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Nutritional Composition, Antioxidant Properties, and In Vitro Alpha-Glucosidase Inhibitory Effects of Functional Biscuits Fortified with Ficus exasperata and Sphenostylis stenocarpa

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Abstract

Oxidative stress and postprandial hyperglycemia are critical factors in the pathogenesis and progression of diabetes mellitus. Developing functional foods with bioactive ingredients offers a promising dietary approach to managing this condition. This study evaluated the *in vitro* antioxidant capacity, α-glucosidase inhibitory effects, nutritional composition, and sensory acceptability of functional biscuits fortified with *Sphenostylis stenocarpa* and *Ficus exasperata*. Four biscuit formulations (varying ratios of *S. stenocarpa* and fermented/unfermented *F. exasperata*) were prepared. The samples were evaluated for total phenolic content (TPC), total flavonoid content (TFC), ABTS radical scavenging, Fe^{2+} chelation, ferric reducing antioxidant power (FRAP), and α-glucosidase inhibition. The two optimal formulations with 40g *F. exasperata* inclusion (B-SS20-fFE40 and B-SS20-uFE40) were further subjected to proximate and sensory analyses. All formulations demonstrated appreciable TPC, Fe^{2+} chelating ability, and ABTS radical scavenging activity with no significant differences ($p > 0.05$) among the groups. However, B-SS20-fFE40 exhibited significantly higher TFC and FRAP. All extracts demonstrated moderate α-glucosidase inhibitory activity. Proximate analysis revealed that the fermented formulation (B-SS20-fFE40) possessed the highest crude protein (10.51 ± 0.717%), whereas the unfermented formulation (B-SS20-uFE40) had higher crude fibre (6.89 ± 0.065%). Sensory evaluation indicated that the B-SS20-uFE40 received the highest overall consumer acceptability score. Fortification with *S. stenocarpa* and *F. exasperata* successfully enhances the nutritional and antioxidant profiles of biscuits. While fermentation optimizes flavonoid extractability and protein content, the unfermented formulation offers superior dietary fibre and sensory qualities. These functional biscuits demonstrate promising potential as supportive dietary snacks for mitigating oxidative stress and managing postprandial blood glucose levels.

INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from impaired insulin secretion, insulin action, or both. The condition is frequently associated with dyslipidemia, oxidative stress, and progressive damage to vital organs, including the kidneys, heart, blood vessels, nerves, and eyes [1, 2]. Type 2 diabetes mellitus, the most prevalent form of the disease, is largely driven by insulin resistance and defective pancreatic β-cell function. Oxidative stress plays a critical role in the onset and progression of diabetes-related complications because excessive production of reactive oxygen species can impair insulin signaling and damage pancreatic β-cells [3].

The global burden of diabetes continues to increase rapidly. According to the International Diabetes Federation, millions of individuals currently live with diabetes worldwide, and the number is projected to rise substantially in coming decades. Although several pharmacological agents are available for glycemic control, including biguanides, sulfonylureas, thiazolidinediones, α-glucosidase inhibitors, DPP-4 inhibitors, GLP-1 receptor agonists, SGLT2 inhibitors, and insulin, their use may be limited by adverse effects, cost, and accessibility challenges, particularly in low-resource settings [4–6]. Consequently, increasing attention has been directed toward medicinal plants and plant-based functional foods as complementary dietary strategies for managing hyperglycemia and oxidative stress.

Plant-based foods are rich sources of bioactive compounds, including phenolics, flavonoids, tannins, alkaloids, saponins, and dietary fibre, many of which possess antioxidant and antidiabetic activities [7]. In particular, inhibition of carbohydrate-hydrolyzing enzymes such as α-glucosidase is an important therapeutic target for reducing postprandial blood glucose elevation. Foods or plant extracts capable of inhibiting α-glucosidase may slow intestinal glucose absorption and contribute to improved glycemic control.

Sphenostylis stenocarpa, commonly known as African yam bean, is an underutilized legume indigenous to West and Central Africa. It is nutritionally valuable due to its appreciable protein content, dietary fibre, minerals, and slow-digesting carbohydrates. Previous studies have reported its antioxidant, antihyperglycemic, hypolipidemic, and low-glycemic properties, suggesting its potential application in functional food development [8–10]. Despite these nutritional advantages, *S. stenocarpa* remains underutilized in industrial food production.

Ficus exasperata, commonly known as sandpaper leaf, is a medicinal plant belonging to the family Moraceae. It is widely distributed in tropical and subtropical regions and has been traditionally used for the management of several health conditions [11, 12]. The leaves contain diverse bioactive compounds, including phenolic acids, flavonoids, tannins, saponins, alkaloids, and glycosides, which have been associated with antioxidant, hypoglycemic, hypolipidemic, anti-inflammatory, antimicrobial, and other pharmacological effects [13–16]. Recent studies have also shown that *F. exasperata* may positively modulate insulin-signaling pathways in diabetic models [17, 18].

Processing methods such as fermentation may further improve the biological quality of plant-based foods. Fermentation can reduce antinutritional factors, improve mineral bioavailability, and release bound phenolic compounds, thereby enhancing antioxidant activity and overall nutritional value [19]. Therefore, incorporating fermented or unfermented *F. exasperata* leaf powder with *S. stenocarpa* flour into a commonly consumed food product may provide a practical approach for developing affordable functional foods with potential antidiabetic benefits.

Biscuits are widely consumed ready-to-eat baked products valued for their affordability, convenience, palatability, and relatively long shelf-life [20]. Their broad consumer acceptance makes them suitable vehicles for delivering functional ingredients. Partial substitution of wheat flour with *S. stenocarpa* flour and fortification with *F. exasperata* leaf powder may enhance the nutritional and therapeutic value of biscuits.

Although the individual health-promoting properties of *S. stenocarpa* and *F. exasperata* have been documented, limited information exists on their combined incorporation into biscuit formulations. In particular, the proximate composition, phenolic and flavonoid contents, antioxidant properties, sensory acceptability, and α-glucosidase inhibitory potential of biscuits fortified with these plant materials remain insufficiently characterized. Therefore, this study evaluated the nutritional composition, antioxidant activity, and in vitro α-glucosidase inhibitory effects of functional biscuits fortified with Sphenostylis stenocarpa and fermented or unfermented Ficus exasperata leaf powder.

MATERIALS AND METHODS

Collection of Plant Samples

The leaves of *Ficus exasperata* was obtained from Akungba Akoko. The raw ingredients required for biscuit formulation and *Sphenostylis stenocarpa* bean seed were purchased at Osele market in Ikare Akoko, Ondo State, Nigeria [7.5248 ºN, 5.7669 ºE]. The leaf samples were identified and authenticated in Plant Science and Biotechnology department Herbarium and Taxonomic Unit (PSBHTU), Adekunle Ajasin University, Akungba Akoko, Ondo State, Nigeria by Dr. O.P. Obembe, a plant taxonomist.

Preparation of plant samples

Ficus exasperata Leaf Powder was prepared according to the method described by Shodehinde et al. [21] as reported by Bello et al. [16]. Preparation of *Ficus exasperata* Leaf Powder involved washing fresh leaves with potable water, shading them to drain, and then fermenting some wrapped in several layers of plantain leaves while air-drying others for three weeks. Both fermented and unfermented samples were pulverized, sieved for uniformity, and stored in airtight containers for biscuit fortification. *Sphenostylis stenocarpa* (African Yam Bean) mature seeds were sorted, rinsed, dried, and milled into fine flour, which was also stored in airtight containers for biscuit formulation.

Preparation of Functional Biscuits

The functional biscuits were formulated following the method of Shodehinde et al. [22]. Wheat flour was partially substituted with *Ficus exasperata* and *Sphenostylis stenocarpa* to investigate dose-dependent synergistic interactions and the effect of fermentation on the bioactivity of the formulations. The blends were prepared in reciprocal ratios (20:40 and 40:20), and separate formulations were produced using fermented and unfermented *Ficus exasperata*. The production process for the biscuits follows the guidelines provided by Oyewole *et al.* [23] with minor adjustments. After 40 minutes of mixing, each sample blend listed in Table 1 produced dough with a nice texture and a hint of firmness. For four minutes, the dough was kneaded on a spotless, flat stainless steel table. A biscuit cutter was used to cut the mixture into shapes after it had been manually rolled into sheets. The dough was baked for 30 minutes at 150^{O}C. After being taken out of the oven, the biscuits were left to come to room temperature. After that, they were packaged and kept for later examination at room temperature.

Table 1
Formulation of functional biscuits

INGREDIENTS	B-SS40-fFE20	B-SS20-fFE40	B-SS40-uFE20	B-SS20-uFE40
Ficus exasperata (g)	20	40	20	40
Sphenostylis stenocarpa (g)	40	20	40	20
Wheat flour (g)	140	140	140	140
Sugarcane (g)	60	60	60	60
Fat (g)	40	40	40	40
Salt (g)	2	2	2	2
Vanila (g)	1	1	1	1
Water (mL)	65	65	65	65
GMS (EULSIFIER)(mg)	0.5	0.5	0.5	0.5

Table 1B-SS40-fFE20 = 40g *Sphenostylis stenocarpa* + 20g Fermented *Ficus exasperata* Biscuit; B-SS20-fFE40 = 20g *Sphenostylis stenocarpa* + 40g Fermented *Ficus exasperata* Biscuit; B-SS40-uFE20 = 40g *Sphenostylis stenocarpa* + 20g Unfermented *Ficus exasperata* Biscuit; B-SS20-uFE40 = 20g *Sphenostylis stenocarpa* + 40g Unfermented *Ficus exasperata* Biscuit.

Preparation of Functional Biscuits Extracts

The prepared biscuits were pulverized into powder form and the extract of each sample was prepared by measuring 5g into 100mL of distilled water, each in separate bottles. The mixtures were shaken in a water bath for uniformity, filtered through filter paper, and the resulting filtrates were used in biochemical assays to evaluate the *in vitro* antioxidant and α-Glucosidase Inhibitory activities of the samples.

In vitro Assays Determination

Determination of Total Phenol Content

The total phenol content was determined according to the method of Singleton *et al.* [24]. Briefly, appropriate dilutions of the food samples extracts were oxidized with 2.5mL of 10% Folin-Ciocalteu's reagent (v/v) and neutralized by 2.0mL of 7.5% sodium carbonate. The reaction mixture was incubated for 40 minutes at 45°C and the absorbance was measured at 765nm. The total phenol content was subsequently calculated as gallic acid equivalent (GAE).

Determination of Flavonoids Content

The total flavonoid content of the food samples extract was determined using a slightly modified method reported by Meda *et al*. [25]. Briefly, 0.5mL of appropriately diluted sample was mixed with 0.5mL methanol, 50µL of 10% $AlCl_3$, 50µL of 1M potassium acetate and 1.4mL water, and allowed to incubate at room temperature for 30 min. Thereafter, the absorbance of the reaction mixture was subsequently measured at 415 nm. The total flavonoids content was subsequently calculated as quercertin equivalent (QUE).

Determination of Ferric Reducing Antioxidant Power

The Ferric reducing antioxidant Power of the food samples extract was determined by assessing the ability of the extract to reduce $FeCl_3$ solution, as described by Oyaizu [26]. A 2.5 mL aliquot was mixed with 2.5 mL of 200 mM sodium phosphate buffer (pH 6.6) and 2.5 mL of 1% potassium ferricyanide. The mixture was incubated at 50°C for 20 minutes. Following this, 2.5 mL of 10% trichloroacetic acid was added, and the mixture was centrifuged at 650 rpm for 10 minutes. Then, 5 mL of the supernatant was measured with an equal volume of water and 1 mL of 0.1% ferric chloride, and the absorbance was measured at 700 nm. Finally, the ferric reducing antioxidant Power was subsequently calculated as Ascorbic acid equivalent (AAE).

$$FRAP = \frac{Absorbamce\ of\ sample\ \times\ Concentration\ of\ standard}{Absorbance\ of\ Standard\ \times\ Concentration\ of\ Sample}$$

Fe Chelation

The ability of the sample to chelate Fe^{2+} was determined using a modified method of Minotti and Aust [27] with a slight modification by Puntel *et al.* [28]. Freshly prepared 500mM $FeSO_4$ (150µl) was added to a reaction mixture containing 168 µl 0.1-M Tris-HCl (pH 7.4), 218- µl saline and the aqueous extract (0–25 µl). The reaction mixture was incubated for 5 min before the addition of 13 µl 0.25% 1, 10-phenanthroline (w/v). The absorbance was subsequently measured at 510 nm in a spectrophotometer.

$$\%\ Fe2 + chelating\ ability = \frac{Absorbance\ of\ Ref\ -\ Absorbance\ of\ sample}{Absorbance\ of\ Ref} \times 100$$

ABTS Radical Scavenging Ability

The total antioxidant power of the extracts was assessed using the ABTS radical model as described by Re et al. [29]. The ABTS radical was generated by reacting 7 mmol/L of ABTS aqueous solution with 2.45 mmol/L of $K_2S_2O_8$ solution in the dark for 16 h and adjusting the absorbance at 734 nm to 0.700 with ethanol. Two hundred microliters of the appropriate dilution of the sample extract was added to 2.0 mL. The absorbance was measured at 734nm after 15 min.

$$\% \, ABTS = \frac{Absorbance \, of \, Ref \, - Absorbance \, of \, sample}{Absorbance \, of \, Ref} \times 100$$

α-Glucosidase Inhibition Assay

Fifty microliters of appropriate dilution of the food sample extracts was added to 100 µl of the α-glucosidase solution (1.0 U/mL) in 1.0M phosphate buffer (pH 6.9) and incubated at 25°C for 10 min. Fifty microliters of 5 mM p-nitrophenyl-α-D glucopyranoside solution in 0.1M phosphate buffer (pH 6.9) was subsequently added. The reaction mixture was incubated at 25°C for 5 min and the absorbance was read at 405nm in the spectrophotometer. The α-glucosidase inhibitory activity of the food sample extract was calculated.

$$\% \, Enzyme \, inhibition = \frac{Absorbance \, of \, Ref \, - Absorbance \, of \, sample}{Absorbance \, of \, Ref} \times 100$$

Proximate Analysis

Proximate analysis of food samples

Based on the preliminary *in vitro* screening, which demonstrated that the 40g inclusion level of *Ficus exasperata* (both fermented and unfermented) in the biscuits sample fortified with *Sphenostylis stenocarpa-Ficus exasperata*, yielded the significantly higher phenolic content and antioxidant activity compared to the 20g level, these two formulations were selected as the ” Optimal Lead Samples”. Consequently proximate analysis was focused on these 40g variants to provide a comprehensive nutritional characterization of the most bioactive formulations.

The proximate composition of the biscuit samples-including moisture, ash, crude fat, crude fiber, crude protein, and carbohydrate content-were determined using standard methods outlined by the Association of Official Analytical Chemists [30]. Carbohydrate was determined by difference as follows: %Carbohydrates = 100 – (%moisture + %fat +%ash + %protein + %crude fibre.

Sensory analysis

In this study, we conducted a sensory analysis following verbal consultation with the institutional ethical board, which confirmed that the study posed no health risks and did not necessitate formal ethical approval. All participants gave their informed verbal agreement, and the study adhered with institutional ethical research norms. During or after the sensory analysis, no negative incidents were documented. Twenty panelists were assigned within 24 hours of manufacturing to conduct sensory analysis. The personnel from Food Science & Technology and Biochemistry served as panelists. The panelists were instructed to evaluate the coded samples for color, taste, aroma, mouth feel, and overall acceptability. All panelists participating in the sensory analysis were thoroughly briefed on the evaluation process, including the scoring criteria and sensory attributes to be assessed, to ensure consistency and reliability

in their feedback. Each sensory attribute was rated on a 9-point hedonic scale (1 = dislike extremely and 9 = like extremely). The panelists were given water to rinse their mouth after each evaluation.

Statistical Analysis

GraphPad Prism 8.1 was used for the statistical analysis, all antioxidant studies were performed in triplicate, statistical significance was evaluated using one way analysis of variance (ANOVA), followed by Turkey's multiple range tests to compare the means. Data points correspond to the mean of independent experiments and error bars (S.E.M); the level of significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

In vitro Antioxidant activity and α-Glucosidase inhibition

Functional biscuits fortified with *Sphenostylis stenocarpa* and either fermented or unfermented *Ficus exasperata* were successfully produced and evaluated for their phytochemical composition, antioxidant capacity, α-glucosidase inhibitory activity, proximate composition, and sensory acceptability. The prepared biscuits showed acceptable physical appearance after baking, indicating that partial substitution of wheat flour with *S. stenocarpa* flour and fortification with *F. exasperata* leaf powder did not negatively affect biscuit formation or structural integrity (Fig. 1). Similar observations have been reported in functional bakery products, where incorporation of legume- or plant-based ingredients improved nutritional quality while maintaining acceptable product characteristics [31, 32].

The total phenolic content of the biscuit samples is shown in Fig. 2. All formulations exhibited appreciable phenolic content, with no significant difference among the groups ($p > 0.05$). This indicates that both fermented and unfermented *F. exasperata*-fortified biscuits retained phenolic compounds after baking. Phenolic compounds are important plant secondary metabolites with strong antioxidant properties, mainly due to their ability to donate hydrogen atoms or electrons and stabilize free radicals [33, 34]. The presence of phenolic compounds in the biscuits is nutritionally relevant because oxidative stress plays a major role in the pathogenesis and progression of diabetes mellitus and its complications [35]. Therefore, the phenolic content observed in all formulations suggests that these biscuits may contribute to dietary antioxidant protection.

The total flavonoid content varied significantly among the biscuit formulations (Fig. 3). The formulations containing 40 g of *F. exasperata*, particularly B-SS20-fFE40 and B-SS20-uFE40, generally showed improved flavonoid content compared with formulations containing 20 g of *F. exasperata*. This suggests that increasing the level of *F. exasperata* enhanced the flavonoid composition of the biscuits. Flavonoids are well-known bioactive compounds with antioxidant, anti-inflammatory, and antidiabetic properties [36, 37]. The relatively higher flavonoid level observed in the fermented formulation may be associated with fermentation-induced breakdown of plant cell wall structures, which can release bound phenolics and flavonoids and improve their extractability [16, 38]. Thus, fermentation may have enhanced the availability of some bioactive compounds in *F. exasperata*.

The ferric reducing antioxidant power of the biscuit samples is presented in Fig. 4. The results showed that the biscuits possessed ferric reducing ability, with some significant variation among formulations. Ferric reducing antioxidant power reflects the electron-donating capacity of antioxidants and is commonly used as an index of reducing potential [27, 39]. The reducing ability of the biscuits may be attributed to the combined effects of phenolics, flavonoids, and other antioxidant phytochemicals present in *F. exasperata* and *S. stenocarpa*. This is important because compounds with reducing power can neutralize oxidants and interrupt free radical chain reactions, thereby protecting cells from oxidative damage [40].

The Fe^{2+} chelating ability of the biscuit extracts is shown in Fig. 5. All samples demonstrated iron-chelating capacity, although no significant difference was observed among the formulations ($p > 0.05$). Metal chelation is an important antioxidant mechanism because transition metals such as iron can catalyze the formation of highly reactive hydroxyl radicals through Fenton-type reactions [27, 40]. By chelating Fe^{2+}, the biscuit extracts may reduce metal-induced oxidative damage. The comparable chelating activities observed among the formulations suggest that both fermented and unfermented samples contained bioactive compounds capable of binding metal ions.

The ABTS radical scavenging activity of the biscuit samples is presented in Fig. 6. All formulations showed ABTS radical scavenging ability, with no significant difference among the groups ($p > 0.05$). The ABTS assay is widely used to assess the ability of antioxidants to quench radical cations and reflects the total radical scavenging potential of food extracts [41]. The observed activity suggests that the fortified biscuits contain antioxidant compounds capable of neutralizing free radicals. This antioxidant potential may be beneficial in reducing oxidative stress, particularly in metabolic disorders such as diabetes, where increased production of reactive oxygen species contributes to tissue damage and disease progression [35].

The α-glucosidase inhibitory activity of the biscuit extracts is shown in Fig. 7. All formulations moderately inhibited α-glucosidase activity, with inhibition values of approximately 23–25%, and no significant differences were observed among the samples ($p > 0.05$). α-Glucosidase is an intestinal enzyme involved in the digestion of complex carbohydrates into absorbable glucose. Inhibition of this enzyme delays carbohydrate digestion and glucose absorption, thereby reducing postprandial hyperglycemia [42, 43]. The inhibitory activity observed in this study may be due to the presence of phenolics and flavonoids, which have been reported to inhibit carbohydrate-hydrolyzing enzymes [37]. Although the inhibition was moderate, the result suggests that these biscuits may have potential as functional snack products for supporting postprandial blood glucose control.

Proximate Analysis and Sensory Evaluation

Based on the antioxidant screening results, B-SS20-fFE40 and B-SS20-uFE40 were selected for proximate analysis because they contained the higher inclusion level of *F. exasperata* and showed relatively stronger bioactive profiles. The proximate composition is presented in Table 2. The moisture

content of B-SS20-uFE40 (6.62 ± 0.271) was higher than that of B-SS20-fFE40 (4.97 ± 0.125). Moisture content is an important determinant of shelf stability in baked products because high moisture can increase susceptibility to microbial spoilage and reduces storage quality [31, 32]. Therefore, the lower moisture content of B-SS20-fFE40 may suggest better potential shelf stability.

The fat content of both selected formulations was relatively low, with B-SS20-uFE40 (2.52 ± 0.027) having slightly higher fat content than B-SS20-fFE40 (2.38 ± 0.142). Low-fat functional snacks may be beneficial for consumers seeking to reduce dietary fat intake, especially individuals at risk of obesity, cardiovascular disease, or metabolic syndrome. The ash content was higher in B-SS20-uFE40 (5.09 ± 0.038), suggesting that the unfermented formulation may contain a higher mineral residue. Ash content provides an estimate of total mineral composition in food materials and is commonly used as an indicator of inorganic nutrient contribution [30].

Crude fibre content was also higher in B-SS20-uFE40 (6.89 ± 0.065) than in B-SS20-fFE40 (4.46 ± 0.238). Dietary fibre is nutritionally important because it slows gastric emptying, reduces glucose absorption, improves satiety, and contributes to better glycemic regulation [44, 45]. The higher fibre content of B-SS20-uFE40 (6.89 ± 0.065) may therefore provide additional benefits for blood glucose management and digestive health. In contrast, crude protein content was higher in B-SS20-fFE40 (10.51 ± 0.717). This may be due to fermentation-related improvement in protein availability or concentration. Fermentation can enhance the nutritional quality of plant-based foods by reducing antinutritional factors and improving protein digestibility [38]. The protein contribution of *S. stenocarpa*, a leguminous crop, may also have improved the protein value of the biscuits.

Carbohydrate content was slightly higher in B-SS20-fFE40 (73.64 ± 0.583) than in B-SS20-uFE40 (70.91 ± 0.434). This is expected because biscuits are cereal-based baked products and generally contain high levels of carbohydrates. However, the presence of fibre, phenolics, flavonoids, and α-glucosidase inhibitory compounds may help moderate carbohydrate digestion and glucose release after consumption. Functional foods that combine carbohydrate with bioactive phytochemicals and fibre may therefore be useful in dietary strategies for glycemic control [37, 46].

The sensory evaluation results are shown in Table 3. B-SS20-uFE40 had the highest scores for color, taste, aroma, and overall acceptability, while B-SS20-fFE40 had the highest score for mouthfeel. The better overall acceptability of the unfermented formulation may be due to its more appealing color, milder taste, and preferable aroma. Fermentation may produce desirable nutritional changes, but it can also introduce stronger flavors or aromas that may reduce consumer preference if not properly optimized [47]. Since consumer acceptability is essential for the successful development of functional foods, the sensory advantage of B-SS20-uFE40 is important. However, the fermented formulation still showed acceptable sensory scores and may offer superior nutritional advantages in terms of protein content and antioxidant bioactivity.

Table 2
Proximate composition of functional biscuits

Proximate	B-SS20-fFE40 (%)	B-SS20-uFE40 (%)
Moisture Content	4.97 ± 0.125	6.62 ± 0.271
Fat Content	2.38 ± 0.142	2.52 ± 0.027
Ash Content	4.31 ± 0.105	5.09 ± 0.038
Crude Fibre	4.46 ± 0.238	6.89 ± 0.065
Crude Protein	10.51 ± 0.717	7.97 ± 0.629
Carbohydrate	73.64 ± 0.583	70.91 ± 0.434
Data are represented in mean ± SD		

Table 3
Sensory evaluation of functional biscuits

Parameters	B-SS20-fFE40	B-SS20-uFE40
Color	4.6 ± 1.342	7 ± 1
Taste	4.4 ± 2.074	5.6 ± 1.517
Aroma	4.4 ± 1.517	5 ± 1
Mouth feel	5.6 ± 2.074	5.2 ± 1.924
Overall acceptability	5.6 ± 1.140	6.8 ± 0.447
Data are represented in mean ± SD		

CONCLUSION

These findings collectively highlight the immense but largely underexploited potential of these indigenous African plant species as functional food ingredients and provide a compelling scientific basis for their incorporation into widely consumed baked products as an affordable, accessible, and culturally acceptable dietary strategy for supporting glycemic regulation and antioxidant defense in at-risk populations. However, *in vivo* studies, glycemic index determination, and bioavailability assessments are recommended to further validate the clinical relevance of these functional biscuits.

Declarations

Conflict of interest:

The authors declare no conflicts of interest relevant to this manuscript.

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Author Contribution

S.A designed the study. S. A., L., and O. V. supervised the study. O.V., J. O., J. A., F. I., S. A., D. O., O. V., B. E., O. T., F. D., G. B., S. O., C. O., S. E., J. A., O. K., and F. A conducted the methodology. S. A., and L., provided the materials. L. and O. V. analyzed and interpreted the results. L., writes the original draft of the manuscript. L. and S. A., reviewed and edited the manuscript. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

Data Availability

All relevant data are within the paper.

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Figures

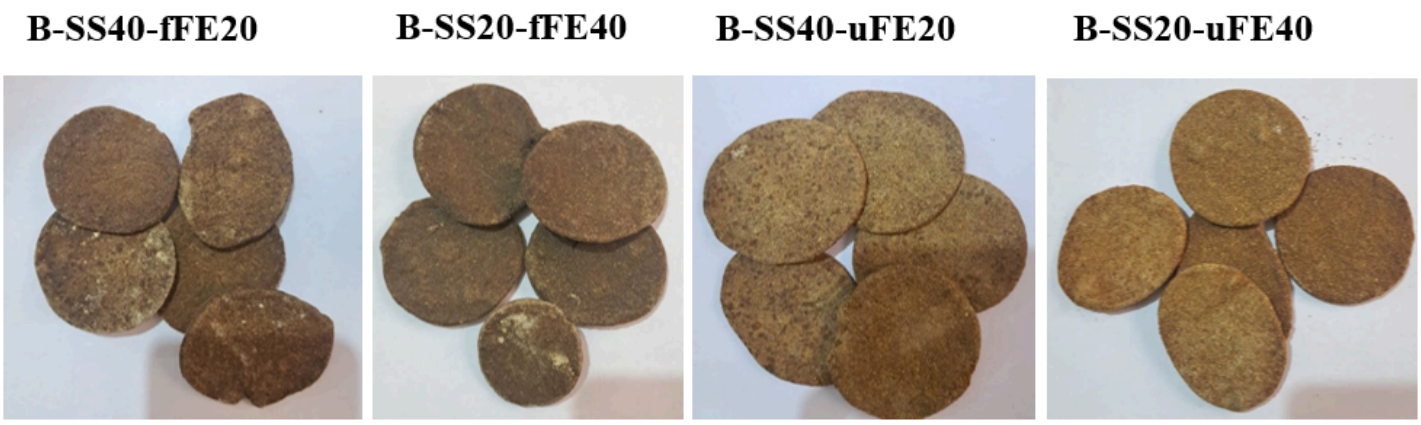

Figure 1

Photo of Biscuits.

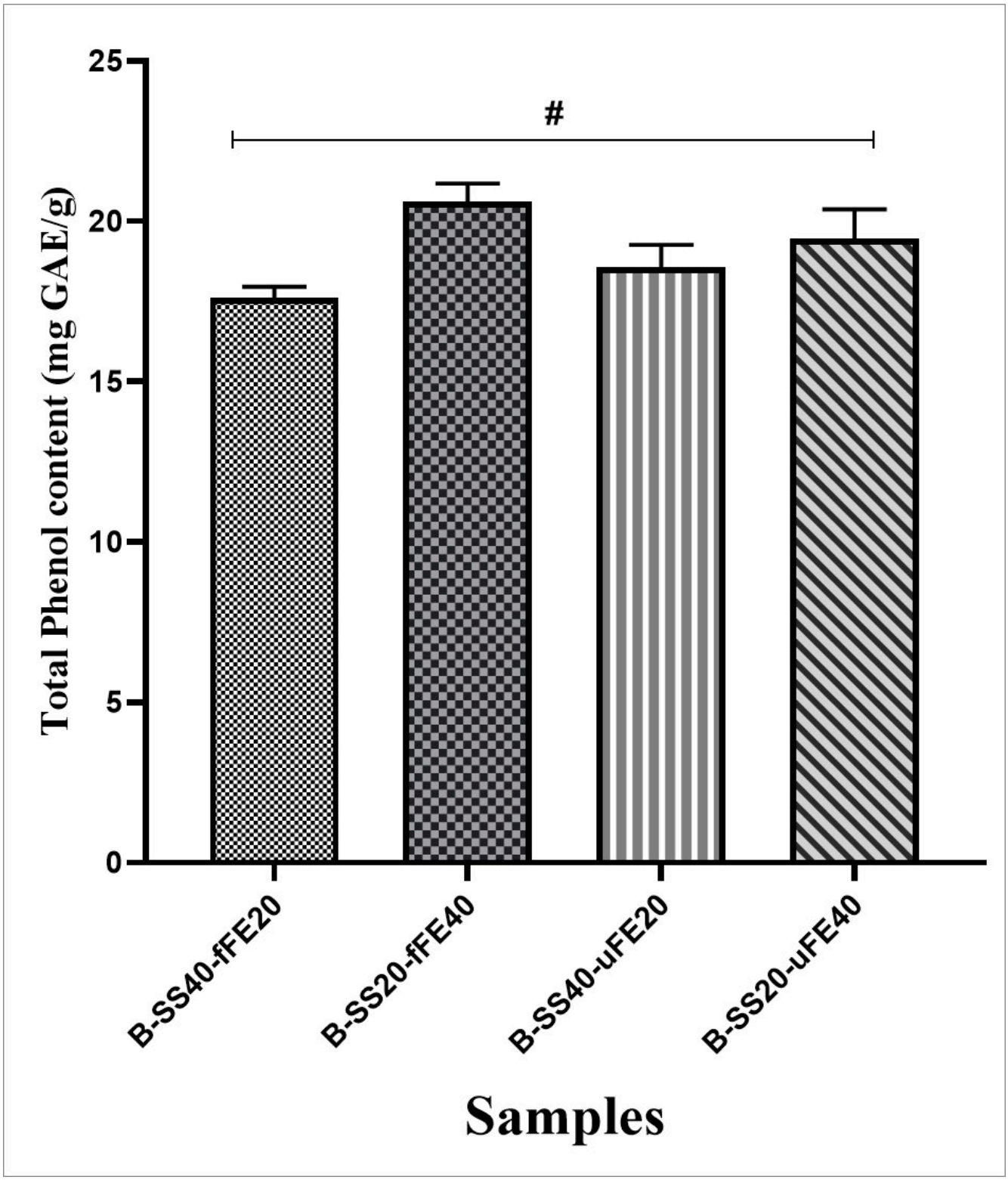

Figure 2

Total Phenol content of Biscuit fortified with *Sphenostylis stenocarpa* and *Ficus exasperata*.

Bars are represented in mean ± SEM. #Values are non-significantly different.

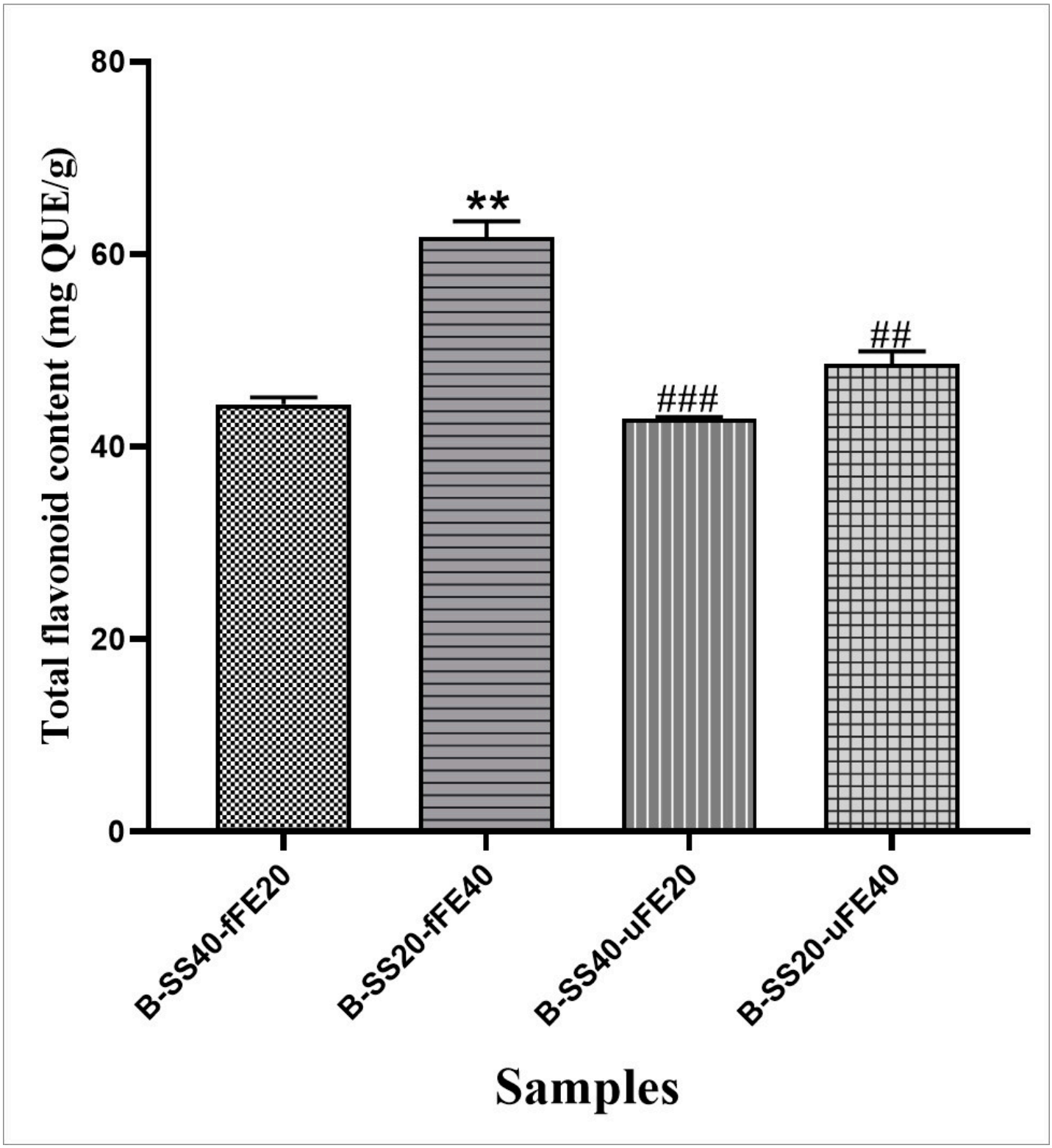

Figure 3

Total Flavonoid content of Biscuit fortified with *Sphenostylis stenocarpa* and *Ficus exasperata*

Bars are represented in mean ± SEM. Values are significantly different **0.001 ≤ p ≤ 0.01 compared to B-SS40-fFE20, ##0.001 ≤ p ≤ 0.01, ###0.0001 ≤ p ≤ 0.001 compared to B-SS20-fFE40.

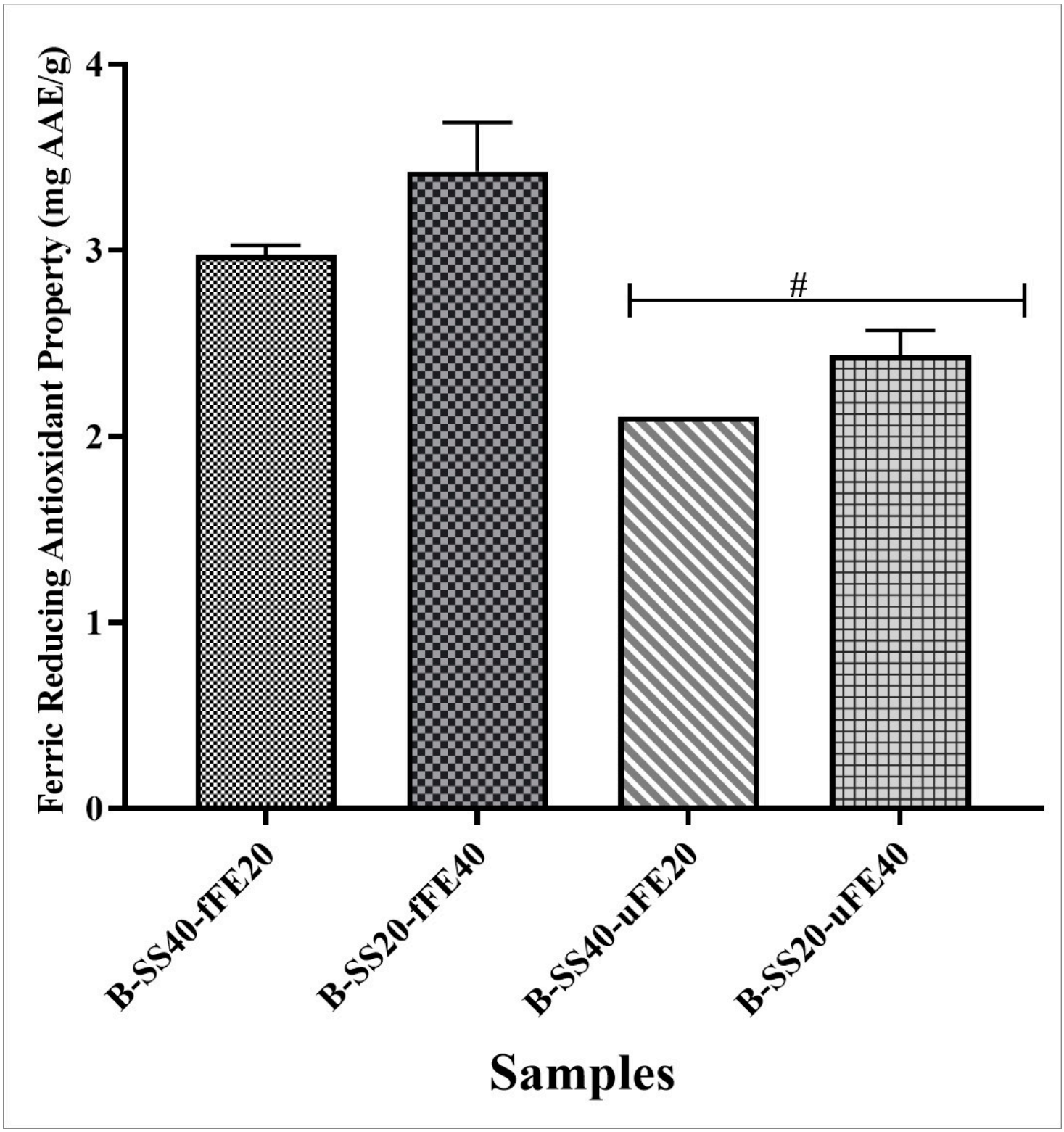

Figure 4

Ferric Reducing Antioxidant Power of Biscuit fortified with *Sphenostylis stenocarpa* and *Ficus exasperata*.

Bars are represented in mean ± SEM. Values are significantly different $^{\#}0.01 \leq p \leq 0.05$ compared to B-SS20-fF40.

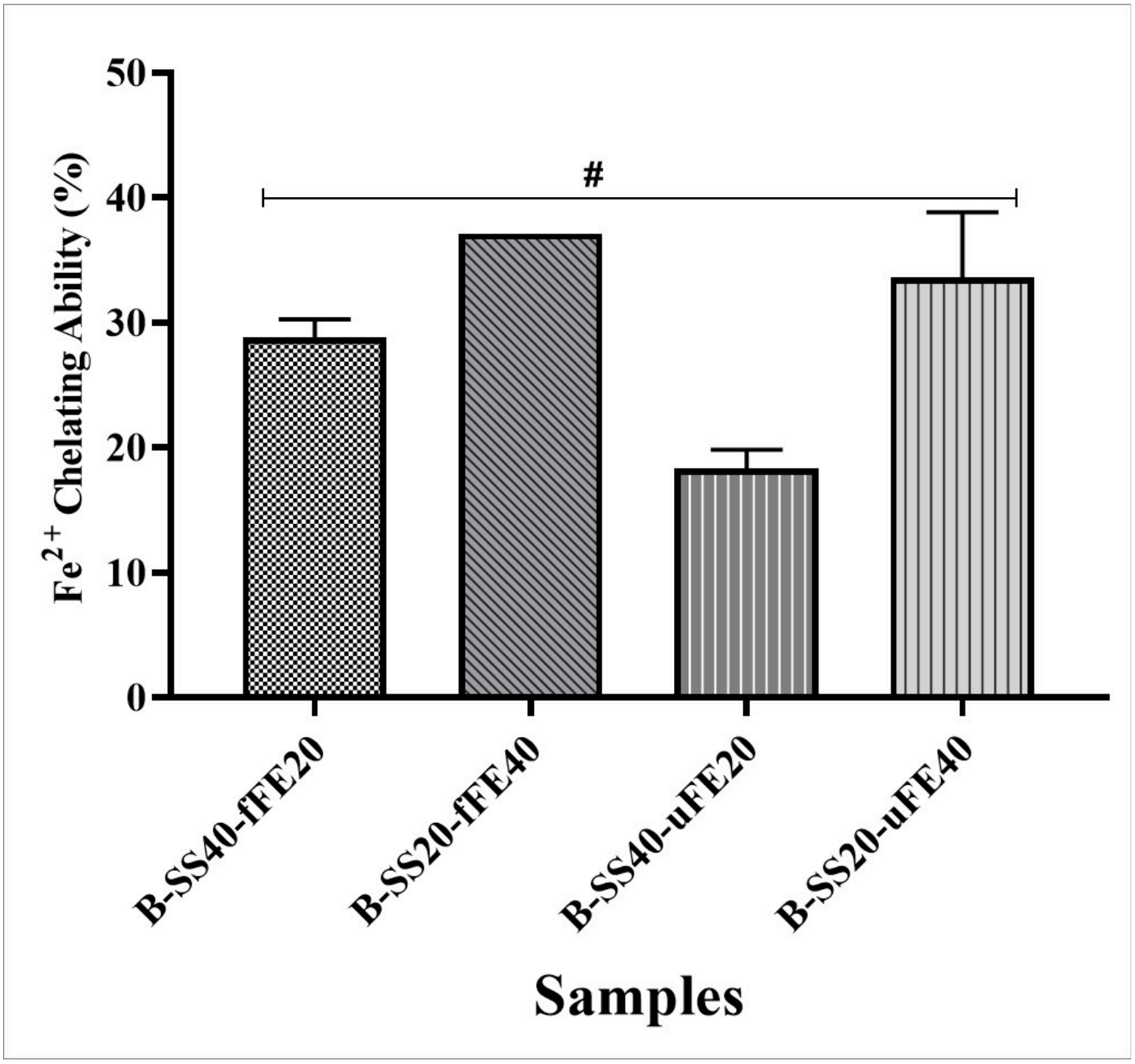

Figure 5

Fe^{2+} Chelating Ability of Biscuit fortified with *Sphenostylis stenocarpa* and *Ficus exasperata*.

Bars are represented in mean ± SEM. $^{\#}$Values are non-significantly different.

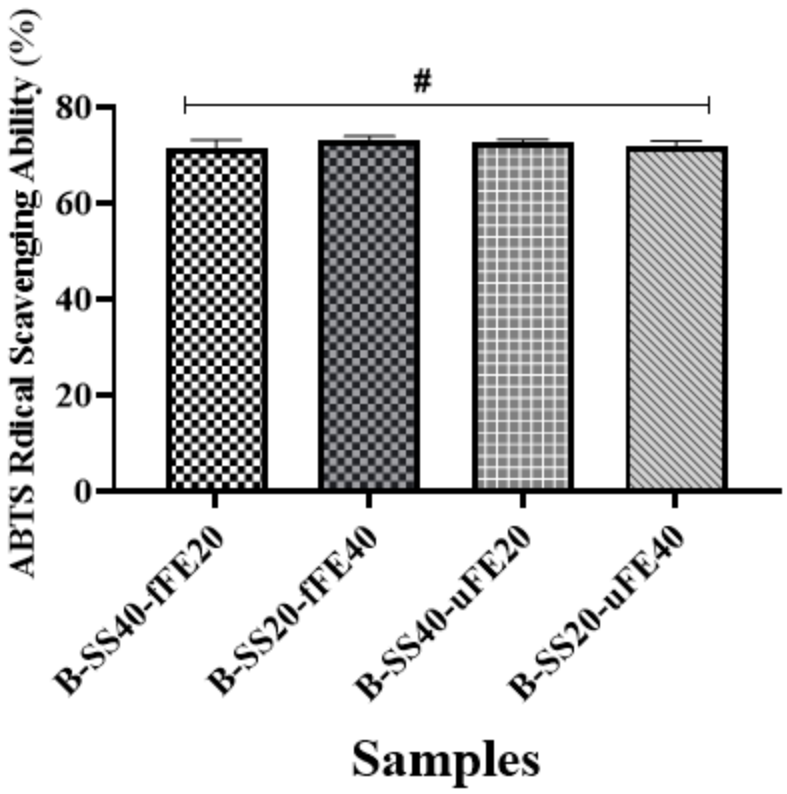

Figure 6

ABTS Radical Scavenging Ability of Biscuit fortified with *Sphenostylis stenocarpa* and *Ficus exasperata*. Bars are represented in mean ± SEM. #Values are non-significantly different.

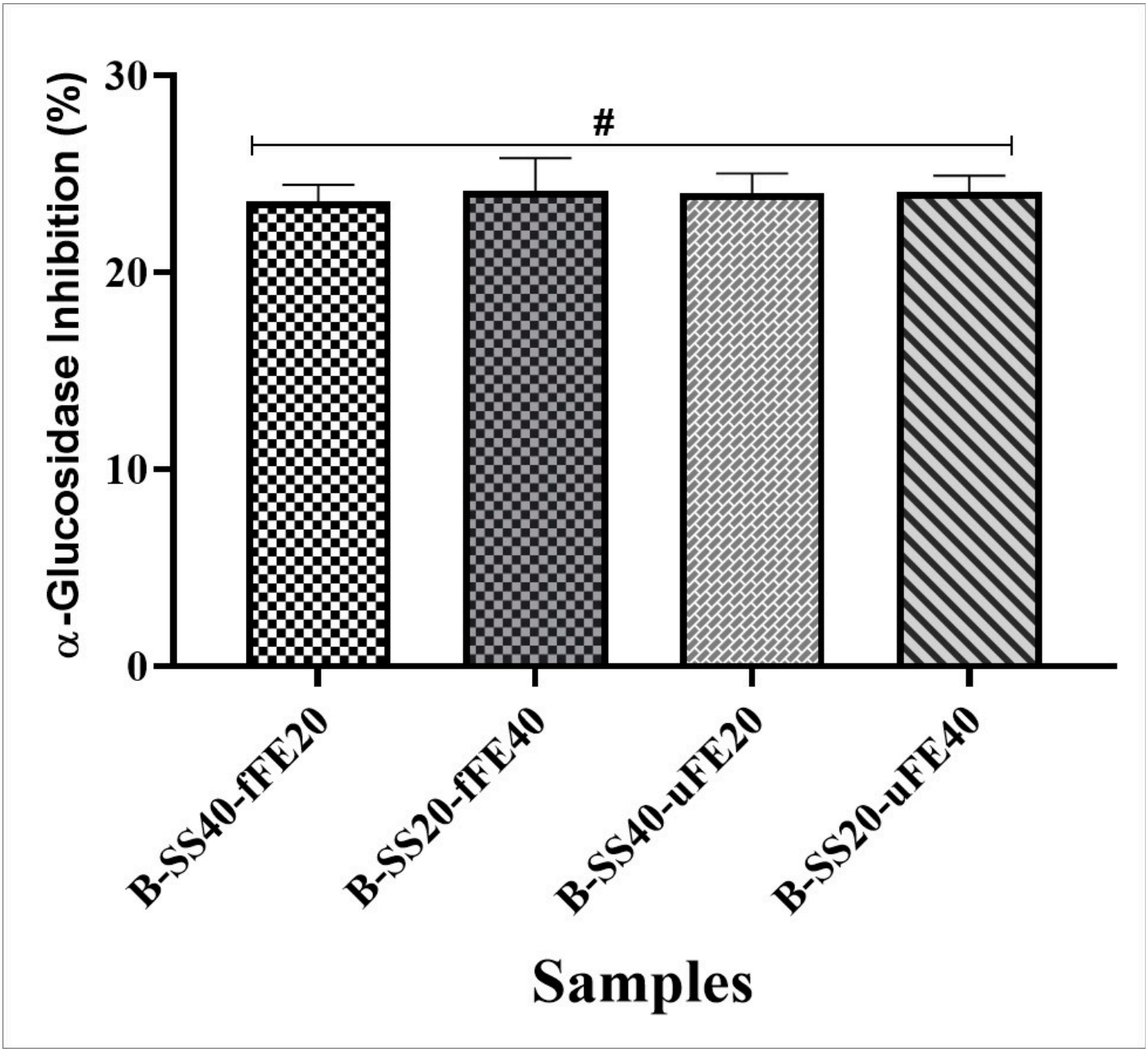

Figure 7

Inhibitory effect of Biscuit fortified with *Sphenostylis stenocarpa* and *Ficus exasperata* on α-Glucosidase.

Bars are represented in mean ± SEM. #Values are non-significantly different.