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Standardisation and quality assessment of finger and pearl millet enriched multigrain cookies for celiac individuals

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Abstract
Celiac disease requires lifelong adherence to a gluten-free diet, yet many commercially available gluten-free foods are nutritionally inadequate. To address this gap, multigrain cookies were developed using germinated finger millet and roasted pearl millet flours in varying ratios, with a wheat-based cookie as control. Sensory evaluation identified the formulation containing finger millet and pearl millet in a 30:70 ratio as most acceptable, which was selected for further analysis. The millet cookies showed higher fat, fiber, and energy compared to the control, while protein levels were similar. Mineral analysis revealed greater calcium, magnesium, and zinc contents in the millet formulation, although iron was higher in the control. Contribution towards Recommended Dietary Allowances (RDA) indicated magnesium enrichment as the key advantage. Shelf-life evaluation confirmed stable sensory qualities, oxidative stability, and microbial safety for 30 days. The findings support millet-based cookies as a nutritious and shelf-stable alternative for gluten-free diets.

Keywords: Multigrain cookies, finger millet, pearl millet, nutritional evaluation, shelf-life, gluten-free diet

1. Introduction
Celiac disease (CeD) is an immune-mediated intestinal disorder caused by the ingestion of gluten, a protein complex present in wheat, barley, and rye. Gluten ingestion leads to villous atrophy and crypt hyperplasia, impairing nutrient absorption and resulting in complications such as anaemia, osteoporosis, and growth retardation (Ge *et al.*, 2024; Lebovits *et al.*, 2023) [1, 2]. A strict adherence to gluten-free diet (GFD) is the only treatment for celiac disease, which alleviates symptoms and enables mucosal recovery (Verma, 2021) [3]. However, commercially available gluten-free products are often nutritionally inadequate, as they are low in dietary fiber, protein, and essential micronutrients such as iron, zinc, calcium, and magnesium (Mędza & Sidorkiewicz, 2023) [4]. This poses a major challenge in ensuring nutritional sufficiency for individuals dependent on a GFD.

Millets being naturally gluten-free and rich in dietary fiber, calcium, iron, magnesium and antioxidants, are increasingly recognised as suitable substitutes for conventional cereals (Patil *et al.*, 2023) [5]. Finger millet (Eleusine coracana) is an excellent source of calcium, whereas pearl millet (*Pennisetum glaucum*) contributes substantial amounts of iron, zinc and magnesium, making both grains valuable ingredients for nutrient enriched functional foods (Selladurai *et al.*, 2023 [6]; Satankar *et al.*, 2020) [7].

Cookies, due to their widespread popularity and consumer acceptability, offer an excellent medium for incorporating nutrient dense ingredients. In this context, the present study was undertaken with the objective of formulating multigrain cookies using blends of finger millet and pearl millet. The developed products were evaluated for their proximate composition, mineral content, storage stability, and contribution to the recommended dietary allowances (RDA) of adults.

2. Materials and Methods
2.1 Raw Material Procurement and Processing
Finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*) grains were procured from local markets in Chandigarh. Finger millet was subjected to germination

(48 h) to enhance nutrient bioavailability and reduce antinutritional factors, followed by sun drying, grinding, and storage in airtight bags. Pearl millet grains were roasted for 10-15 min to improve flavour and reduce antinutrients before milling. Both flours were stored in airtight containers under refrigeration until further use.

2.2 Formulation of Multigrain Cookies
Three formulations of multigrain cookies were developed by varying the proportions of finger millet and pearl millet flours, while a wheat-based cookie served as the control. Other ingredients (jaggery, butter, baking powder, and nut powder) were kept constant across formulations (Table 1).

Table 1: Ingredient Composition of Multigrain Cookies

Ingredients	Sample 1	Sample 2	Sample 3	Control
Ragi/FM (g)	50	60	30	-
Bajra/PM (g)	50	40	70	-
Wheat flour (g)	-	-	-	100
Jaggery (g)	50	50	50	50
Unsalted Butter (g)	70	70	70	70
Baking powder(tsp)	1	1	1	1
Nuts powder (g) (Almonds, cashews, walnuts)	40	40	40	40

Average yield: 22 cookies (11g/cookie)

The preparation process of multigrain cookies is illustrated in Figure 1, highlighting the key steps from ingredient mixing to baking and storage.”

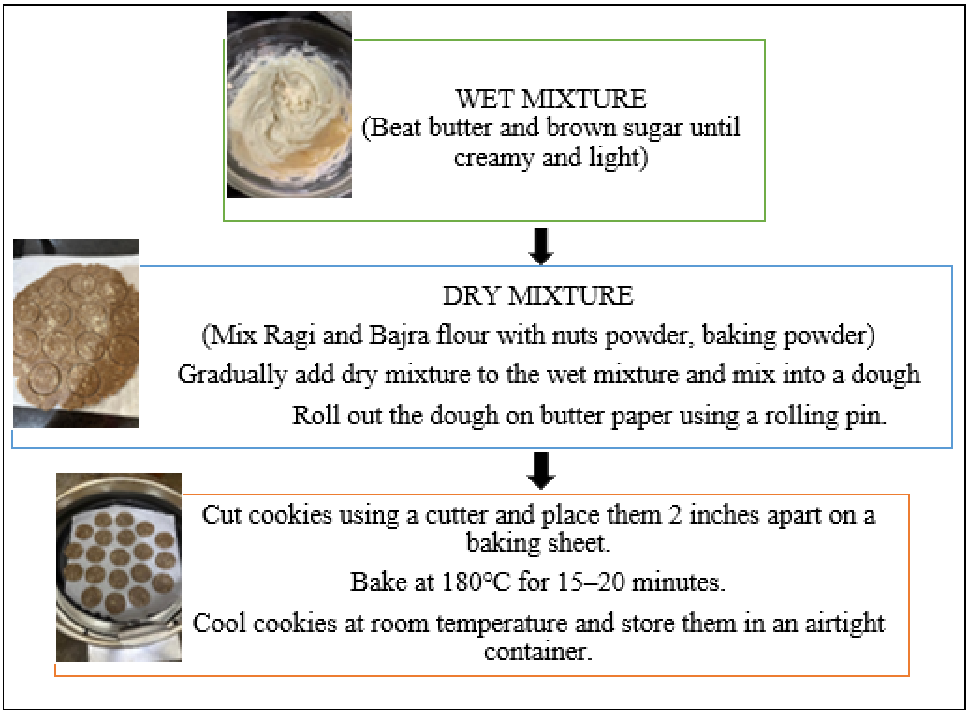

Fig 1: Flowchart of the Preparation Process of Multigrain Cookies

2.3 Sensory Evaluation
The sensory attributes of the developed multigrain cookies were evaluated using a 9-point hedonic scale ranging from “1 = dislike extremely” to “9 = like extremely.” A panel of 14 semi-trained members from the Department of Foods and Nutrition, Government Home Science College, Chandigarh was recruited to assess key quality parameters, including appearance, colour, aroma, texture, taste, flavour, and overall acceptability. Coded samples of each formulation were presented in a randomized order under uniform conditions. The mean scores obtained for each attribute were used to determine the most acceptable formulation for subsequent nutritional and shelf-life analysis.

Fig 2: Samples for Sensory Evaluation of Multigrain Cookies

2.4 Proximate and Mineral Analysis
The most acceptable formulation identified through sensory evaluation was subsequently selected for detailed proximate and mineral analysis. Proximate composition, including moisture, crude protein, fat, crude fiber, total ash, carbohydrate, and energy, was determined using standard AOAC (2012) and FSSAI (2023) procedures. Protein was estimated by the Kjeldahl method, fat by Soxhlet extraction, and carbohydrates by difference, while energy was calculated using Atwater factors. Mineral analysis (calcium, magnesium, iron, and zinc) was performed following Indian Standard (IS) methods, with calcium and magnesium estimated by EDTA titration and iron and zinc quantified using acid digestion and IS:7765-1975 protocol.

2.5 RDA Reference Values
For assessing the nutritional adequacy of the developed cookies, the mineral composition (calcium, iron, zinc, and magnesium) was compared against the Recommended Dietary Allowances (RDA) for Indian adults as specified by the ICMR-NIN (2024). Separate values were considered for adult men and women to calculate the percentage contribution of the product towards daily requirements (RDA, 2020).

2.6 Shelf-Life Evaluation
Multigrain Cookies were stored in airtight containers at ambient temperature (45℃, 75% RH) and tested on day 0, day 16, and day 30. Parameters included:
- Moisture content (vacuum oven method)
- Rancidity (peroxide value, free fatty acids)
- Microbial safety (total plate count, yeast & mold, coliforms)
- Sensory quality (colour, texture, aroma, taste, overall acceptability)

2.7 Statistical Analysis
All experiments were carried out in triplicate, and results were expressed as mean ±standard deviation (SD). Data were analysed using SPSS software. One-way ANOVA followed by Tukey's HSD was applied to compare proximate and mineral values among samples at a significance level of $p<0.05$.

3. Results and Discussion
3.1 Sensory Evaluation
The sensory attributes of the multigrain cookies formulated with varying ratios of finger millet (FM) and pearl millet (PM) were compared with a wheat-based control using a 9-point hedonic scale and are illustrated in Figure 3.
Among the experimental samples, Sample 3 (FM:PM = 30:70) achieved the highest scores across most attributes, including appearance (8.21±0.97), taste (8.00±0.96), flavour (8.14±1.03), and overall acceptability (7.91±0.82), indicating strong consumer preference. Sample 1 (FM:PM = 50:50) and Sample 2 (FM:PM = 60:40) received moderate acceptability, with overall scores of 7.10±0.76 and 7.17±0.80, respectively. The control sample (100% wheat flour) performed well (overall acceptability 7.56±1.02), but was slightly outperformed by Sample 3 in key attributes such as taste, flavour, and appearance.

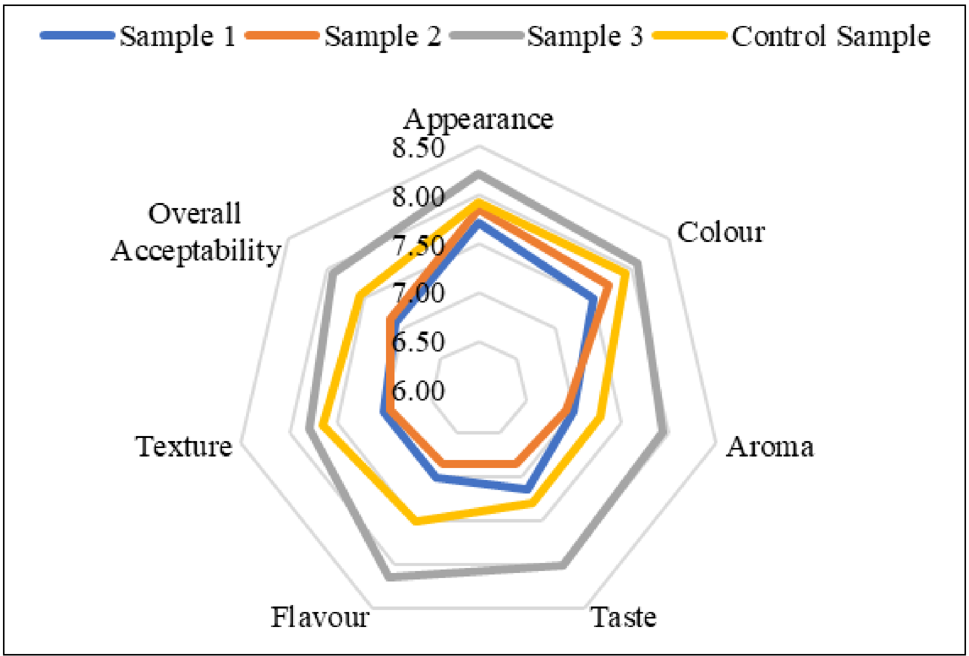

Fig 3: Radar Chart Depicting Sensory Analysis of Multigrain Cookies of all Samples

Similar results were reported by Sinha and Sharma (2017) [9], who found that cookies prepared with 50% finger millet flour received the highest sensory scores for taste, texture, and appearance, comparable to the control. These findings support the present study, where the millet-only formulation (Sample 3) demonstrated superior acceptability.

Proximate Analysis
The proximate composition of the most acceptable millet-based multigrain cookie formulation (FM:PM = 30:70) was compared with the wheat-based control, and the results are presented in Table 2.

Table 2: Proximate Composition of Multigrain Cookies (Per 100g)

Parameters	Millet Sample	Control
Moisture (g)	2.57±0.48[ns]	1.52±0.51
Total Ash (g)	1.85±0.33 [ns]	1.74±0.21
Energy (kcal)	520.42±0.51**	512.26±0.52
Carbohydrate (g)	56.71±0.55**	61.95±0.46
Protein (g)	9.78±0.46 [ns]	9.68±0.42
Fat (g)	28.45±0.27**	25.03±0.20
Crude Fiber (g)	5.21±0.17 [ns]	4.89±0.39

Values are expressed as mean ±SD; ***p*<0.01, ns = non-significant

The moisture content of millet cookies (2.57±0.48 g/100 g) was slightly higher than that of the control (1.52±0.51 g/100 g). Total ash content also showed a slight increase in the millet-based cookies (1.85±0.33 g/100 g) compared with the control (1.74±0.21 g/100 g), reflecting the higher mineral density of finger and pearl millet. A significant reduction in carbohydrate content ($p<0.01$) was observed in the millet cookies (56.71±0.55 g/100 g) compared with the control (61.95±0.46 g/100 g), which attributed to the higher fiber fraction in millet flours. The protein content remained comparable between the two formulations (9.78±0.46 g/100 g vs. 9.68±0.42 g/100 g; ns).

Notably, the fat content was significantly higher ($p<0.01$) in the millet-based cookies (28.45±0.27 g/100 g) relative to the control (25.03±0.20 g/100 g). The crude fiber content was marginally greater in the millet cookies (5.21±0.17 g/100 g) compared to the control (4.89±0.39 g/100 g), though the difference was statistically non-significant.

In terms of caloric value, the millet cookies recorded a significantly higher energy content (520.42±0.51 kcal/100 g) than the control (512.26±0.52 kcal/100 g; $p<0.01$). This difference can be attributed to the increased fat and nutrient density imparted by the millet flours and nut ingredients.

Similar improvements in the mineral profile of millet-based cookies have been reported by Radhika *et al.* (2019) [10] who observed moisture content of 4.32%, protein 9.2%, fat 13.6%, ash content 1.87% and crude fiber 2.51% in cookies prepared from pearl millet and finger millet blended with soybean and groundnut flours.

3.3 Mineral Analysis

The mineral composition of the most acceptable multigrain cookie formulation (FM:PM = 30:70) was compared with the control, and the comparative values for iron, calcium, magnesium, and zinc are illustrated in Figure 4.

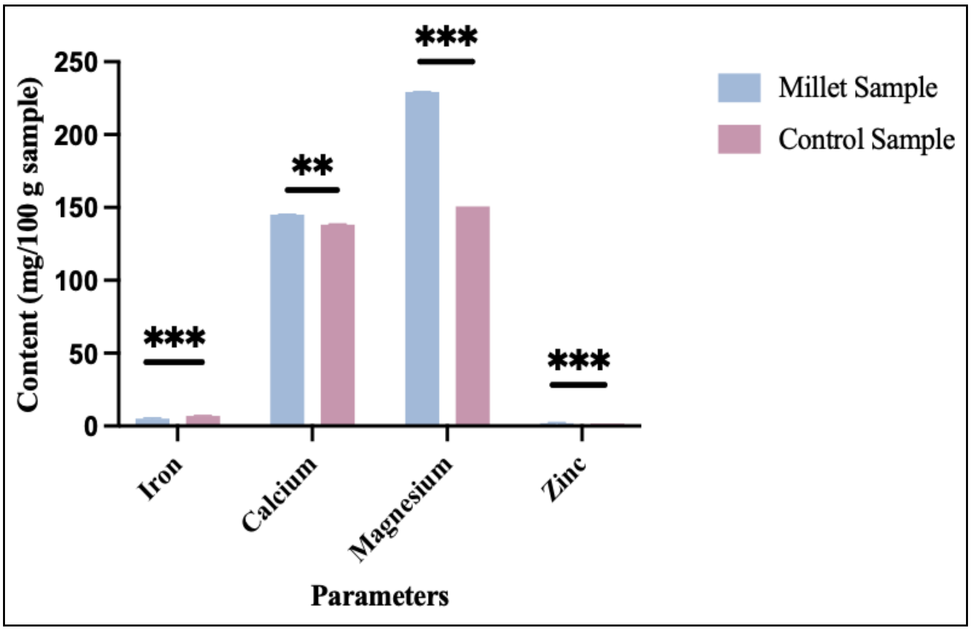

Fig 4: Graphical Representation of Comparative Analysis of Mineral Composition of Multigrain Cookies (mg/100g); Statistical significance: ***p*<0.01, ****p*<0.001

The mineral composition of the millet-based multigrain cookies showed statistically significant increase ($p<0.001$) in iron content in the control (6.99±0.51 mg/100 g) compared to the millet-based cookies (5.10±0.56 mg/100 g). However, the millet formulation demonstrated significantly higher levels of other minerals, particularly calcium (145.18±0.19 mg/100 g vs. 138.26±0.58 mg/100 g; $p<0.01$), magnesium (229.30±0.44 mg/100 g vs. 150.71±0.14 mg/100 g; $p<0.001$), and zinc (1.96±0.64 mg/100 g vs. 1.79±0.06 mg/100 g; $p<0.001$).

In line with the present findings, Garg and Sharma (2024) [11] also reported significantly higher calcium (312.32 mg/100g) and iron (2.95 mg/100g) in cookies developed using germinated finger millet and pearl millet blends, reinforcing the mineral-enhancing potential of these grains in gluten-free formulations.

3.4 RDA Reference Values

The contribution of the millet-based multigrain cookies (FM:PM = 30:70) and the control towards the Recommended Dietary Allowances (RDA) for adult men and women (ICMR-NIN, 2024) is presented in Table 3.

Table 3: Contribution of Multigrain Cookies to Daily RDA Values (per 100g)

Mineral	RDA Men (mg/day)	RDA Women (mg/day)	Millet Product (mg/100g)	% RDA Men	% RDA Women	Control Sample (mg/100g)	% RDA Men	% RDA Women
Calcium	1000	1000	145.18 mg	14.52%	14.52%	138.26 mg	13.83%	13.83%
Magnesium	440	370	229.30 mg	52.11%	61.97%	150.71 mg	34.25%	40.73%
Iron	19	29	5.10 mg	26.84%	17.59%	6.99 mg	36.79%	24.10%
Zinc	17	13.2	1.96 mg	11.53%	14.85%	1.79 mg	10.53%	13.56%

The millet-based formulation provided markedly higher magnesium (229.30 mg/100 g), meeting 52.1% of the requirement for men and 62.0% for women, compared to 34.3% and 40.7% from the control. Calcium contribution was similar between the two (14.5% vs. 13.8%). The control sample was superior in iron (36.8% for men, 24.1% for women) compared to millet cookies (26.8% and 17.6%). For zinc, both products offered modest contributions (~11-15% of RDA), with millet cookies slightly higher. Thus, the millet-based formulation demonstrated a distinct nutritional advantage through its magnesium enrichment while maintaining comparable calcium and zinc levels. Magnesium is particularly significant in the diet of celiac patients, as intestinal malabsorption often predisposes them to deficiencies that can contribute to bone demineralization, impaired muscle and nerve function, and increased risk of fatigue and metabolic disturbances.

Shelf-life Evaluation of Multigrain Cookies

The shelf-life evaluation of millet-based multigrain cookies was carried out over 30 days of storage under ambient conditions. The changes in sensory attributes, chemical quality parameters, and microbial safety are presented in Table 4.

Table 4: Shelf-life Evaluation of Multigrain Millet Cookies over 30 days of Storage

S. No.	Parameters	Units	Initial Day	16th Day	30th Day
1	Colour	-	Light Brown	Light Brown	Light Brown
2	Texture	-	Coarse	Coarse	Coarse
3	Aroma	-	Complies	Complies	Complies
4	Taste	-	Characteristic	Characteristic	Characteristic
5	Moisture	g/100g	2.08	2.16	2.18
6	Peroxide Value	meq/kg	2.39	2.47	2.37
7	Free Fatty Acids	g/100g	1.20	1.36	1.32
	Microbiological Analysis				
8	Total Plate Count	cfu/gm	327	355	414
9	Yeast & Mould Count	cfu/gm	<10	<10	<10
10	Coliform Count	cfu/gm	<10	<10	<10

The sensory attributes of multigrain millet cookies, including colour, texture, aroma, and taste, remained stable during 30 days of storage, with no noticeable deterioration. Moisture content showed only a slight increase (2.08 to 2.18 g/100 g), while peroxide value (2.39 to 2.37 meq/kg) and free fatty acids (1.20 to 1.32 g/100 g) indicated good oxidative stability and minimal hydrolytic changes.

Microbiological analysis confirmed product safety, with total plate counts rising moderately from 327 to 414 cfu/g over 30 days, while yeast, mould, and coliform counts remained undetectable (<10 cfu/g). These results demonstrate that the millet-based cookies maintained chemical, microbial, and sensory stability throughout the storage period, supporting their suitability for extended shelf-life under ambient conditions.

Likewise, Rahman *et al.* (2025) [12] observed a gradual increase in microbial load over a 28-day storage period, yet values remained within safe limits (<10^6 cfu/g). Products made with germinated multigrain flour showed higher microbial counts (3.34×10^1 to 4.96×10^1 cfu/g) compared to ungerminated flour (3.26×10^1 to 4.76×10^1 cfu/g), reflecting greater nutrient availability in germinated flours but confirming product safety throughout storage.

A similar study by Anggraini *et al.* (2021) [13] reported that the moisture content of millet-based cookies increased slightly from 3.32% to 3.40% during a 14-day storage period. Peroxide values rose modestly from 0.56 to 0.75 meq/kg, reflecting good oxidative stability, while microbial counts remained <3.0×10^3 cfu/g with no yeast or mold detected. These results align with the present study, confirming the oxidative stability and microbial safety of millet cookies during storage.

Conclusion

The present study demonstrated that multigrain cookies developed using germinated finger millet and roasted pearl millet flours can serve as a nutritious and acceptable gluten-free product. Sensory evaluation identified the FM:PM; 30:70 formulation as the most preferred, with superior scores for appearance, taste, and flavour compared to the control. Proximate analysis confirmed that millet cookies provided higher fat, fiber, ash, and energy values, while maintaining comparable protein content. Mineral analysis highlighted a distinct nutritional advantage through significantly higher calcium, magnesium, and zinc contents, with RDA assessment showing that 100 g of millet cookies contributed over half of the daily magnesium requirement for adults. Shelf-life evaluation confirmed stable sensory, oxidative, and microbial quality for at least 30 days, supporting product safety and storage stability. Therefore, the findings establish millet-based multigrain cookies as a functional, gluten-free alternative with strong potential to enhance dietary adequacy, particularly for individuals with celiac disease.

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