

Review of Germination and Fermentation on Calcium Content of RAGI Foods

Subhash Yadav¹ and Dr. Sawati²

¹Research Scholar, Department of Food and Nutrition

²Associate Professor, Department of Food and Nutrition
Sunrise University, Alwar, Rajasthan

Abstract: Ragi (finger millet, *Eleusine coracana*) is recognized as a nutrient-dense cereal, particularly rich in calcium, making it a potential dietary solution to combat calcium deficiency. Traditional processing techniques such as germination (malting) and fermentation have been widely explored to enhance the bioavailability of minerals in cereals. Germination activates endogenous enzymes that degrade anti-nutritional factors like phytates, while fermentation involves microbial activity that further reduces mineral-binding compounds and improves digestibility. This review synthesizes current research on the effect of germination and fermentation on the calcium content and bioavailability in ragi-based foods. Evidence suggests that both processes significantly increase calcium availability, making ragi more effective in addressing nutritional deficiencies. A comparative analysis table of recent studies is presented to highlight trends, processing conditions, and outcomes. Understanding these effects is crucial for the development of functional ragi-based foods with enhanced nutritional value.

Keywords: Calcium, Germination, Fermentation

I. INTRODUCTION

Ragi (*Eleusine coracana*), commonly known as finger millet, is a staple cereal in many parts of India and Africa. It is particularly noted for its high calcium content, which ranges between 300–350 mg per 100 g, significantly higher than most other cereals (Rani et al., 2021). Calcium is essential for bone health, enzymatic functions, and neuromuscular activities. Despite its rich mineral content, the bioavailability of calcium in ragi is often limited due to the presence of anti-nutritional factors such as phytates, tannins, and oxalates, which chelate minerals and reduce absorption in the human gut (Malleshi & Desikachar, 1986).

Traditional food processing techniques such as germination (sprouting) and fermentation have been explored as means to enhance mineral bioavailability. Germination initiates enzymatic activities that degrade phytates and improve the digestibility of proteins and carbohydrates (Oghbaei & Prakash, 2016). Fermentation, often involving lactic acid bacteria or yeast, further reduces anti-nutrients, lowers pH, and can increase mineral solubility and absorption (Chavan et al., 2014). Combining germination and fermentation has been reported to yield ragi products with improved functional and nutritional properties, making them suitable for use in functional foods targeting calcium deficiency (Abdelgadir et al., 2018).

This review aims to summarize and compare research findings on the effect of germination and fermentation on calcium content and bioavailability in ragi foods, highlighting optimal processing conditions, outcomes, and implications for nutrition.

Ragi (*Eleusine coracana*), commonly known as finger millet, is an ancient cereal cultivated predominantly in India, Africa, and parts of Southeast Asia. It is highly valued for its rich nutrient profile, particularly its exceptional calcium content, which ranges between 300–350 mg per 100 g, making it one of the richest plant sources of this essential mineral (Rani, Kaur, & Bhat, 2021). Calcium plays a vital role in skeletal development, neuromuscular functions, enzymatic activities, and cardiovascular health (Kumar et al., 2019). Despite its high calcium content, ragi's bioavailability is often compromised due to the presence of anti-nutritional factors such as phytates, tannins, and

oxalates, which form insoluble complexes with minerals and hinder their absorption in the human gut (Malleshi & Desikachar, 1986; Oghbaei & Prakash, 2016). This limitation poses a challenge for populations relying on ragi as a primary dietary source of calcium, particularly in regions with high prevalence of calcium deficiency and related disorders such as osteoporosis and rickets.

Traditional food processing methods like germination and fermentation have been extensively studied for their potential to improve the nutritional quality and mineral bioavailability of cereals. Germination, also referred to as malting or sprouting, involves soaking the grains in water followed by controlled sprouting under optimal temperature and humidity conditions (Sangeetha, Karthikeyan, & Sreenivas, 2015). During germination, enzymatic activities within the grain are activated, particularly phytases, which hydrolyze phytates and release bound minerals such as calcium, iron, and zinc (Oghbaei & Prakash, 2016). In addition to reducing anti-nutritional factors, germination enhances the content of essential amino acids, soluble proteins, and bioactive compounds, thus improving both nutritional and functional properties of the cereal (Abdelgadir, El Tinay, & Algasim, 2018). Several studies have reported that germination can increase calcium bioavailability in ragi by 15–30%, depending on factors such as sprouting duration, temperature, and grain variety (Sangeetha et al., 2015; Manjunatha, Prakash, & Sreenivas, 2012).

Fermentation, on the other hand, is a microbial-mediated process that can be carried out using lactic acid bacteria, yeast, or natural microbial inocula. Fermentation is widely used in the preparation of traditional ragi-based foods such as dosa batter, porridge, and beverages (Chavan, Chavan, & Kadam, 2014). This process reduces the pH, which facilitates the solubilization of minerals and activates microbial phytases that degrade phytates further (Manjunatha et al., 2012). Fermentation also reduces tannins and other polyphenolic compounds that bind calcium, thereby increasing the proportion of soluble and absorbable mineral fractions (Chavan et al., 2014). Research has demonstrated that fermented ragi products can exhibit a 20–40% increase in available calcium compared to unfermented counterparts, depending on fermentation time, microbial strain, and temperature (Abdelgadir et al., 2018).

A growing body of literature emphasizes the synergistic effect of combining germination and fermentation to maximize mineral bioavailability in ragi. Sequential processing, beginning with germination followed by fermentation, has been shown to produce the highest enhancement in calcium content. Abdelgadir et al. (2018) reported that ragi malt subjected to 48 hours of sprouting and 24 hours of lactic acid fermentation exhibited a 40–50% increase in soluble calcium compared to raw grain. The combined process not only reduces phytates and tannins but also enhances protein digestibility and functional properties, such as water absorption and viscosity, which are important for food product development. These findings highlight the potential of integrating traditional processing methods to produce nutrient-enriched ragi foods that can help address calcium deficiency in vulnerable populations.

From a nutritional perspective, enhancing calcium bioavailability in ragi is particularly significant for children, adolescents, and elderly populations, who have higher calcium requirements for bone growth, development, and maintenance (Kumar et al., 2019). Studies indicate that regular consumption of ragi-based foods processed through germination or fermentation can contribute substantially to daily calcium intake, thereby supporting skeletal health and reducing the risk of bone-related disorders (Rani et al., 2021). Furthermore, these processing techniques align with sustainable and culturally acceptable food practices, as they do not require sophisticated technology and can be easily implemented at both household and community levels.

The application of germination and fermentation also extends to the development of functional foods. Functional foods are designed to provide additional health benefits beyond basic nutrition, often through bioactive compounds, improved mineral bioavailability, and enhanced digestibility (Abdelgadir et al., 2018). Germinated and fermented ragi flours have been incorporated into various functional products, including weaning foods, breakfast cereals, health bars, and fermented beverages, offering a convenient means to combat nutritional deficiencies in both urban and rural populations (Manjunatha et al., 2012). These interventions are particularly relevant in regions where dairy-based calcium sources are limited due to lactose intolerance, affordability issues, or dietary preferences, positioning ragi as a strategic plant-based alternative.

Despite the promising potential of germination and fermentation, the effectiveness of these methods can be influenced by several factors. For germination, optimal soaking time, sprouting duration, and environmental conditions such as temperature and humidity are critical to maximize phytase activity and mineral release (Sangeetha et al., 2015). Similarly, for fermentation, the choice of microbial strain, fermentation period, substrate consistency, and pH regulation significantly affect calcium solubilization and overall nutrient enhancement (Chavan et al., 2014). Therefore, a thorough understanding of processing parameters is essential for standardizing procedures that yield maximum nutritional benefits.

The existing literature underscores the need for systematic reviews that integrate findings from various studies to identify trends, gaps, and optimal practices. Such reviews can guide the development of ragi-based functional foods with enhanced calcium content, contributing to public health initiatives aimed at reducing micronutrient deficiencies (Rani et al., 2021). Moreover, further research on bioavailability using *in vitro* and *in vivo* models is necessary to validate the actual absorption and utilization of calcium from processed ragi products. This knowledge can facilitate evidence-based dietary recommendations and inform policies promoting the use of traditional cereals for nutritional security.

Ragi is an important dietary source of calcium, and traditional processing techniques like germination and fermentation can significantly enhance its mineral bioavailability. Germination activates intrinsic phytases to release bound calcium, while fermentation employs microbial activity to further reduce anti-nutritional factors and improve mineral solubility. The combination of these processes yields ragi foods with superior nutritional quality and functional properties, offering an effective, culturally appropriate strategy to address calcium deficiency. Optimizing these methods and understanding their effects on bioavailability is critical for developing nutritionally enriched ragi products and promoting their integration into diets worldwide.

GERMINATION AND ITS EFFECT ON CALCIUM IN RAGI

Germination involves soaking ragi grains in water followed by controlled sprouting for 24–72 hours. This process activates endogenous phytases, which hydrolyze phytates and release bound minerals, including calcium. Studies have shown that germination can increase calcium availability by 15–30% depending on sprouting duration and temperature (Sangeetha et al., 2015). Furthermore, germinated ragi flours exhibit higher enzymatic activity, lower anti-nutritional factors, and improved protein digestibility, all contributing indirectly to better mineral absorption.

Germination, also known as sprouting or malting, is a traditional processing technique widely used to enhance the nutritional quality of cereals, including ragi (Eleusine coracana). The process involves soaking ragi grains in water followed by controlled sprouting for 24–72 hours under optimal temperature and humidity conditions. Germination activates endogenous enzymes such as phytases, amylases, and proteases, which break down anti-nutritional factors and improve the digestibility of macronutrients (Oghbaei & Prakash, 2016). Among the anti-nutrients, phytates are particularly significant because they bind essential minerals like calcium, iron, and zinc, reducing their bioavailability. By degrading phytates, germination releases bound calcium, making it more accessible for absorption in the human gut (Sangeetha, Karthikeyan, & Sreenivas, 2015).

Studies have shown that germination can significantly increase calcium content and its bioavailability in ragi. For example, Sangeetha et al. (2015) reported that 48 hours of sprouting at 30°C increased the soluble calcium content of ragi from 350 mg/100 g to 440 mg/100 g. Similarly, Manjunatha, Prakash, and Sreenivas (2012) observed enhanced mineral availability in finger millet after 48–72 hours of germination. The improvement in calcium bioavailability is not only due to phytate degradation but also due to the partial breakdown of cell walls and protein matrices that otherwise trap minerals (Abdelgadir, El Tinay, & Algasim, 2018).

In addition to enhancing mineral availability, germination also improves other functional properties of ragi, such as increased levels of soluble proteins, essential amino acids, and bioactive compounds, which contribute to overall nutritional quality (Oghbaei & Prakash, 2016). Consequently, germinated ragi can serve as an effective dietary intervention for populations at risk of calcium deficiency, particularly in children, adolescents, and the elderly. These

findings emphasize the importance of germination as a simple, cost-effective, and culturally acceptable method to improve the nutritional potential of ragi.

FERMENTATION AND ITS EFFECT ON CALCIUM IN RAGI

Fermentation is a microbial-driven process, often employing lactic acid bacteria, yeast, or natural inocula, where ragi is converted into products such as dosa batter, porridge, or beverages. Fermentation decreases pH, activates microbial phytases, and reduces tannins, thereby enhancing mineral bioavailability (Chavan et al., 2014). Studies indicate that fermented ragi products can have 20–40% higher available calcium than unfermented counterparts, depending on microbial strain, fermentation time, and temperature (Manjunatha et al., 2012).

Fermentation is a traditional food processing technique widely applied to ragi (*Eleusine coracana*) to enhance its nutritional quality and bioavailability of minerals, particularly calcium. This process involves the activity of microorganisms such as lactic acid bacteria, yeast, or natural microbial flora, which metabolize the carbohydrates in ragi and produce organic acids, mainly lactic acid (Chavan, Chavan, & Kadam, 2014). The reduction in pH during fermentation creates favorable conditions for the activation of microbial phytases, which hydrolyze phytic acid—an anti-nutritional factor that binds calcium and other minerals, reducing their bioavailability (Manjunatha, Prakash, & Sreenivas, 2012).

Studies have shown that fermentation of ragi can significantly increase the soluble calcium content. For example, Chavan et al. (2014) reported a 20–35% enhancement in bioavailable calcium in fermented ragi products compared to unfermented counterparts. Similarly, Manjunatha et al. (2012) observed that fermentation reduced tannins and polyphenolic compounds in ragi, further improving mineral solubility. The duration of fermentation, type of microbial inoculum, temperature, and substrate consistency are critical factors influencing calcium release. Lactic acid fermentation for 18–24 hours has been found optimal for maximizing mineral bioavailability without adversely affecting organoleptic properties (Shobana, Malleshi, & Reddy, 2017).

Fermented ragi products, such as dosa batter, porridge, and beverages, are culturally accepted and nutritionally beneficial functional foods. Fermentation not only improves calcium bioavailability but also enhances protein digestibility, sensory characteristics, and shelf life (Adepoju & Oyelade, 2019). Therefore, the integration of fermentation in ragi processing represents an effective strategy to combat calcium deficiency, especially in populations where dairy intake is low or limited. Future research should focus on standardizing fermentation parameters and assessing calcium bioavailability through *in vivo* studies to optimize functional ragi food products.

COMBINED EFFECT OF GERMINATION AND FERMENTATION

Sequential processing, starting with germination followed by fermentation, has been reported to maximize calcium bioavailability. Abdelgadir et al. (2018) demonstrated that ragi malt subjected to 48 hours of sprouting and 24 hours of lactic fermentation exhibited the highest soluble calcium content, along with enhanced protein digestibility. This synergistic effect is attributed to cumulative phytate degradation and improved enzymatic accessibility.

The combined application of germination and fermentation has been reported to maximize the nutritional potential of ragi (*Eleusine coracana*), particularly in enhancing calcium content and bioavailability. Germination activates endogenous enzymes such as phytases, which hydrolyze phytates and release minerals that are otherwise bound and unavailable for absorption (Oghbaei & Prakash, 2016). Fermentation, typically carried out using lactic acid bacteria or yeast, further reduces anti-nutritional factors like tannins and residual phytates, while lowering the pH, thereby improving mineral solubility (Chavan, Chavan, & Kadam, 2014).

Research has demonstrated that sequential processing, starting with germination followed by fermentation, produces ragi foods with significantly higher soluble calcium levels than either process alone. Abdelgadir, El Tinay, and Algasim (2018) reported that ragi malt subjected to 48 hours of germination followed by 24 hours of lactic acid fermentation exhibited a 40–50% increase in bioavailable calcium compared to raw grain. This synergistic enhancement is attributed

to cumulative phytate degradation and improved protein digestibility, which facilitates better mineral absorption (Shobana, Malleshi, & Reddy, 2017).

Furthermore, the combined process positively influences functional properties such as water absorption, viscosity, and texture, making the processed ragi suitable for diverse food applications including porridges, fermented beverages, and health bars (Manjunatha, Prakash, & Sreenivas, 2012). From a public health perspective, these enriched ragi products can serve as cost-effective, culturally acceptable solutions to combat calcium deficiency, particularly in children, adolescents, and elderly populations (Rani, Kaur, & Bhat, 2021).

The integration of germination and fermentation offers a promising approach to enhance the nutritional quality of ragi, especially calcium bioavailability, while also improving functional and sensory attributes. Optimizing process parameters such as sprouting duration, fermentation time, and microbial strains is critical to maximize these benefits and support the development of functional ragi-based foods.

COMPARATIVE STUDIES OF CALCIUM ENHANCEMENT IN RAGI FOODS

Study	Processing Technique	Conditions	Calcium Content (mg/100g)	Observations
Sangeetha et al., 2015	Germination	48 h, 30°C	350 → 440	Increased bioavailable calcium due to phytate degradation
Chavan et al., 2014	Fermentation	24 h, 28°C, lactic acid bacteria	350 → 480	Lower pH and microbial phytase activity enhanced calcium
Manjunatha et al., 2012	Fermentation	18 h, natural inoculum	360 → 470	Significant reduction in tannins and phytates
Abdelgadir et al., 2018	Germination + Fermentation	48 h sprouting + 24 h lactic fermentation	340 → 500	Synergistic enhancement in soluble calcium
Rani et al., 2021	Germination	72 h, 32°C	355 → 460	Optimal sprouting duration for mineral release

II. CONCLUSION

Germination and fermentation are effective traditional techniques for improving calcium content and bioavailability in ragi foods. While germination activates endogenous phytases to release bound minerals, fermentation leverages microbial activity to further reduce anti-nutritional factors. The combination of both processes provides a synergistic effect, yielding ragi-based foods with enhanced nutritional quality. These findings have significant implications for functional food development, especially in regions facing widespread calcium deficiency. Future research should focus on optimizing processing parameters and evaluating bioavailability in human clinical trials to establish evidence-based dietary recommendations.

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