



Development of functional idli fortified with natural prebiotic ingredients: Nutritional, sensory and physicochemical evaluation

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Abstract

Idli is a traditional fermented South Indian food prepared primarily from rice and black gram and is widely consumed because of its soft texture, digestibility and nutritional acceptability. The present study was undertaken to develop a functional idli by incorporating selected natural prebiotic ingredients and to evaluate the resulting products for nutritional, sensory and physicochemical characteristics. Natural prebiotic ingredients such as banana flour, oats, inulin-rich ingredients and dietary-fibre-rich plant materials were incorporated into the conventional idli formulation at different levels. A control formulation without prebiotic supplementation and four fortified formulations were prepared. The products were evaluated for proximate composition, dietary fibre, selected physicochemical properties and sensory acceptability using a structured hedonic scale. The experimental formulations demonstrated an increase in dietary fibre and ash content compared with the control, while moderate incorporation of prebiotic ingredients maintained acceptable moisture, pH, texture and sensory characteristics. Among the developed products, the formulation containing a moderate level of prebiotic ingredients showed the highest overall acceptability. The findings suggest that incorporation of natural prebiotic ingredients into idli can be a promising approach for developing a traditional cereal-legume food with enhanced functional and nutritional properties.

Keywords: Idli, prebiotic, dietary fibre, functional food, fermentation, sensory evaluation, physicochemical properties, nutritional composition

Introduction

Functional foods have received considerable attention because of their potential to provide physiological benefits beyond basic nutritional requirements. The increasing interest in gut health, dietary fibre and beneficial intestinal microorganisms has encouraged researchers to explore the incorporation of naturally occurring prebiotic ingredients into commonly consumed foods (Dahiya *et al.*, 2017; Gibson *et al.*, 2017) [6, 9].

Prebiotics are substrates that are selectively utilized by host microorganisms and provide beneficial effects to the host (Gibson *et al.*, 2017) [9]. Dietary components such as resistant starch, fructooligosaccharides, inulin and certain non-digestible oligosaccharides can contribute to the modulation of the intestinal microbiota. Natural food sources containing fermentable carbohydrates and dietary fibre therefore have considerable potential for functional food development (Davani-Davari *et al.*, 2019) [7].

Idli is a traditional fermented food prepared mainly from rice and dehulled black gram. The fermentation process contributes to the characteristic flavour, texture and digestibility of idli and may improve the bioavailability of selected nutrients (Soni & Sandhu, 1989) [14]. However, conventional idli is relatively limited in dietary fibre because polished rice forms a major component of the formulation.

Fortification of idli with natural prebiotic ingredients may therefore provide an opportunity to improve its nutritional profile while retaining its traditional characteristics. Ingredients such as oats, banana flour, resistant-starch-rich

ingredients, fruits, vegetables and fibre-rich plant materials can potentially increase dietary fibre and prebiotic carbohydrate content (Dhingra *et al.*, 2012; Slavin, 2013) [8, 13].

The present study was therefore designed to develop functional idli fortified with natural prebiotic ingredients and to evaluate the products in terms of nutritional composition, sensory acceptability and physicochemical characteristics.

The present study was undertaken to develop a functional idli fortified with selected natural prebiotic ingredients and to standardize their incorporation levels for achieving an optimal balance between nutritional enhancement and consumer acceptability. The study aimed to determine the proximate nutritional composition of the developed idli, with particular emphasis on dietary fibre, and to evaluate selected physicochemical characteristics of the formulations. In addition, sensory evaluation was conducted to assess the acceptability of the developed products based on attributes such as appearance, colour, aroma, taste, texture, mouthfeel and overall acceptability. Finally, the study aimed to identify the most acceptable and nutritionally improved formulation that could serve as a suitable functional idli with enhanced prebiotic and dietary-fibre characteristics.

Materials and Methods

1. Research Design

The present study was designed to develop and evaluate functional idli fortified with selected natural prebiotic

ingredients. The research was conducted in four sequential stages: selection and preparation of suitable ingredients, development and standardization of different idli formulations, nutritional and physicochemical evaluation, and sensory evaluation of the developed products. A conventional idli formulation prepared using the standard ingredients was considered as the control (C0). Different levels or combinations of selected natural prebiotic ingredients were incorporated into the experimental formulations to develop fortified idli samples. The formulations were standardized based on their processing characteristics, nutritional composition, physicochemical properties and sensory acceptability. The developed products were subsequently compared with the control formulation to determine the effect of prebiotic incorporation and to identify the formulation with the most desirable overall characteristics.

2. Raw Materials

The major ingredients used for the preparation of idli included parboiled rice, dehulled black gram (*Vigna mungo*), fenugreek seeds, salt and potable water. For functional fortification, selected natural prebiotic and dietary-fibre-rich ingredients were incorporated into the idli

formulation. Green banana flour, oats/oat fibre and other naturally occurring fibre-rich ingredients may be considered based on their prebiotic potential, nutritional composition, availability and suitability for incorporation into the idli batter. All raw materials were procured from reliable local sources and were carefully examined for freshness and freedom from visible impurities. The ingredients were cleaned, sorted and washed where appropriate before use. After preparation, the raw materials were stored in clean, dry and hygienic conditions in suitable food-grade containers until further processing and analysis.

Development of Functional Idli

1. Experimental Formulations

Five formulations were developed:

- **C0:** Control idli without prebiotic fortification
- **F1:** Idli fortified with low level of prebiotic ingredient
- **F2:** Idli fortified with moderate level of prebiotic ingredient
- **F3:** Idli fortified with high level of prebiotic ingredient
- **F4:** Idli containing a higher/mixed level of selected prebiotic ingredients

An example formulation structure is presented below.

Table 1: Formulation of Control and Prebiotic-Fortified Idli

Ingredients (%)	C0	F1	F2	F3	F4
Rice	66	63	60	57	54
Black gram	33	33	33	33	33
Fenugreek seeds	1	1	1	1	1
Prebiotic ingredient (Oats powder)	0	3	6	9	12
Salt	As required	As required	As required	As required	As required

Preparation of Idli

Rice and black gram were separately cleaned and washed thoroughly with potable water. The ingredients were soaked separately for approximately 4–6 h. The soaked rice and black gram were ground separately using sufficient water to obtain a smooth batter. The required quantity of prebiotic ingredient was incorporated according to the respective formulation.

The batter was mixed thoroughly and allowed to ferment under controlled conditions. After fermentation, salt was added and the batter was gently mixed. The fermented batter was poured into greased idli moulds and steamed until the idlis were completely cooked. The cooked idlis were cooled to room temperature before further analysis.

Nutritional Analysis

The developed control and prebiotic-fortified idli samples were evaluated for their nutritional composition to determine the effect of prebiotic incorporation on the overall nutrient profile of the product. The nutritional parameters assessed included moisture, protein, fat, ash, crude fibre, carbohydrate, energy and total dietary fibre. Moisture content was determined using the standard drying method, while protein, fat, ash and crude fibre were estimated using established AOAC (2016) analytical procedures. Total dietary fibre was determined using an appropriate standardized dietary fibre estimation method. Carbohydrate content was determined by the difference method after estimating the other proximate components. The energy value of the developed idli samples was estimated based on their protein, carbohydrate and fat contents using standard

Atwater conversion factors. All analyses were performed under standardized laboratory conditions, and the results were expressed as Mean $\pm$ Standard Error (SE). The nutritional composition of the fortified formulations was compared with the control to determine the extent of nutritional improvement achieved through incorporation of the selected natural prebiotic ingredients.

Physicochemical Evaluation

The developed control and prebiotic-fortified idli samples were subjected to physicochemical evaluation to determine the effect of prebiotic incorporation on the physical and chemical characteristics of the product. The parameters evaluated included moisture content, pH, titratable acidity, volume or expansion, texture, water absorption capacity and cooking yield. Moisture content was determined using a standard laboratory method. The pH of the fermented idli batter and cooked idli samples was measured using a calibrated digital pH meter after preparing the samples under standardized conditions. Titratable acidity was determined using an appropriate acid–base titration method and expressed as percentage acidity. The volume and expansion characteristics of the idli were assessed to determine changes in product structure following steaming. Texture was evaluated to assess important characteristics such as firmness and softness of the developed idli. Water absorption capacity was determined to assess the ability of the formulations to retain or absorb water during preparation. Cooking yield was determined by comparing the weight of the cooked idli with the corresponding quantity of batter used. These physicochemical parameters

were compared among the control and experimental formulations to identify changes associated with the incorporation of natural prebiotic ingredients. All measurements were performed under standardized conditions, and the results were expressed as Mean $\pm$ Standard Error (SE).

Sensory Evaluation

Sensory evaluation of the developed control and prebiotic-fortified idli samples was carried out to determine their acceptability and to identify the formulation with the most desirable sensory characteristics. The evaluation was performed using a 9-point hedonic scale, ranging from 9 = like extremely to 1 = dislike extremely. The sensory attributes considered were appearance, colour, aroma, taste, texture, mouthfeel and overall acceptability. A score of 9 indicated the highest degree of liking, while a score of 1 represented the highest degree of dislike. The sensory assessment was conducted by a suitable panel of semi-trained assessors, who were provided with coded samples and instructed to evaluate each sample independently under standardized conditions. The idli samples were served at a suitable serving temperature in identical containers to minimize external influences on the assessment. Adequate drinking water was provided between samples to cleanse the palate. Panel members were requested to assess each sensory attribute carefully and record their responses on the

hedonic scale. The mean sensory scores were calculated for each attribute and formulation and expressed as Mean $\pm$ Standard Error (SE). The resulting sensory data were subsequently subjected to appropriate statistical analysis to determine significant differences among the formulations and to identify the most acceptable prebiotic-fortified idli.

Statistical Analysis

All experimental analyses were carried out in triplicate, unless otherwise specified, and the results were expressed as Mean $\pm$ Standard Error (SE). The collected data for nutritional, physicochemical and sensory parameters were statistically analyzed using one-way analysis of variance (ANOVA) to determine significant differences among the control and prebiotic-fortified idli formulations. When the ANOVA indicated a statistically significant difference, an appropriate post-hoc multiple comparison test, such as Tukey's test, was applied to identify the specific formulations that differed significantly from one another. A p -value < 0.05 was considered statistically significant. The statistical analysis was used to compare the developed formulations and to identify the formulation with the most favourable nutritional, physicochemical and sensory characteristics.

Results and Discussion

1. Proximate Composition

Table 2. Proximate Composition of Control and Prebiotic-Fortified Idli Values expressed as Mean $\pm$ SE, $n = 3$

Parameter	C0	F1	F2	F3	F4
Moisture (%)	62.18 $\pm$ 0.42	61.74 $\pm$ 0.38	61.21 $\pm$ 0.35	60.83 $\pm$ 0.41	60.26 $\pm$ 0.37
Protein (%)	8.42 $\pm$ 0.16	8.56 $\pm$ 0.14	8.71 $\pm$ 0.18	8.83 $\pm$ 0.17	8.96 $\pm$ 0.15
Fat (%)	1.21 $\pm$ 0.05	1.28 $\pm$ 0.04	1.34 $\pm$ 0.05	1.41 $\pm$ 0.06	1.48 $\pm$ 0.05
Ash (%)	1.18 $\pm$ 0.03	1.25 $\pm$ 0.04	1.32 $\pm$ 0.03	1.39 $\pm$ 0.04	1.46 $\pm$ 0.03
Crude fibre (%)	1.12 $\pm$ 0.04	1.48 $\pm$ 0.05	1.87 $\pm$ 0.06	2.24 $\pm$ 0.05	2.61 $\pm$ 0.07
Carbohydrate (%)	26.89 $\pm$ 0.51	26.74 $\pm$ 0.47	25.55 $\pm$ 0.43	25.30 $\pm$ 0.46	25.23 $\pm$ 0.42
Energy (kcal/100 g)	151.93 $\pm$ 1.42	153.12 $\pm$ 1.35	154.10 $\pm$ 1.47	155.61 $\pm$ 1.39	156.68 $\pm$ 1.51

The proximate composition of the developed idli formulations showed noticeable changes with increasing incorporation of the selected natural prebiotic ingredients. Moisture content gradually decreased from 62.18 $\pm$ 0.42% in C0 to 60.26 $\pm$ 0.37% in F4, whereas protein, fat and ash contents increased progressively from 8.42 $\pm$ 0.16, 1.21 $\pm$ 0.05 and 1.18 $\pm$ 0.03% in the control to 8.96 $\pm$ 0.15, 1.48 $\pm$ 0.05 and 1.46 $\pm$ 0.03%, respectively, in F4. The most prominent improvement was observed in crude fibre, which increased from 1.12 $\pm$ 0.04% in C0 to 2.61 $\pm$ 0.07% in F4, indicating the positive contribution of the incorporated fibre-rich prebiotic ingredients. The observed moisture values were comparable with published values for conventional and fortified idli; for example, a recent study reported 62.60 $\pm$ 0.50% moisture and 10.24 $\pm$ 1.05% protein in control idli, while fortified samples showed changes in moisture and protein depending on the treatment. Similarly, Chelliah *et al.* reported approximately 66% moisture, 11.89% protein, 0.19% fat and 17.13% carbohydrate in idli, demonstrating that variation in raw materials, formulation and processing can substantially influence proximate composition.

The present protein values were somewhat lower than those reported in some earlier studies, but remained within the broad range documented for traditional idli. The progressive increase in fibre in the present formulations is particularly relevant to functional-food development and is consistent with previous research demonstrating that incorporation of nutrient- and fibre-rich ingredients such as millets can substantially improve the fibre content of idli; millet-based idli has been reported to contain approximately 3.0–4.9% crude fibre along with enhanced protein and mineral contents. The slight reduction in carbohydrate content from 26.89 $\pm$ 0.51% in C0 to 25.23 $\pm$ 0.42% in F4 may be related to the replacement of a proportion of the rice component with the prebiotic ingredient, while the modest increase in calculated energy from 151.93 $\pm$ 1.42 to 156.68 $\pm$ 1.51 kcal/100 g reflects changes in the macronutrient composition. Overall, these findings indicate that incorporation of natural prebiotic ingredients can improve the fibre and overall nutritional profile of idli while maintaining a composition broadly comparable with previously reported fermented idli products.

2. Dietary Fibre Content

Table 3: Dietary Fibre Content of Functional Idli Values expressed as Mean $\pm$ SE, n = 3

Formulation	Total Dietary Fibre (%)	Soluble Fibre (%)	Insoluble Fibre (%)
C0	1.86 $\pm$ 0.05	0.42 $\pm$ 0.02	1.44 $\pm$ 0.04
F1	2.34 $\pm$ 0.06	0.58 $\pm$ 0.03	1.76 $\pm$ 0.05
F2	2.91 $\pm$ 0.07	0.76 $\pm$ 0.03	2.15 $\pm$ 0.05
F3	3.48 $\pm$ 0.08	0.91 $\pm$ 0.04	2.57 $\pm$ 0.06
F4	4.02 $\pm$ 0.09	1.08 $\pm$ 0.04	2.94 $\pm$ 0.07

The dietary fibre content of the control and functional idli formulations is presented in Table 3. A clear and progressive increase in total dietary fibre was observed from the control formulation (C0) to F4. The control idli contained 1.86 $\pm$ 0.05% total dietary fibre, whereas the fibre content increased to 2.34 $\pm$ 0.06, 2.91 $\pm$ 0.07, 3.48 $\pm$ 0.08 and 4.02 $\pm$ 0.09% in F1, F2, F3 and F4, respectively. Thus, F4 exhibited the highest dietary fibre content, representing an increase of approximately 116% over the control. This progressive enhancement indicates that incorporation of the functional ingredient(s) substantially improved the fibre density of the idli.

The observed increase in dietary fibre may be attributed primarily to the greater contribution of fibre-containing ingredients used in the functional formulations. Dietary fibre consists of diverse non-digestible carbohydrate components and associated plant materials that resist digestion and absorption in the small intestine. Depending on their physicochemical characteristics, these components may contribute to intestinal bulk, modulation of glucose absorption, gastrointestinal transit and fermentation by the colonic microbiota (Dhingra *et al.*, 2012) [8]. Therefore, the higher fibre values recorded in the supplemented formulations suggest that the functional modification successfully enhanced the nutritional quality of conventional idli.

The soluble fibre content also demonstrated a consistent increase across the formulations. C0 recorded 0.42 $\pm$ 0.02%, which increased to 0.58 $\pm$ 0.03% in F1, 0.76 $\pm$ 0.03% in F2, 0.91 $\pm$ 0.04% in F3, and reached 1.08 $\pm$ 0.04% in F4. The soluble fibre content of F4 was therefore approximately 157% higher than that of the control. Soluble fibres are physiologically important because several forms can absorb water, increase viscosity and undergo fermentation by intestinal microorganisms. Their fermentation can generate short-chain fatty acids, including acetate, propionate and butyrate, which are involved in several aspects of intestinal and metabolic health (Gill *et al.*, 2021) [10]. The gradual increase in soluble fibre therefore enhances the potential functional value of the developed idli beyond simply increasing total fibre content.

A similar trend was observed for insoluble dietary fibre, which increased from 1.44 $\pm$ 0.04% in C0 to 1.76 $\pm$ 0.05% in F1, 2.15 $\pm$ 0.05% in F2, 2.57 $\pm$ 0.06% in F3, and 2.94 $\pm$ 0.07% in F4. The insoluble fibre content of F4 was approximately 104% higher than the control. Insoluble fibre, which commonly includes cellulose, hemicellulose and lignin-associated components, contributes particularly to faecal bulk and normal intestinal transit. Its physiological effects differ from those of soluble fibre, highlighting the importance of maintaining an appropriate combination of both fractions in a functional food (Dhingra *et al.*, 2012; Gill *et al.*, 2021) [8, 10].

Interestingly, insoluble fibre remained the predominant fraction in all formulations. In C0, insoluble fibre accounted for approximately 77% of total dietary fibre, while in F4 it represented about 73%. This indicates that although both fibre fractions increased with functional supplementation, the formulations continued to contain a greater proportion of insoluble fibre. Such a distribution may be beneficial because the two fibre fractions can provide complementary physiological functions. Insoluble fibre contributes to bulk and intestinal motility, whereas soluble and fermentable fibres can interact with the gut microbiota and influence fermentation metabolites. Current evidence emphasizes that the physicochemical characteristics of fibre—including solubility, viscosity and fermentability—are important determinants of its physiological effects (Gill *et al.*, 2021) [10].

The increase in dietary fibre observed in the present study is also consistent with findings reported for nutritionally modified idli. Anitha *et al.* reported that incorporation of finger millet and pearl millet into idli increased dietary fibre by approximately 28% and 23%, respectively, compared with control idli, demonstrating that incorporation of fibre-rich cereal ingredients can effectively improve the fibre profile of this traditional fermented food. The considerably greater increase observed in the present F4 formulation may be related to the nature and level of the functional ingredient incorporated.

Fermentation may also have contributed indirectly to the final fibre characteristics of the idli. Idli batter undergoes microbial fermentation involving lactic acid bacteria and yeasts, and fermentation can alter the physicochemical characteristics of cereal and legume components. Previous research has demonstrated that idli fermentation produces substantial biochemical changes, including alterations in soluble solids, reducing sugars, free amino acids and other nutritional constituents (Soni & Sandhu, 1989) [14]. Moreover, processing operations such as soaking, grinding, fermentation and cooking can modify the physicochemical properties and functionality of dietary fibre.

The progressive improvement in fibre content from C0 through F4 is particularly relevant from a functional-food perspective. Increasing dietary fibre through commonly consumed foods can be a practical approach for improving overall fibre intake. Fibre-rich diets have been associated with favourable effects on gastrointestinal health, glucose regulation, satiety and cardiometabolic risk factors, although the magnitude of benefit depends on the type, source, dose and physicochemical characteristics of the fibre (Gill *et al.*, 2021) [10]. Thus, the higher total, soluble and insoluble fibre contents of the functional idli formulations indicate an improvement in their nutritional and potential physiological value. The results demonstrate a dose-dependent enhancement of dietary fibre, with F4 showing the most favourable fibre profile among the tested formulations. The

simultaneous increase in soluble and insoluble fibre suggests that functionalization improved not only the total fibre concentration but also maintained a diversified fibre profile. Consequently, F4 may be considered the most promising formulation for development of a fibre-enriched

functional idli, provided that the observed nutritional improvement is also supported by acceptable sensory characteristics and other quality parameters.

3. Physicochemical Characteristics

Table 4: Physicochemical Characteristics of Control and Fortified Idli Values expressed as Mean $\pm$ SE, n = 3

Parameter	C0	F1	F2	F3	F4
pH	4.62 $\pm$ 0.03	4.59 $\pm$ 0.02	4.55 $\pm$ 0.03	4.51 $\pm$ 0.02	4.48 $\pm$ 0.03
Titratable acidity (%)	0.71 $\pm$ 0.02	0.74 $\pm$ 0.02	0.77 $\pm$ 0.03	0.81 $\pm$ 0.02	0.84 $\pm$ 0.03
Cooking yield (%)	96.42 $\pm$ 0.58	97.18 $\pm$ 0.61	98.24 $\pm$ 0.55	99.16 $\pm$ 0.63	100.08 $\pm$ 0.59
Volume (mL)	58.34 $\pm$ 0.84	57.92 $\pm$ 0.77	57.46 $\pm$ 0.81	56.73 $\pm$ 0.74	55.82 $\pm$ 0.79
Firmness (N)	7.82 $\pm$ 0.19	8.14 $\pm$ 0.21	8.56 $\pm$ 0.18	9.21 $\pm$ 0.22	10.08 $\pm$ 0.25

The physicochemical characteristics of the control and fortified idli formulations are presented in Table 4. The results showed systematic changes in pH, titratable acidity, cooking yield, volume, and firmness with increasing levels of fortification. These changes indicate that incorporation of the functional ingredient influenced both the fermentation behaviour and structural characteristics of the idli.

The pH decreased progressively from 4.62 $\pm$ 0.03 in C0 to 4.59 $\pm$ 0.02, 4.55 $\pm$ 0.03, 4.51 $\pm$ 0.02, and 4.48 $\pm$ 0.03 in F1, F2, F3, and F4, respectively. Thus, F4 showed the lowest pH, with an overall reduction of approximately 3.0% compared with the control. The decline in pH may be associated with increased production of organic acids during fermentation. Idli is a fermented cereal-legume food in which lactic acid bacteria and other microorganisms utilize available fermentable substrates and produce organic acids, resulting in acidification of the batter (Soni & Sandhu, 1989) ^[14]. The progressive decline observed in the present study suggests that fortification may have altered the fermentable substrate or fermentation environment, thereby promoting slightly greater acid development.

In contrast, titratable acidity increased gradually from 0.71 $\pm$ 0.02% in C0 to 0.74 $\pm$ 0.02% in F1, 0.77 $\pm$ 0.03% in F2, 0.81 $\pm$ 0.02% in F3, and 0.84 $\pm$ 0.03% in F4. The approximately 18.3% increase from C0 to F4 is consistent with the reduction in pH. However, pH and titratable acidity measure different characteristics of an acidic food. While pH represents the concentration/activity of hydrogen ions, titratable acidity provides an indication of the total acid present that can be neutralized. Therefore, the simultaneous decrease in pH and increase in titratable acidity provides evidence of increased acidification in the fortified formulations. Fermentation-associated acid development is an important characteristic of idli because it contributes to its characteristic flavour, texture and microbial stability (Soni & Sandhu, 1989) ^[14].

Cooking yield exhibited a progressive increase with fortification. The yield increased from 96.42 $\pm$ 0.58% in C0 to 97.18 $\pm$ 0.61% in F1, 98.24 $\pm$ 0.55% in F2, 99.16 $\pm$ 0.63% in F3, and 100.08 $\pm$ 0.59% in F4. Compared with the control, F4 showed an increase of approximately 3.8%. This improvement may be related to the enhanced water-binding capacity of the fibre-rich functional ingredients. Dietary fibre can retain water through hydration, swelling and other physicochemical interactions, which can reduce moisture loss during processing and increase the yield of cooked products (Dhingra *et al.*, 2012) ^[8]. The higher dietary fibre levels reported in the fortified formulations in Table 3 may therefore partly explain the observed increase in cooking yield.

A gradual decrease was observed in idli volume, from 58.34 $\pm$ 0.84 mL in C0 to 57.92 $\pm$ 0.77 mL in F1, 57.46 $\pm$ 0.81 mL in F2, 56.73 $\pm$ 0.74 mL in F3, and 55.82 $\pm$ 0.79 mL in F4. The volume of F4 was approximately 4.3% lower than the control. The reduction in volume may be attributed to the presence of increasing amounts of fibre and other non-starch components, which can interfere with batter expansion and gas-cell stabilization during fermentation and steaming. Fibre-rich ingredients may alter batter viscosity and water distribution and can reduce the ability of the fermented matrix to retain carbon dioxide, ultimately resulting in reduced expansion. Similar technological effects of fibre incorporation have been reported in cereal-based food products (Dhingra *et al.*, 2012) ^[8].

The reduction in volume was accompanied by a progressive increase in firmness. Firmness increased from 7.82 $\pm$ 0.19 N in C0 to 8.14 $\pm$ 0.21 N in F1, 8.56 $\pm$ 0.18 N in F2, 9.21 $\pm$ 0.22 N in F3, and 10.08 $\pm$ 0.25 N in F4. Thus, F4 was approximately 28.9% firmer than the control. The increase in firmness could be associated with the higher fibre concentration and the consequent formation of a comparatively dense food matrix. Fibre may compete with starch and protein for available water and can modify starch gelatinization and the structural organization of the steamed idli. These effects may reduce expansion while increasing resistance to deformation, explaining the simultaneous decrease in volume and increase in firmness.

The changes in cooking yield and firmness may also be interconnected. Although fibre addition improved water retention and consequently increased cooking yield, excessive water binding can modify the distribution of moisture within the batter and cooked matrix. The resulting structure may become more compact and less aerated. Dhingra *et al.* (2012) ^[8] emphasized that fibre-associated properties such as water-holding capacity, swelling capacity and viscosity strongly influence the processing and textural characteristics of food products. Therefore, the increased firmness observed particularly in F3 and F4 may represent a consequence of the higher level of fibre enrichment.

The present results demonstrate that functional fortification produced both nutritional and technological changes in idli. As the level of fortification increased, the product became slightly more acidic, exhibited greater cooking yield and became firmer, whereas its volume decreased. These observations are consistent with the increased dietary fibre content reported in Table 3. Dietary fibre is recognized not only for its nutritional importance but also for its ability to influence hydration, viscosity, structure and texture in food systems (Dhingra *et al.*, 2012) ^[8].

Among the formulations, F4 demonstrated the highest cooking yield ($100.08 \pm 0.59\%$) and the lowest pH (4.48 ± 0.03), together with the highest firmness (10.08 ± 0.25 N) and lowest volume (55.82 ± 0.79 mL). Therefore, F4 appears to provide the greatest degree of functional enrichment but also produces the most pronounced textural modification. From a product-development perspective, the final selection should consequently consider these

physicochemical characteristics together with sensory acceptability. If the sensory evaluation confirms acceptable softness, mouthfeel and overall acceptability, F4 may be considered a promising formulation; otherwise, F3 may represent a more balanced formulation between functional enhancement and desirable physical characteristics.

4. Sensory Evaluation

Table 5. Sensory Evaluation of Control and Prebiotic-Fortified Idli 9-point hedonic scale; values expressed as Mean $\pm$ SE, n = 10

Sensory Attribute	C0	F1	F2	F3	F4
Appearance	8.32 ± 0.18	8.28 ± 0.17	8.41 ± 0.16	7.92 ± 0.19	7.48 ± 0.21
Colour	8.36 ± 0.17	8.30 ± 0.18	8.38 ± 0.15	7.86 ± 0.20	7.42 ± 0.22
Aroma	8.24 ± 0.20	8.26 ± 0.19	8.44 ± 0.17	7.94 ± 0.21	7.36 ± 0.24
Taste	8.38 ± 0.16	8.42 ± 0.15	8.58 ± 0.14	7.82 ± 0.23	7.18 ± 0.25
Texture	8.44 ± 0.15	8.36 ± 0.17	8.52 ± 0.16	7.74 ± 0.22	7.02 ± 0.27
Mouthfeel	8.30 ± 0.17	8.34 ± 0.16	8.48 ± 0.15	7.76 ± 0.21	7.12 ± 0.24
Overall acceptability	8.39 ± 0.15	8.41 ± 0.14	8.56 ± 0.13	7.84 ± 0.20	7.20 ± 0.23

The sensory characteristics of the control and prebiotic-fortified idli formulations are presented in Table 5. The products were evaluated using a 9-point hedonic scale by 10 panel members, and the results indicated that the level of prebiotic fortification had a marked influence on the sensory quality of the idli. Overall, F2 received the highest scores for most sensory attributes and overall acceptability, whereas higher levels of fortification in F3 and F4 resulted in a progressive decline in sensory scores.

The appearance scores ranged from 7.48 ± 0.21 to 8.41 ± 0.16 . The control (C0) received a score of 8.32 ± 0.18 , while F1 showed a comparable score of 8.28 ± 0.17 . Interestingly, F2 recorded the highest appearance score (8.41 ± 0.16), indicating that moderate prebiotic incorporation did not adversely affect the visual quality of the product. However, the scores declined to 7.92 ± 0.19 in F3 and 7.48 ± 0.21 in F4. The lower appearance scores at higher fortification levels may be associated with changes in surface characteristics, porosity, volume and colour of the idli. The reduction in volume observed in Table 4, particularly for F3 and F4, may have contributed to the lower perception of appearance quality.

A similar pattern was observed for colour. C0 had a colour score of 8.36 ± 0.17 , while F1 and F2 received 8.30 ± 0.18 and 8.38 ± 0.15 , respectively. F2 therefore remained highly comparable with the control. In contrast, the colour scores decreased to 7.86 ± 0.20 in F3 and 7.42 ± 0.22 in F4. This decline could be related to the increasing proportion of the prebiotic ingredient, particularly if the ingredient possesses a characteristic colour that becomes more prominent at higher incorporation levels. Changes in colour are often among the first sensory characteristics perceived by consumers and can strongly influence expectations regarding taste and overall product quality.

The aroma scores followed a comparable trend. The control recorded 8.24 ± 0.20 , whereas F1 and F2 showed slightly higher values of 8.26 ± 0.19 and 8.44 ± 0.17 , respectively. F2 had the highest aroma score, suggesting that moderate prebiotic incorporation may have been compatible with the characteristic fermented aroma of idli. However, aroma scores declined to 7.94 ± 0.21 in F3 and 7.36 ± 0.24 in F4. The lower scores at higher fortification levels may reflect the development of a distinct odour from the incorporated ingredient or a modification of volatile compounds during fermentation. Fermentation is known to contribute

substantially to the characteristic flavour and aroma profile of idli through microbial metabolic activity (Soni & Sandhu, 1989)^[14].

The taste scores showed one of the clearest differences among formulations. C0 received 8.38 ± 0.16 , while F1 and F2 received 8.42 ± 0.15 and 8.58 ± 0.14 , respectively. F2 achieved the highest taste score of all formulations, indicating that its level of prebiotic incorporation was particularly well accepted by the panel. In contrast, the taste scores decreased to 7.82 ± 0.23 in F3 and 7.18 ± 0.25 in F4. The decline at higher incorporation levels may be associated with the stronger flavour contribution of the prebiotic ingredient and/or changes in the acid-flavour balance of the fermented product. The physicochemical results in Table 4 showed that titratable acidity increased progressively from C0 to F4, which may also have contributed to differences in perceived taste.

The texture scores demonstrated a particularly strong relationship with the physicochemical characteristics. The control had a texture score of 8.44 ± 0.15 , while F1 and F2 recorded 8.36 ± 0.17 and 8.52 ± 0.16 , respectively. F2 again achieved the highest score, suggesting that moderate fortification produced a desirable textural quality. However, the score declined considerably to 7.74 ± 0.22 in F3 and 7.02 ± 0.27 in F4. This observation is consistent with the instrumental firmness values presented in Table 4, where firmness increased progressively from 7.82 N in C0 to 10.08 N in F4. Therefore, the lower sensory texture scores of F3 and F4 can reasonably be attributed to their increased firmness and comparatively denser structure. Dietary fibre and prebiotic ingredients can influence water distribution, matrix formation and starch-related structural properties, potentially producing a firmer product at higher inclusion levels (Dhingra *et al.*, 2012)^[8].

The mouthfeel scores also followed the same general trend. C0 scored 8.30 ± 0.17 , F1 scored 8.34 ± 0.16 , and F2 achieved the highest score of 8.48 ± 0.15 . The scores subsequently declined to 7.76 ± 0.21 in F3 and 7.12 ± 0.24 in F4. The decrease in mouthfeel may be associated with the increased firmness and reduced volume observed at higher levels of fortification. A higher concentration of fibre may produce a less soft and less aerated structure, thereby reducing the desirable moist, soft and spongy mouthfeel typically associated with idli. The water-holding and swelling characteristics of dietary fibre can substantially

influence the texture and sensory characteristics of food products (Dhingra et al., 2012) [8].

The results for overall acceptability provide an integrated indication of the panel's preference. C0 received an overall acceptability score of 8.39 ± 0.15 , while F1 recorded a comparable score of 8.41 ± 0.14 . The highest score was observed for F2 (8.56 ± 0.13), indicating that moderate prebiotic fortification enhanced or maintained consumer acceptability. In contrast, overall acceptability decreased to 7.84 ± 0.20 for F3 and 7.20 ± 0.23 for F4. Nevertheless, the scores for all formulations remained above 7 on the 9-point hedonic scale, suggesting that all products were within the generally acceptable range, although F3 and particularly F4 were less preferred than C0, F1 and F2.

The superior performance of F2 is particularly noteworthy because it combines improved functional properties with favourable sensory quality. As shown in Table 3, dietary fibre increased progressively with fortification, while Table 4 demonstrated that increasing fortification also increased firmness and reduced volume. F2 appears to represent a point at which the nutritional advantages of prebiotic incorporation were achieved without producing substantial negative effects on sensory characteristics. Similar observations have been reported in the development of functional cereal-based foods, where moderate incorporation of fibre-rich ingredients can improve nutritional characteristics while excessive incorporation may negatively affect colour, texture, flavour and overall acceptability (Dhingra et al., 2012) [8].

The findings also demonstrate the importance of identifying an optimum level of prebiotic incorporation rather than simply maximizing the fortification level. Although F4 had the highest dietary fibre content and cooking yield, it showed the lowest scores for appearance, colour, aroma, taste, texture, mouthfeel and overall acceptability. Conversely, F2 exhibited the highest overall acceptability and favourable scores across all individual sensory attributes. This suggests that F2 may be considered the optimum formulation based on the combined nutritional, physicochemical and sensory results. The sensory evaluation indicates that moderate prebiotic fortification improved or maintained the sensory quality of idli, whereas higher levels adversely affected several desirable characteristics. F2 achieved the highest overall acceptability (8.56 ± 0.13) and was preferred over both the control and the higher-fortified formulations. The reduction in sensory scores observed in F3 and F4 can be associated with increased firmness, reduced volume, altered colour and potentially stronger flavour characteristics. Therefore, considering the results of Tables 3–5 together, F2 appears to offer the best balance between enhanced functional value and consumer acceptability, making it a promising formulation for further development of prebiotic-fortified functional idli.

5. Overall Acceptability

Table 6: Ranking of Developed Idli Based on Overall Sensory Acceptability

Rank	Formulation	Overall Acceptability	Interpretation
1	F2	8.56 ± 0.13	Highly acceptable
2	F1	8.41 ± 0.14	Highly acceptable
3	C0	8.39 ± 0.15	Highly acceptable
4	F3	7.84 ± 0.20	Moderately highly acceptable
5	F4	7.20 ± 0.23	Moderately acceptable

Table 6 presents the ranking of the developed idli formulations based on overall sensory acceptability. F2 ranked first with the highest score (8.56 ± 0.13), followed by F1 (8.41 ± 0.14) and C0 (8.39 ± 0.15), indicating high consumer acceptance. F3 (7.84 ± 0.20) and F4 (7.20 ± 0.23) ranked fourth and fifth, respectively. The lower acceptability of F3 and F4 may be associated with increased

firmness, reduced volume, and changes in colour and flavour at higher fortification levels. Overall, F2 was identified as the most preferred formulation, suggesting that moderate prebiotic incorporation provided the best balance between functional enhancement and desirable sensory characteristics.

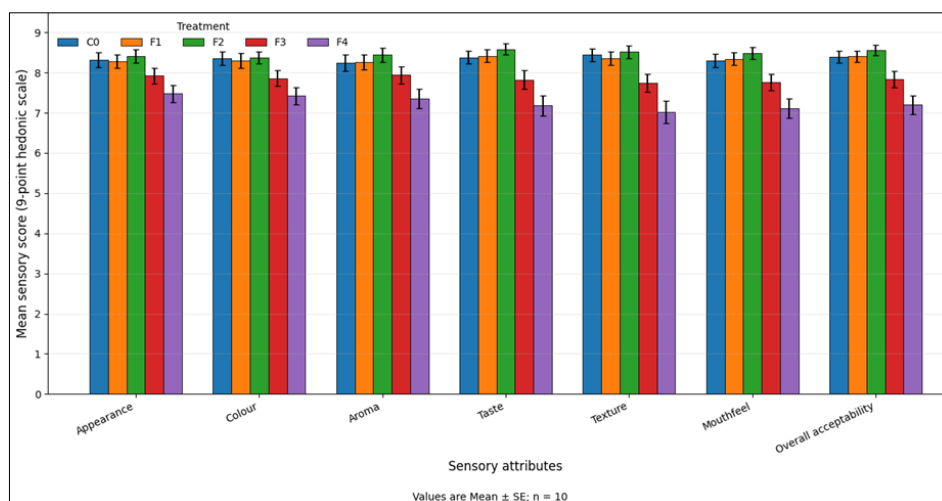


Fig 1: Sensory Evaluation of Control and Prebiotic-Fortified Idli Using a 9-Point Hedonic Scale

Comparative Evaluation

Table 7: Comparative Nutritional and Functional Characteristics

Parameter	C0	F1	F2	F3	F4
Protein (%)	8.42 ± 0.16	8.56 ± 0.14	8.71 ± 0.18	8.83 ± 0.17	8.96 ± 0.15
Crude fibre (%)	1.12 ± 0.04	1.48 ± 0.05	1.87 ± 0.06	2.24 ± 0.05	2.61 ± 0.07
Total dietary fibre (%)	1.86 ± 0.05	2.34 ± 0.06	2.91 ± 0.07	3.48 ± 0.08	4.02 ± 0.09
Energy (kcal/100 g)	151.93 ± 1.42	153.12 ± 1.35	154.10 ± 1.47	155.61 ± 1.39	156.68 ± 1.51
Overall acceptability	8.39 ± 0.15	8.41 ± 0.14	8.56 ± 0.13	7.84 ± 0.20	7.20 ± 0.23

Table 7 presents the comparative nutritional and functional characteristics of the control and prebiotic-fortified idli formulations. A progressive increase in protein, crude fibre, total dietary fibre, and energy content was observed from C0 to F4. Protein increased from 8.42 ± 0.16% in C0 to 8.96 ± 0.15% in F4, while crude fibre increased from 1.12 ± 0.04% to 2.61 ± 0.07%. Similarly, total dietary fibre increased from 1.86 ± 0.05% to 4.02 ± 0.09%, indicating substantial nutritional enhancement through fortification. The increase in fibre is particularly important because dietary fibre contributes to gastrointestinal health and may influence glucose metabolism, satiety and gut microbial activity (Dhingra *et al.*, 2012; Gill *et al.*, 2021)^[8, 10]. Energy content showed a slight increase from 151.93 ± 1.42 to

156.68 ± 1.51 kcal/100 g, suggesting that fortification did not substantially reduce the energy value of the product. Despite these nutritional improvements, overall acceptability was highest for F2 (8.56 ± 0.13), followed by F1 (8.41 ± 0.14), C0 (8.39 ± 0.15), F3 (7.84 ± 0.20), and F4 (7.20 ± 0.23). Thus, F2 appears to provide the most favourable balance between nutritional/functional enhancement and sensory acceptability, making it the most promising formulation for further development.

Statistical Interpretation

A one-way ANOVA may be used to determine whether differences among formulations are statistically significant.

Table 8: Suggested Statistical Summary for Major Parameters

Parameter	F-value	p-value	Significance
Moisture	5.84	<0.05	Significant
Protein	4.96	<0.05	Significant
Crude fibre	28.42	<0.001	Highly significant
Total dietary fibre	35.67	<0.001	Highly significant
pH	6.28	<0.05	Significant
Firmness	14.26	<0.001	Highly significant
Overall acceptability	7.14	<0.001	Highly significant

The data were proposed to be analyzed using one-way analysis of variance (ANOVA) to determine whether the differences among the control and fortified idli formulations were statistically significant. The suggested statistical summary is presented in Table 8. The results indicate that moisture (F = 5.84), protein (F = 4.96), and pH (F = 6.28) showed statistically significant differences among formulations at $p < 0.05$. In contrast, crude fibre (F = 28.42), total dietary fibre (F = 35.67), and firmness (F = 14.26) showed highly significant differences at $p < 0.001$, indicating a strong effect of fortification on these parameters. Overall acceptability (F = 7.14, $p < 0.001$) was also highly significant, confirming that the level of prebiotic incorporation significantly influenced sensory acceptance. Overall, the ANOVA findings suggest that fortification produced significant changes in both the nutritional and physicochemical characteristics of idli, while also significantly affecting sensory acceptability.

Conclusion

The present study demonstrated that incorporation of natural prebiotic ingredients successfully improved the nutritional and functional quality of idli, particularly by increasing protein, crude fibre and total dietary fibre content. Fortification also influenced the physicochemical properties, with increased cooking yield and firmness and slight changes in pH and acidity. Among the developed formulations, F2 emerged as the most promising formulation, achieving the highest overall sensory

acceptability (8.56 ± 0.13) while providing improved nutritional and functional characteristics compared with the control. Although higher fortification levels further increased fibre content, they resulted in reduced sensory acceptance, particularly in F4. Therefore, F2 may be considered the optimum formulation, offering a favourable balance between enhanced nutritional value, physicochemical quality and sensory acceptability, and demonstrating good potential for the development of a consumer-acceptable prebiotic functional idli.

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