significantly higher than the components producing GFM. This resulted in an increase in the ash content of GFM in parallel with the addition rate of FSF, which was added according to the substitution principle with the GFFM.

In contrast to moisture and ash values, protein content of GMFs decreased with the addition of FSF. This is because corn flour and rice flour, which are present in the gluten-free flour mixture and whose protein content is higher than the other ingredients, decreased proportionally with the addition of FSF. The lipid content of FSF is higher than the lipid content of the ingredients used in producing GFMs. Therefore, it increased the lipid content of the GFMs to a limited extent. The GFM with 30% substitution of FSF was the rank first in lipid content. However, it should be noted that the high lipid content of GFMs is due to the high ratio of margarine (60 g margarine/100 g flour) used in their formulation (as seen in Table 1).

The TDF content of GMF exhibited a notable increase with the incorporation of FSF. While GMF's TDF content was 3.20% without FSF, it increased to 13.13% with a 30% FSF substitution level. The most significant shortcoming of gluten-free products is their relatively low dietary fiber content. This is because the production of these products involves the use of low-fiber substances such as rice flour, rice starch, and corn starch. This study suggests that using FSF could enhance the fiber content of gluten-free muffins and other gluten-free products. Additionally, the detected rise in TDF in formulations containing FSF in comparison to control enables these GFM to be included in the label that is attributed "High in dietary fiber," in accordance with the Regulation (European Commission) No. 1924/2006 (European Commission, 2006), nutrition claims.

In agreement with our results, Palacioi et al. (2018) found that incorporating squash seed flour at two levels (10 and 20% w/w) in commercial gluten-free premix increased total dietary fiber and fat contents compared to control samples. Saeidi et al. (2018) found significant positive linear effects of pomegranate seed powder (0–50%) and transglutaminase enzyme (0–1.2%) on the ash and fiber contents of gluten-free cake made from rice flour which is in line with the results of the present study.

The unbound, accessible, or free water in food products is described by their a_w, which is the ratio of the vapor pressure of the product's water to that of pure water at the same temperature (Singh et al., 2015). Adding FSF at different ratios did not make a significant difference on a_w. Adding FSF at different ratios did not make a significant difference on a_w. There was a statistically significant increase ($p<0.05$) in the a_w values of GFM (0.74-0.76) with the addition of FSF compared to the control (0.71). This rise is attributable to the elevated moisture content of GFMs after FSF substitution. However, adding FSF at increasing rates did not have a significant effect ($p>0.05$) on this value. This finding agrees with that reported by Ozgolet et al. (2024) in which GFM enhanced with milk thistle seed proteins had water activity values ranging from 0.749 to 0.774. In contrast, Bhaduri (2013) stated higher a_w values (0.816-0.835) in their study involved replacing rice flour with varying proportions of quinoa flour (25%, 50%, 75%, and 100%). The study found that gluten-free flour-formulated muffins exhibited lower a_w than those made with wheat flour. Aw is a critical factor influencing the quality and stability of muffins, as well as their texture, flavor, and

shelf life. Higher aw levels, as in the present study (a_w > 0.6) can lead to a softer texture, while lower levels may result in a drier product. This is crucial for maintaining the desired mouthfeel in muffins (Rajchasom et al., 2012). In our study, the hardness of GFMs measured by TPA and sensory evaluations such as texture and mouthfeel was much better with the addition of FSF compared to the control, supporting this idea. The rate of non-enzymatic browning, which affects color and flavor, peaks at a_w between 0.6 and 0.7. However, studies indicate that this effect may vary, suggesting that optimal baking conditions must be tailored to specific formulations (Rajchasom et al., 2012). A study found that a water content of 77.87% was optimal for gluten-free muffins, leading to increased specific volume and moisture retention (Kurek et al., 2021). Proper a_w levels help maintain the desired texture, preventing gluten-free products from becoming too dry or too moist. Like all foods, gluten-free products with high a_w are more susceptible to microbial spoilage. Inconclusion, formulating gluten-free products requires careful consideration of a_w to ensure the desired texture, ensuring they meet consumer expectations for quality and taste.

Physical properties of gluten-free muffins

Table 4 presents the quantitative measurements for various physical attributes of GFM, including volume, specific volume, volume index, total volume index, baking loss, symmetry index, uniformity index, and top and bottom shrinkage.

Table 4. Physical properties of gluten-free muffins

Physical Properties	FSF† substitution level			
	0	10	20	30
Volume (mL)	70.34^{d}	73.34^{c}	75.6 ^{b}	79.34^{a}
Specific Volume (mL/g)	2.30^{d}	2.40^{c}	2.50^{b}	2.62^{a}
Volume Index (mm)	101.00^{b}	106.34^{a}	107.34^{a}	107.40^{a}
Total Volume Index (mm)	237.67^{c}	244.33^{a}	246.0 ^{a}	247.67^{a}
Baking Loss (%)	13.77^{a}	12.63^{b}	12.00^{c}	11.84^{d}
Symmetry Index (mm)	17.00^{a}	16.67^{b}	13.67^{c}	12.67^{d}
Uniformity Index (mm)	1.00^{a}	0.67^{b}	0.33^{c}	0.00^{d}
Top Shrinkage Value (mm)	13.67^{a}	13.34^{a}	12.67^{b}	11.34^{c}
Bottom Shrinkage Value (mm)	11.00^{a}	10.34^{b}	8.34^{c}	8.00^{d}

Note: There is no statistical difference (Duncan test, p > 0.05) between the data shown with the same letter in the same row.

† FSF: Fig Seed Flour.

As the percentage of FSF substituted with the GFFM rose, there was a linear increase in the volume and specific volume of the GFM. This result contrasts with our study (Özkan and Gül, 2021) on gluten-containing muffins, in which we found that the volume of the muffins decreased as the FSF ratio increased. The specific volume of a muffin is influenced by how well the batter expands and retains gas during baking. Adding FSF to muffins that contain gluten may have caused the muffins to shrink because the dietary fibers in the FSF weakened and broke down the structure of the gluten. On the other hand, the substitution of FSF with another GFFM in GFM may have caused a hydrocolloid and mucilage effect. *Ficus carica* produces mucilage that has garnered attention for its potential applications in pharmaceuticals and food products. The bioactive properties of mucilage come from its polysaccharides, such as glucose, galactose, and rhamnose (Zhang et al., 2024). Mucilage isolated from *Ficus carica* fruits is biocompatible, biodegradable, and exhibits better mucoadhesive properties than synthetic polymers (Basu et al., 2010). A novel polysaccharide (FCPW80-2) isolated from *Ficus carica* has a complex structure comprising various sugar linkages, which enhances its functional properties (Du et al., 2018). The mucilage extracted from *Ficus carica* kernels exhibits unique properties that make it suitable for various gluten-free formulations. The quest for gluten-free alternatives, such as FSF, in the present study that mimic the properties of gluten may lead to various innovative strategies in food technology.

Although the volume index and total volume index values of GFM rose relative to the control sample, no significant difference was identified between GFM samples containing different ratios of FSF in terms of these two parameters. Gomez et al. (2010a) observed similar results, discovering that substituting wheat flour with wheat and oat fibers around the 24% fiber addition significantly enhanced the volume, volume index, and specific volume of cakes. This is in-line with the finding by Haas et al. (2022), who reported that the volume of gluten-free cakes did not decrease as the teff percentages increased. Similarly, Ho et al. (2019) found that gluten-free muffins' volume,

specific volume and height did not change significantly as the percentage of pumpkin flour substitution increased. In contrast, other researchers have noted a reduction in the size of cakes when using different types of fiber, such as Andean grain flours (Vidaurre Ruiz et al., 2022) and tigernut dietary fiber (Na et al., 2023). The reason for these differences compared to our study may be due to the different fiber sources used. However, the high amount of dietary fiber in the FSF may have acted as a hydrocolloid. As it is known, hydrocolloids such as xanthan gum are alternative ingredients to gluten, and they modify the water absorption of dough and improve the muffin quality characteristics (Singh et al., 2015). Based on these comparisons, FSF was shown to be an effective flour substitute for GFM. As the rate of FSF substitution increased, the overall physical attributes of GFM improved, particularly in terms of volume, as illustrated in Figure 1.

Volume is a crucial component that significantly impacts the quality of a cake, as well as the preferences of consumers.



Figure 1. Visual appearance of crust (above) and crumb (below) of GFM. A: Control prepared from GFFM (45% potato starch, 40% rice flour, 8% corn flour, and 7% corn starch). A: GFFM-FSF (90:10), B: GFFM-FSF (80:20), C: GFFM-FSF (70:30), GFM: Gluten-free muffins, GFFM: Gluten-free flour mixture, FSF: Fig seed flour.

The inclusion of FSF in the samples reduced cooking loss compared to the control group. Furthermore, despite an increase in FSF replacement rates, cooking losses decreased. The decrease in the cooking loss of GFM as the FSF ratio increases can be attributed to the high water-binding capacity of dietary fibers. The addition of FSF increased GFMs' dietary fiber content, increasing their moisture content as well. Furthermore, at the concentration used in our study, FSF may form a gel, indicating that it has a greater capacity to absorb and retain water. The high water-binding capacity of dietary fibers significantly influences cooking losses in food products, particularly low-fat formulations. Various studies demonstrate that dietary fibers can enhance moisture retention, reducing cooking losses and improving product quality. Dietary fibers from milling and fruit processing byproducts—like FSF—possess high water absorption properties that help retain moisture in gluten-free doughs and prevent moisture loss, leading to improved texture and shelf life. (Tsatsaragkou et al., 2016; Föste et al., 2020). Adding tiger nut dietary fiber (TDF) in rice muffins demonstrated a proportional increase in water- and oil-holding capacity, leading to lower baking losses and improved texture (Na et al., 2023). Fibers from sources like maize and oats have been shown to enhance the hydration of gluten-free batters, resulting in a more aerated structure and better crumb quality (Sabanis et al., 2009).

The symmetry index is a quantitative measure used to assess the surface morphology of the upper portions of cakes. It assumes a positive value when the cakes exhibit a curved structure and a negative value when they collapse (İpek and Dizlek, 2018). Table 4 shows that all the GFMs have a positive symmetry index.

The uniformity index measures the cake's degree of symmetry. To achieve an ideal cake, the index value should be 0. This implies that both parts of the cake are the same size. A non-zero value, meaning it is either positive or negative, indicates that one half of the cake is higher than the other (Dizlek and Altan, 2021). A higher uniformity index score indicates greater surface unevenness in the muffin (Topkaya, & Isik, 2019). Our study determined the uniformity index of cakes with 30% FSF to be 0. This demonstrates that a 30% substitution rate can produce an ideal cake. Conversely, as the FSF ratio decreased, the uniformity index value fell, with the maximum value observed in the control sample. Based on these findings, the inclusion of FSF enhanced the uniformity index values of GFM, reaching their optimal level when the substitution level reached 30%.

Table 4 revealed that the control sample's top and bottom shrinkage values were higher than those of the FSF-containing GFM. These two values decreased as the FSF substitution rate increased, and 30% FSF substitution yielded the best values.

Color properties of gluten-free muffins

Crust and crumb color values of GFM are given in Table 5. In the crust, the control sample had the highest L*, a*, and b* values. As the FSF ratio increased, the crust and crumb L* and b* decreased, so GFM became darker than the control. GFM redness values increased with increasing FSF ratios. The darkening of the colors in GFM is expected when the lighter constituents of GFFM, such as rice flour, maize starch, and potato starch, are replaced with the darker FSF. Like other baked goods, the color of muffins is influenced by several chemical reactions that occur during baking, primarily the Maillard reaction and caramelization (Lee et al., 2024). Adding dietary fibers, such as apple pomace and brewers' spent grain, can affect the color change in muffins by altering the Maillard reaction dynamics and increasing the browning index (Lukinac et al., 2015). colorSignificant changes in the internal color values of GFM were observed with the addition of FSF. These changes can be clearly seen in Figure 1. The color of the muffin crumb is the primary criterion consumers consider when purchasing the product. The sensory test revealed that, in terms of crumb color, people preferred the GFM containing FSF over the control.

Table 5. Crust and crumb color properties of gluten-free muffins

FSF† (%)	Crust			Crumb		
	L*	a*	b*	L*	a*	b*
0	46.24^{a}	16.23^{a}	21.30^{a}	75.79^{a}	1.79^{d}	26.50^{a}
10	42.60^{b}	14.74^{b}	19.20^{b}	69.70^{b}	6.14^{c}	23.26^{b}
20	41.33^{b}	13.54^{b}	18.80^{c}	57.85^{c}	7.10^{b}	19.20^{c}
30	41.20^{c}	13.25^{c}	18.10^{c}	54.32^{d}	8.13^{a}	18.84^{d}

Note: There is no statistical difference (Duncan test, $p > 0.05$) between the data shown with the same letter in the same column.

† FSF: Fig Seed Flour.

Textural properties of gluten-free muffins

TPA is a popular twofold compression approach for determining the textural properties of food products. In a TPA test, samples are compressed twice with a texture analyzer to determine their behavior during mastication. TPA parameters of GFM, as compared with the control muffin, are shown in Table 6.

Table 6. Textural properties of gluten-free muffins

FSF † (%)	Hardness (g)	Adhesiveness (g.sec)	Springiness	Cohesiveness	Gumminess (g)	Chewiness	Resilience
0	1107.43^{a}	0.49^{a}	0.74^{a}	0.49^{a}	948.00^{a}	681.24^{a}	0.24^{a}
10	814.23^{c}	0.48^{a}	0.71^{b}	0.48^{a}	656.41^{b}	464.50^{b}	0.24^{a}
20	825.03^{c}	0.44^{b}	0.72^{b}	0.41^{b}	619.10^{c}	447.03^{c}	0.22^{b}
30	842.17^{b}	0.41^{b}	0.70^{b}	0.42^{b}	607.74^{d}	432.95^{d}	0.21^{b}

Note: There is no statistical difference (Duncan test, $p > 0.05$) between the data shown with the same letter in the same column

† FSF: Fig Seed Flour

Hardness is defined as the force required to compress food between the teeth. The control sample exhibits the greatest hardness value of 1107.43 g. There is an inverse relationship between hardness and volume (Gomez et al. 2010b; Jabeen et al., 2022). This argument can, therefore be used to explain why the control GFM with the lowest volume gives the highest hardness. Incorporating varying ratios of FSF into the GFFM substantially reduced the hardness values of the GFM, resulting in a softer texture. This can be attributed to the higher water-binding capacity of dietary fibers in FSF and the higher moisture content of FSF-containing GMF compared to control muffins. In agreement with our results, Singh et al. (2016) developed a gluten-free rice muffin with a black carrot pomace

dietary fiber concentrate. They observed a gradual reduction in muffin firmness from 2.4 N (control) to 2.4, 2.0, and 1.3 N when it was added at 0, 3, 6, and 9%, respectively.

Contrary to our findings, some studies have reported that the hardness values of muffins increased with the addition of dietary fibers. In this context, Sahan et al. (2024) reported that substitution of rice flour with okra seed powder at increasing levels (0%, 15%, 30% and 45%) resulted in a significant increase in muffin firmness from 1700.63 g (control) to 4316.38 g (with 45% okra seed powder). Palacio et al. (2018) also found a significant increase (from ~ 1.4 N to ~ 2.4 N) in the gluten-free muffins firmness with the addition of squash seed flour at 20%. The significant decrease in the hardness values of GFM with the addition of FSF in the present study may be also attributed to the higher total lipid content of FSF. Gluten-free products such as bread and cakes sold in the market are generally hard. However, the softness of GFM is a feature desired by consumers. According to our research, adding FSF to GFM, which imparts softness, indicates a higher consumer appreciation and a longer shelf life. Thus that, FSF will have an important usage advantage in industrial GFM or cake production.

Adhesiveness results allow us to conclude that the addition of FSF at 10% resulted in a GMF that did not differ significantly from the control muffin and also that formulations both with FSF at 20% and %30 caused a decrease in this parameter compared to the control formulation. The area under the negative peak when the probe withdraws following the initial compression is used to calculate adhesiveness, a measure of stickiness (Anonymous, 2024). Springiness is the rate at which the sample returns after being compressed to the stated deformation. The springiness of GFM decreased with the addition of FSF, but different substitution levels of FSF did not make a significant ($p > 0.05$) difference in this value. ANOVA results showed that the addition of FSF at 10% had no significant effect ($p > 0.05$) on cohesiveness, while an increase in its substitution level to 20% and 30% led to a significant ($p < 0.05$) decrease in this parameter. The simplest approach to measure cohesiveness in food is the energy or the amount of time it takes to break down a food until it is acceptable enough to swallow. The cohesiveness will be 0 if the sample's structure is totally destroyed during the initial compression. If the sample is entirely elastic and undamaged by the first compression, this ratio equals 1.0. This property for most food products will be classified between 0 and 1, as our research indicated that the cohesiveness of both GFM and control muffins fell within this range. Conversely, low values for this parameter suggest that products are difficult to handle and slice (Rosa et al., 2015). The results demonstrated that the control sample and the GFM containing 10% FSF were more cohesive than the other formulations due to their lower fiber content, making them easier to handle and slice. GMF's gumminess and chewability parameters, which had increasing amounts of FSF, were found to be lower when compared to the control sample. A positive area under the TPA curve is used to measure chewiness. This measurement accurately measures the 'work' of this test. Thus, a greater area value implies a higher energy requirement for the test, which results in a tougher/chewier product to bite. Consumers may have difficulties while eating muffins with high chewiness. These observations concluded that the GFM with the addition of FSF was softer and, therefore, easier to chew than the control sample without FSF, which required more force. These results also align with the findings of the sensory analysis. Panelists noted that the control sample was more difficult to chew than the samples containing FSF, whereas GFM became easier to chew as the proportion of FSF increased.

Sensorial properties of gluten-free muffins

Figure 2 illustrates the sensory properties of GFM with different formulas. Substituting GFFM with different ratios of FSF improved the sensory properties of GFM compared to the control sample. The GFM containing 20% and 30% FSF exhibited greater sensory appeal and received comparable scores.

However, 20% FSF-added GFM were the most appreciated regarding crust and crumb color, crumb pore structure, textural properties, aroma, taste/flavour, and general appreciation. As the FSF ratio increased, GFM became softer because of their higher moisture content than the control. According to the instrumental measurements, as mentioned before, partial replacement with FSF increased the moisture content of GFM and significantly decreased their hardness. Therefore, with the addition of FSF at rising rates, the eating quality of GFM increased; they became softer and easier to chew. In terms of aroma, smell, taste, and flavor, adding FSF increased the sensory appreciation of GFM. Generally, consumers do not prefer gluten-free products with high levels of fiber additives because they reduce their technological and sensory quality. However, using FSF in high ratios (20%) resulted in increased sensory appreciation and did not significantly negatively impact the overall quality characteristics of GFM. As a result, using FSF in GFM can prevent the formation of a hard, tough, dry, difficult-to-eat structure, which is a significant problem in GFM and reduces consumer appreciation. In contrast to our study, studies are reporting that GFM with high fiber content, such as sugar beet fiber (Saeidy, et al., 2023), and watermelon rind powder (Çelik and Isık, 2023) received lower sensory scores and were less liked. In this context, we can consider FSF as a potential substitute for other fiber sources, as it enhances the sensory scores of GFM without significantly altering their technological quality.

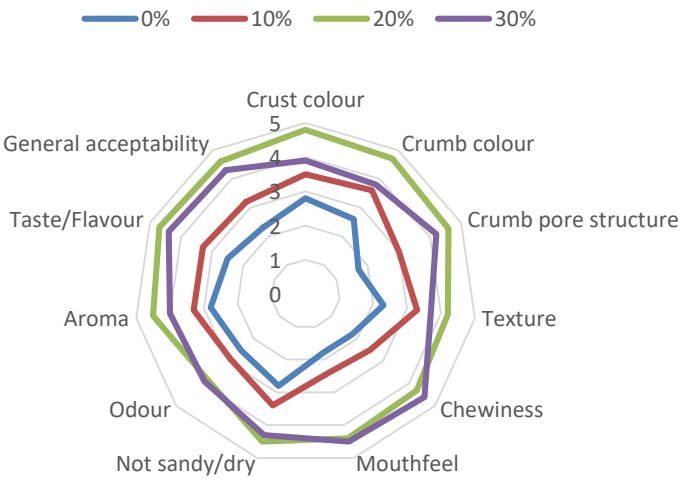


Figure 2. Sensorial properties of gluten-free muffins.

CONCLUSIONS

The production of bakery goods and pastries is a significant subsector of the food industry. Today, consumers are interested in foods that are rich in nutrients and have positive effects on human health. The production of muffins, an essential component of bakery goods, is increasing, taking on a variety of shapes and compositions. However, there are limits to the variety and nutritional value of gluten-free muffins and other gluten-free foods. Refined flours often form the basis of these foods. Therefore, nutrient deficiencies, such as essential vitamins, minerals, protein, and dietary fiber, are still a major problem in gluten-free diets. Because of this, gluten-free food manufacturers need to look for alternative flours that offer a wider range of nutrients. FSF is a potential source of these alternative flours. The present study found that substituting FSF with GFFM in GFM significantly increased the nutritional content of these muffins without adversely affecting their technological properties. Consequently, it is possible to produce GFM with acceptable sensory and technological quality by substituting FSF up to 20% with a GFFM for individuals with coeliac disease or those who prefer a gluten-free diet. This research reveal how FSF may enhance gluten-free products and provide valuable insights for formulation and product development.

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Conflicts of Interest

The authors declare that they do not have any conflict of interest.

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