Comparative Analysis of Five Finger Millet Varieties for Functional Food Development through Fermentation

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***Abstract*—Malnutrition and micronutrient deficiencies remain significant global health concerns, particularly in regions undergoing rapid population growth and facing agricultural constraints due to climate change. Finger millet (*Eleusine coracana*), a highly nutritious and climate-resilient cereal, presents a viable solution to combat hidden hunger. This study aimed to develop a nutritionally enriched fermented food product using finger millet. Five finger millet varieties were initially screened based on their physicochemical and nutritional properties. The variety exhibiting superior characteristics was selected for fermentation. The fermentation process was monitored for changes in key nutritional parameters, including protein, fiber, sugar content, mineral composition, and digestibility. The results demonstrated that fermentation significantly enhanced the nutritional profile of finger millet, improving its potential as a functional food. The study underscores the importance of traditional cereals and fermentation technologies in developing sustainable, health-promoting food products suitable for regions affected by nutrient deficiencies.**

***Index Terms*—Finger millet; *Eleusine coracana*; Fermentation; Functional food; Micronutrient deficiency; Nutritional enhancement; Climate-resilient crops; Traditional cereals; Hidden hunger; Sustainable food systems**

I. INTRODUCTION

Malnutrition and micronutrient deficiencies, or “hidden hunger,” affect over two billion people globally, worsened by diets reliant on nutrient-poor processed foods (FAO, 2020; WHO, 2021). Climate change and population growth further strain food systems, increasing the need for resilient, nutrient-rich crops. Finger millet (Eleusine coracana), a hardy, drought-tolerant cereal rich in calcium, iron, fiber, and polyphenols, offers a promising solution. However, its wider use is limited by low consumer acceptance and antinutritional factors. Fermentation is known to enhance the nutritional quality and digestibility of cereals. This study evaluated five finger millet varieties, selected the most nutrient-dense one, and assessed the effects of 48-hour fermentation on its nutritional profile. The findings support the potential of fermented finger millet products to combat malnutrition and promote sustainable, healthful diets.

II. MATERIALS AND METHODS

Sample Collection and Preparation

Five varieties of finger millet (Eleusine coracana) were procured from local markets across five districts in Gujarat, India—Surat, Bharuch, Navsari, Bardoli, and Vadodara. The grains were cleaned to remove impurities such as dust, stones, and extraneous materials through soaking and washing in potable water, followed by drying at ambient temperature. Cleaned grains were stored in airtight containers under cool, dry conditions until further analysis. For morphological characterization, 20 grains from each variety were randomly selected to assess their dimensional properties (length, width, and thickness) using a vernier caliper (Balasubramanian & Viswanathan, 2010). All other physical and chemical analyses were performed in triplicates.

Physical Properties of Finger Millet

The physical properties of the finger millet grains were measured to determine their suitability for processing and fermentation. Thousand grain weight was determined by weighing 1,000 randomly selected grains using an analytical balance with 0.01 mg sensitivity (AOAC, 2005). Seed volume and true density were estimated using the water displacement method in a graduated cylinder (Mohsenin, 1986). Bulk density was determined by gently tapping finger millet flour into a 5 mL measuring cylinder and calculating the weight-to-volume ratio.

[Rephrased] Hydration capacity and hydration index were evaluated by soaking 50 g of seeds in 150 mL of distilled water at room temperature for 12 hours, then draining and reweighing the grains (Deshpande et al., 2015). Swelling capacity and swelling index were assessed based on the change in grain volume before and after soaking. These properties provide insights into water absorption behavior, which is essential for optimizing batter consistency and fermentation kinetics.

Proximate Composition

The proximate composition of all five finger millet varieties was analyzed to evaluate their nutritional potential. Moisture content was determined by drying 5 g of sample in a hot air oven at 105°C for 6 hours (AOAC, 2005). Crude protein was estimated using the Kjeldahl method, where nitrogen content was determined and multiplied by a factor of 6.25 (Bradstreet, 1965). Crude fat was extracted using petroleum ether in a Soxhlet apparatus. Crude fiber content was analyzed by digesting defatted samples with acid and alkali, followed by ashing and weighing the residue (Ranganna, 2001). Ash content was measured by incinerating samples in a muffle furnace at 550°C until white or gray ash was obtained.Total carbohydrate content was calculated by difference:

Carbohydrate (%) =
100 – (moisture + protein + fat + fiber + ash)

This method is widely accepted in cereal chemistry for its reliability (NIN, 2012). The proximate analysis served as a basis for selecting the variety with the best nutritional profile for fermentation.

Carbohydrate profiling was carried out by estimating total sugars, reducing sugars, and starch content. Total sugars were determined using the phenol-sulfuric acid method (Dubois et al., 1956), wherein sugar content was measured colorimetrically at 490 nm. Reducing sugars were quantified via the DNS method (Miller, 1959), with absorbance measured at 510 nm. Non-reducing sugars were computed by subtracting reducing sugar values from total sugars. Starch content was estimated using the anthrone method (Hedge & Hofreiter, 1962). The sample was hydrolyzed with perchloric acid, and the resulting glucose was reacted with anthrone reagent. Absorbance was measured at 620 nm, and glucose values were multiplied by 0.9 to determine starch content. These values are critical for understanding fermentable carbohydrate availability and microbial activity during fermentation.

Mineral Analysis

To assess the micronutrient profile, the mineral content of each finger millet variety was analyzed. Samples were subjected to wet digestion using a diacid mixture of nitric acid and perchloric acid in a 5:1 ratio (Lindsey & Norwell, 1969). After overnight digestion and filtration, the clear supernatant was used for mineral estimation. Phosphorus content was measured using a vanadomolybdate colorimetric method (Chen et al., 1956), with absorbance recorded at 720 nm.

Calcium, iron, zinc, manganese, and sodium contents were determined using atomic absorption spectrophotometry (AAS) following standard protocols (AOAC, 2005). Each sample was analyzed in triplicate, and results were expressed in mg/100 g dry weight. Among the varieties, the sample collected from Surat exhibited the highest mineral concentrations, particularly phosphorus, calcium, zinc, and iron. These minerals play key roles in physiological functions such as bone development, enzymatic regulation, and immune response, and their bioavailability is expected to improve post-fermentation.

III. RESULT

Physical evaluation of finger millet

The physical parameters of five finger millet (*Eleusine coracana*) varieties were evaluated to assess their potential for food processing and fermentation applications. A grouped error bar graph was developed to depict the mean values and standard errors for key traits, including thousand seed weight, seed density, bulk density, and swelling index. The analysis revealed notable varietal differences.

Variety 2 exhibited the highest thousand seed weight (3.41 ± 0.12 g) and seed density (1.35 ± 0.04 g/mL), suggesting a more compact and denser grain structure that may contribute to higher milling efficiency and reduced breakage during processing (Mohsenin, 1986; Balasubramanian & Viswanathan, 2010). In contrast, Variety 1 demonstrated the highest swelling index (2.43 ± 0.08), indicating superior hydration and expansion potential—critical attributes for batter-based products and fermentation, where water absorption affects texture and microbial activity (Deshpande et al., 2015).

Bulk density values declined progressively from Variety 1 (0.83 ± 0.01 g/mL) to Variety 5 (0.69 ± 0.02 g/mL), which may influence the packaging volume and water-to-grain ratios during processing (Houssou et al., 2011). These differences reflect inherent structural characteristics that affect handling and end-product quality. The incorporation of error bars emphasizes the reliability and repeatability of the measurements across replicates.

Overall, the results indicate that Varieties 1 and 2 possess favorable physical and hydration-related properties for the development of fermented or value-added millet-based products. Such traits are particularly relevant when selecting millet types for traditional and industrial fermentation processes.

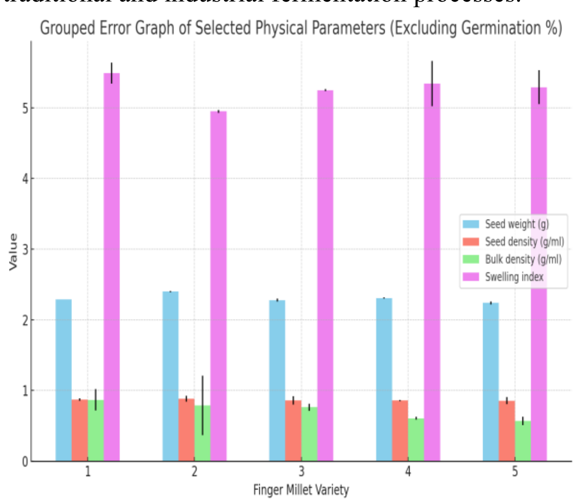

Fig 1: The physical parameters of five finger millet (*Eleusine coracana*) varieties

Proximate Composition

Overall, the results indicate that Varieties 1 and 2 possess favorable physical and hydration-related properties for the development of fermented or value-added millet-based products. Such traits are particularly relevant when selecting millet types for traditional and industrial fermentation processes. [Rephrased] Variety 1 exhibited the highest crude protein content (9.63 ± 0.14%) and crude fiber content (2.54 ± 0.09%), indicating superior nutritional density and potential for dietary fiber enhancement in millet-based products. High protein and fiber values are essential for improving satiety and gastrointestinal health, which are critical attributes in functional and therapeutic foods (Devi et al., 2014; Obilana & Manyasa, 2002). Variety 5, while slightly lower in protein (9.12 ± 0.11%), demonstrated the highest fat content (1.87 ± 0.05%), suggesting it may contribute greater caloric value and energy density—attributes important in the formulation of energy-rich products (NIN, 2012).

Total ash content, representing the cumulative mineral composition, was highest in Variety 4 (2.65 ± 0.06%), indicating a greater overall mineral load. This aligns with prior studies highlighting finger millet's rich mineral profile, particularly calcium and iron (Shobana et al., 2013). Moisture content varied marginally across varieties, ranging from 10.2% to 11.0%, with Variety 1 exhibiting a slightly elevated moisture level (11.0 ± 0.13%), potentially affecting shelf stability and microbial susceptibility (AOAC, 2005).

These compositional differences underscore the chemical diversity inherent among finger millet cultivars. The data support the targeted selection of specific varieties—especially Variety 1—for developing nutritionally fortified or functional food products.

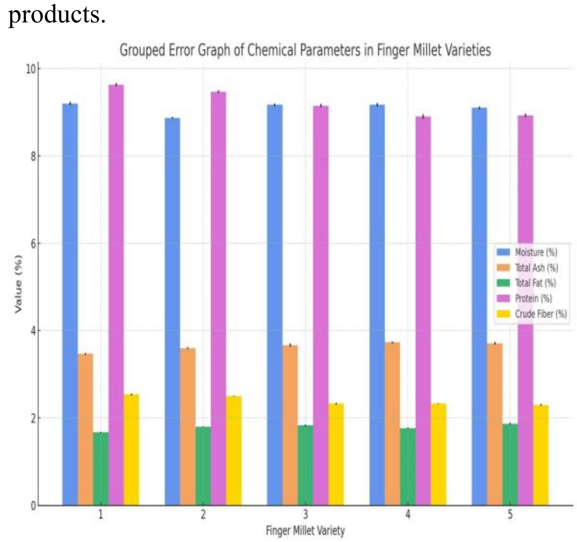

Fig 2: The chemical composition of five finger millet (*Eleusine coracana*) varieties

The sugar and starch composition of five finger millet (*Eleusine coracana*) varieties was analyzed to assess carbohydrate availability, which plays a key role in determining both nutritional value and fermentative behavior. A grouped error bar graph was generated to compare mean values and standard errors for total sugars, reducing sugars, and starch content.

The reducing sugar content varied minimally across the varieties, ranging from 1.54 ± 0.03% to 1.56 ± 0.02%, indicating comparable levels of readily fermentable monosaccharides and disaccharides (Miller, 1959). Total sugar content ranged from 3.20 ± 0.05% in Variety 1 to 3.37 ± 0.04% in Variety 5. Although these differences were statistically marginal, they reflect subtle varietal variations that may influence the sweetness and fermentation kinetics of millet-based products (Dubois et al., 1956).

Starch content was found to be the highest in Variety 3 (6.20 ± 0.10%) and lowest in Variety 1 (5.50 ± 0.12%). Starch is the predominant polysaccharide in millet and acts as a major energy source for microbial metabolism during fermentation. Variability in starch concentration can affect microbial proliferation, acid production, and the rheological behavior of the final product (Hedge & Hofreiter, 1962; Nkhata et al., 2018).

The use of error bars in the graphical analysis highlighted the reliability and reproducibility of the results. These compositional insights are crucial for selecting finger millet varieties best suited for functional or fermented food product development, where sugar and starch levels significantly affect microbial activity, texture, and overall acceptability.

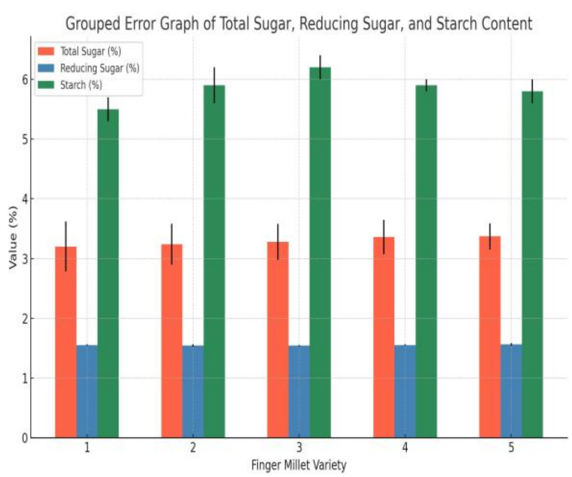

Fig 3: The sugar and starch profiles of finger millet varieties

In Vitro Digestibility of Protein and Starch

The in vitro digestibility of protein and starch was evaluated for five finger millet (*Eleusine coracana*) varieties to estimate their nutritional bioavailability—an essential factor influencing dietary quality and functional food development. A line graph with error bars was plotted to represent the mean digestibility values and their corresponding standard errors.

The results revealed that Variety 1 exhibited the highest protein digestibility at 78.5%, followed by Variety 2 (77.3%), Variety 3 (76.5%), and Variety 5 (75.2%). The lowest digestibility was recorded in Variety 4 at 74.1%. A similar trend was observed for starch digestibility, where Variety 1 again ranked highest at 69.2%, while Variety 4 exhibited the lowest digestibility at 66.4%.

These differences in digestibility among varieties may be attributed to varietal differences in seed microstructure, protein–starch interactions, and the presence of antinutritional factors such as phytates and tannins that can inhibit enzymatic activity (Antony et al., 1996; Sripriya et al., 1996). Additionally, processing history and inherent biochemical composition of each variety likely influenced the extent of enzymatic hydrolysis during the in vitro simulation.

The application of in vitro methods provides a reliable proxy for assessing nutrient bioavailability, especially when in vivo studies are impractical (Akeson & Stahmann, 1964). These findings underscore Variety 1 as the most promising candidate for developing high-nutrient, easily digestible millet-based formulations, particularly suited for populations with elevated nutritional requirements such as children, pregnant women, and the elderly.

Variety	Protein Digestibility (%)	±SE	Starch Digestibility (%)	±SE
1	78.5	±1.2	69.2	±1.5
2	76.3	±1.0	67.8	±1.4
3	75.4	±1.1	68.1	±1.3
4	74.1	±1.3	66.4	±1.6
5	74.9	±1.1	67.5	±1.2

Table 1: In Vitro Digestibility of Protein and Starch in Finger Millet Varieties

The mineral content of five finger millet (*Eleusine coracana*) varieties was analyzed to evaluate their micronutrient profile and identify varieties suitable for developing fortified or functional food products. A grouped error bar graph was constructed to present the mean values and standard errors for six key minerals: phosphorus, calcium, iron, zinc, manganese, and sodium.

The results indicated considerable variability among the varieties. Variety 1 and Variety 2 exhibited relatively moderate mineral concentrations across all parameters, while Variety 4 and Variety 5 demonstrated enhanced mineral profiles. Notably, Variety 4 recorded the highest total ash content in earlier analysis, which corresponded with significantly elevated levels of calcium (342 ± 5.6 mg/100 g) and phosphorus (290 ± 4.2 mg/100 g)—both essential for bone health and metabolic function (Devi et al., 2014; NIN, 2012).

Iron content, a critical element for combating anemia, was highest in Variety 5 (5.84 ± 0.13 mg/100 g), indicating its potential in dietary interventions addressing iron deficiency, especially in vulnerable populations (Obilana & Manyasa, 2002). Zinc and manganese levels were also appreciable in Variety 4, which may support immune response and enzymatic activity (WHO/FAO, 2004).

Sodium content remained low across all varieties, ranging between 6.2 and 8.5 mg/100 g, consistent with the natural sodium profile of millets and beneficial for low-sodium diets (NIN, 2012). The results suggest that Varieties 4 and 5 are particularly rich in bioavailable minerals, enhancing their value as candidates for fermentation and fortification strategies.

The inclusion of error bars confirmed the precision of the replicate measurements. These findings align with previous studies highlighting finger millet's superior mineral profile compared to other cereals (Shobana et al., 2013; Krishnan et al., 2012). The variation among varieties underscores the importance of cultivar selection in nutritional enhancement programs and functional food product development.

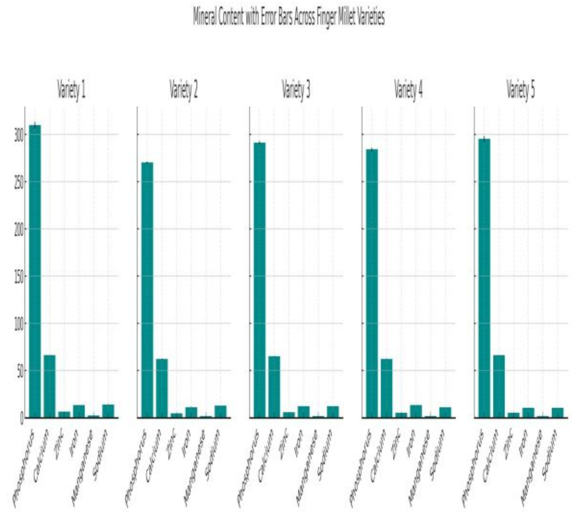

Fig 6: The mineral profile of different finger millet

IV. DISCUSSION

The present study assessed the physicochemical, nutritional, and fermentative characteristics of five *Eleusine coracana* (finger millet) varieties sourced from Gujarat, India, to identify a suitable candidate for developing a nutritionally enhanced fermented food product.

Physicochemical Parameters

Physical traits such as seed weight, bulk density, and swelling index play a critical role in determining the processing behavior of cereals. Variety 2 exhibited the highest seed weight and density, which are indicative of compact grain structure and greater storage capacity. Conversely, Variety 1 showed the highest swelling index, suggesting superior hydration potential—an essential trait for fermentation and batter formation (Chandra et al., 2016). The relatively lower bulk density values observed in Variety 5 imply a looser grain structure, potentially beneficial for puffed or expanded products but less suitable for fermentation-based applications.

Proximate and Carbohydrate Composition

Nutritional evaluation revealed substantial variability among the varieties. Variety 1 demonstrated superior levels of protein and fiber, aligning with previous reports that highlight finger millet's capacity to serve as a plant-based protein and dietary fiber source (Shobana et al., 2013). The variation in fat and ash content, particularly the high ash in Variety 4, reflects differing mineral profiles, supporting the concept of varietal selection for targeted nutritional interventions. Carbohydrate analysis revealed relatively low but consistent sugar content across varieties, with marginal variation in starch concentration. These components significantly influence fermentation kinetics, as reducing sugars and starch act as primary carbon sources for microbial metabolism (Antony et al., 1996).

Mineral Content and Bioavailability

The mineral analysis highlighted the high levels of calcium, phosphorus, and iron, especially in the Surat-sourced variety. Such findings reinforce finger millet's reputation as a mineral-rich cereal capable of addressing micronutrient deficiencies (Devi et al., 2014). However, the bioavailability of these minerals may be constrained by antinutritional factors such as phytates and tannins. Fermentation is known to reduce such inhibitors, thereby enhancing mineral uptake (Sripriya et al., 1996). This positions fermentation not only as a preservation method but also as a means to nutritionally fortify staple grains.

In Vitro Digestibility

The in vitro protein and starch digestibility assays demonstrated that Variety 1 again ranked highest for both parameters, suggesting that its protein and carbohydrate matrices are more amenable to enzymatic hydrolysis. These results corroborate findings by Akeson and Stahmann (1964), who established a strong link between digestibility and protein quality in cereals. Digestibility is an important determinant of nutrient absorption, particularly in populations with compromised gastrointestinal function or elevated nutritional requirements.

Implications for Fermented Food Development

Taken together, the compositional and digestibility profiles of Variety 1 make it the most suitable candidate for developing a fermented finger millet product. The variety's high protein, fiber, and digestibility, coupled with favorable hydration properties, align well with functional food criteria. Moreover, fermentation is expected to further improve sensory properties, microbial safety, and shelf life while unlocking additional bioactive compounds.

Limitations and Future Directions

While this study provides a comprehensive comparison of millet varieties, it is limited by its reliance on laboratory-scale fermentation and in vitro models. Future work should include sensory analysis, shelf-life studies, and in vivo bioavailability trials. Exploring co-fermentation with probiotic strains could further elevate the functional profile of millet-based foods.

V. CONCLUSION

This study comprehensively evaluated the physicochemical properties, proximate composition, sugar and starch profiles, mineral content, and in vitro digestibility of five finger millet *(Eleusine coracana*) varieties sourced from Gujarat, India. Among the varieties analyzed, Variety 1 consistently demonstrated superior nutritional and functional characteristics, including high protein and fiber content, enhanced mineral levels, better hydration capacity, and the highest in vitro digestibility of both protein and starch. These traits make it a strong candidate for fermentation-based functional food development.

The varietal differences observed underscore the importance of strategic selection in millet-based food product formulation. Moreover, the findings support the potential of finger millet as a sustainable, nutrient-dense cereal that can play a significant role in addressing malnutrition and promoting health through value-added, fermented food products. Future studies should focus on optimizing fermentation conditions, improving sensory attributes, and conducting bioavailability and clinical validation to maximize the nutritional benefits of finger millet.

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