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FORMULATION AND EVALUATION OF IRON FORTIFIED MILLET BASED NUTRACEUTICAL EDIBLE CUPS

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Abstract:

Background: Iron deficiency anemia remains one of the most prevalent micronutrient deficiencies worldwide, particularly among women and children. Functional foods enriched with iron offer an effective dietary strategy to improve iron intake. Millets are nutrient-dense cereals rich in dietary fiber, minerals, antioxidants, and bioactive compounds, making them suitable ingredients for nutraceutical product development.
Objective: The present study aimed to formulate and evaluate iron-fortified millet-based nutraceutical cups using finger millet flour and foxtail millet flour enriched with ferrous sulphate and to assess their physicochemical, nutritional, microbiological, and sensory characteristics.
Methods: Four formulations (F1 and F4) containing finger millet flour, foxtail millet flour, jaggery, milk powder, almond powder, ghee, ferrous sulphate, and citric acid were prepared. The products were evaluated for organoleptic properties, weight variation, moisture content, ash value, pH, iron content, texture, nutritional composition, and microbial quality using standard analytical methods.
Results: The optimized formulation (F4) demonstrated superior sensory characteristics, including improved color, aroma, taste, texture, and overall acceptability. Moisture content was lower in F4 (5.6%) than F1 (6.2%), indicating better storage stability. Iron content increased from 12.8 mg/100 g in F1 to 17.6 mg/100 g in F4 following fortification. The ash value, protein content, texture, and caloric value were also improved. Microbiological analysis confirmed that both formulations complied with acceptable food safety standards.
Conclusion: Iron-fortified millet-based nutraceutical cups developed in this study exhibited enhanced nutritional quality, high iron content, good sensory acceptability, and microbiological safety. The optimized formulation has potential as an affordable functional food for improving dietary iron intake and reducing the risk of iron deficiency anemia.

Keywords: Iron fortification, Millets, Nutraceuticals, Functional foods, Finger millet, Foxtail millet, Iron deficiency anemia

1. INTRODUCTION

Iron deficiency remains one of the most prevalent micronutrient deficiencies worldwide and is recognized as a major public health challenge affecting approximately two billion people. It is the leading cause of nutritional anemia, particularly among infants, adolescents, women of reproductive age, and pregnant women. Iron deficiency adversely affects cognitive development, immune function, physical performance, and work productivity, thereby contributing significantly to the global burden of disease [1,2]. In developing countries, inadequate dietary intake of bioavailable iron and poor dietary diversity continue to be the primary causes of iron deficiency anemia, making nutritional intervention an important public health priority [3]. Food fortification has emerged as one of the most effective, practical, and economically feasible strategies for combating micronutrient deficiencies without requiring major changes in dietary habits. Iron fortification of commonly consumed foods has been successfully implemented in many countries and has demonstrated significant improvements in iron status and reductions in anemia prevalence among vulnerable populations [4,5]. The success of iron fortification depends on the choice of iron compound, food matrix compatibility, processing conditions, and consumer acceptance. Ferrous sulphate is widely recognized as one of the most suitable iron fortificants because of its high bioavailability and affordability, although formulation optimization is essential to minimize undesirable sensory changes [6].

In recent years, increasing consumer awareness regarding healthy eating habits has accelerated the development of functional foods and nutraceutical products. Nutraceuticals are foods or food components that provide health benefits beyond basic nutrition and contribute to disease prevention and health promotion. Functional food development focuses on incorporating biologically active compounds, vitamins, minerals, dietary fiber, and antioxidants into convenient food products capable of improving nutritional status and reducing the risk of chronic diseases [7,8]. Millets have gained considerable attention as nutrient-dense cereals because of their exceptional nutritional composition and environmental sustainability. These ancient grains are rich sources of dietary fiber, high-quality proteins, essential amino acids, vitamins, minerals, and numerous phytochemicals, including phenolic acids and flavonoids. Unlike refined cereals, millets possess a low glycemic index, making them suitable for diabetic individuals and those at risk of metabolic disorders. Their gluten-free nature also makes them appropriate for people with celiac disease and gluten intolerance [9,10].

Among different millet varieties, finger millet (*Eleusine coracana*) is particularly valued for its high calcium content, appreciable iron concentration, and antioxidant properties. Foxtail millet (*Setaria italica*) contains significant quantities of dietary fiber, proteins, minerals, and bioactive compounds that contribute to improved cardiovascular health, glycemic regulation, and digestive function. The regular consumption of millet-based foods has been associated with reduced risks of obesity, cardiovascular diseases, type 2 diabetes, and several chronic inflammatory conditions [11,12]. Although millets naturally contain iron, the bioavailability of plant-derived non-heme iron is often limited due to the presence of phytates, tannins, and polyphenolic compounds that inhibit mineral absorption. Consequently, several processing techniques, including germination, fermentation, roasting, and fortification, have been investigated to improve iron bioavailability in millet-based foods. The addition of organic acids such as citric acid further enhances iron absorption by maintaining iron in its more soluble ferrous form [13,14]. Ready-to-eat functional foods have become increasingly popular because of urbanization, changing lifestyles, and increasing demand for convenient, nutritious food products. Nutraceutical cups represent an innovative category of functional foods that can serve as efficient carriers for micronutrients while maintaining desirable sensory characteristics. Developing millet-based nutraceutical cups fortified with iron provides a promising strategy for improving dietary iron intake while simultaneously delivering the nutritional and health benefits associated with millet consumption [15]. Several investigators have reported successful incorporation of iron fortificants into cereal-based products with improvements in nutritional quality and consumer acceptability. However, relatively few studies have focused on developing iron-fortified millet-based nutraceutical cups combining finger millet, foxtail millet, and natural ingredients such as jaggery, almond powder, and milk powder. Furthermore, limited information is available regarding the physicochemical properties, nutritional composition, microbial safety, and sensory acceptability of such products [16–18]. Therefore, the present study was undertaken to formulate and evaluate iron-fortified millet-based nutraceutical cups using finger millet flour, foxtail millet flour, jaggery, milk powder, almond powder, ferrous sulphate, and citric acid. The developed formulations were evaluated for physicochemical characteristics, nutritional composition, iron content, texture, microbial quality, and sensory acceptability to identify the optimized formulation with the greatest potential as a functional food for improving dietary iron intake and contributing to the prevention of iron deficiency anemia.

2. MATERIALS AND METHODS:

Materials: Finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), jaggery, skimmed milk powder, almond powder, ghee were procured from a certified local supplier in Telangana, India. Ferrous sulphate (analytical grade) was obtained from a pharmaceutical chemical supplier and used as the iron fortificant. All chemicals and reagents used for analytical studies were of analytical reagent (AR) grade.

Formulation of Iron-Fortified Millet-Based Nutraceutical Cups

Four formulations (F1, F2, F3, and F4) were prepared by varying the proportions of millet flour and ferrous sulphate while maintaining other ingredients within acceptable sensory limits. Finger millet flour and foxtail millet flour were selected because of their superior nutritional composition and functional properties. Ferrous sulphate was incorporated as the iron fortificant, whereas citric acid was added to enhance iron bioavailability.

Table 1. Composition of formulations:

Ingredients	**F1 (g)**	**F2 (g)**	**F3(g)**	**F4(g)**
Finger millet flour	45	50	55	60
Foxtail millet flour	45	50	55	60
Milk powder	10	15	20	25
Jaggery	20	20	20	20
Almond powder	10	15	20	25
Ferrous sulphate	0.5	0.7	0.8	0.9
Ghee	5mL	6mL	7mL	8mL

Preparation of Nutraceutical Cups

Millet grains were cleaned to remove dust, foreign matter, and damaged kernels, followed by washing with potable water. The grains were dried in a hot-air oven at 55°C until moisture content reached approximately 10–12%. The dried grains were milled into fine flour and sieved through a 60-mesh sieve.

The millet flour was blended with milk powder, almond powder, powdered jaggery, ferrous sulphate, and citric acid. Melted ghee was added, followed by gradual addition of water to obtain homogeneous dough. After resting for 15 minutes, the dough was molded into cup-shaped structures using stainless steel molds and baked in a preheated hot-air oven at 170°C for 18 minutes. The baked cups were cooled to room temperature and packed in airtight food-grade containers for further evaluation.

Physicochemical Evaluation

The prepared formulations were evaluated using standard analytical procedures.

- Organoleptic evaluation
- Weight variation

- Moisture content
- Ash value
- pH determination
- Texture analysis
- Iron estimation
- Nutritional analysis
- Microbial evaluation

Moisture content and ash value were determined according to AOAC standard methods. pH was measured using a calibrated digital pH meter. Iron estimation was performed using UV–Visible spectrophotometry. Microbial quality was assessed by total plate count and detection of *Escherichia coli* and yeast/mold according to standard microbiological methods.

Sensory Evaluation:

Sensory evaluation was conducted using a **9-point Hedonic Scale**. Appearance, colour, aroma, taste, texture, and overall acceptability were evaluated by a panel of ten semi-trained members. Scores ranged from 1 (dislike extremely) to 9 (like extremely).

Statistical Analysis

All experiments were carried out in triplicate, and the results are expressed as mean ± standard deviation. Statistical analysis was performed using one-way ANOVA followed by Tukey's post hoc test. Differences were considered statistically significant at $\mathbf{p < 0.05}$.

3. RESULTS:

Table 2. Organoleptic evaluation of iron-fortified millet-based nutraceutical cups

Parameter	**F1**	**F2**	**F3**	**F4**
Appearance	Good	Excellent	Good	Excellent
Colour	Light Brown	Brown	Light Brown	Thick Brown
Aroma	Pleasant	Pleasant	Pleasant	Pleasant
Taste	Sweet	sweet taste	Sweet	Highly acceptable sweet taste
Texture	Crisp	Crisp	Crisp	Crisp and Smooth
Overall Acceptability	Good	Good	Good	Excellent

The sensory evaluation demonstrated that formulation F4 received the highest overall acceptability score owing to its improved colour, flavour, texture, and sweetness. Similar observations have been reported for millet-based fortified foods where optimization of ingredient composition significantly enhanced consumer preference [20, 21].

Table 3. Physicochemical characteristics

Parameter	F1	F2	F3	F4
Average weight (g)	24.8 ± 0.3	26.2 ± 0.2	28.2 ± 0.2	30.2 ± 0.2
Moisture (%)	6.2	5.6	4.5	3.5
Ash (%)	2.5	2.9	2.9	3.0
pH	6.5	6.4	6.3	6.1
Hardness (kg/cm^2)	4.2	4.4	4.6	4.9

The physicochemical analysis demonstrated that formulation F4 possessed superior quality characteristics compared with F1. The lower moisture content (3.5%) observed in F4 indicates better shelf stability by reducing the likelihood of microbial growth during storage. The higher ash content (3.0%) reflects increased mineral concentration resulting from greater millet content and iron fortification. The near-neutral pH values indicate product stability and suitability for consumption. The increased hardness value observed in F4 suggests improved structural integrity and crispness after baking. These findings agree with previous studies on fortified cereal-based functional foods [14,17].

Table 4. Nutritional composition

Parameter	F1	F2	F3	F4
Protein (%)	8.5	8.8	9.2	9.6
Fat (%)	5.8	5.9	6.2	6.5
Carbohydrate (%)	65.2	64.2	64.8	63.8
Energy (kcal/100 g)	345	350	355	360
Iron (mg/100 g)	12.8	14.2	15.4	17.6

The nutritional analysis confirmed that formulation F4 exhibited superior nutritional quality. Protein and fat contents increased due to higher incorporation of millet flour, almond powder, and milk powder, whereas carbohydrate content decreased slightly because of the increased proportion of nutrient-dense ingredients. The most significant improvement was observed in iron concentration, which increased from 12.8 mg/100 g in F1 to 17.6 mg/100 g in F4, confirming the effectiveness of ferrous sulphate fortification. The increased caloric value further enhances the product's suitability as a nutrient-rich functional food. Similar improvements have been reported in previous iron-fortified millet products [16].

Table 5. Microbiological quality

Test	F1	F2	F3	F4	Standard Limit
Total Plate Count	$<10^2$ CFU/g	$<10^2$ CFU/g	$<10^2$ CFU/g	$<10^2$ CFU/g	$<10^4$ CFU/g

Yeast and Mold	Absent	Absent	Absent	Absent	Absent
E. coli	Absent	Absent	Absent	Absent	Absent

The microbiological quality confirmed that both formulations complied with acceptable food safety standards [21]. Microbiological analysis demonstrated that both formulations satisfied acceptable food safety standards. The total plate count remained well below the permissible limit, while yeast, molds, and *Escherichia coli* were absent in both samples. These findings indicate that the baking process, hygienic handling, and appropriate packaging effectively controlled microbial contamination. The low moisture content of the formulations also contributed to improved microbial stability. Similar microbiological safety has been reported in baked millet-based products by FAO/WHO

4. DISCUSSION

The present investigation demonstrated that iron-fortified millet-based nutraceutical cups can be successfully formulated with acceptable physicochemical, nutritional, microbiological, and sensory characteristics. Finger millet and foxtail millet contributed substantially to the nutritional quality owing to their high dietary fiber, protein, minerals, and antioxidant constituents. Similar nutritional characteristics have been reported by Saleh et al. [19] and Devi et al. [20].

Iron fortification significantly increased iron concentration from **12.8 mg/100 g** to **17.6 mg/100 g**, confirming successful incorporation of ferrous sulphate into the product matrix. Comparable improvements in iron content following fortification have been reported by Kumar et al. [16] and Hurrell and Egli [3]. Lower moisture content observed in F4 suggests improved shelf stability because microbial growth is directly associated with moisture availability. Similar findings have been reported for baked functional foods by Desai and Kulkarni [17].

The higher ash value obtained in formulation F4 indicates increased mineral concentration resulting from both millet composition and iron fortification. Gupta et al. [14] similarly observed increased mineral content in fortified cereal products. Texture analysis demonstrated superior hardness and structural integrity in F4. This may be attributed to the increased proportion of millet flour and optimized baking conditions. Similar results have been reported in millet-based bakery products by Pathania and Kaur [18].

The microbiological quality of both formulations complied with international food safety standards, indicating that baking and hygienic processing effectively minimized microbial contamination [21]. Sensory evaluation revealed excellent consumer acceptance of formulation F4 despite higher iron concentration. The addition of jaggery, almonds, milk powder, and ghee effectively masked any undesirable metallic flavour associated with ferrous sulphate. Patel et al. [22] also reported improved acceptability in fortified cereal products through appropriate flavour optimization.

Overall, formulation F4 exhibited superior nutritional composition, physicochemical quality, microbial safety, and sensory characteristics, making it a promising functional food for combating iron deficiency anemia.

5. CONCLUSION

Iron-fortified millet-based nutraceutical cups were successfully formulated using finger millet, foxtail millet, jaggery, milk powder, almond powder, and ferrous sulphate. Among the prepared formulations, F4 demonstrated superior nutritional composition, higher iron content, lower moisture content, improved texture, greater mineral content, and better sensory acceptability. Microbiological evaluation confirmed product safety, while physicochemical analysis indicated good stability.

The developed product may serve as a convenient, nutritious, and affordable functional food capable of improving dietary iron intake and contributing to the prevention of iron deficiency anemia, particularly among nutritionally vulnerable populations. Future research should investigate iron bioavailability, storage stability under commercial conditions, antioxidant activity, and large-scale consumer acceptance.

CONFLICT OF INTEREST

The authors declare that there are **no conflicts of interest** regarding the publication of this research.

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