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Influence of Cooking and Fermentation on Nutrient and Anti-nutrient Profiles of Millet and Rice

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Abstract

This study investigates how the traditional processing methods, such as cooking and fermentation, affect the nutritional, anti-nutritional, and mineral composition of the six edible grains, including the three rice varieties (*Oryza sativa*: Matta, Boiled and Brown rice) and the three millets (foxtail, jowar and pearl millet). The grains were analyzed in their raw, cooked, and fermented forms. The carbohydrates and the protein content were determined along with the anti-nutritional compounds such as the flavonoids, oxalates, phenolics, phytates and the tannins. The mineral concentrations of calcium, potassium, iron, magnesium, manganese, and zinc were determined using Atomic Absorption Spectroscopy. The results showed that cooking significantly reduced carbohydrate content by 85-90% across all grains, while fermentation caused an even greater reduction of up to 95%. Protein levels were grain-specific, and fermentation generally enhanced the protein concentration by 20-50%. Flavonoid content was reduced by 70-90% while phytates, and oxalates were reduced substantially by 60-90% through both treatments due to leaching and thermal degradation, while the phenolic content increased by 25-40%, particularly in the foxtail millet. The tannin levels decreased with cooking by 40-60%, but they increased after the fermentation, likely due to the enzymatic release of the bound compounds. Mineral concentrations were consistently declined in the cooking and fermented forms, yet fermentation improved bioavailability by reducing the anti-nutrients. Overall, the cooking was more effective in lowering the anti-nutritional factors, whereas the fermentation enhanced the protein and improved the accessibility of the essential minerals such as iron and zinc. These findings emphasizes the importance of the traditional household processing methods in enhancing the nutritional quality of rice and millet-based diets, particularly in the regions dependent on cereal staples.

Keywords: Bioavailability, Fermentation, Millet, Mineral content, Rice varieties

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Introduction

Whole grains are widely known as an essential part of a healthy diet. Despite this understanding, many people consistently fail to meet the recommended intake of at least three servings per day (Slavin, Jacobs, Marquart, & Wiemer, 2001). Dietary choices are strongly influenced by regional biodiversity and local food availability, which significantly impact the mineral content of the consumed diets (Penafiel, Lachat, Espinel, Van Damme, & Kolsteren, 2011). Humans require at least 49 nutrients to maintain their optimal physiological functions, including 23 mineral elements that participate in various metabolic and biochemical processes (Fraga, 2005; Welch & Graham, 2004). Although needed in smaller quantities, these minerals must be consumed regularly (Welch & Graham, 2004).

Macrominerals such as sodium (Na), potassium (K), and chloride (Cl) are principally important as they maintain and regulate intracellular compounds. The electrochemical gradient is maintained by these elements across the cell membrane, which is crucial for signal transmission, metabolic transport and cell extractability (Quintaes & Diez-Garcia, 2015). It is also said that depending on the kind of food matrix composition, the bio-accessibility of minerals such as iron (Fe), zinc (Zn), calcium (Ca), and magnesium (Mg) varies significantly (Suliburska & Krejpcio, 2014).

Millets are rich source of micro and macro nutrients, and they also contain a higher concentration of essential amino acids and minerals compared to commonly consumed cereals such as wheat and rice (Nakandalage *et al.*, 2016). Health benefits attributed to millets include antioxidant, hypoglycaemic, anti-inflammatory, anti-ulcer, and cholesterol-lowering effects.

For over half of the global population, rice (*Oryza sativa*) is the common principal staple food, which offers and provides energy from carbohydrates and also provides essential macro and micronutrients for human health (Nakandalage *et al.*, 2016). Rice provides a primary source of energy through complex carbohydrates that meet metabolic energy needs (Shrestha, Baruah, Subhash, Ananthan, & Longvah, 2020). Furthermore, it also provides moderate amounts of protein, which are primarily rich in amino acids such as lysine and methionine (Nakandalage *et al.*, 2016). Rice is also rich in critical micronutrients such as Fe, Zn, Mg, Mn and B-complex vitamins, which play an important role in redox balance and enzymatic functions (Perera, Seneweera, & Hirotsu, 2018; Wairich, Ricachenevsky, & Lee, 2022). However, the bioavailability of these micronutrients is often affected and compromised by the anti-nutritional factors for instance the phytates and the oxalates (Fukushima *et al.*, 2020) and therefore understanding its nutritional composition and methods to retain these micronutrients through cooking and fermentation is important to enhance the dietary quality of rice-based foods, especially in the regions where micronutrient deficiency are prevalent and where rice is also a primary staple food (Kumari & Roy, 2023; Wairich *et al.*, 2022).

The traditional method of processing food, such as cooking and fermentation, plays an important role in enhancing the nutritional quality of staple foods like rice, especially for economically vulnerable people. These methods happen to be accessible and inexpensive, making them highly suitable for the low-resource setting. Cooking is said to increase the digestibility of the macronutrients, soften the fibrous structure, and reduce microbial contamination. It also causes the thermal degradation of anti-nutritional compounds such as phytates and tannins, causing an increase in the bioavailability of minerals (Kumari & Roy, 2023; Savard *et al.*, 2019). Moreover, the fermentation can enrich foods with probiotics and the B-vitamins, making it a low-cost nutritional strategy for people who have limited access to diversified diets (Domán *et al.*, 2023; Neocleous, Shammas, Phedonos, Phylactou, & Skordis, 2014).

This comparative analysis of the grains in their raw, cooked, and fermented forms is essential to understand how the traditional processing of the grains influences their nutritional and anti-nutritional profiles. As cooking is a universal household practice, it induces the thermal and structural changes that affect the nutrient content by leaching and degradation (Savard *et al.*, 2019). Fermentation is a time-tested preservation and enhancement technique that reduces the anti-nutritional factors and improves the bioavailability of the grains, which is important in cereal-based diets (Siqueira *et al.*, 2020). Fermentation is regarded as a transformative method that increases the nutritional quality of food. It facilitates the combination of different plant-based proteins and supports the development of more sustainable dietary options (Wairich *et al.*, 2022). Thus, this study aimed to analyze and compare the level of carbohydrates and protein content, anti-nutritional factors like flavonoids, oxalates, tannins, phenolics and phytates along with the mineral profile of six edible grains, matta rice, boiled rice, brown rice, foxtail millet *(Setaria italica*), jowar millet (*Sorghum bicolor),* and pearl millet (*Pennisetum glaucum)* in their raw, cooked and fermented form.

Materials and Methods

Sample Collection and Identification

Three commonly consumed rice (*Oryza sativa)* varieties, such as matta rice (OsMR), boiled rice (OsBoR), and brown rice (OsBR), and three millets varieties such as foxtail millet (FM) *(Setaria italica*), jowar millet (JW) (*Sorghum bicolor),* and pearl millet (PM) (*Pennisetum glaucum)* were procured from a local market in Bengaluru, Karnataka, India and were subjected to the estimation of nutritional and anti-nutritional and mineral content at three different form like raw, cooked and fermentation. The raw form refers to cleaned and dried uncooked grains and is directly used for the analysis. For the cooked form, about 40 g of each grain was boiled in 400 mL of water at 100 °C for a specific duration, depending on the grain type. The rice samples were generally cooked within 20-25 minutes, while the millets required about 30-40 minutes for complete softening. Cooking was performed in a semi-closed vessel, simulating the typical household cooking practices. After cooking, starch-rich water (leachate) was decanted, and the softened grains were used for further analysis. For the fermented state, the above cooked grains were subjected to a fermentation process naturally. Briefly, the cooked and decanted grains were transferred to sterile containers, separately, and loosely covered with a lid to allow air exchange and incubated at ambient room temperature (27–30 °C) for 12 hours. No microbial starter culture was added, allowing spontaneous fermentation. The process relied solely on the native microbiota present on the grains and in the surrounding environment. This method aimed to facilitate natural fermentation, representing traditional household practices, rather than any controlled ageing or preservation. Following fermentation, the grains were subjected to nutritional, phytochemical, and anti-nutritional analyses and compared with corresponding raw and cooked forms to evaluate the impact of processing on their compositional characters.

Nutrient and Antinutrient Analysis

Nutrient content, such as carbohydrate (Nielsen, 2010) and protein (Lowry, Rosebrough, Farr, & Randall, 1951) contents, was estimated in all six grains of their three different forms of processing. Similarly, anti-nutritional factors such as total flavonoid content, oxalate (Domán *et al.*, 2023), total phenolic content (Siqueira *et al.*, 2020), phytate (Siqueira *et al.*, 2020) and total tannin content were estimated using standard protocols, in all three forms.

The grain samples of 0.2g each were soaked in 5 ml of methanol and covered with aluminium foil for 48 hours for the complete exudation of the phytochemicals. This solution was then filtered using the Whatman filter paper, and 1ml of filtrate was mixed with 10% aluminium chloride and 1M sodium acetate. After 45 minutes of incubation in the dark at room temperature, the absorbance was measured at 415nm. Quercetin (0.1 mg/ml) was used as the standard (Bag, Grihanjali Devi, & Bhaigyabati, 2015).

Oxalate estimation

Oxalate estimation was performed by following the method of Abaza (1967). The sample was digested in 6N HCl in a boiling water bath for 1 hour. After filtration and evaporation, concentrated ammonia was added until the solution turned faint yellow. The mixture was reheated at 90 °C, and 5% $CaCl_2$ was added. After overnight settling, the precipitate was dissolved while boiling. The solution was then left overnight and filtered, and the precipitate was dissolved in 10ml of 20% H_2SO_4, heated to 70^{o}c for 10min and titrated against N/20 of $KMnO_4$ to near endpoint (colorless to pink).

$$\text{Oxalate (\%)} = \frac{\text{ml of } KMnO_4 \times \text{Molecular weight of KMnO4} \times \text{Equivalent weight of oxalate}}{\text{Weight of the sample}} \times 100$$

Total Phenolics estimation

Approximately 1g of each grain was extracted with 10 mL of ethanol (80%) for 1 hour and centrifuged at 10,000 rpm for 20 minutes. To the supernatant, Folin-Ciocalteu reagent and distilled water were added. After 6 min, sodium carbonate (7%) was added, and the volume was then adjusted to 6ml with distilled water. The mixture was incubated at room temperature for 90 minutes in the dark. Absorbance was measured at 760nm using gallic acid (0.2 mg/ml) as the standard (Dewanto, Xianzhong, Adom, & Liu, 2002).

Phytate Estimation

For phytate estimation, 2g of each grain was treated with 2% hydrochloric acid and incubated for 3 hours. After filtration, the extract was treated with ferric chloride (0.00195g/ml) after adding 0.3% ammonium thiocyanate (0.3%) until a brownish-yellow color persisted for ~5 min (Harris & Mosher, 1934).

$$\text{Total phytic acid} = \frac{\text{Titre value} \times 0.00195 \times 1.9 \times 100}{2}$$

Total Tannins estimation

About 500mg of grain was shaken with 50ml of distilled water for 1 hour. A 1ml aliquot of the filtrate was mixed with 0.05 M ferric chloride in 0.1 N hydrochloric acid and 0.008 M potassium ferrocyanide. Absorbance was read at 760nm within 10 minutes. A standard was prepared using tannic acid to get 1mg/L and measured (Okwu & Orji, 2007; Van Buren & Robinson, 1969).

Mineral Content Analysis

The mineral content in the selected grain samples, such as zinc (Zn), iron (Fe), copper (Cu), calcium (Ca), magnesium (Mg), manganese (Mn), and potassium (K), was estimated using Atomic Absorption Spectroscopy in all three forms (PerkinElmer Analyst 400, USA). For digestion, 10 ml of concentrated nitric acid was added to each form and allowed to pre-digest for 30 minutes at room temperature. Samples were then heated until initial digestion was complete, followed by the addition of 2-3 mL perchloric acid. Heating continued until the solution became clear (PerkinElmer Analyst 400, USA)

Statistical Analysis

All experiments were performed in triplicate, and the obtained data were then expressed as mean ± standard deviation (SD). The data obtained were then subjected to statistical analysis using SPSS software (version 24) to identify significant differences among the treatments. The values were considered statistically significant at p-value < 0.05.

Results and Discussion

Nutrient Analysis

Carbohydrate and protein contents were assessed across all six selected grains in their raw, cooked, and fermented forms. The results revealed significant changes in the carbohydrate level which was highest in the raw state across all grains. Among the rice varieties, OsMR showed the highest carbohydrate content (10.71 ± 0.12%), followed by OsBoR (10.44± 0.05%) and OsBR (10.01± 0.12%). The millet varieties JW, PM, and FM followed in descending order, with FM registering the lowest (6.58± 0.13%) (Table 1). However, in the cooked and fermented state, a marked reduction in carbohydrate content was observed. The loss is due to the leaching of soluble starch during cooking and decanting (Agrawal, Hidame, & Gurla, 2011). The loss during fermentation is likely due to the utilization of simple sugars by lactic acid bacteria, which consume carbohydrates during their metabolic activity (Nielsen, 2010). Similarly, protein content varied significantly with the state of processing. In the raw state, millet varieties registered higher protein levels than rice varieties. PM registered the highest protein content (35.71±0.13%), followed by FM > JW (Table 1). Among the rice varieties, OsBoR had the highest protein content (32.39±0.17%), while OsMR showed relatively lower values.

Cooking affected the protein content variably, possibly due to the reduction in moisture content, leading to a higher concentration of protein (Bastías, Balladares, Acuña, Quevedo, & Muñoz, 2017; Liu, Zheng, & Chen, 2019). OsBoR registered the highest post-cooking protein content, followed by OsMR and OsBR. However, JW and FM showed substantial reductions in protein content post-cooking, indicating potential protein denaturation or leaching.

Fermentation generally led to an increase in protein content across most of the selected grains in the current study. The highest protein concentration was found in OsBR, followed by OsBoR>JW. The increase in the protein content is likely attributed to the reduction of carbohydrates and fats during the fermentation process, resulting in a proportional enrichment of protein in the dry matter (Nkhata, Ayua, Kamau, & Shingiro, 2018). However, the relatively high protein values obtained in the present study may also reflect methodological limitations (Lowry's method) (Everette *et al.*, 2010). This method is known to overestimate protein concentrations due to interference from phenolic and other reducing compounds present in grain extract, which can yield inflated protein (Rodríguez, Bianchi, Simonato, Rizzi, & Tironi, 2025; Everette *et al.*, 2010; Marks, Buchsbaum, & Swain, 1985; Smith, 1982). Comparative evaluations of protein estimation techniques such as Dumas, Kjeldahl and Lowry methods have reported that indirect and colorimetric assays may overstate true protein values by a substantial margin. Therefore, the higher protein content observed in the present study may partly result from matrix interference rather than actual biological protein levels (~1-2%) (Mæhre, Dalheim, Edvinsen, Elvevoll, & Jensen, 2018; Hayes, 2020; Redmile-Gordon, Brookes, Goulding, & Hirsch, 2013). Thus, these findings indicate that both cooking and fermentation processes, with the extent of change being grain-specific and process-dependent.

Table 1- Nutritional values in three different states of the selected grain

Grains	Processing stage of grains					
	Carbohydrate (%)			Protein (%)		
	Raw	Cooked	Fermented	Raw	Cooked	Fermented
OsMR	10.71±0.12^{a}	1.16±0.06^{b}	0.91±0.11^{a}	29.43±0.09^{a}	17.82±0.19^{c}	25.31±0.90^{b}
OsBR	10.01±0.03^{c}	1.14±0.06^{b}	0.47±0.04^{c}	29.24±0.10^{b}	16.61±0.65^{c}	49.14±0.10^{a}
OsBoR	10.44±0.05^{b}	0.69±0.10^{c}	0.36±0.01^{d}	32.39±0.17^{b}	28.50±0.40^{c}	38.53±0.30^{a}
JW	9.97±0.04^{c}	1.51±0.09^{a}	0.36±0.01^{d}	31.99±0.11^{a}	7.60±0.11^{c}	31.15±0.31^{b}
PM	9.22±0.04^{d}	1.24±0.09^{b}	0.89±0.05^{a}	35.71±0.13^{a}	9.48±0.15^{c}	28.27±0.17^{b}
FM	6.58±0.13^{e}	0.71±0.16^{c}	0.61±0.07^{b}	33.39±0.07^{a}	5.66±0.22^{c}	29.10±0.58^{b}

Different superscripts in each column indicate a significant difference ($p < 0.05$)

Anti-nutrent Analysis

Cooking and fermentation significantly influenced the levels of flavonoids, oxalates, phenolics, phytates and tannins across the six selected grains. Cooking led to a consistent reduction in flavonoid content in all grain varieties (Fig. 1), primarily due to the leaching of the water-soluble compounds into the cooking medium and thermal degradation of the flavonoid compounds (Jiménez-Monreal, García-Diz, Martínez-Tomé, Mariscal, & Murcia, 2009; Turkmen, Sari, & Velioglu, 2005). PM retained the highest amount of flavonoids post-cooking (0.70±0.03), followed by OSMR=OsBR= JW>FM>OsBoR. A significant difference was among the cooked grains of PM and FM, showing distinctive profiles. In millet varieties, fermentation further decreased the flavonoid content, with a significant difference (P<0.05). While in rice varieties OsBoR and OsMR exhibited the highest flavonoid content, with a significant difference after the fermentation (1.17±0.11 and 1.11±0.04), followed by OsBR>PM=FM>JW, a decrease that can be directly correlated with the enzymatic degradation and microbial metabolism (Adebo *et al.*, 2021)

Similarly, cooking resulted in a considerable decrease in the oxalate levels of particularly PM (Fig. 2). This decrease can be attributed to the rupture of the grain (plant cell) during the process of boiling, allowing the oxalates to leach into the water, which is normally discarded. High heat is also said to break down the cell walls and release the oxalates (Maqbool *et al.*, 2021). In general, cooking is said to reduce the oxalate content by 60-90% (Shi, Arntfield, & Nickerson, 2018). After cooking, the JW retained the highest level of oxalate, followed by OsMR>OsBoR>FM>PM= OsBR (Fig. 2). In contrast, the fermentation had a minimum impact on the oxalate levels. OsMR, FM, PM and JW continued to show the highest oxalate content, followed by OsBR=OsBoR (Fig. 2). The limited fermentation of the oxalate is likely due to the short fermentation time (<24 hours), which might not have led to microbial degradation of oxalates. The reason is that the oxalate degradation is time and pH-sensitive (Adebo *et al.*, 2021). The presence of tannins and oxalate content in the rice samples of the present study aligns with previous reports, suggesting that these compounds are naturally concentrated in the bran and husk layers of rice grains and are retained to varying degrees in brown and minimally polished varieties (Alotaibi, Babiker, Alshammari, & Yahya, 2024; Irakli, Lazaridou, & Biliaderis, 2020). The comparatively higher levels in the OsMR, OsBR, and OsBoR can be attributed to their limited polishing and their partial retention of the bran and the aleurone layers (Bhat *et al.*, 2020). These outer layers are rich in phenolic compounds, tannins and oxalates that remain bound to the cell wall components such as cellulose, hemicellulose and lignin (Bhat *et al.*, 2020; Wisetkomolmat *et al.*, 2022). In contrast to the flavonoids and the oxalates, the grains are said to have a notable increase in the phenolic content upon cooking (P<0.05) (Fig. 3). This is more likely due to the disruption of the cell walls and cleavage of the ester and the ester bonds during thermal treatment which results in the release of the phenolics that are more extractable. Cooking is also said to inactivate the polyphenol oxidase enzymes, which are generally said to degrade the phenols (Limberger-Bayer, De Francisco, Chan, Oro, Ogliari, & Barreto, 2014; Turkmen *et al.*, 2005). FM has recorded the highest phenolic content in the cooked state, followed by OsBR>JW=OsMR>OsBoR=PM (Fig. 3). Among all varieties, FM was significantly different from the other grains, while OsMR and OsBoR formed the lowest group. Nevertheless, fermentation led to a slight reduction in the phenolic content due to the microbial utilization of phenolics as the carbon source and their conversion into the volatile forms that are not captured by the Folin-Ciocalteu assay (Arguedas-Villa, Kovacevic, Allen, Stephan, & Tasara, 2014). In the fermented state, PM recorded the highest phenolic content, followed by OsBoR>JW=FM=OsMR=OsBR, showing the lowest values (Fig. 3). Cooking also led to a reduction in the phytate levels in all the grains, although the difference was not statistically significant among the cooked samples (P>0.05). This reduction is again due to the leaching of the water-soluble phytates into the cooking medium and partial breakdown of the phytic acids at the elevated temperature (Lang, Whitney, & Steinberg, 1982; Li, Beta, Sun, & Corke, 2006). In the cooked state, all the grains showed a decrease in the phytate levels (Fig. 4). Among the raw grains, JW exhibited the highest phytate content, followed by the OsBR=OsMR=OsBoR=FM=PM (Fig.4). After the fermentation, there is only a marginal reduction in the phytate content, particularly in PM, JW. FM maintained the highest level, followed by the OsBR>OsMR>OsBoR=FM=PM. Although there is a difference among the grains, this is not statistically significant (P>0.05). This effect is due to the insufficient endogenous phytate activity under the suboptimal fermentation conditions (Sheethal *et al.*, 2022).

In the case of tannins, the cooking caused a significant decrease in all the grains. The highest post-cooking tannin content was observed in OsMR, followed by PM>FM>OsBoR>JW (Fig. 5). This decrease is also attributed to the leaching of the water-soluble tannins into cooking water and thermal polymerisation of tannins, which makes them less reactive in spectrophotometric assays. Remarkably, there was a sharp increase in the tannin content by fermentation, with OsBR and FM exhibiting the highest value, followed by OsBoR=JW>OsMR>PM (Fig. 5). This increase in the tannin content is due to the microbial enzyme action, such as the cellulases and the proteases, which liberate the bonded tannins, making them more extractable. Moreover, fermentation can also generate phenolic compounds that bond with protein and carbohydrates to form mimic tannin-like structures that are more quantifiable in spectrophotometric assays (Chung, Wong, Wei, Huang, & Lin, 1998; Olives Barba, Cámara Hurtado, Sánchez Mata, Fernández Ruiz, & López Sáenz De Tejada, 2006).

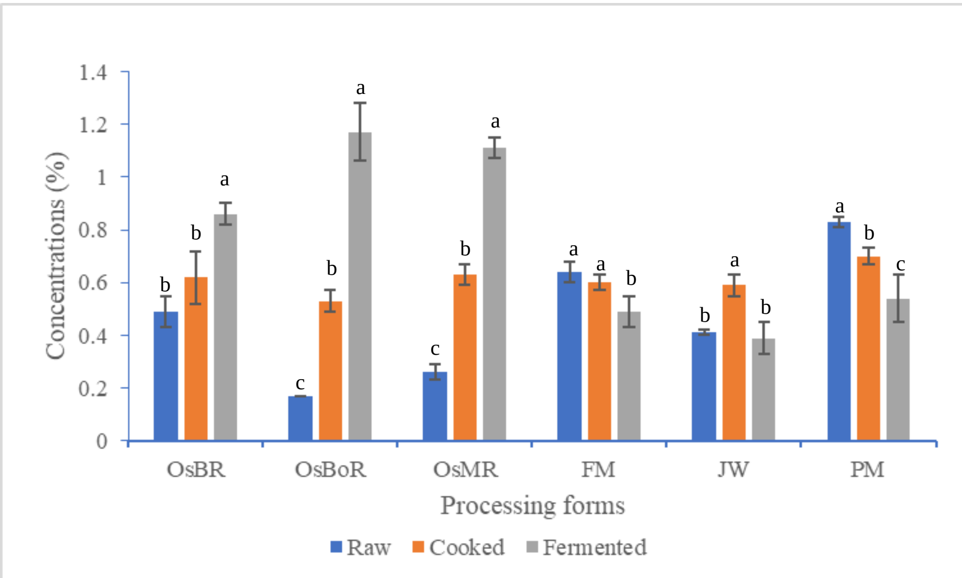

Fig. 1. Concentration of flavonoids present in different states of cooking
Different alphabets within each group indicate a statistically significant difference (p < 0.05)

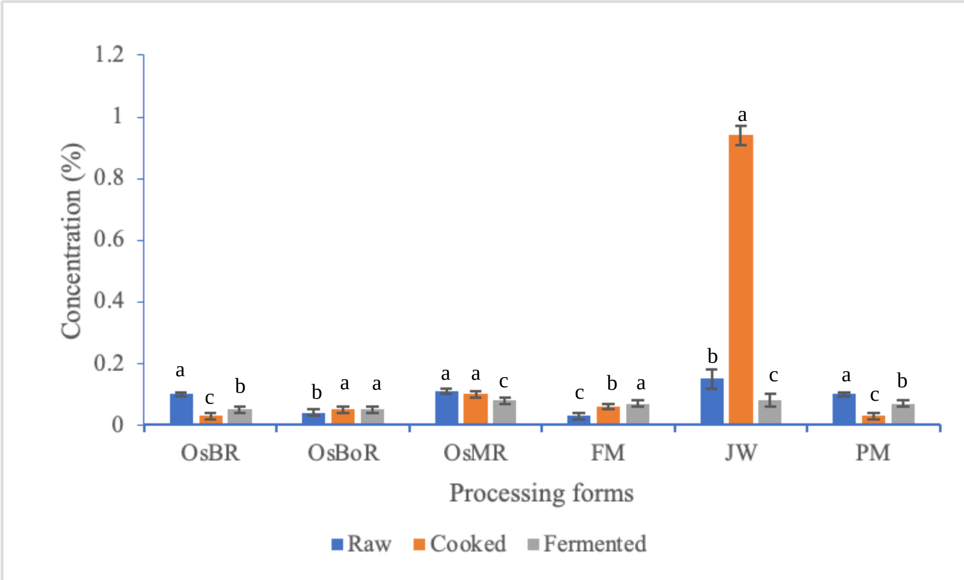

Fig. 2. Concentration of Oxalates in raw, cooked, and fermented forms of selected grains

Different alphabets within each group indicate a statistically significant difference ($p < 0.05$)

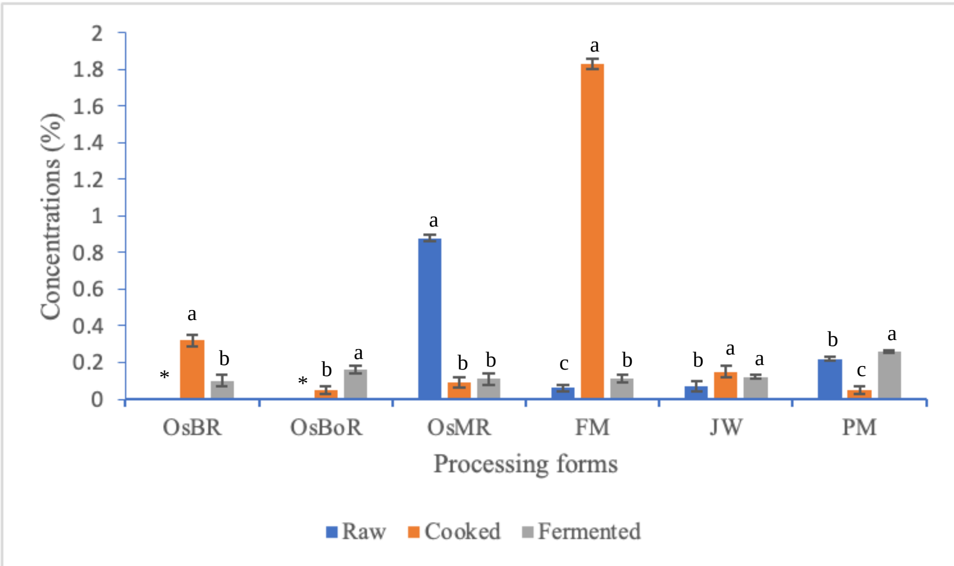

Fig. 3. Concentration of Phenolic in raw, cooked, and fermented forms of selected grain

Different alphabets within each group indicate a statistically significant difference ($p < 0.05$). *Indicate below detectable values.

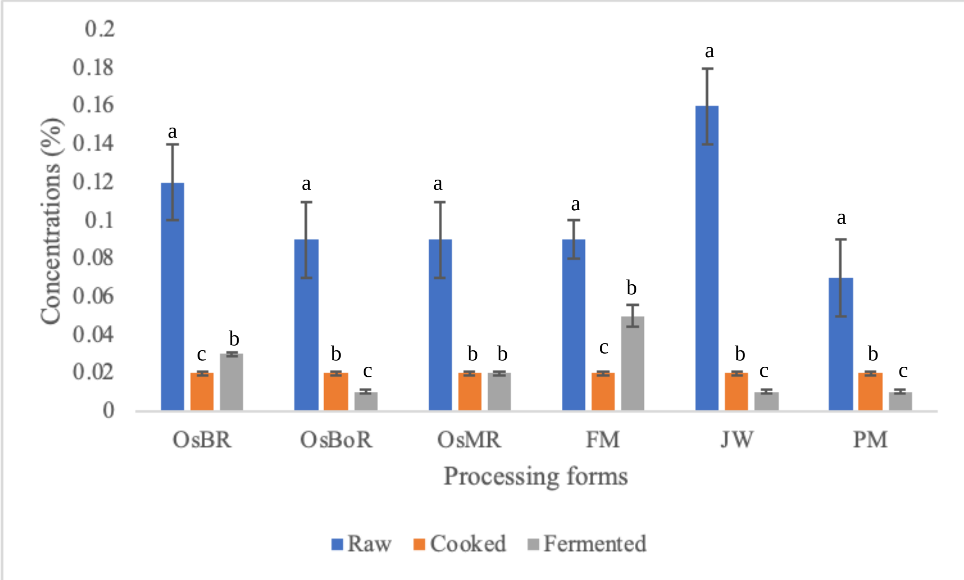

Fig. 4. Concentration of Phytates in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicate a statistically significant difference ($p < 0.05$)

This decrease is also attributed to the leaching of the water-soluble tannins into cooking water and thermal polymerisation of tannins, which makes them less reactive in spectrophotometric assays. Remarkably, there was a sharp increase in the tannin content by fermentation, with OsBR and FM exhibiting the highest value, followed by OsBoR=JW>OsMR>PM (Fig. 5). This increase in the tannin content is due to the microbial enzyme action, such as the cellulases and the proteases, which liberate the bonded tannins, making them more extractable. Moreover, fermentation can also generate phenolic compounds that bond with protein and carbohydrates to form mimic tannin-like structures that are more quantifiable in spectrophotometric assays (Chung *et al.*, 1998; Olives Barba *et al.*, 2006).

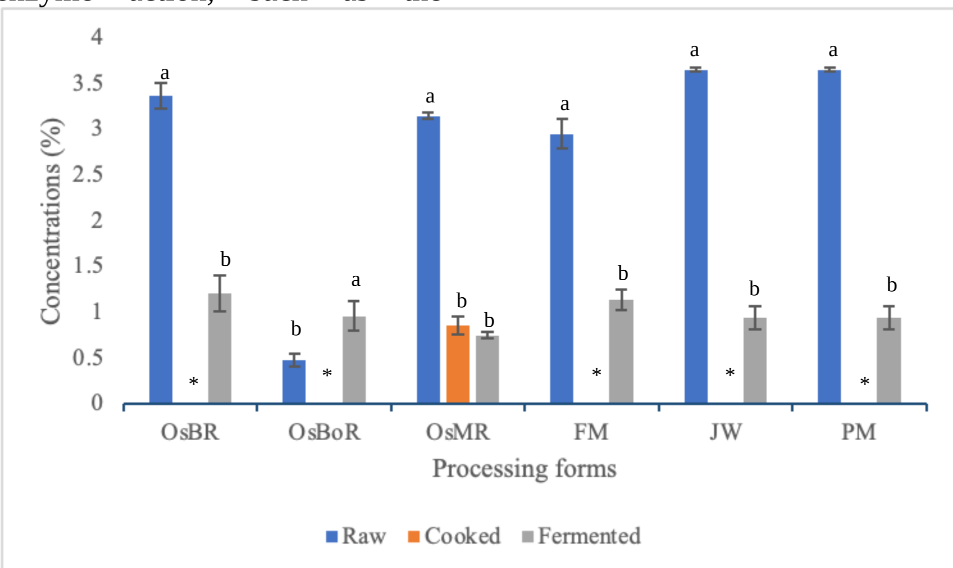

Fig. 5. Concentration of Tannins in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicate a statistically significant difference ($p < 0.05$); * indicate below detectable values.

Mineral Content Analysis

We have also analyzed the elemental content of Calcium, Iron, Potassium, Magnesium, Manganese, and Zinc across all six selected grains in their raw, cooked, and fermented states. Across the six elements, the raw grain consistently exhibited the highest concentrations, followed by cooked and fermented, with a statistically significant reduction seen among the grains (P<0.05). In the unprocessed grains, the minerals are found in their native forms and are bound to phytic acid, fiber or the protein complexes, although their bioavailability is less, their total availability remains the highest. In the raw state of the grains, FM had recorded the highest content of Ca (0.06264 ± 0.00046), followed by PM>JW>OsBR>OsBoR>OsMR (Fig. 6), while FM had the highest Fe content (0.00723 ± 0.02), followed by JW >OsBR>OsBoR>PM>OsMR (Fig. 7). K was found to be at a higher level in PM and JW compared to other grains with significant difference (P<0.05), followed by FM>OsBR>OsBoR>OsMR (Fig. 10). Mg followed a similar pattern: FM>OsBR>JW>PM>OsBoR>OsMR (Fig. 8). Mn was highest in OsBR and FM followed by>JW>PM>OsMR>OsBoR (Fig. 9). Zn content followed the trend FM> PM> JW> OsBR= OsMR> OsBoR (Fig. 11). Copper was below detectable limits (BDL) in most samples. Upon cooking, there was a significant reduction in the elemental content, which showed a significant statistical difference (P<0.05), except for magnesium in its raw state. Here, the boiling or steaming can cause the minerals to leach out into the cooking water, which explains the drop in the mineral content (Meiners *et al.*, 1976; Moyo, 2024). OsMR was found to have retained the highest calcium content after post-cooking, while the OsBR and OsMR had relatively high Fe and K content. Fermentation further reduced the elemental levels, where OsMR showed high retention of Zn and Fe, while JW retained calcium. This reduction is due to the solubilization and microbial uptake. Fermentation is also reported to break down the antinutritional factors, increasing the bioavailability of the minerals even if their total content is low (Gibson, 2007; Hemalatha, Platel, & Srinivasan, 2005). When compared to all the other treatments, elemental degradation was found to follow the trend Raw>cooked>fermented, which shows a notable statistical difference among the grains and the treatment, suggesting that cooking and fermentation influence the bioavailability of the elements in a grain-specific manner.

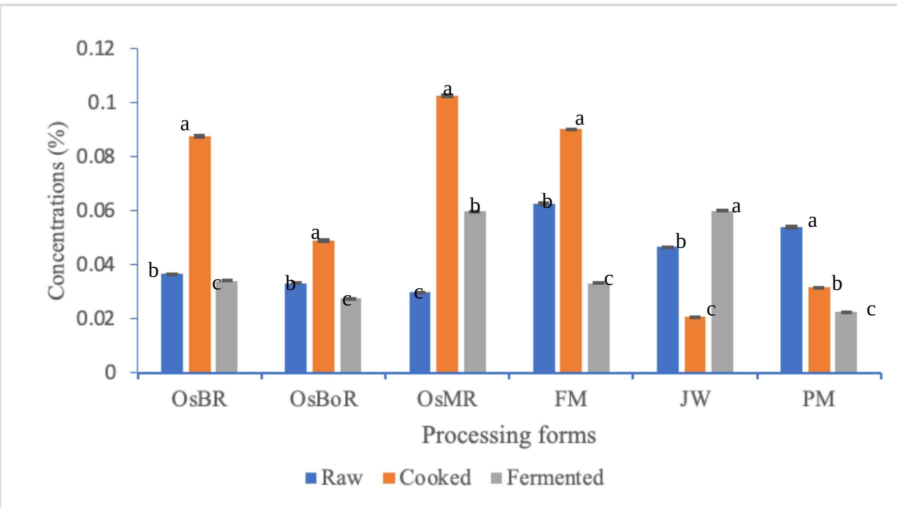

Fig. 6. Concentration of Calcium in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicate a statistically significant difference (p < 0.05)

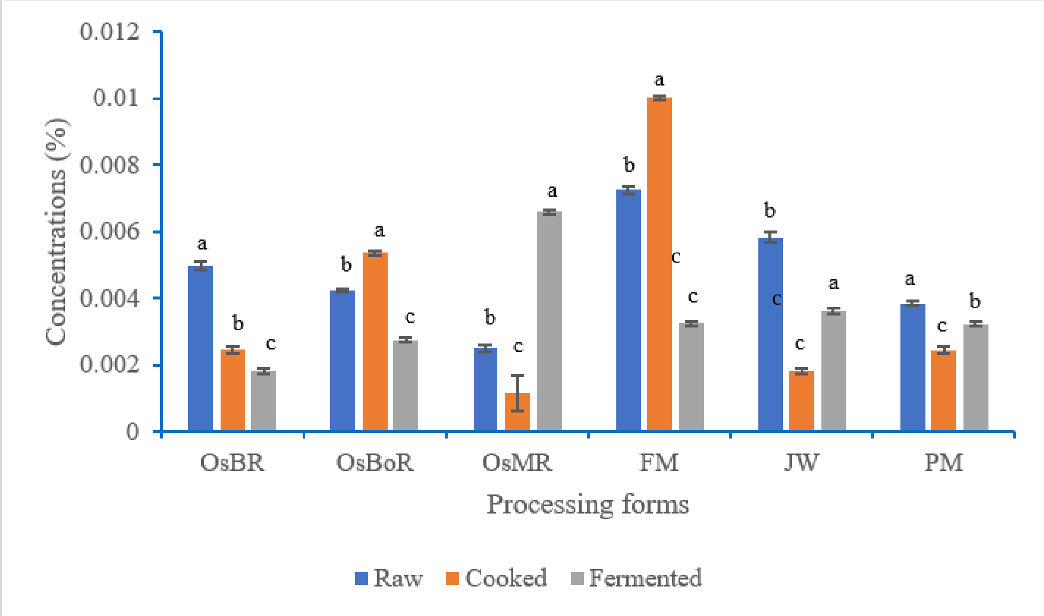

Fig. 7. Concentration of iron in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicates a statistically significant difference ($p < 0.05$)

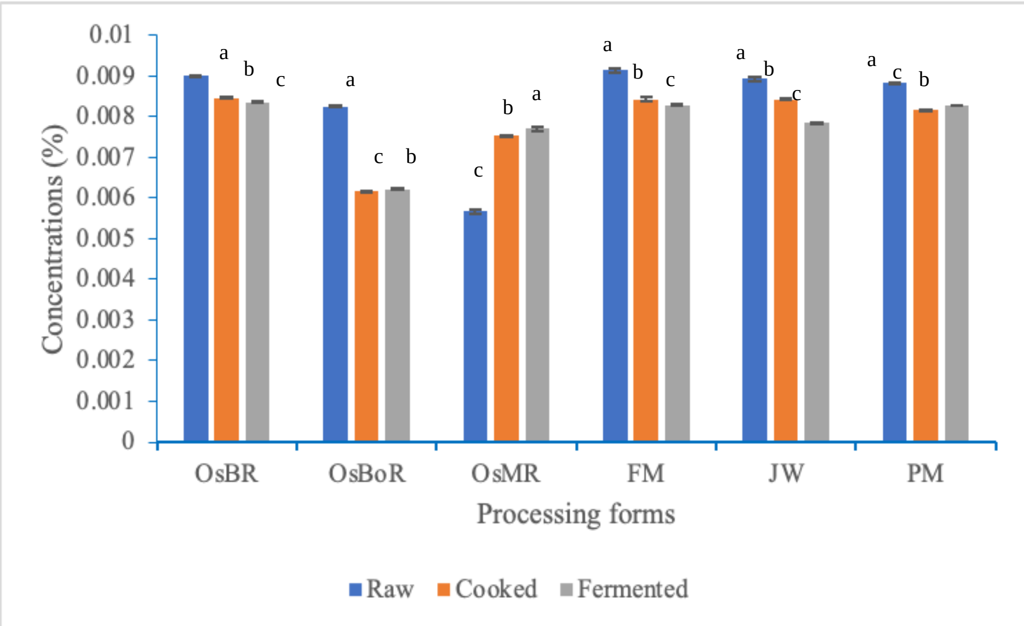

Fig. 8. Concentration of magnesium in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicate a statistically significant difference ($p < 0.05$)

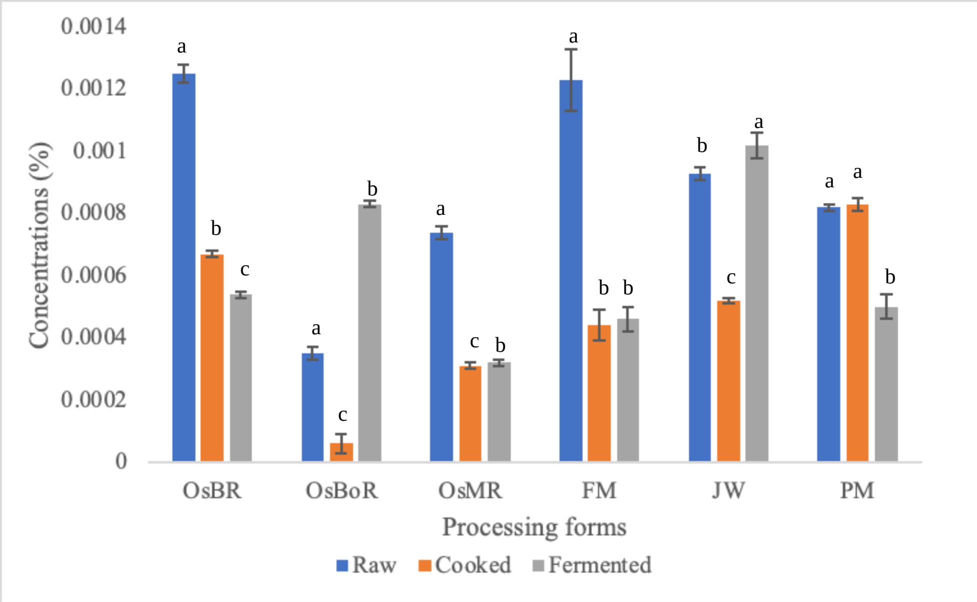

Fig. 9. Concentration of Manganese in raw, cooked, and fermented forms of selected grain
Different alphabets within each group indicate a statistically significant difference ($p < 0.05$).

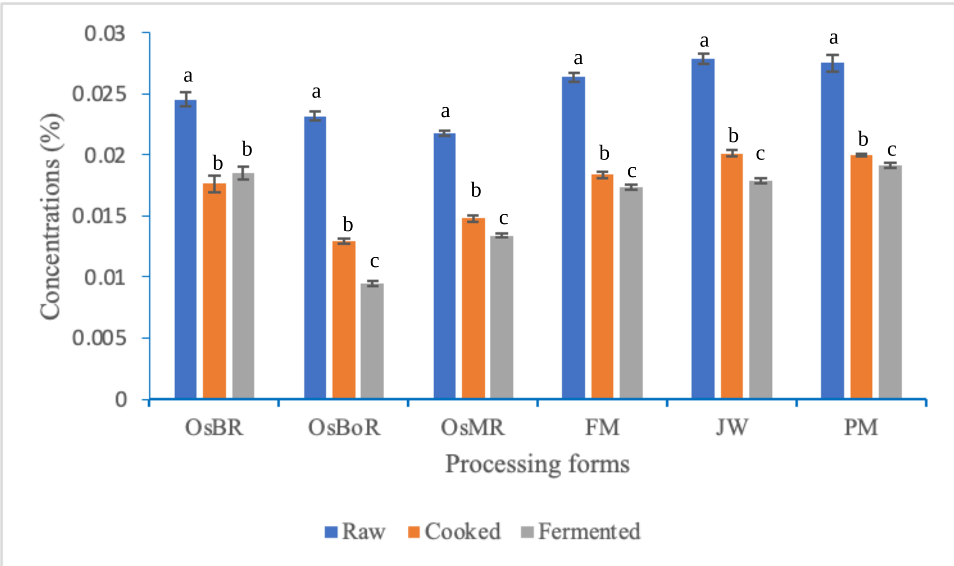

Fig. 10. Concentration of Potassium in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicate a statistically significant difference ($p < 0.05$)

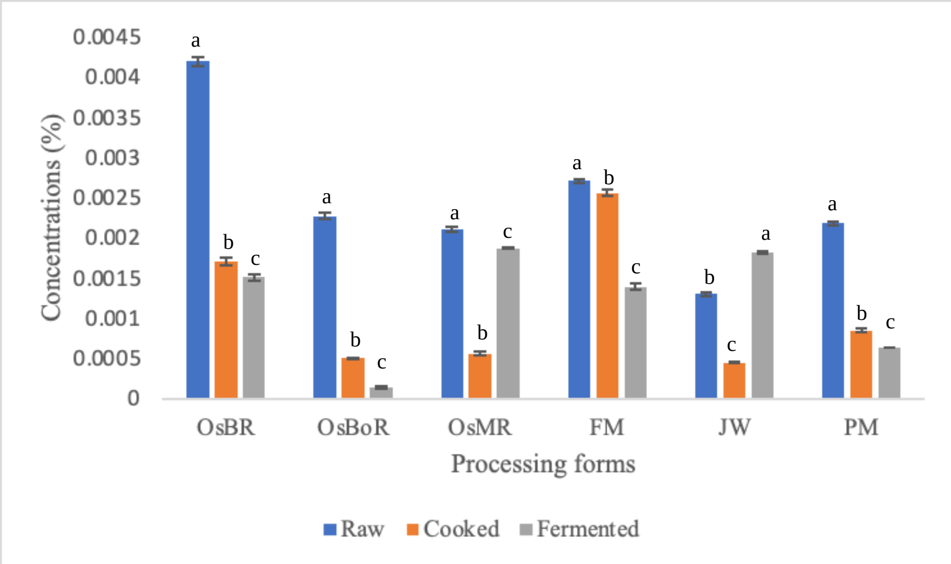

Fig. 11. Concentration of Zinc in raw, cooked, and fermented forms of selected grains
Different alphabets within each group indicate a statistically significant difference ($p < 0.05$)

Conclusion

The current study demonstrated that both cooking and fermentation notably influenced the nutritional and anti-nutritional compositions of the selected grains. Cooking primarily resulted in a marked reduction of carbohydrate, oxalates, phytates and tannins, mainly due to the leaching and thermal degradation. Fermentation, on the other hand, caused an improvement in the protein level and also caused a reduction in several anti-nutrients; a decline in the mineral content was also observed. In spite of the apparent decline in the mineral content, the breakdown of the anti-nutrients caused an increase in the bioavailability of the minerals. Importantly, the RDA (recommended dietary allowance) have recommended that the essential nutrients, such as protein intake, have to be at least 46g/day for women and 56g/day for men, while Fe intake is of 18mg/day for women of age 19-50 and 8mg/day for men and Zn levels are 8-11 mg/day, i.e 8mg/day for women and 11mg/day for men (DeLoughery, 2017). In this study, fermentation has been shown to be the most effective method in enhancing the bioavailability of protein and minerals such as Fe and Zn. Cooking was found to be more effective in reducing the anti-nutritional factors which tend to hinder the nutritional uptake (Evans & Lawrenson, 2017; Quintaes & Diez-Garcia, 2015). Although a decline in the mineral content was observed, the bioavailability was increased due to the breakdown of the anti-nutritional factors. These findings highlight the importance of traditional fermentation technique as a promising approach for the nutrient uptake from the grains and support better dietary outcomes (Hur, Lee, Kim, Choi, & Kim, 2014). To build on the findings of this study, one can explore the bioavailability studies, microbial profiling, extended fermentation durations, comparison of natural fermentation with that of starter cultures, sensory and shelf-life evaluation and application in functional foods.

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Authors Contribution

Merin Rose Jeeson: Data curation, Formal analysis, Investigation, Methodology, Visualization, writing – original draft. **Krishnakumar Velayudhannair:** Conceptualization, Formal analysis, Project administration, Supervision, Validation, Writing – review and editing.

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تأثیر پخت و تخمیر بر پروفایل‌های مواد مغذی و ضدمغذی در ارزن‌ها و برنج

جیسون رز مرین[1]- ولیودهنیار کریشنا کومار[1*]

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چکیده

این مطالعه به بررسی تأثیر روش‌های سنتی فرآوری، شامل پخت و تخمیر، بر ترکیب مواد مغذی، ضدمغذی و مواد معدنی شش غله خوراکی می‌پردازد؛ سه رقم برنج (*Oryza sativa* ماتّا، برنج پخته و برنج قهوه‌ای) و سه نوع ارزن (ارزن دم‌روباهی، جوار و ارزن مرواریدی). غلات در سه حالت خام، پخته و تخمیرشده مورد تجزیه‌وتحلیل قرار گرفتند. میزان کربوهیدرات و پروتئین همراه با ترکیبات ضدمغذی شامل فلاونوئیدها، اگزالات‌ها، فنولیک‌ها، فیتات‌ها و تانن‌ها اندازه‌گیری شد. غلظت مواد معدنی شامل کلسیم، پتاسیم، آهن، منیزیم، منگنز و زینک با استفاده از دستگاه جذب اتمی تعیین گردید. نتایج نشان داد پخت، میزان کربوهیدرات را در تمامی غلات به‌طور معنی‌داری بین ۸۵ تا ۹۰ درصد کاهش می‌دهد، در حالی‌که تخمیر کاهش بیشتری تا حدود ۹۵ درصد ایجاد می‌کند. مقدار پروتئین وابسته به نوع غله بود و تخمیر به‌طور کلی موجب افزایش ۲۰ تا ۵۰ درصدی پروتئین می‌شد. میزان فلاونوئیدها بین ۷۰ تا ۹۰ درصد کاهش یافت و فیتات‌ها و اگزالات‌ها نیز در اثر هر دو تیمار، به‌دلیل نفوذپذیری و تخریب حرارتی، به‌طور قابل‌توجهی بین ۶۰ تا ۹۰ درصد کاهش پیدا کردند؛ در مقابل، محتوای ترکیبات فنولیک به‌ویژه در ارزن دم‌روباهی، ۲۵ تا ۴۰ درصد افزایش یافت. سطح تانن‌ها در اثر پخت بین ۴۰ تا ۶۰ درصد کاهش یافت، اما پس از تخمیر افزایش نشان داد که احتمالاً ناشی از آزادسازی آنزیمی ترکیبات متصل است. غلظت مواد معدنی در هر دو حالت پخته و تخمیرشده کاهش یافت؛ با این حال، تخمیر با کاهش ضدمغذی‌ها، قابلیت زیست‌فراهمی مواد معدنی را بهبود بخشید. در مجموع، پخت در کاهش عوامل ضدمغذی مؤثرتر بود، در حالی‌که تخمیر موجب افزایش پروتئین و بهبود دسترسی‌پذیری مواد معدنی ضروری مانند آهن و روی شد. این یافته‌ها اهمیت روش‌های سنتی خانگی در بهبود کیفیت تغذیه‌ای رژیم‌های غذایی مبتنی بر برنج و ارزن را به‌ویژه در مناطقی که وابسته به غلات هستند، نشان می‌دهد.

واژه‌های کلیدی: ارزن، ارقام برنج، تخمیر، زیست‌فراهمی، محتوای معدنی

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