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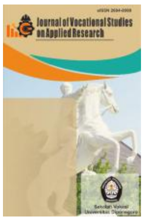

Review Article

Formulation of Analog Rice High in Fiber and Protein Based on Corn and Sorghum with the Addition of Moringa Leaves: A Review

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Abstract

Reliance on refined white rice as the dominant staple in many developing nations has been linked to dietary imbalances, particularly a lack of protein, fiber, and essential micronutrients. One potential alternative is analog rice, which is created from non-rice flours through extrusion or cold-molding methods and offers opportunities to diversify diets while supporting the utilization of indigenous crops. This review focuses on the development of analog rice formulated with corn (*Zea mays*) and sorghum (*Sorghum bicolor*) as primary bases, supplemented with *Moringa oleifera* leaf powder to enhance its nutritional value in terms of protein, fiber, and micronutrient content. Corn plays a vital role in providing starch functionality required during extrusion, sorghum contributes additional dietary fiber and phytochemicals, and Moringa leaves supply concentrated amounts of protein, minerals, and vitamins. Research indicates that incorporating Moringa at moderate levels (approximately 2–8%) enhances the nutrient profile without majorly affecting consumer perception, while higher inclusion rates often introduce bitterness and a greenish hue that lower acceptability. This article consolidates evidence on nutritional outcomes, production techniques, sensory limitations, and directions for further investigation, with particular focus on extrusion conditions, nutrient preservation, anti-nutritional factors, and consumer responses. Combining corn, sorghum, and Moringa shows considerable promise for generating functional staple foods with superior nutritional attributes, though additional studies remain necessary regarding nutrient bioavailability, clinical efficacy, storage behavior, and strategies for broader market adoption.

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1. Introduction

Rice remains the principal dietary staple for more than half of the global population, with Asia and parts of Africa being the most dependent regions (FAO, 2021). In nations such as Indonesia, Thailand, and the Philippines, it provides over half of the daily caloric supply (Rouhani et al., 2011). Despite this significance, polished white rice is composed largely of starch and contains only minimal amounts of protein, fiber, vitamins, and minerals. Excessive reliance on rice consumption has been associated with widespread nutritional problems, including protein-energy malnutrition, deficiencies in key micronutrients such as iron, zinc, and vitamin A, as well as increasing rates of non-communicable diseases like diabetes (Muthayya et al., 2014). In this context, diversifying staple food sources through the incorporation of nutritionally superior cereals such as corn and sorghum has been recognized as an important dietary strategy (Sarwar et al., 2013).

To overcome these dietary limitations, the promotion of staple food diversification has become a strategic approach. One innovation is analog rice, which consists of rice-like granules formulated from various carbohydrate and protein sources. Unlike conventional rice fortification strategies, analog rice enables flexible formulation by integrating nutrient-dense local crops with specific functional properties (Nadhifa et al., 2025). Such an approach not only

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improves dietary quality but also lessens dependence on rice and strengthens local agricultural systems.

Among the potential raw materials, corn (Zea mays) and sorghum (Sorghum bicolor) are widely cultivated in tropical regions such as Southeast Asia and sub-Saharan Africa. Both cereals are climate-resilient, drought-tolerant, and nutritionally beneficial (Aguiar et al., 2023). Sorghum is valued for its fiber, moderate protein content, and polyphenolic compounds, while corn provides the starch characteristics necessary for extrusion processes. Enrichment with Moringa oleifera leaf powder further boosts the nutritional value, as these leaves are notably high in proteins, vitamins, minerals, and antioxidant compounds (Chiș et al., 2023). Moringa has demonstrated broad potential as a functional food ingredient across tropical and subtropical regions due to its exceptional phytochemical richness and wide cultivability (Nouman et al., 2014; Wei et al., 2026).

This review specifically aims to: (1) evaluate the potential of corn (Zea mays) and sorghum (Sorghum bicolor) as primary carbohydrate bases for analog rice formulation; (2) assess the effectiveness of Moringa oleifera leaf powder supplementation in improving the protein, fiber, and micronutrient profile of analog rice; (3) analyze the influence of extrusion processing parameters on nutritional retention and sensory quality; and (4) identify current research gaps and future directions for the commercialization of corn–sorghum–Moringa analog rice as a functional staple food. By synthesizing evidence from experimental, nutritional, and technological studies, this review aims to provide a consolidated scientific foundation to guide future product development and policy recommendations in the area of staple food diversification.

2. Ingredient Selection, Rationale, and Review Methodology

This review was conducted through a systematic literature search using databases including Scopus, Web of Science, PubMed, and Google Scholar. Search terms included combinations of: "analog rice," "artificial rice," "corn flour extrusion," "sorghum functional food," "Moringa oleifera fortification," "dietary fiber staple food," and "protein-enriched rice alternative." Articles published between 2010 and 2025 were prioritized, with a focus on peer-reviewed experimental studies, systematic reviews, and meta-analyses. Studies were selected based on relevance to nutritional composition, processing technology, sensory evaluation, and consumer acceptance of analog rice or closely related cereal-based formulations. A total of more than 50 references were reviewed and synthesized. The following subsections outline the scientific rationale for the selection of each key ingredient.

Corn is one of the world's most extensively cultivated cereals and holds particular importance in analog rice production because of its starch profile. The starch in corn contributes to key functional properties such as gelatinization, expansion, and overall grain stability during extrusion (Sutrisno et al., 2024). From a nutritional perspective, corn typically provides 8–11% protein, dominated by zein proteins, though it is deficient in essential amino acids like lysine and tryptophan (Nuss & Tanumihardjo, 2010). Additionally, corn supplies 4–5% lipids, primarily unsaturated fatty acids, and contains carotenoids such as lutein and zeaxanthin, which are associated with maintaining healthy vision. The type and quantity of fatty acids present in cereal grains such as corn have also been shown to influence in vitro starch digestibility and the expected glycaemic index of cereal-based products (Annor et al., 2015).

In analog rice applications, corn flour has demonstrated good performance in producing rice-like grains with favorable cooking and textural attributes, particularly when combined with other cereal or tuber flours (Mahendradatta et al., 2025). Studies on corn–sorghum composite extrudates have confirmed that formulation ratios and extrusion conditions jointly determine the physico-chemical quality of the final product (Sharma et al., 2015). Its mild flavor and light coloration also increase consumer acceptability, making corn an ideal base ingredient when blended with sorghum and Moringa.

Sorghum, widely cultivated in Asia and Africa, is recognized for its resilience under drought and heat conditions. Nutritionally, it contains 10–15% protein, 65–75% carbohydrates, and 6–15% dietary fiber (Aguiar et al., 2023). Sorghum is also rich in phenolic compounds such as tannins and anthocyanins, which are linked to antioxidant and anti-inflammatory functions (Widowati & Luna, 2022).

Dietary advantages of sorghum include lowering glycemic response, promoting satiety, and enhancing digestive health through its fiber content (Prasad et al., 2014). However, the presence of anti-nutrients such as phytates and tannins can negatively impact protein digestibility and mineral absorption. Tannin–protein interactions in sorghum have been studied extensively, and evidence shows that tannins form complexes with proteins that substantially reduce their digestibility and bioavailability (Duodu et al., 2003). Treatment of sorghum with fungal enzymes such as those from Aspergillus niger has been explored as a means to correct poor protein quality caused by high tannin content (Somadder et al., 2025). Processing treatments including decortication, soaking, fermentation, and extrusion have been shown to diminish these compounds, thereby improving its nutritional value (Tamilselvan & Kushwaha, 2020). For example, traditional fermentation and cooking have been reported to improve the soluble zinc and iron content of sorghum-based porridges, suggesting beneficial effects on mineral bioavailability (Hemalatha et al., 2006). The effects of sorghum tannins across different processing methods and their nutritional implications have been reviewed in detail, underscoring the importance of variety selection and pre-treatment strategies (Ojo, 2022).

Within analog rice formulations, sorghum enhances both fiber and protein levels, though high substitution rates can reduce grain whiteness and consumer preference. Using sorghum in balanced proportions with corn helps overcome these limitations. The incorporation of sorghum flour with Moringa leaf powder has been shown to yield composite flours with improved nutritional composition and functional properties suitable for staple food applications (Amin et al., 2025).

Moringa oleifera, commonly known as the “miracle tree,” originates from South Asia and is cultivated widely in tropical environments. Its leaves are recognized as one of the most nutrient-rich plant resources, providing 20–30% protein (on a dry-weight basis), significant amounts of essential amino acids, dietary fiber, calcium, iron, and vitamins A and C, as well as antioxidant compounds such as quercetin and chlorogenic acid (Islam et al., 2021). A comprehensive assessment of Moringa's nutritional composition has confirmed its broad suitability as a food ingredient and dietary supplement across a range of applications (Sultana, 2020). However, certain morphological parts of the Moringa tree also contain anti-nutritional factors including oxalates, phytates, and trypsin inhibitors, which must be considered during processing (Makkar & Becker, 1997).

Moringa has been studied extensively for its role in alleviating malnutrition, especially in communities where rice or starch-based staples dominate the diet (Chiș et al., 2023). Clinical supplementation studies have demonstrated that Moringa leaf powder can significantly improve body weight and nutritional status in malnourished children when incorporated into daily food rations (Tshingani et al., 2017). The nutritional and phytochemical profile of Moringa varies depending on seed treatment and processing method — raw, germinated, and fermented forms each exhibit distinct compositional characteristics that influence their suitability for food fortification (Ijarotimi et al., 2013). When incorporated into analog rice, it substantially increases protein and micronutrient content. Nonetheless, higher inclusion levels (above 8%) often cause sensory issues due to its bitter flavor and greenish appearance. Approaches such as blanching, drying, and microencapsulation have been recommended to mitigate these drawbacks while preserving nutrients (Patil et al., 2022). Studies incorporating dried Moringa leaves into baked goods such as cookies have demonstrated changes in rheological and organoleptic properties that are dose-dependent, suggesting that processing method and inclusion level must be co-optimized (Dachana et al., 2010). Furthermore, the processing method applied to Moringa seed flour— whether drying, boiling, or fermentation— significantly affects its chemical composition and microbial safety (Joel et al., 2020).

The primary method used in analog rice production is extrusion, a process that applies high pressure, temperature, and shear to gelatinize starch, denature proteins, and form rice-like granules (Liu et al., 2022). Figure 1 and Figure 2 show the production processes of analog rice using the hot and cold extrusion methods, respectively. Key parameters such as screw speed, temperature, moisture level, and die design determine the final product's texture, cooking properties, and nutrient retention. Studies on extruded rice flour-based products have confirmed that physicochemical properties, starch digestibility, and estimated glycaemic index are all significantly influenced by the composition of the flour blend and extrusion settings (Suklaew et al., 2020).

For formulations combining corn, sorghum, and Moringa, extrusion must carefully balance the starch gelatinization properties of corn, the fiber contributions from sorghum, and the sensitivity of Moringa’s vitamins to heat. Research shows that extrusion can decrease anti-nutritional compounds while improving protein digestibility (Widowati & Luna, 2022). However, high processing temperatures may lead to degradation of heat-sensitive nutrients, including vitamin C and carotenoids present in Moringa (Umerah et al., 2019). A comparative study of extrusion against other cooking methods — including boiling, steaming, and roasting — found that extrusion produced distinct anti-nutritional profiles in Moringa leaf products, highlighting the need for method-specific optimization to minimize nutrient losses (Mbah et al., 2012).

Although extrusion dominates, cold molding with binders has also been applied in analog rice production. This approach preserves more nutrients but often produces grains with lower structural stability and shorter shelf life (Nadhifa et al., 2025). To improve cohesion, hydrocolloids, modified starches, or protein isolates are commonly introduced as binders.

Recent technological innovations—such as infrared-assisted drying, microwave-aided extrusion, and nutrient encapsulation—are now being investigated as strategies to optimize nutrient retention and improve sensory properties, thereby enhancing consumer acceptance.

3. Results and Discussion

The balance between corn and sorghum proportions in analog rice plays a key role in determining both nutritional value and sensory appeal. Corn contributes a light flavor and desirable structural characteristics, whereas sorghum enriches the product with dietary fiber and bioactive components. Research indicates that mixing corn and sorghum at ratios of approximately 60:40 or 70:30 achieves an optimal compromise between texture and nutrient composition (Aguiar et al., 2023). Increasing sorghum levels further raises fiber content but often diminishes grain whiteness and reduces consumer liking. These findings are consistent with studies on corn–sorghum composite extrudates, which confirm that both formulation ratio and process parameters must be jointly optimized to achieve acceptable product quality (Sharma et al., 2015). The combination of sorghum and Moringa has also been shown to produce flour blends with enhanced functional and nutritional properties, reinforcing the value of multi-ingredient formulation approaches (Amin et al., 2025).

Fortification with Moringa oleifera leaf powder at concentrations between 2–8% has been shown to markedly elevate protein, fiber, and micronutrient levels while maintaining acceptable sensory quality (Mahendradatta et al., 2025). However, inclusion above 10% typically results in bitterness and green coloration that limit consumer acceptance (Chiș et al., 2023). Techniques such as encapsulation, blending with natural flavoring agents, or employing lighter-colored Moringa extracts are potential solutions for enabling higher incorporation levels.

The nutritional quality of corn–sorghum formulations is also shaped by protein digestibility, which can be significantly limited by tannin–protein interactions inherent to sorghum (Duodu et al., 2003). Pre-treatment strategies such as enzymatic treatment with Aspergillus niger have demonstrated the capacity to correct poor sorghum protein quality, resulting in extrudates with improved amino acid availability (Somadder et al., 2025). Additionally, the fatty acid composition of corn influences the in vitro starch digestibility of the final product, which has implications for glycaemic management in target consumer groups (Annor et al., 2015).

To address the textural challenges posed by fibrous materials, the addition of functional ingredients such as hydrocolloids (xanthan, guar gum), protein isolates from soy or whey, and enzymatic cross-linkers like transglutaminase has been utilized in analog rice formulations (Sutrisno et al., 2024). These agents help improve grain integrity, minimize breakage, and enhance overall cooking quality.

Sensory characteristics remain central to consumer acceptance. Evidence suggests that analog rice containing up to 5% Moringa is generally perceived positively in terms of taste, color, aroma, and texture (Mahendradatta et al., 2025). Beyond this threshold, however, the intensification of bitterness and green hues significantly reduces preference. These sensory outcomes align with observations in other Moringa-fortified food products, where even small changes in inclusion level altered the organoleptic profile (Dachana et al., 2010). The nutritional gains associated with Moringa fortification — including enhanced protein density, mineral content, and phytochemical richness — must therefore be weighed against the sensory trade-offs at varying inclusion rates (Ijarotimi et al., 2013; Sultana, 2020).

Consumer awareness is another determining factor. Educating populations about the health and nutritional benefits of Moringa-enriched analog rice can increase tolerance toward slight sensory drawbacks. Clinical evidence demonstrating the efficacy of Moringa supplementation in addressing malnutrition outcomes can serve as a basis for public health communication campaigns targeting food product acceptance (Tshingani et al., 2017). Moreover, cultural habits

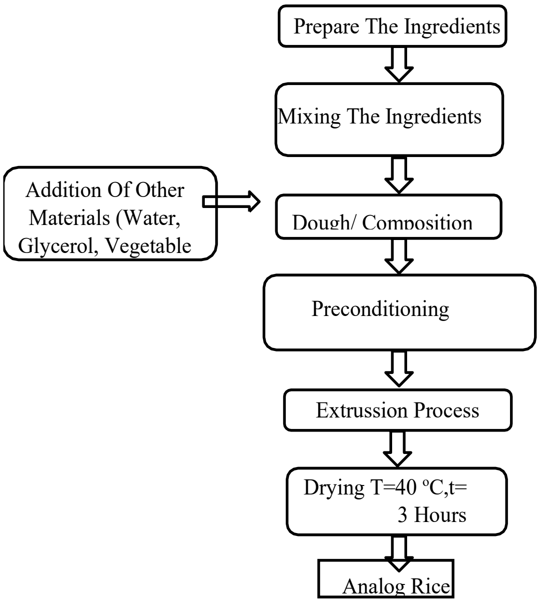

Figure 1. Production process of analog rice using the hot extrusion method.

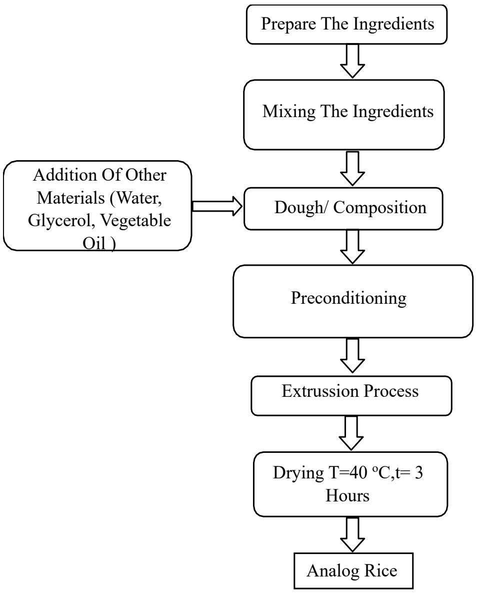

Figure 2. Production process of analog rice using the cold extrusion method.

strongly shape acceptance; for example, communities familiar with leafy green foods may be more receptive to products with higher Moringa content. The global cultivability of Moringa and its recognized role as a multipurpose food crop in tropical communities further supports the feasibility of its incorporation into locally-produced staple foods (Nouman et al., 2014).

From a safety and quality standpoint, the presence of anti-nutritional compounds in both Moringa and sorghum requires attention. In sorghum, tannin content varies significantly by variety and is responsive to processing, with important implications for protein and mineral bioavailability (Ojo, 2022). Traditional processing methods such as fermentation have been shown to improve mineral solubility in sorghum-based foods (Hemalatha et al., 2006). Similarly, Moringa processing affects both its chemical composition and microbial safety, reinforcing the need for standardized preparation protocols (Joel et al., 2020). Both ingredients also contain naturally occurring anti-nutritional factors — including oxalates and phytates in Moringa, and tannins and phytates in sorghum — that should be monitored and minimized in final product formulations (Makkar & Becker, 1997).

With respect to processing technology, extruded products from rice flour blends have shown distinct starch digestibility profiles and glycemic index values depending on flour composition and extrusion settings, indicating that analog rice formulations require product-specific parameter optimization (Suklaew et al., 2020). Comparative evaluations of extrusion against other cooking methods for Moringa-containing products provide further evidence that method selection critically impacts the anti-nutritional and sensory profile of the final food (Mbah et al., 2012). More broadly, the nutritional importance of cereal-based staples in human diets underscores the public health significance of improving their nutrient density through scientifically validated fortification strategies (Sarwar et al., 2013).

4. Conclusion

The synthesis of evidence presented in this review confirms that the combination of corn, sorghum, and Moringa oleifera leaf powder represents a nutritionally superior and technologically feasible approach to producing functional analog rice. Corn provides the starch matrix essential for extrusion integrity, sorghum contributes dietary fiber and bioactive polyphenols, and Moringa markedly elevates protein density and micronutrient content. Together, these three ingredients address multiple dimensions of nutritional inadequacy that are prevalent among rice-dependent populations.

However, several important challenges must be resolved before this product can transition from laboratory promise to widespread practical use. First, clinical bioavailability studies using randomized controlled designs are urgently needed to verify whether the nutritional improvements observed in vitro translate to measurable health outcomes in target populations. Second, the optimization of extrusion parameters—particularly for preserving Moringa's heat-sensitive vitamins and mitigating anti-nutritional factors from sorghum tannins—requires systematic, multi-variable experimentation across different equipment types and scales.

This review recommends the following actions: (1) For researchers: prioritize in vivo and clinical studies on bioavailability and chronic disease biomarkers; investigate Moringa encapsulation technologies for use in high-temperature processing; and conduct variety-specific studies on sorghum anti-nutritional content. (2) For food industry practitioners: develop standardized production protocols for corn–sorghum–Moringa analog rice and invest in shelf-life and packaging optimization. (3) For policymakers: integrate analog rice development into national food security and diversification strategies; provide regulatory clarity on functional food labeling; and support pilot programs in schools and community health centers in high-malnutrition regions.

In conclusion, corn–sorghum analog rice fortified with Moringa leaf powder holds significant promise as a functional staple food that can contribute to nutrition security, diet diversification, and the sustainable utilization of local crop resources. Realizing this potential will require coordinated efforts across scientific, industrial, and policy domains.

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