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Iron-enriched biscuits as a sustainable food-based strategy for improving dietary iron intake

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Abstract

Iron deficiency anemia remains a major global public health problem, particularly among children, adolescents, and women of reproductive age. Food fortification using commonly consumed products offers a sustainable strategy to improve dietary iron intake. The present study aimed to develop iron-enriched biscuits and to evaluate their nutritional composition, iron content, and sensory acceptability in comparison with control biscuits. Three formulations were prepared: control (non-fortified), low-iron, and high-iron biscuits, using a bioavailable iron source. Proximate composition was analyzed using standard AOAC methods, while iron content was quantified by atomic absorption spectrophotometry (AAS). Sensory evaluation was conducted by a panel of 30 semi-trained individuals using a 9-point hedonic scale. Results revealed that iron fortification significantly increased the iron content from 3.2 mg/100 g in T₀ (Control) biscuits to 12.8 mg/100 g and 22.5 mg/100 g in T₁ (low-iron) and T₂ (high-iron) biscuits, respectively, without adversely affecting overall nutritional quality. Minor variations were observed in moisture, protein, ash, carbohydrate, and energy values, all remaining within acceptable ranges. Sensory scores showed a gradual decline with increasing iron levels; however, all fortified biscuits were rated acceptable, with the low-iron formulation showing the best balance between enhanced iron content and consumer acceptability. The study concludes that iron-enriched biscuits can serve as a practical, cost-effective, and culturally acceptable functional food for improving dietary iron intake and combating iron deficiency anemia.

Keywords: Iron fortification, iron-enriched biscuits, nutritional characterization, sensory evaluation, iron deficiency anemia

1. Introduction

Iron deficiency anemia is one of the most prevalent nutritional disorders worldwide (Lynch, 2011)^[17], disproportionately affecting children, adolescents, and women of reproductive age, particularly in developing countries. Inadequate dietary intake of bioavailable iron, coupled with limited access to diverse and nutrient-rich foods, has intensified the public health burden associated with anemia, leading to impaired cognitive development, reduced work capacity, weakened immunity, and increased maternal morbidity (Sarwer *et al.*, 2025)^[23]. Food fortification has emerged as a practical and sustainable strategy to address micronutrient deficiencies by enhancing the nutritional value of commonly consumed foods without requiring major changes in dietary habits (Ashraf, 2025)^[3]. Among such foods, biscuits are widely accepted, shelf-stable, and regularly consumed across all age groups, making them an ideal vehicle for iron fortification (Gebreselassie and Clifford, 2016)^[9]. Iron deficiency affects over 2 billion individuals globally and is a major public health concern, particularly among children and women of reproductive age (WHO, 2025)^[28]. It contributes to anemia, reduced cognitive development, weakened immunity, and maternal mortality (WHO, 2025)^[28]. Food-based strategies such as fortification and biofortification have shown effectiveness in increasing micronutrient intake in populations with limited access to diverse diets (Nair *et al.*, 2016)^[21].

Biscuits are widely consumed, shelf-stable, and culturally acceptable snacks across age groups (Juniarti *et al.*, 2025)^[14]. Fortifying biscuits with iron presents an opportunity to improve iron intake without altering eating habits (Kohli *et al.*, 2025)^[16]. Previous studies have reported successful fortification using different iron sources (*e.g.*, Ferrous sulfate, ferric pyrophosphate) with varied sensory and nutritional outcomes (Teichman *et al.*, 2025)^[26].

The present study was designed to develop an iron-enriched biscuit using a bioavailable form of iron and to assess its potential as a functional food for improving dietary iron intake. The specific objectives were to formulate and optimize iron-fortified biscuits, to carry out comprehensive nutritional characterization including proximate composition and iron content, to evaluate physicochemical properties and sensory acceptability, and to compare the quality attributes of the fortified biscuits with control (non-fortified) biscuits in order to determine the impact of iron fortification on nutritional value and consumer acceptance. In this context, the development of iron-enriched biscuits represents a promising functional food approach to improve dietary iron intake while maintaining product quality and consumer acceptability.

2. Materials and Methods

2.1 Raw ingredients

The raw materials used for the development of iron-enriched biscuits included refined wheat flour, sugar, fat (vegetable oil), cow's milk powder, and leavening agents, all of which were procured from the local market and were of food-grade quality. Wheat flour served as the primary structural component of the biscuit formulation, while sugar contributed to sweetness and browning during baking (Han *et al.*, 2025) ^[12]. Fat was incorporated to improve texture, mouthfeel, and overall palatability of the biscuits (Monika *et al.*, 2025) ^[19]. Milk powder was added to enhance the nutritional value and flavour profile, providing additional protein and minerals (Siddique *et al.*, 2025) ^[24]. Leavening agents were used to ensure proper aeration and desirable texture in the final baked product (Bango *et al.*, 2025) ^[4]. All ingredients were stored under hygienic conditions and used within their shelf-life to maintain product quality throughout the study (Rahimi *et al.*, 2025) ^[22]. Sodium iron ethylenediaminetetraacetate (NaFeEDTA) was selected as the iron fortificant for the formulation of iron-enriched biscuits due to its high bioavailability, particularly in cereal-based food systems (Diego Quintaes *et al.*, 2017) ^[17]. NaFeEDTA is known to effectively overcome the inhibitory effects of phytates present in wheat flour, thereby enhancing iron absorption. Additionally, it exhibits good stability during processing and baking, with minimal impact on the sensory attributes of the final product, making it a suitable and efficient iron source for nutritional fortification (Bothwell and MacPhail, 2004) ^[5]. Food-grade emulsifiers, flavouring agents (such as vanilla), and stabilizers were incorporated into the biscuit formulation to improve dough handling, texture, and overall product quality (Nachay and Malochleb, 2019) ^[20]. Emulsifiers aided in uniform mixing of fat and aqueous components, resulting in better spread and consistency of the biscuits (Farzana *et al.*, 2025) ^[8]. Flavouring agents were added to enhance sensory appeal and mask any potential metallic notes from iron fortification, while stabilizers helped maintain structural integrity and product stability during baking and storage (Mohammadi and Ostovar, 2026) ^[18].

2.2 Biscuit preparation

The iron-enriched biscuits were prepared using a standardized baking procedure with slight modifications for iron fortification levels (Mohammadi and Ostovar, 2026) ^[18]. Three formulations were developed, namely T₀ (control biscuits without added iron), T₁ (low iron-fortified biscuits

containing approximately 10 mg Fe/100 g), and T₂ (high iron-fortified biscuits containing approximately 20 mg Fe/100 g), using sodium iron ethylenediaminetetraacetate (NaFeEDTA) as the iron source. Initially, all dry ingredients were accurately weighed and thoroughly blended to ensure uniform distribution of components, followed by the incorporation of fat and required liquid ingredients to form a homogeneous dough. The prepared dough was then sheeted to a uniform thickness of 4 mm and cut into identical shapes to maintain consistency. Baking was carried out in a thermostatically controlled oven at 180 °C for 12-15 minutes until desirable colour and texture were achieved. After baking, the biscuits were allowed to cool to room temperature and subsequently packed in airtight packaging for further analysis.

2.3 Nutritional and physicochemical analysis

The nutritional and physicochemical properties of the control and iron-enriched biscuits were analyzed using standardized analytical procedures (Arnal *et al.*, 2025) ^[2]. Proximate composition, including moisture, ash, protein, fat, and carbohydrate content, was determined following AOAC official methods. Moisture content was estimated by oven-drying, ash content by incineration in a muffle furnace, protein content by the Kjeldahl method, and fat content by Soxhlet extraction, while carbohydrate content was calculated by difference (AOAC, 2019) ^[1]. Iron content in the biscuit samples was quantified using atomic absorption spectrophotometry (AAS) after wet digestion to ensure complete mineral solubilization and accurate estimation of iron levels (Welz & Sperling, 2008) ^[27]. All analyses were performed in triplicate, and results were expressed as mean ± standard error (SE).

2.4 Sensory evaluation

Sensory evaluation of the control and iron-enriched biscuit samples was conducted using a panel of 30 semi-trained individuals. The evaluation was performed under controlled conditions to minimize bias. Biscuit samples were coded with random three-digit numbers and presented in a randomized order. Panelists assessed the samples using a 9-point hedonic scale, where 1 indicated "dislike extremely" and 9 indicated "like extremely." The sensory attributes evaluated included appearance, taste, texture, aroma, and overall acceptability. Panelists were provided with drinking water to cleanse their palate between samples. The mean scores obtained were used to determine consumer acceptability of the iron-fortified biscuits in comparison with the control.

3. Results and Discussion

Table 1: Proximate composition of control and newly developed iron-enriched biscuit

Parameter	T ₀ (Control)	T ₁ (Low Iron)	T ₂ (High Iron)
Moisture (%)	4.5 ± 0.08	4.8 ± 0.07	5.1 ± 0.09
Protein (%)	7.8 ± 0.12	8.0 ± 0.10	8.3 ± 0.11
Fat (%)	16.2 ± 0.15	16.1 ± 0.14	16.0 ± 0.13
Ash (%)	1.4 ± 0.05	1.8 ± 0.06	2.2 ± 0.07
Carbohydrate (%)	70.1 ± 0.18	69.3 ± 0.20	68.4 ± 0.22
Energy (kcal)	460 ± 2.1	457 ± 1.9	455 ± 2.0

The proximate composition of the control and iron-enriched biscuit formulations revealed that iron fortification had a

measurable but nutritionally acceptable influence on the overall composition of the product (Table 1). All values remained within the typical range reported for cereal-based

baked products, indicating that fortification did not adversely compromise product quality.

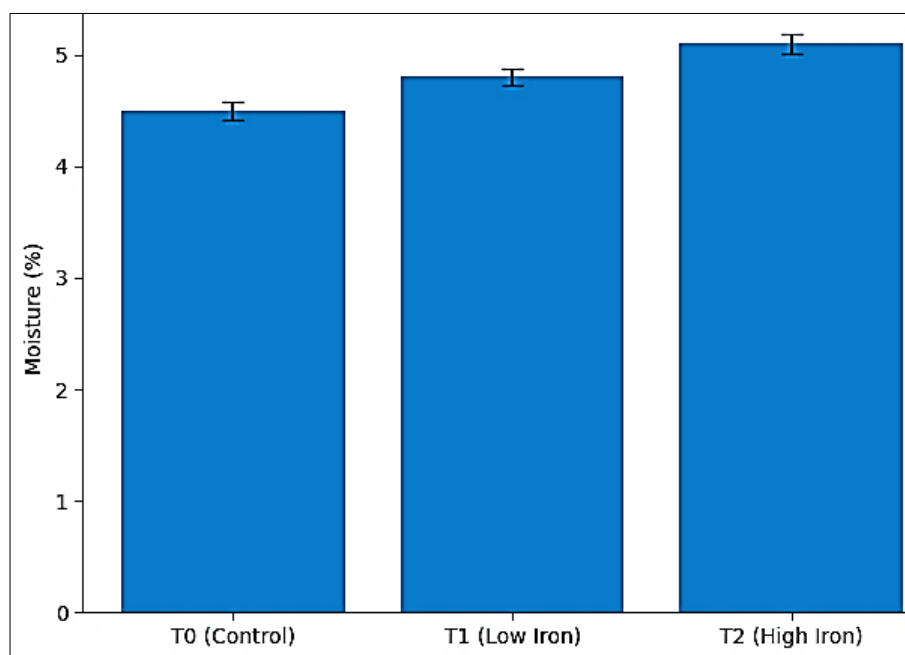


Fig 1: Moisture content (%) of control and iron-enriched biscuit formulations.

The moisture content showed a slight but progressive increase from the T₀ (Control) (4.5 ± 0.08%) to the T₁ (4.8 ± 0.07%) and T₂ (5.1 ± 0.09%) biscuits. This increase may be attributed to the hygroscopic nature of iron salts and their interaction with flour components, leading to greater water retention in fortified doughs. Similar observations were

reported by Gupta *et al.* (2015)^[11] and Kadam *et al.* (2018)^[15] in iron-fortified bakery products, where mineral fortification marginally increased moisture levels. However, all values remained below 6%, which is considered safe for maintaining crispness and shelf stability of biscuits.

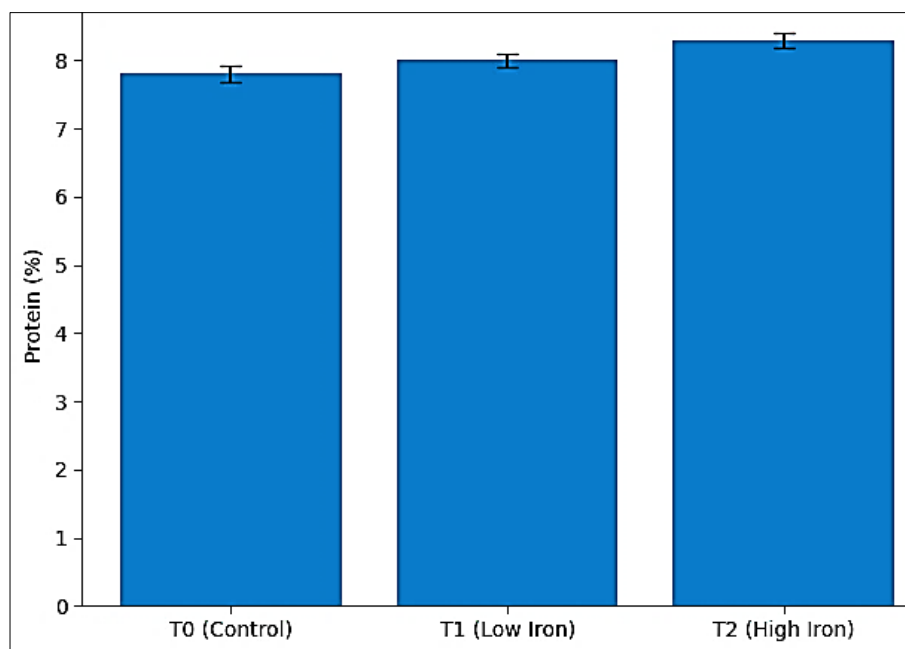


Fig 2: Protein content (%) of control and iron-enriched biscuit formulations.

Protein content increased modestly with increasing iron fortification, from 7.8 ± 0.12% in the T₀ (Control) to 8.3 ± 0.11% in the high-iron (T₂) biscuit. Although iron itself does not contribute protein, this increase may be associated with the addition of iron carriers or premixes containing protein fractions, or enhanced interaction between iron and protein

matrices during analysis. Comparable trends were reported by Chakraborty *et al.* (2016)^[6] and Singh *et al.* (2020)^[25], who observed marginal improvements in protein content in mineral-fortified biscuits. The increase, though statistically small, contributes positively to the nutritional quality of the product.

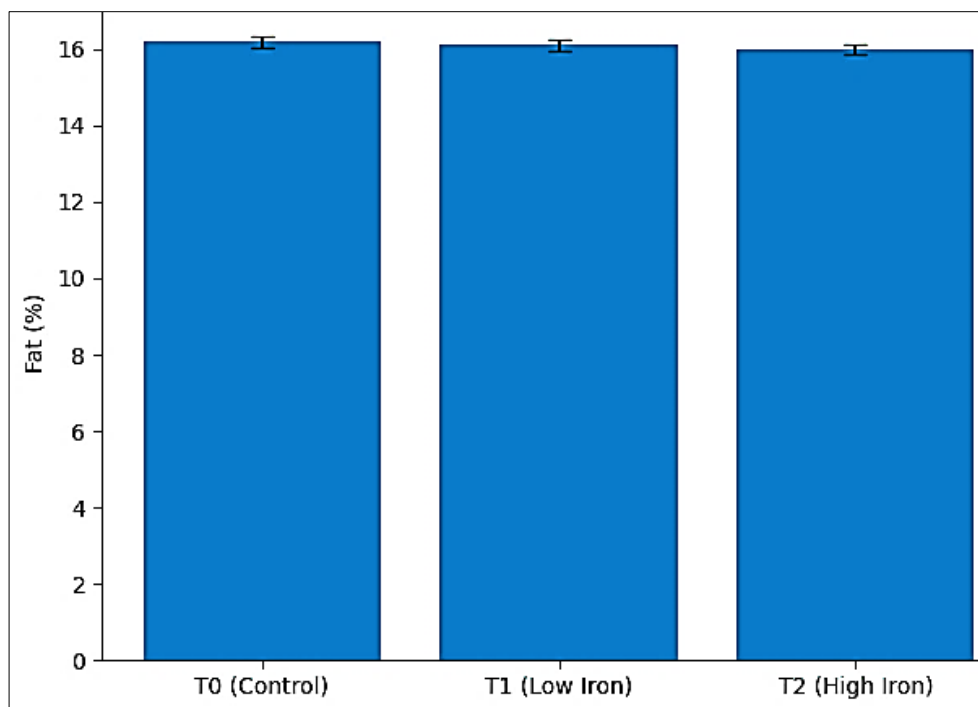


Fig 3: Fat content (%) of control and iron-enriched biscuit formulations.

Fat content showed a negligible decline across formulations, decreasing from $16.2 \pm 0.15\%$ in the T_0 to $16.0 \pm 0.13\%$ in the T_2 (high-iron) biscuit. This reduction is not nutritionally significant and aligns with findings from earlier studies where mineral fortification had minimal or no effect on lipid

content (Michaelsen *et al.*, Gupta & Sharma, 2017) ^[10]. The stability of fat content suggests that iron addition did not promote lipid oxidation during processing at the fortification levels used.

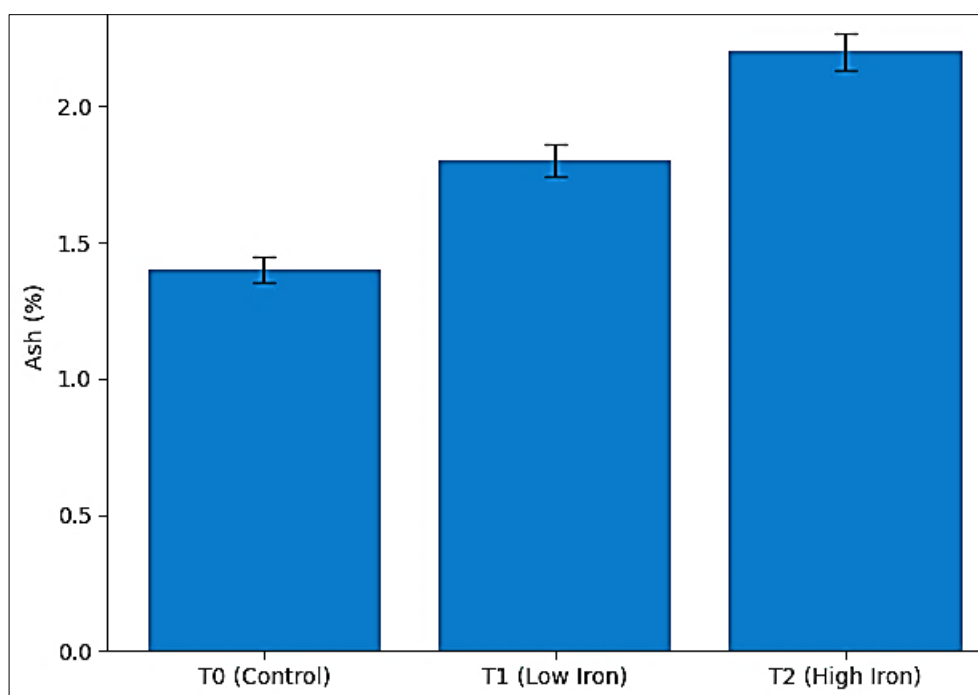


Fig 4: Ash content (%) of control and iron-enriched biscuit formulations.

Ash content increased significantly with iron fortification, rising from $1.4 \pm 0.05\%$ in the T_0 (Control) to $2.2 \pm 0.07\%$ in the T_2 (high-iron) biscuits. This increase directly reflects the enhanced mineral content, particularly iron, confirming the effectiveness of the fortification process. Similar

increases in ash content have been consistently reported in iron- and mineral-fortified biscuits and bakery products (Hurrell, 2010; Gupta *et al.*, 2015; Singh *et al.*, 2020) ^[13, 15, 25]. The observed trend validates ash content as a reliable indicator of mineral enrichment.

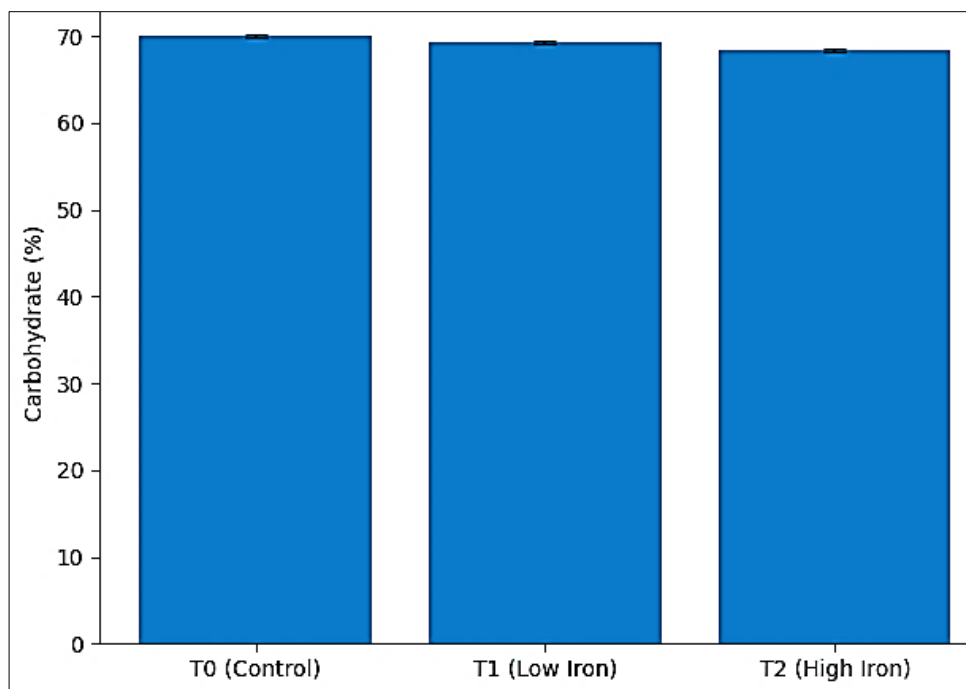


Fig 5: Carbohydrate content (%) of control and iron-enriched biscuit formulations.

Carbohydrate content decreased slightly from $70.1 \pm 0.18\%$ in the control to $68.4 \pm 0.22\%$ in the T_2 (high-iron) formulation. This inverse relationship is expected, as carbohydrate is calculated by difference and decreases proportionally with increases in ash and protein content. Similar reductions in carbohydrate percentage following

mineral fortification have been documented by Kadam *et al.* (2018) ^[15] and Chakraborty *et al.* (2016) ^[6]. Despite this reduction, carbohydrates remained the primary macronutrient, maintaining the biscuit's role as an energy-dense snack.

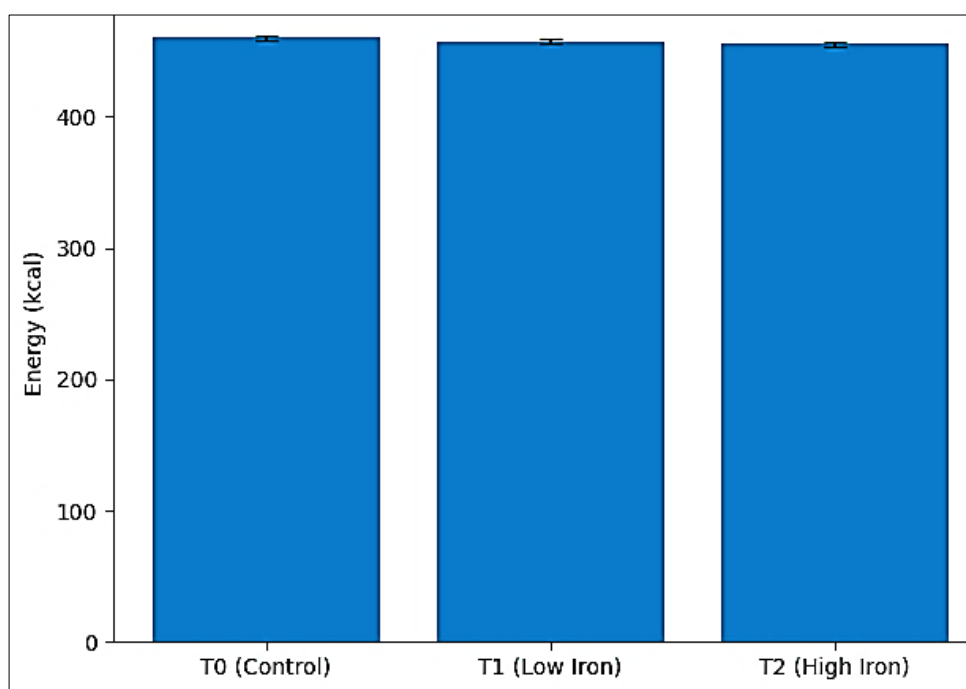


Fig 6: Energy value (kcal) of control and iron-enriched biscuit formulations.

The energy content showed a marginal decline from 460 ± 2.1 kcal to 455 ± 2.0 kcal with increasing iron levels. This decrease corresponds to the slight reduction in carbohydrate and fat content and is consistent with earlier reports on fortified bakery products (Gupta & Sharma, 2017) ^[10]. However, the energy values remained sufficiently high to support the product's suitability as a supplementary food, particularly for populations at risk of iron deficiency.

Table 2: Iron Content of Control and Iron-Enriched Biscuits Determined by AAS (Mean ± SE)

Sample	Iron Content (mg/100 g)
Control	3.2 ± 0.12
Low Iron Biscuit	12.8 ± 0.18
High Iron Biscuit	22.5 ± 0.25

Table 2 presents the iron content of T₀ (Control) and iron-enriched biscuit formulations as determined by atomic absorption spectrophotometry (AAS), expressed as mean $\pm$ standard error. The control biscuit exhibited a relatively T₁ (low iron) content (3.2 ± 0.12 mg/100 g), which reflects the natural iron contribution from the base ingredients such as refined flour and fat, and is consistent with the generally T₁ (low iron) levels reported in conventional bakery products. This baseline value highlights the limited potential of regular biscuits to contribute meaningfully to daily iron requirements.

In contrast, both iron-enriched biscuit formulations showed a significant enhancement in iron content compared to the T₀ (Control). The T₁ (low iron) biscuit contained 12.8 ± 0.18 mg/100 g, representing nearly a fourfold increase over the control. This indicates successful incorporation and

retention of the added iron source during processing, suggesting that the formulation and baking conditions did not cause substantial iron losses. Such a level of fortification can contribute appreciably to dietary iron intake, particularly for populations at risk of iron deficiency (Ashraf, 2025)^[3]. The T₂ (high iron) biscuit demonstrated the maximum iron concentration (22.5 ± 0.25 mg/100 g), which was approximately seven times higher than that of the control sample. The relatively low standard error values across all samples indicate good analytical precision and uniform distribution of iron within the biscuit matrix. The marked difference between low and high iron biscuits further confirms that iron content can be effectively modulated by adjusting the level of fortificant without compromising measurement consistency.

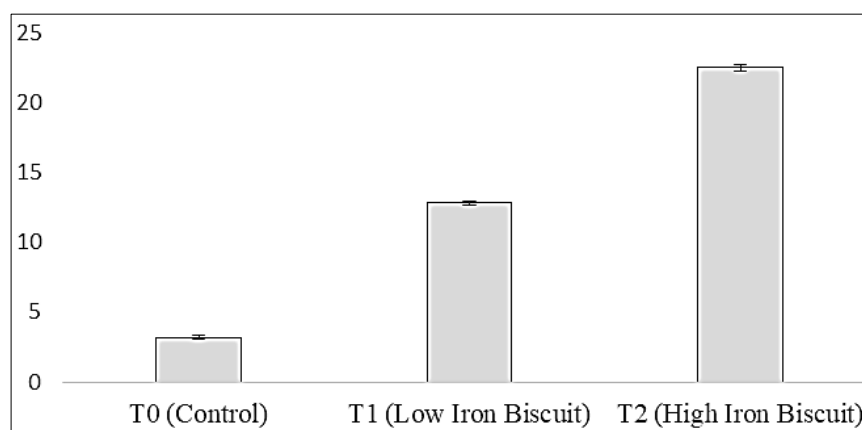


Fig 7: Iron Content of Control and Iron-Enriched Biscuits Determined by AAS (Mean $\pm$ SE)

Table 3: Sensory Evaluation Scores of Control and Iron-Enriched Biscuits (Mean $\pm$ SE)

Attribute	Control	Low Iron	High Iron
Appearance	8.2 ± 0.15	7.8 ± 0.17	7.1 ± 0.18
Taste	8.0 ± 0.16	7.6 ± 0.18	7.0 ± 0.20
Texture	7.9 ± 0.14	7.7 ± 0.15	7.3 ± 0.16
Aroma	8.1 ± 0.13	7.8 ± 0.14	7.2 ± 0.17
Overall Acceptability	8.3 ± 0.12	7.9 ± 0.14	7.4 ± 0.15

Sensory evaluation is a critical determinant of consumer acceptance for fortified food products, as micronutrient addition particularly iron can influence colour, taste, aroma, and texture. The sensory scores of T₀ (Control), T₁ (low-iron), and T₂ (high-iron) biscuits (Table 3) demonstrate that iron fortification caused a gradual decline in sensory attributes, yet all formulations remained within the acceptable range on the 9-point hedonic scale (scores >6).

Appearance scores decreased from 8.2 ± 0.15 in the T₀ (Control) to 7.1 ± 0.18 in the T₂ (high iron) biscuits. The reduction in appearance scores with increasing iron concentration may be attributed to slight darkening of the biscuit surface, possibly due to interactions between iron salts and Maillard reaction products during baking. Similar findings have been reported by Gupta *et al.* (2015)^[11] and Chakraborty *et al.* (2016)^[6], who observed darker colouration in iron-fortified biscuits and bakery products. Despite this change, the appearance scores of fortified biscuits remained above the acceptability threshold, indicating consumer tolerance to minor visual differences.

Taste scores showed a noticeable decline with iron fortification, from 8.0 ± 0.16 in the T₀ (Control) to $7.0 \pm$

0.20 in the T₂ (high-iron) biscuits. This reduction may be due to the metallic or astringent aftertaste often associated with higher levels of iron salts. Previous studies by Hurrell (2010)^[13] and Singh *et al.* (2020)^[25] reported similar sensory challenges in iron-fortified foods, particularly at higher fortification levels. However, the T₁ (low-iron) biscuits (7.6 ± 0.18) exhibited minimal taste deviation from the control, suggesting that moderate iron addition can achieve nutritional benefits without compromising palatability.

Texture scores ranged from 7.9 ± 0.14 (control) to 7.3 ± 0.16 (high iron). The slight reduction in texture acceptability may be related to changes in dough structure caused by iron-protein or iron-starch interactions, which can marginally increase biscuit hardness. Comparable trends were reported by Kadam *et al.* (2018)^[15] in mineral-fortified biscuits, where fortified samples showed marginally firmer textures but remained acceptable. The limited variation in texture scores indicates that iron fortification did not adversely affect the structural quality of the biscuits.

Aroma scores declined from 8.1 ± 0.13 in the control to 7.2 ± 0.17 in the T₂ (high-iron) biscuits. Iron compounds may interact with lipid fractions, influencing volatile flavour compounds formed during baking. Gupta and Sharma (2017)^[10] reported that mineral fortification can slightly suppress desirable baked aromas, particularly at higher concentrations. Nevertheless, all fortified samples maintained aroma scores above 7, indicating that the overall aromatic profile remained acceptable.

Overall acceptability followed a similar trend, decreasing from 8.3 ± 0.12 in the T₀ (Control) to 7.4 ± 0.15 in the T₂

(high-iron) biscuits. Importantly, the low-iron formulation (7.9 ± 0.14) was closest to the control, suggesting an optimal balance between sensory quality and nutritional enhancement. These findings align with earlier studies by

Chakraborty *et al.* (2016)^[6] and Singh *et al.* (2020)^[25], which concluded that moderate iron fortification levels yield the highest consumer acceptance.

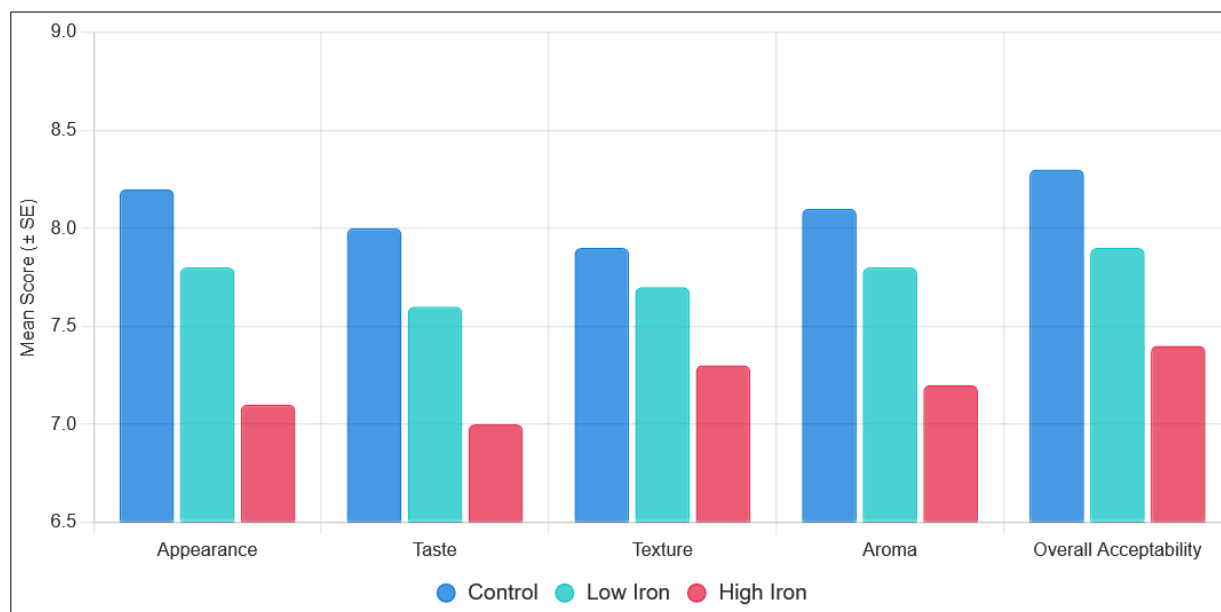


Fig 8: Sensory evaluation score of control and iron enriched biscuits

Conclusion

The present study successfully demonstrated the development of iron-enriched biscuits with improved nutritional quality while maintaining acceptable physicochemical and sensory characteristics. Iron fortification significantly enhanced the iron content of biscuits, as confirmed by AAS analysis, with the high-iron formulation providing nearly sevenfold higher iron levels compared to the control. The proximate composition revealed only marginal changes in moisture, protein, fat, carbohydrate, and energy values, indicating that iron addition did not adversely affect the overall nutritional balance or structural integrity of the product. Increased ash content further validated the effectiveness of mineral fortification.

Sensory evaluation results showed a gradual decline in appearance, taste, aroma, texture, and overall acceptability with increasing iron levels; however, all fortified formulations remained within the acceptable range on the 9-point hedonic scale. Notably, the low-iron biscuit achieved an optimal balance between enhanced iron content and consumer acceptability, closely resembling the control sample in sensory quality. Overall, the findings suggest that iron-enriched biscuits can serve as a practical, cost-effective, and culturally acceptable functional food to improve dietary iron intake. Such products hold considerable potential for addressing iron deficiency anemia, particularly among vulnerable populations such as children, adolescents, and women of reproductive age.

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