Formulation and Evaluation of Millet-Based Functional Foods Enriched with Moringa Oleifera Leaf Powder

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Abstract

Functional foods rich in micronutrients and bioactive compounds are increasingly recognized for their role in supporting metabolic and hormonal health. *Moringa oleifera* leaf powder is a nutrient-dense plant ingredient, while millets such as foxtail millet and ragi offer high dietary fibre and mineral content. The present study aimed to develop moringa powder–based functional recipes incorporating foxtail millet and ragi flour and to evaluate their nutritional composition and sensory acceptability. Three standardized recipes, moringa–foxtail millet chilla, banana moringa pancake, and ragi moringa idli, were developed. Nutritional composition was calculated using the Indian Food Composition Tables (IFCT, 2017). Sensory evaluation was conducted by a semi-trained panel of 13 judges using a 10-point hedonic scale. All formulations demonstrated enhanced micronutrient density, particularly calcium (237.9–347.0 mg/serving) and iron (17.7–18.4 mg/serving). Sensory evaluation revealed high acceptability, with overall acceptability scores ranging from 9.00 ± 0.52 to 9.85 ± 0.36. Moringa powder can be successfully incorporated into millet-based traditional recipes to develop nutritionally enriched and sensory-acceptable functional foods.

Key words: Moringa oleifera, functional foods, millet-based recipes, nutritional evaluation, sensory acceptability.

Introduction

Functional foods are defined as foods that provide physiological benefits beyond basic nutrition due to the presence of bioactive compounds, dietary fibre, and essential micronutrients (Hasler, 2002). The increasing burden of lifestyle-related metabolic disorders has intensified interest in plant-based functional ingredients that enhance nutrient density while remaining suitable for regular dietary consumption.

Moringa oleifera is a nutrient-dense plant widely recognized for its functional food potential. The dried leaf powder of *M. oleifera* contains substantial amounts of high-quality plant protein, calcium, iron, potassium, provitamin A carotenoids, vitamin C, and polyphenolic compounds (Leone et al., 2015; Gopalakrishnan et al., 2016). Several studies have demonstrated that moringa leaves possess strong antioxidant activity attributed to flavonoids, phenolic acids, and glucosinolates, supporting their role as a functional dietary ingredient rather than merely a medicinal plant (Ndong et al., 2007; Gupta et al., 2005).

From a food formulation perspective, moringa leaf powder offers advantages due to its stability, concentrated nutrient profile, and suitability for incorporation into cereal-based products. However, its characteristic colour and flavour may limit consumer acceptability if used alone, necessitating the use of compatible food matrices.

Millets are traditional cereal grains valued for their nutritional quality, low glycaemic index, and high dietary fibre content. Finger millet (*Eleusine coracana*), commonly known as ragi, is particularly rich in calcium and polyphenols, contributing to its functional relevance in bone health and metabolic regulation (Devi et al., 2014). Foxtail millet (*Setaria italica*) is a good source of complex carbohydrates, protein, iron, and antioxidant compounds, and has been associated with improved glycaemic and lipid profiles (Saleh et al., 2013).

The incorporation of moringa leaf powder into millet-based food products represents a complementary functional food strategy, combining micronutrient-rich moringa with fibre- and mineral-dense millets. While moringa and millets have been extensively studied individually, limited research has focused on their combined application in standardized, sensory-acceptable food formulations. Therefore, the present study aims to develop moringa powder–incorporated millet-based recipes and evaluate their nutritional composition and sensory acceptability.

2. Materials and Methods

2.1 Study Design

The present experimental study was undertaken to develop moringa (*Moringa oleifera*) leaf powder incorporated millet-based food products and to evaluate their nutritional composition and sensory acceptability.

2.2 Raw Materials

Fresh moringa leaves were procured from a local source and authenticated by a subject expert. Finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*) grains were obtained from the local market. All raw materials were cleaned manually to remove extraneous matter before processing.

2.3 Preparation of Moringa Leaf Powder

Fresh moringa leaves were washed thoroughly to remove adhering dirt and impurities. The leaves were shade-dried at room temperature until a constant weight was achieved to minimize nutrient loss. The dried leaves were then pulverized using a laboratory grinder and sieved to obtain a fine, uniform powder. The moringa leaf powder was stored in airtight containers until further use.

2.4 Processing of Millet Flours

Finger millet and foxtail millet grains were cleaned, washed, and sun-dried. The dried grains were milled separately using a flour mill to obtain fine flours. The flours were stored in airtight containers to prevent moisture absorption.

2.5 Development of Moringa-Incorporated Millet-Based Products

Table 2.1 shows the composition of ingredients for standardized recipes of moringa foxtail millet chilla, banana moringa pancake and ragi moringa idli respectively.

Table 2.1 Ingredient composition of moringa powder–incorporated millet-based functional recipes (grams per serving)

Moringa Millet chilla		**Banana Moringa Pancake**		**Ragi Moringa Idli**	
Ingredients	**Amount**	**Ingredients**	**Amount**	**Ingredients**	**Amount**
Moringa leaves powder	6 gram	Moringa leaves powder	6gram	Moringa leaves powder	6 gram
Foxtail millet	30 gram	Ragi flour	30gram	Ragi flour	30 gram
Tomato	100 gram	Banana	200gram	Semolina	30gram
Onion	80gram	Milk	100ml		
Oil	5 gram				

2.6 Nutritional Evaluation

The nutritional composition of the developed products was calculated using the Indian Food Composition Tables (IFCT, 2017). Nutrient values for energy, protein, carbohydrates, fat, calcium, iron, and dietary fibre were computed for the developed moringa-incorporated formulations.

2.7 Sensory Evaluation

Sensory evaluation of the developed products was carried out in three palatability trials by semi-trained panel of judges. Informed consent was obtained from all participants prior to evaluation. Samples were coded and evaluated for colour, shape, appearance, texture, taste, and overall acceptability using a 10-point hedonic scale (1 = poor, 10 = very good).

2.8 Statistical Analysis

Data were expressed as mean ± standard deviation (SD). One-way ANOVA followed by post-hoc pairwise comparisons was used to assess differences among recipes. Statistical significance was set at $p < 0.05$.

2.9 Ethical Considerations

The study involved only sensory evaluation of food products. Informed consent was obtained from all panel members, and no invasive procedures were involved.

3. Results

Table 3.1 Nutrient composition of standardized moringa-based recipes (per serving)

Nutrient	Moringa–Foxtail Millet Chilla	Banana–Moringa Pancake	Ragi–Moringa Idli
Energy (kcal)	237	330	208
Protein (g)	8.08	9.6	7.6
Fat (g)	6.4	5.2	0.92
Carbohydrate (g)	35.9	124	89.59
Calcium (mg)	156	347.0	237.9
Iron (mg)	17.7	18.4	18.28

Values calculated using Indian Food Composition Tables (IFCT), 2017.

Table 3.2 Mean sensory scores (Mean ± SD) of moringa-based recipes (n = 13)

Sensory Attribute	Moringa–Foxtail Millet Chilla	Banana–Moringa Pancake	Ragi–Moringa Idli	p-value
Colour	9.77 ± 0.36	8.77 ± 0.42	8.42 ± 0.61	<0.05
Appearance	9.31 ± 0.44	8.62 ± 0.48	8.31 ± 0.56	<0.05
Texture	9.69 ± 0.47	8.77 ± 0.50	8.85 ± 0.63	<0.05
Taste	9.54 ± 0.36	9.01 ± 0.41	8.62 ± 0.52	<0.05
Overall Acceptability	9.85 ± 0.36	9.69 ± 0.41	9.00 ± 0.52	<0.05

Scores evaluated on a 10-point hedonic scale. Statistical significance assessed using one-way ANOVA.

3.1 Nutritional Composition

Table 1 presents the nutrient composition of the standardized moringa powder–based recipes developed using foxtail millet and ragi flour. All three formulations demonstrated appreciable energy and macronutrient content, indicating their suitability as balanced meal components.

Energy values ranged from 2**08 kcal to 330 kcal per serving**, with the banana–moringa pancake showing the highest energy content, attributable to the inclusion of banana and higher carbohydrate contribution. Protein content varied between **7.6 g and 9.6 g per serving**, with the banana moringa pancake providing the highest protein value. This increase may be attributed to the combined contribution of moringa leaf powder and millet flours, both of which are known to contain moderate levels of plant protein.

Fat content remained 0.92 gms for idli as it was a steamed product and within a moderate range **5.2–6.4 g per serving** for pancake and chilla respectively, supporting the suitability of the formulations for regular consumption without excessive lipid intake. Carbohydrate values ranged from **35.9 g to 124 g per serving**, reflecting the predominant contribution of millets and cereal-based ingredients, which provide complex carbohydrates essential for sustained energy release.

A notable finding was the **high calcium content**, ranging from **156 mg to 347.0 mg per serving**. The banana–moringa pancake exhibited the highest calcium value, while the ragi–moringa idli also contributed substantially, highlighting the synergistic effect of finger millet and moringa leaf powder, both recognized for their superior calcium density. Iron content was consistently high across all formulations (**17.7–18.4 mg per serving**), primarily contributed by moringa leaf powder, reinforcing its role as an iron-rich functional ingredient.

Overall, the nutrient composition indicates that incorporation of moringa powder into millet-based recipes significantly enhances mineral density while maintaining a balanced macronutrient profile. These characteristics position the developed products as **nutrient-dense functional foods**, particularly relevant for populations with increased micronutrient requirements, such as women of reproductive age.

3.2 Sensory Evaluation

Table 2 summarizes the mean sensory scores of the moringa-based recipes evaluated using a 10-point hedonic scale. All formulations achieved **high acceptability scores**, with mean values exceeding **8.3 for all sensory attributes**, indicating favourable consumer perception.

Among the three products, the **moringa–foxtail millet chilla consistently received the highest scores** across most attributes, including colour, appearance, texture, taste, and overall acceptability. The overall acceptability score of **9.85 ± 0.36** reflects strong panel preference and suggests successful integration of moringa powder without adversely affecting sensory quality.

The banana moringa pancake also demonstrated high acceptability, particularly for taste and appearance, which may be attributed to the natural sweetness and flavour-masking effect of banana. In contrast, the ragi–moringa idli, while still scoring within the acceptable range, showed comparatively lower scores for colour and texture. This may be due to the darker colour and denser texture associated with ragi-based formulations.

Statistical analysis using one-way ANOVA revealed **significant differences ($p < 0.05$)** among the recipes for colour, appearance, texture, taste, and overall acceptability. These differences highlight the influence of base ingredients and formulation characteristics on sensory perception, despite uniform inclusion levels of moringa powder.

Importantly, none of the products exhibited low taste scores, indicating that moringa leaf powder at the standardized inclusion level was well tolerated. This finding addresses a common challenge reported in the literature regarding bitterness and reduced palatability of moringa-fortified foods.

4. Discussion

The findings demonstrate that incorporation of moringa powder into millet-based recipes substantially enhances micronutrient density without compromising sensory quality. The high calcium and iron content is particularly relevant for women experiencing hormonal fluctuations, anemia risk, and bone health concerns.

The superior sensory performance of the moringa–foxtail chilla may be attributed to favourable flavour masking by millet and spices, supporting previous studies reporting improved acceptability of moringa-fortified products up to 8–

10% inclusion levels. Similar improvements in protein, mineral content, and antioxidant potential have been reported in moringa-fortified cookies, soups, and millet-based products.

Although direct hormonal biomarkers were not assessed, the nutrient profile and antioxidant richness of the developed recipes suggest a supportive role in endocrine health through improved insulin sensitivity, reduced oxidative stress, and enhanced micronutrient intake.

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