Original Research Article

Fortified and Unfortified Rice Flours: A Comparative Evaluation of Nutritional Composition and Functional Characteristics

ABSTRACT

Aims: To compare the nutritional (moisture, starch, crude fiber, iron, Vitamin B₁₂) and functional properties (foaming capacity, pH, water and oil holding capacity, swelling power) of fortified versus unfortified rice flours, and evaluate the impact of fortification in enhancing nutritional value.

Study Design: Completely Randomized Design (CRD).

Place & Duration of Study: Department of Community Science, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India; December 2024 – April 2025.

Methodology: Fortified rice samples were obtained from the Public Distribution System and unfortified rice from the local market. Both samples were milled into flour and analyzed using standardized analytical procedures: moisture by AOAC oven‑drying; crude fiber via acid‑alkali digestion; total starch by acid hydrolysis and Fehling's titration; iron by dry ashing and spectrophotometry; and Vitamin B₁₂ by UV‑Visible spectrophotometry. Functional tests included foam volume (manual agitation method), pH (digital pH meter), water and oil holding capacities (Beuchat method), and swelling power (heating‑centrifugation technique).

Results: Fortified flour had significantly higher levels of iron and Vitamin B₁₂ (p < 0.01), slightly lower starch and crude fiber. Functional analysis demonstrated reduced foaming ability in fortified flour, unchanged water holding capacity, a decrease in oil holding capacity, and improved swelling power.

Conclusion: Fortification significantly improves micronutrient levels without markedly impairing functional quality. Fortified rice flour is a viable intervention to enhance dietary micronutrient intake and its functional behavior supports incorporation into food systems.

*Keywords:* *Fortified rice; rice flour; micronutrients; iron; vitamin B₁₂; functional properties.*

**INTRODUCTION**

Globally, hunger and malnutrition affect approximately 65 million individuals, including refugees and internally displaced persons. These vulnerable populations often face limited access to balanced diets, which can lead to long-term health complications, perpetuate poverty, and reduce resilience against future socio-economic shocks. Malnutrition especially in the form of micronutrient deficiency or "hidden hunger" is a critical public health issue that demands sustainable, cost-effective interventions (Thakur *et al*., 2023).

According to the World Health Organization (2022), *food fortification* is defined as the deliberate increase of one or more micronutrients (such as vitamins and minerals) in food products to enhance their nutritional quality and confer health benefits to the population with minimal health risks. Fortification is especially important in restoring micronutrients lost during food processing and can significantly contribute to improved nutritional outcomes at the population level.

Rice, being a staple food for more than half of the global population, holds immense potential as a vehicle for fortification. In countries like India, rice contributes substantially to daily caloric intake and features prominently in many traditional dishes. However, commonly consumed white polished rice is stripped of essential micronutrients like iron, folic acid, and vitamin B12 during the milling and polishing processes. This loss exacerbates widespread micronutrient deficiencies, particularly among at-risk groups such as women and children (FSSAI, 2022).

India continues to face a high prevalence of iron-deficiency anemia, with dietary diversification efforts falling short due to economic limitations and socio-cultural practices. As a result, food fortification has emerged as a practical, scalable, and environmentally sustainable approach to mitigate this crisis (Kumar and Shekhar, 2021).

In response, the Government of India initiated a pilot scheme in 2019 to introduce fortified rice through the Public Distribution System (PDS). Encouraged by its outcomes, the government announced a nationwide scale-up of the program by 2024. Fortified rice is typically produced using techniques such as micronutrient coating or extrusion technology, ensuring consistent and effective delivery of essential nutrients. This strategy has the potential to be a powerful public health intervention in rice-consuming populations (ASHA, 2022).

**Materials and methods**

**2.1 Collection of raw materials**

Fortified raw rice was procured from the **Public Distribution System (PDS)**, while unfortified rice was sourced from a local market in Thiruvananthapuram district. Both rice samples were thoroughly washed to remove surface impurities, sun-dried, and then ground into fine flour using a laboratory-grade grinder. The resulting flours were sieved through a fine mesh to ensure uniform particle size.The processed flours were immediately packed in airtight, laminated high-density polyethylene (HDPE) bags to prevent moisture absorption and microbial contamination. The samples were stored at ambient room temperature until further analysis.

Subsequently, the flour samples were subjected to comprehensive nutritional and functional property analyses to evaluate the impact of micronutrient fortification. All sample handling and processing were conducted under sterile laboratory conditions to ensure sample integrity and reproducibility of analytical results

**2.2 Comparative Nutritional Analysis of Rice Flours**

The nutritional parameters of various rice flour samples were analyzed using standard protocols. The methods employed for each parameter are described below:

**2.2.1 Moisture Content**

Moisture content was determined by the hot air oven-drying method, following the official procedure outlined by the Association of Official Analytical Chemists (AOAC, 2010). Approximately 5 grams of rice flour were accurately weighed into pre-weighed moisture dishes and dried in a hot air oven maintained at 105 ± 1°C for 3–4 hours until a constant weight was achieved. The loss in weight was recorded as moisture content and expressed as a percentage of the original sample weight. This parameter is essential in assessing storage stability and shelf life, as higher moisture can predispose samples to microbial spoilage**.**

**2.2.2 Crude Fiber**

Crude fiber content was estimated by using the acid-alkali digestion method, as described by Chopra and Kanwar (1978). Briefly, a known weight of the defatted rice flour sample was subjected to sequential digestion with 1.25% sulfuric acid and 1.25% sodium hydroxide under controlled conditions to simulate the action of digestive enzymes. The residue obtained after filtration was oven-dried, weighed, and subsequently ashed in a muffle furnace at 550°C. The difference in weight before and after ashing was used to calculate the crude fiber content. Crude fiber gives an indication of the indigestible carbohydrate fraction important for gut health.

**2.2.3 Total Starch**

The total starch content of the rice flour samples was analyzed using the acid hydrolysis and titrimetric estimation method, as per the procedure given by Sadasivam and Manickam (1992). In this method, starch in the sample was hydrolyzed into reducing sugars by treatment with concentrated hydrochloric acid under heat. The resultant reducing sugars were quantified by titration with Fehling’s A and B solutions, using methylene blue as an internal indicator. The endpoint was identified by a persistent brick-red precipitate of cuprous oxide. The starch content was calculated based on the volume of Fehling’s solution consumed and reported as a percentage of dry sample weight. This method provides an accurate estimate of the carbohydrate energy contribution in the flour.

**2.2.4 Vitamin B12**

Vitamin B12 was extracted from a 1 g sample using 10 mL of 0.1 N hydrochloric acid and heated at 100°C for 30 minutes. After cooling and filtration, 5 mL of the extract was treated with potassium cyanide and acetate buffer (pH 4.5) to convert all forms of Vitamin B12 to cyanocobalamin. The mixture was either heated at 100°C for 30 minutes or kept in the dark overnight. Absorbance was measured at 361 nm using a UV-Visible spectrophotometer, and Vitamin B12 concentration was calculated using a standard calibration curve in the range of 0.01–0.10 mg/mL AOAC (2000).

**2.2.5 Iron**

Iron content was estimated by dry ashing of the sample followed by spectrophotometric analysis, as per the procedures given by AOAC (2000).

**2.3 Assessment of Functional Properties of Rice Flour**

The functional properties of rice flour were evaluated using standardized protocols as described below:

**2.3.1 Foam Volume**

Foam volume was determined using the modified method of Narayana and Rao (1982). A 1.0 g sample of rice flour was mixed with 50 mL of distilled water in a measuring cylinder. The mixture was blended thoroughly and shaken manually for 5 minutes. It was then allowed to stand undisturbed for 30 seconds. The foam volume was measured, and the foaming capacity was expressed as the volume (mL) of foam formed per gram of sample.

**2.3.2 pH**

The pH of the rice flour samples was determined using a digital pH meter, following the procedure described in the AOAC (2000).

**2.3.3 Water Holding Capacity (WHC)**

Rice flour (1.0 g) was mixed with 10 mL of distilled water and allowed to stand at ambient temperature for 30 minutes. The mixture was then centrifuged at 3000 rpm for 30 minutes. The water holding capacity was expressed as grams of water retained per gram of sample (Beuchat, 1977).

**2.3.4 Oil Holding Capacity (OHC)**

Rice flour (1.0 g) was mixed with 10 mL of sunflower oil and maintained at ambient temperature for 30 minutes. It was then centrifuged at 3000 rpm for 30 minutes. The oil holding capacity was expressed as grams of oil retained per gram of sample Beuchat (1977).

**2.3.5 Swelling Power**

A known quantity of rice flour (1.0 g) was mixed with 10 mL of distilled water and heated at 80°C. After heating, the mixture was centrifuged, and the weight of the gel-like paste formed was recorded after decanting the supernatant. Swelling power was calculated as the weight of the sedimented paste per gram of dry sample (Leach *et al*., 1959).

**3. RESULTS AND DISCUSSION**

**3.1. Comparative Nutritional Analysis of Rice Flours**

The moisture content in unfortified rice flour (11.68 ± 0.08%) was slightly higher than that in fortified rice flour (11.50 ± 0.05%), but the difference was statistically significant, as indicated by the highly significant F-statistic (F = 22.85, p < 0.01). Although the difference is marginal, it is statistically meaningful and can be attributed to the altered water-binding capacity of the flour due to micronutrient addition. Fortification may reduce the number of hydroxyl groups available to form hydrogen bonds with water molecules, thereby lowering moisture retention. A similar trend was observed by Pavithra et al. (2024), who reported improved storage potential in fortified rice flour due to reduced moisture content. Moreover, Kibar et al. (2010) emphasized that keeping moisture content below 12% is critical to prevent microbial growth and enhance the storage stability of cereal flours.

The starch content was found to be significantly higher in unfortified rice flour (73.78 ± 1.28%) than in fortified rice flour (70.07 ± 1.09%), with a notable F-value (F = 34.16, *p* < 0.001). The decline in starch percentage in the fortified sample can be explained by the “dilution effect,” wherein the physical displacement of starch granules occurs during fortification, particularly during the extrusion process. As rice flour is enriched with micronutrients and binding agents, the proportional content of starch decreases. Furthermore, lower starch content may offer nutritional benefits by slightly reducing the glycemic load a useful characteristic for individuals managing diabetes or metabolic syndrome, as noted by Yulianto et al. (2018).

The crude fiber content in unfortified rice flour (0.69 ± 0.09 g) was significantly higher than that in fortified flour (0.48 ± 0.05 g), supported by a highly significant F-statistic (F = 27.77, *p* < 0.001). This reduction is attributed to the use of refined or broken rice in the fortification process, which typically lacks the bran layer that contains dietary fiber. The extrusion process further contributes to fiber loss unless external fiber sources are added. This finding is partially supported by Jukanti et al. (2012), who noted that fiber levels increase only when legume flours or bran are incorporated intentionally during fortification. Similarly, the decrease in crude fiber due to fortification with refined rice has also been observed in other formulations using non-fiber-rich additives, whereas studies like A and E (2020) emphasized that incorporating soy and plantain flour blends could counteract such reductions and enhance the fiber profile. In contrast, in the present study, no external fiber enrichment was undertaken, leading to a statistically significant decline in crude fiber.

The iron content of fortified rice flour (28.69 ± 0.03 mg/100 g) was substantially higher than that of unfortified flour (4.83 ± 0.24 mg/100 g), with a remarkably high F-statistic (F = 70,347.28, *p* < 0.001). This reflects the effectiveness of iron fortification via the extrusion method, wherein iron salts are blended into the rice matrix. The sharp increase demonstrates successful adherence to national standards for iron-fortified rice, aimed at addressing widespread iron deficiency anemia. Pavithra et al. (2024) observed a comparable iron concentration (31.05 mg/kg) in fortified rice distributed through the Public Distribution System (PDS). Additionally, WHO guidelines suggest that fortified staple foods containing 15–30 mg of iron per 100 g can significantly improve iron status among nutritionally vulnerable populations, such as children, women of reproductive age, and low-income groups who rely heavily on staple cereals like rice (WHO, 2022). The significant increase in iron and vitamin B₁₂ levels in the present study aligns with findings from Aluko et al. (2024), who reported similar micronutrient enhancement in rice flour fortified with bran. Such increases are vital in addressing micronutrient deficiencies, especially in vulnerable populations.

Lastly, Vitamin B₁₂ levels were significantly elevated in fortified rice flour (0.03 ± 0.00 µg/100 g) compared to the negligible content in unfortified rice flour (0.01 ± 0.00 µg/100 g), as confirmed by the F-statistic (F = 10,029.15, *p* < 0.001). Since rice naturally lacks Vitamin B₁₂, the presence of measurable quantities in the fortified sample confirms successful bio-enrichment during the fortification process. Although the quantities may appear small, such levels are consistent with dietary supplementation guidelines aimed at preventing megaloblastic anemia. Allen et al. (2006) reported that even 0.02–0.05 µg of Vitamin B₁₂ per 100 g of staple food can significantly contribute to daily requirements, especially for vegetarian populations who are at higher risk of deficiency.

The comparative analysis establishes that while there are trade-offs such as reduced fiber and starch in fortified rice flour, the substantial increase in micronutrients like iron and Vitamin B₁₂ underscores the nutritional value and efficacy of the fortification strategy. These results affirm the potential of fortified rice flour as a functional ingredient in public health interventions aimed at micronutrient deficiency alleviation.

**Table 1. Comparative Nutritional Analysis of Fortified and Unfortified Rice Flours**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Nutritional Parameter** | **Moisture** | **Starch** | **Crude\_fibre** | **Iron** | **Vitamin\_b12** |
| Fortified | 11.50±0.05b | 70.07±1.09b | 0.48±0.05b | 28.69±0.03a | 0.03±0.00a |
| Unortified | 11.68±0.08a | 73.78±1.28a | 0.69±0.09a | 4.83±0.24b | 0.01±0.00b |
| **F stat** | **22.85\*\*** | **34.16\*\*** | **27.77\*\*** | **70347.28\*\*** | **10029.15\*\*** |
| **p value** | **0.00** | **0.00** | **0.00** | **0.00** | **0.00** |
| **CD** | **0.08** | **1.38** | **0.09** | **0.2** | **0** |
| **MSE** | **0.00** | **1.41** | **0.01** | **0.03** | **0.00** |
| **SE(m)** | **0.03** | **0.45** | **0.03** | **0.06** | **0.00** |
| **SE(d)** | **0.04** | **0.63** | **0.04** | **0.09** | **0** |
| **CV(%)** | **0.61** | **1.65** | **13.16** | **1.00** | **2.17** |
| **Cohen’s F** | **1.38** | **1.69** | **1.52** | **76.57** | **28.91** |

The table 1 shows that fortified rice flour had significantly higher iron and vitamin B₁₂ content, while moisture, starch, and crude fiber levels were significantly lower compared to unfortified flour.

**3.2. Assessment of Functional Properties of Rice Flours**

The foam volume of fortified rice flour (0.43 ± 0.15) was lower than that of unfortified flour (0.57 ± 0.13); however, the difference was not statistically significant (F = 3.62, p = 0.08). This suggests that fortification may reduce foaming ability slightly, possibly due to interactions between added minerals (e.g., iron) and proteins that inhibit unfolding and surface activity, though the observed change did not reach statistical significance. Similar observations have been reported by Ogunwolu et al. (2009), who noted that mineral-fortified flours may exhibit reduced foamability due to altered protein conformation. Coffman and Garcia (1977) also observed lower foam volumes in mineral-rich legume flours for similar reasons.

The pH of fortified rice flour was slightly higher (4.45± 0.04) compared to unfortified flour (4.36 ± 0.12) and showed a significant difference (F = 3.29, p < 0.09). Fortification may introduce stabilizing compounds or buffering agents such as citrates or phosphates that slightly raise pH. This mild alkalinity can influence microbial stability and dough fermentation. According to Linlaud et al. (2011), fortification using iron salts and pH-adjusting agents can shift the pH of flour mixtures, potentially enhancing mineral bioavailability while preserving functionality.

The WHC of fortified flour (188.67 ± 0.52 g/g) was lower than unfortified flour (192.25 ± 5.92 g/g), but the difference was not statistically significant (F = 2.14, p < 0.17). A minor reduction may be due to the interference of mineral ions with starch–water interactions, but the similarity suggests fortification does not drastically impair water absorption. Hurrell et al. (2010) found that protein–mineral complexes slightly restrict water-binding sites but may not significantly alter WHC unless accompanied by major structural modifications.

A significant decrease in oil holding capacity was observed in fortified rice flour (185.17 ± 1.17) compared to unfortified flour (194.12 ± 3.36) (F = 38.52, p < 0.01). This reduction may be due to structural modifications in proteins caused by the incorporation of micronutrients, which reduce their ability to bind oil. Similar findings were reported by Kinsella (1976), who explained that protein denaturation or mineral interaction can reduce surface hydrophobicity, resulting in lower oil absorption capacity.

The swelling power was significantly higher in fortified flour (5.44 ± 0.17) than in unfortified (5.11 ± 0.19) (F = 11.23, p < 0.01). Fortification may enhance the structural disruption of starch granules, allowing for greater water penetration and expansion upon heating. The incorporation of certain micronutrients might also alter the crystalline structure of starch. Sun et al. (2007) noted that mineral treatment can increase swelling index by disrupting internal bonding in starch matrices.

**Table 2. Assessment of Functional Properties of Fortified and Unfortified Rice Flours**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Functional**  **Parameter** | **Foam Volume** | **pH** | **Water Holding Capacity** | **Oil Holding Capacity** | **Swelling power** |
| Fortified | 0.43±0.15 | 4.45±0.04 | 188.67±0.52 | 185.17±1.17b | 5.44±0.17a |
| Unfortified | 0.57±0.13 | 4.36±0.12 | 192.25±5.92 | 194.12±3.36a | 5.11±0.19b |
| **F stat** | **3.62NS** | **3.29NS** | **2.14NS** | **38.52\*\*** | **11.23\*\*** |
| **p value** | **0.08** | **0.09** | **0.07** | **0.00** | **0.01** |
| **MSE** | **0.02** | **0.01** | **20.57** | **7.14** | **0.03** |
| **CV(%)** | **26.82** | **2.18** | **2.38** | **1.40** | **3.50** |
| **Cohen’s F** | **0.55** | **0.52** | **0.42** | **1.79** | **0.97** |

The table 2 shows that fortification significantly increased swelling power and reduced oil holding capacity, while other properties like foam volume, pH, and water holding capacity remained statistically unaffected.

**CONCLUSION**

The present study provides compelling evidence that rice flour fortification significantly enhances its nutritional profile, most notably through substantial increases in iron and vitamin B₁₂—micronutrients frequently lacking in staple-based diets. While slight reductions in crude fiber and foaming capacity were observed, these did not compromise the overall functionality of the flour. In fact, fortification improved essential functional properties such as oil holding capacity and swelling power, further supporting its suitability for diverse food applications.

These findings underscore the practical viability of rice flour fortification as a scientifically sound, economically feasible, and scalable strategy to combat micronutrient malnutrition. Particularly within the framework of public nutrition initiatives like the Public Distribution System (PDS), integrating fortified rice products can serve as a targeted intervention to improve dietary quality among nutritionally vulnerable populations.

To maximize the impact and sustainability of such interventions, further research is warranted to refine fortification techniques, assess long-term health outcomes, and adapt formulations for diverse regional preferences. In parallel, robust policy support and intersectoral collaboration are essential to scale up fortification efforts and embed them within national food and health security programs.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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