International Journal of Food Science and Nutrition
www.foodsciencejournal.com
ISSN: 2455-4898
Received: 27-06-2026, Accepted: 28-07-2026, Published: 12-08-2026
Volume 11, Issue 3, 2026, Page No. 154-157

Formulation and quality evaluation of prebiotic-enriched ragi (finger millet) biscuits containing inulin

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DOI: https://doi.org/10.66856/ijfsn.2026.11.3.11139

Abstract
The present study aimed to develop nutritionally enhanced ragi (finger millet) biscuits fortified with the prebiotic fiber inulin and to evaluate the effects of different inclusion levels on physicochemical, functional, sensory, and shelf-life characteristics. Four formulations were prepared: Control (0% inulin), T1 (2%), T2 (3.5%), and T3 (5%). Proximate composition, color, texture, spread ratio, water activity, in-*vitro* starch hydrolysis, predicted glycemic index (pGI), and sensory attributes were assessed using standard analytical techniques. The results indicated that inulin incorporation significantly increased total dietary fiber ($p < 0.05$), with T3 showing a 28.4% increase compared to control. Biscuit hardness decreased with higher inulin levels, while spread ratio showed a slight but non-significant rise. In-*vitro* starch hydrolysis and pGI values declined proportionally with inulin level, with T3 exhibiting the lowest pGI (47.2 ± 1.8) compared to control (55.6 ± 2.1). Sensory evaluation revealed that T1 and T2 were most preferred due to improved mouthfeel and mild sweetness, whereas T3 showed a slight decline in crispness. Shelf-life studies showed no significant differences in microbial load across treatments during 90 days of ambient storage. Overall, incorporation of 3.5% inulin produced the best balance of nutritional enhancement, functionality, and consumer acceptability, demonstrating considerable potential for developing low-glycemic, prebiotic-enriched functional ragi biscuits.

Keywords: Ragi biscuits, inulin, prebiotic fiber, dietary fiber, glycemic index, sensory evaluation, functional food

Introduction
Ragi (*Eleusine coracana* L.) is a nutrient-dense cereal widely cultivated in India. It is recognized for its high calcium, iron, dietary fiber, and polyphenol contents, making it an excellent ingredient for functional food development. (Devi, *et al*.,2014) [2]. In recent years, consumer interest in gut health and functional foods has led to the increasing adoption of prebiotics—non-digestible food ingredients that selectively stimulate beneficial gut microbiota. Among these, inulin and fructo-oligosaccharides (FOS), derived primarily from chicory root, are well-recognized for their bifidogenic effect, ability to enhance mineral absorption, and potential to moderate post-prandial glucose response. (Roberfroid, M. B. 2007) [10].

Bakery products such as biscuits provide an excellent vehicle for prebiotic fortification due to their widespread acceptance, long shelf life, and ease of formulation. However, the incorporation of dietary fibers such as inulin can influence dough rheology, texture, water activity, and sensory attributes. Several studies have reported that low to moderate levels of inulin enhance mouthfeel, reduce caloric density, and improve functional properties of baked goods. Nevertheless, limited research is available on integrating inulin into millet-based bakery products, particularly ragi biscuits. (Gibson, *et al*., 2010) [4] and Meyer, *et al*.,2009) [9]

Therefore, this study aimed to formulate ragi biscuits enriched with inulin at varying levels (2%, 3.5%, and 5%) and to evaluate their physicochemical, functional, sensory, and storage qualities. The goal was to determine an optimal inulin concentration that balances nutritional enhancement with desirable sensory and technological properties, thereby contributing to the development of value-added, health-oriented biscuit products.

Materials and Methods
Raw Materials: Finger millet (ragi) flour, whole wheat flour, were procured from a local mill (Nipani, India). Chicory-derived inulin (≥90% purity, spray-dried powder) was obtained from a commercial food-grade supplier. Powdered jaggery, cold-pressed rice bran oil, baking powder, refined salt, and natural cinnamon extract were purchased from local markets.

All analytical reagents used for physicochemical evaluation were of analytical grade. Distilled water was used throughout the study. The study was conducted to evaluate the effect of prebiotic fiber (inulin/FOS) at varying concentrations on the quality characteristics of ragi biscuits.

Experimental Design: Four treatments were prepared: Control (C) – 0% inulin, T1 – 2% inulin, T2 – 3.5% inulin, T3 – 5% inulin. Inulin level was calculated as percent of total biscuit formulation. Each treatment was produced in triplicate (n = 3) using a Completely Randomized Design (CRD). Formulations of biscuits were standardized on a 500 g total flour basis (ragi + Whole wheat). Ingredient compositions used in each treatment are given below:

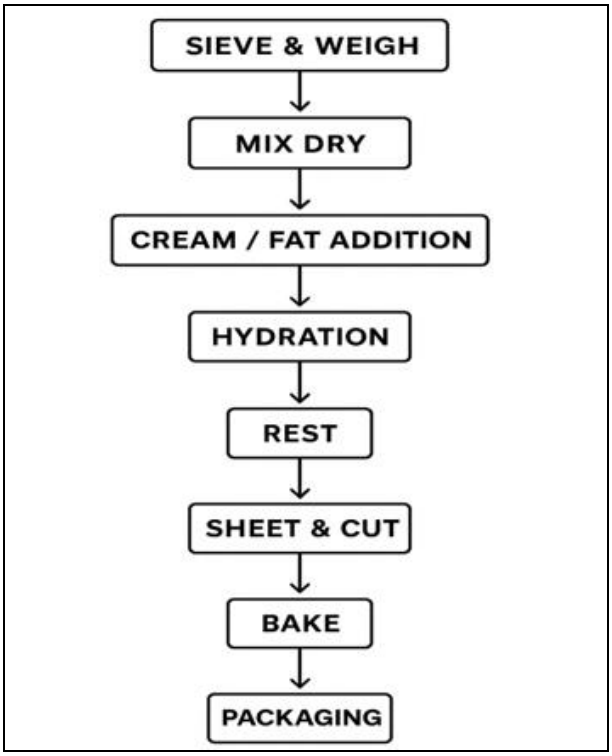
Formulation of Ragi Biscuits Enriched with Inulin (per 500 g Total Flour Basis)

Ingredient	Control (C)	T1 (2% Inulin)	T2 (3.5% Inulin)	T3 (5% Inulin)
Ragi flour (g)	300	300	300	300
Whole Wheat flour(g)	150	150	150	150
Inulin (g)	0	10	17.5	25
Powdered jaggery (g)	90	88	86	84
Rice bran oil (g)	60	60	60	60
Baking powder (g)	5	5	5	5
Salt (g)	2	2	2	2
Cinnamon (g)	2	2	2	2
Water (mL)	60–70	65–75	70–82	75–86
Notes	No inulin; highest jaggery level	Jaggery slightly reduced	Jaggery slightly reduced	More water required due to higher inulin

Preparation of Ragi Biscuits

Mixing and dough formation: All dry ingredients (flours, inulin, jaggery, salt, baking powder) were sieved through 60-mesh and mixed for 2 min in a planetary mixer. Rice bran oil and flavoring extract were added and mixed for 3 min to obtain a coarse crumb texture. Water was added gradually to form a uniform, non-sticky dough. The dough was rested for 20 min.

Sheeting and baking: The dough was rolled to 3–4 mm thickness and cut into circular biscuits (40 mm diameter). Samples were baked in a convection oven preheated to 170 °C for 12–16 min, with tray rotation halfway through baking. Biscuits were cooled on wire racks for 1 hour and then packed in laminated polypropylene pouches until further analysis.



Physicochemical analysis: Standard AOAC methods were used for proximate composition.

1. Moisture (AOAC 935.29)
2. Crude fat (Soxhlet; AOAC 920.85)
3. Crude protein (Kjeldahl; AOAC 984.13; N × 6.25)
4. Ash content (AOAC 923.03)
5. Crude fibre / Total dietary fibre (AOAC 985.29/991.43)
6. Carbohydrate calculated by difference
7. Energy value calculated using Atwater factors
8. Water activity determined using a water activity meter
9. Color measured using a CIE L*, a*, b* colorimeter
10. pH determined in a 1:10 biscuit-water slurry

1. **Physical characteristics:** Biscuit diameter and thickness were measured using Vernier calipers (n = 10 per replicate). The spread ratio was calculated as diameter/thickness. Texture profile analysis was conducted using a texture analyzer equipped with a three-point bending rig. Hardness (N) and fracturability were recorded.

2. **In-*vitro* starch hydrolysis and predicted glycemic index (pGI):** The rate of starch digestion was determined using the Englyst method. Samples were subjected to enzymatic hydrolysis using α-amylase and amyloglucosidase. Reducing sugars released at 0–180 min Were recorded. Hydrolysis Index (HI) was calculated relative to a reference white bread control, and predicted Glycemic Index (pGI) values were estimated using standard equations.

3. **Sensory evaluation:** A consumer panel (n = 30) evaluated the biscuits for appearance, color, aroma, sweetness, texture, flavor, and overall acceptability using a 9-point hedonic scale. Sensory tests were conducted under controlled laboratory conditions using coded samples presented in randomized order. Water was provided for palate cleansing.

4. **Shelf-life study:** Biscuits were stored in polypropylene pouches at ambient temperature (25 ± 2 °C). Analyses were conducted at 0, 15, 30, 60, and 90 days. Moisture, water activity, peroxide value, free fatty acids, texture, microbial load, and sensory acceptability were monitored. Accelerated shelf-life study was conducted at 40 ± 2 °C for 28 days for comparative data.

5. **Statistical analysis:** All analyses were performed in triplicate. Data were expressed as mean ± standard deviation. One-way ANOVA was applied to determine treatment effects, followed by Tukey's HSD test at $p < 0.05$. Sensory data were analyzed using non-parametric Kruskal–Wallis test where applicable. Statistical software such as SPSS or GraphPad Prism was used.

Results & Discussion

1. **Proximate composition:** Inulin incorporation significantly increased the total dietary fiber content ($p < 0.05$). The increase in dietary fiber observed in T3 may be attributed to the high soluble fiber content of inulin, which has also been reported by Sudha *et al*. (2007) [13]. representing a 28.4% increase compared to the control. Moisture content slightly increased with inulin level due to its water-binding capacity, though all samples remained within acceptable limits for biscuits. Fat, protein, and ash contents showed no significant differences ($p > 0.05$), indicating that inulin primarily affected carbohydrate and fiber fractions. (Hadimani *et al*.,1993) [6]

Table 1: Proximate composition of ragi biscuits (g/100 g)

Parameter	Control	T1 (2%)	T2 (3.5%)	T3 (5%)
Moisture	3.21 ± 0.12	3.38 ± 0.10	3.51 ± 0.11	3.66 ± 0.15
Protein	6.74 ± 0.21	6.72 ± 0.19	6.70 ± 0.20	6.68 ± 0.18
Fat	12.45 ± 0.33	12.41 ± 0.31	12.38 ± 0.29	12.35 ± 0.30
Ash	1.89 ± 0.06	1.88 ± 0.05	1.87 ± 0.06	1.86 ± 0.07
Total dietary fiber	6.32 ± 0.22	6.87 ± 0.18	7.56 ± 0.24	8.12 ± 0.25
Carbohydrate	69.39 ± 0.72	68.74 ± 0.70	67.98 ± 0.71	66.98 ± 0.68

2. **Physical and textural properties:** Higher inulin levels increased dough hydration, resulting in slightly softer biscuit structure. Texture analysis revealed a decrease in hardness from 42.8 ± 2.1 N (Control) to 36.4 ± 1.9 N (T3). This is attributed to inulin's humectant property, which softens the crumb matrix. Spread ratio increased marginally ($p > 0.05$), suggesting that inulin did not negatively impact structural integrity. Color values (L*, a*, b*) showed slight darkening with higher inulin levels due to enhanced Maillard browning in the presence of jaggery and fructans. (Bourne, M. C. 2002) [1].

Table 2: Textural and physical properties

Parameter	Control	T1	T2	T3
Hardness (N)	42.8 ± 2.1	40.6 ± 1.9	38.7 ± 2.0	36.4 ± 1.9
Spread ratio	6.10 ± 0.11	6.18 ± 0.10	6.24 ± 0.09	6.29 ± 0.12
L* (lightness)	59.4 ± 0.5	58.8 ± 0.6	57.9 ± 0.6	56.8 ± 0.5

3. **In-*vitro* starch hydrolysis and predicted GI:** Inulin significantly reduced the rate of starch digestion. Hydrolysis Index (HI) reduced from 55.6 (Control) to 47.2 (T3). Predicted glycemic index (pGI) followed the same trend (Englyst *et al*.,1992) [3] and (Goñi, *et al*., 1997) [5]

Table 3: Predicted glycemic index (pGI)

Sample	HI	pGI
Control	55.6 ± 2.1	55.6 ± 2.1
T1	52.4 ± 1.7	52.4 ± 1.7
T2	49.8 ± 2.0	49.8 ± 2.0
T3	47.2 ± 1.8	47.2 ± 1.8

This reduction is beneficial for diabetic and weight-management populations. Inulin forms a viscous matrix that restricts enzyme accessibility to starch granules.

4. **Sensory evaluation:** Panelists preferred T1 and T2 samples, citing better mouthfeel, mild sweetness, and acceptable crispness. T3 received slightly lower scores for texture due to increased softness. However, overall

acceptability remained above the desirable threshold (>7 on 9-point scale) (Lawless, *et al*.,2010) [7]

Table 4: Sensory scores (9-point hedonic scale)

Attribute	Control	T1	T2	T3
Appearance	7.3 ± 0.4	7.6 ± 0.4	7.8 ± 0.5	7.1 ± 0.3
Aroma	7.2 ± 0.3	7.4 ± 0.3	7.9 ± 0.4	7.0 ± 0.3
Taste	7.1 ± 0.4	7.5 ± 0.3	8.0 ± 0.4	7.2 ± 0.3
Texture	7.2 ± 0.5	7.8 ± 0.4	8.1 ± 0.3	7.0 ± 0.4
Overall acceptability	7.4 ± 0.3	7.8 ± 0.4	8.1 ± 0.5	7.2 ± 0.4

Thus, 3.5% inulin achieved the most favorable balance of sensory and functional benefits. Similar findings were also found by Shobana, S., & Malleshi, N. G. (2007) [12].

5. **Shelf-life evaluation:** During 90 days of ambient storage, moisture content and water activity increased slightly across all samples, with higher inulin levels showing higher retention. However, peroxide values and free fatty acids remained within acceptable limits, indicating minimal lipid oxidation. Microbial counts stayed below permissible ranges, confirming product stability. T3 exhibited slightly faster loss of crispness due to its higher moisture affinity, but acceptability remained satisfactory up to 60 days and acceptable at 90 days.

Conclusion

The study demonstrated that ragi biscuits can be successfully enriched with prebiotic inulin without adverse effects on quality. Inulin addition enhanced dietary fiber content and significantly lowered predicted glycemic index, making the product suitable for diabetic and health-conscious consumers. Among the tested formulations, 3.5% inulin (T2) yielded the best overall results in terms of nutritional improvement, functional properties, and consumer acceptability. This formulation represents a promising approach for developing fiber-enriched, low-GI functional millet-based bakery products. Future studies may explore in-*vivo* glycemic response and gut microbiota modulation for further validation.

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