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Nutritional composition, bioactive compounds, and health benefits of finger millet: A comprehensive review

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Abstract

Finger millet, also called ragi (*Eleusine coracana*), is a highly nutritious cereal grown widely across Africa and Asia. It is packed with essential nutrients, including calcium, dietary fiber, vitamins, minerals like iron, magnesium, zinc, and phosphorus, and important amino acids. Beyond its basic nutrition, ragi is rich in bioactive compounds such as polyphenols and flavonoids, which act as antioxidants and help protect the body from damage caused by free radicals. Eating finger millet has been linked to many health benefits, including better blood sugar control, stronger bones, heart protection, reduced inflammation, and lower risk of chronic diseases such as diabetes, cancer, and neurological disorders. Both traditional and modern processing methods like soaking, germination, malting, popping, and milling can improve its nutrient content, increase mineral absorption, and reduce anti-nutrients like phytic acid and tannins. This review summarizes the nutritional profile, bioactive compounds, processing methods, and health benefits of finger millet, emphasizing its potential as a functional food and a sustainable option for healthier diets.

Keywords: Finger millet, nutrition, polyphenols, flavonoids, antioxidants, functional food

Introduction

Millets are small-grained, warm-season annual cereals belonging to the grass family (*Poaceae*). Several millet species, including pearl millet, kodo millet, finger millet, foxtail millet, and other small millets, are known for their drought tolerance and adaptability to harsh environmental conditions. These grains are widely used for both food and non-food applications, such as the preparation of bread, cookies, muffins, chapati, energy bars, and biscuits (Hassan *et al.*, 2002) [5]. Millets play an important role in subtropical and tropical regions of the world due to their resistance to pests and diseases. Among them, finger millet (*Eleusine coracana*) is one of the most important and widely cultivated millets, particularly in India and Africa. In India, finger millet is commonly known as ragi or mandua and is grown across several regions of the country.

Finger millet is cultivated in more than 25 countries across Asia and Africa and accounts for approximately 12% of the total millet-cultivated area worldwide. In India, finger millet occupies about 1.19 million hectares, with an annual production of approximately 1.98 million tonnes and an average yield of around 1,661 kg/ha (Jagati *et al.*, 2021) [7]. It serves as a major source of calories and protein for large segments of the population, especially among low-income communities in developing countries. India is the world's leading producer of finger millet, contributing nearly 60% of the global production. Although South Karnataka alone contributes about 58% of India's finger millet output, awareness of its nutritional and health benefits remains limited among the population. Globally, finger millet ranks fourth among millets, with India holding the sixth position in overall cereal production.

Finger millet grains are small in size, measuring approximately 1.2-1.8 mm in diameter, and are generally spherical to round in shape. The grains possess a thin membranous pericarp and a seed coat that encloses the embryo and endosperm. It is available in a wide range of colours, including white, tan, red, yellow, violet, and brown. Among these, red

finger millet is the most widely cultivated and is commonly grown in countries such as Sri Lanka, Nepal, Madagascar, Uganda, Japan, and several regions of Africa and Asia. The grain is processed through methods such as milling, malting, fermentation, popping, and roasting, and is used in the preparation of various products including noodles, vermicelli, pasta, traditional Indian sweets (halwa), papads, soups, and bakery items. Finger millet comes under millets and used in the development of geriatric, neonatal, and health foods in both natural and modified forms (Ramashia *et al.*, 2019) [15]. Finger millet is nutritionally rich and contains significant amounts of carbohydrates, protein, dietary fibre, calcium, iron, and essential minerals such as magnesium, manganese, and phosphorus, which contribute to reduced risk of cardiovascular diseases. Phosphorus plays a key role in tissue development and energy metabolism. Finger millet is also a good source of phytochemicals such as phytic acid and phytates, which are reported to help lower cholesterol levels and reduce the risk of cancer, while also supporting weight management, diabetes control, and body temperature regulation. It contains beneficial bioactive compounds including ferulic acid, quercetin, and ferulic acid-rich arabinoxylans, which contribute to its antioxidant, anti-inflammatory, anti-atherosclerotic, and antimicrobial properties. An important advantage of finger millet is that it is naturally gluten-free, making it suitable for individuals with gluten intolerance or digestive disorders. Due to its high iron content, finger millet is effective in addressing iron deficiency, particularly among women and adolescent girls. Consequently, finger millet has gained recognition as a functional ingredient in the formulation of foods for children, pregnant women, patients, and the elderly. Additionally, its low glycaemic index makes it beneficial for controlling blood glucose levels.

2. Morphological Features of Finger Millet

Finger millet belongs to the family *Poaceae* and the genus *Eleusine* and is a predominantly self-pollinated grass crop cultivated in India, Africa, Nepal, and several Asian countries. It is rich in polyphenols, calcium, and iron and serves as a staple food in many regions of central and eastern Africa as well as parts of India and Nepal. The crop is well adapted to semi-arid and tropical regions due to its resistance to drought, pests, and pathogens, and it has a short growing season with the ability to produce under harsh environmental conditions. Finger millet is developing a pleasant aroma when cooked or roasted and are associated with several health-promoting properties. A major advantage of finger millet is its excellent storage stability, as the grains can be stored for long periods without significant insect damage, making it particularly valuable in food-insecure and drought-prone areas. In addition to providing nutritious grains for human consumption, the crop also produces straw that is widely used as animal feed, especially in rainfed regions. Nutritionally, finger millet is considered one of the most valuable cereals, providing good amounts of protein, essential minerals such as calcium and iron, and important amino acids, particularly methionine, which is often limited in diets based on staples like cassava, polished rice, and maize. Notably, finger millet contains approximately 8-10 times more calcium than wheat or rice and offers higher levels of protein and mineral nutrients compared to major cereals such as wheat, rice, and sorghum.

It is an annual herbaceous cereal crop, growing to a height of 30-150 cm and maturation starts in 75-160 days. Leaves are narrow, grass-like and produce many tillers and nodal branches. The panicle consists of a group of digitally arranged spikes referred to as a finger. The inflorescence is a panicle with 4-19 finger-like spikes that takes after a clenched hand when developed, consequently the name finger millet. The seed pericarp is autonomous from the part and can be handily expelled from the seed coat. Finger millet is a staple food in numerous African and South Asian nations. It is additionally viewed as a starvation crop as it is effectively put away for lean years. Finger millet is additionally used to make alcohol ("arake" or "areki" in Ethiopia) and brew, which yields results utilized for domesticated animals taking care of (FAO, 2012). The pericarp is thin and papery. Its outer layer comprises isodiametric cell with wavy walls. The inner layer is less robust with deep coloured. Aleuronic cells are small and single layer. Endosperm is generally friable. The tannins are present in testa. The grains are round and oval in shape and light brown to reddish brown or dark brown colour.

3. Nutritional Composition of Finger Millet

Compared to major cereals such as wheat and rice, finger millet is particularly rich in micronutrients, including vitamins and minerals. It contains high levels of calcium (220-450 mg/100 g), dietary fibre (19.1%), protein (7.3%), carbohydrates (72.6%), and total minerals (about 3%), along with bioactive components such as phytates (0.48%), tannins (0.61%), phenolic compounds (0.3-3%), and trypsin inhibitory factors, which contribute to its functional properties. Finger millet *also* has a well-balanced protein profile, providing higher amounts of essential amino acids such as lysine, threonine, and valine than many other types of millet. Important amino acids present include isoleucine (4.4 g), leucine (9.5 g), methionine (3.1 g), and phenylalanine (5.2 g), which are often deficient in other starchy staple foods.

Table 1: Nutritional Composition of Finger millet

S. No.	Particulars	Values
1	Carbohydrate %	66.82 - 72.6
2	Protein %	7.16 - 7.7
3	Fat %	1.3 - 1.92
4	Crude Fiber %	3.6 - 11.18
5	Ash %	2.1 - 2.7
6	Calcium (mg/100 g)	344 - 364
7	Phosphorus (mg/100 g)	210 - 250
8	Iron (mg/100 g)	3.9 - 6.3

Source: IFCT (2017), ICMR-National Institute of Nutrition (NIN), Hyderabad.

3.1 Carbohydrates

Carbohydrates in finger millet are mainly present as starch, contributing about 59.4-70.2% of the grain content. The starch granules are polygonal to rhombic in shape. Amylopectin constitutes nearly 80-85% of the starch fraction, while amylose accounts for about 15-20%. Finger millet *also* contains approximately 1.04% free sugars. Other carbohydrate components reported include starch (59.5-61.2%), pentosans (6.2-7.2%), cellulose (1.4-1.8%), and lignin (0.04-0.6%). The dietary fibre content of finger millet is considerably higher than that of brown rice, and its overall carbohydrate content is lower than polished rice, which may contribute to improved glycaemic response.

3.2 Protein

The protein content of finger millet generally ranges between 6% and 8%, although values as low as 5% and as high as 12% have been reported depending on the variety and environmental conditions. Prolamins and glutelins constitute the major protein fractions in finger millet. Compared to other millets, finger millet exhibits a more balanced nutritional profile, with essential amino acids accounting for about 44.75% of the total amino acid content, which is higher than the FAO reference protein value of 33.9%. Finger millet is particularly rich in valine, lysine, and threonine, and its sulfur-containing amino acid composition is comparable to that of milk. It contains essential amino acids such as tryptophan, valine, isoleucine, methionine, and threonine, which play crucial roles in metabolism, tissue repair, muscle regeneration, and maintenance of nitrogen balance. Isoleucine supports muscle repair and blood formation, while methionine acts as a sulfur donor necessary for the synthesis of natural antioxidants such as glutathione. Methionine also aids in fat metabolism and detoxification processes in the body.

3.3 Lipids

Finger millet contains a low lipid content of approximately 1.5%, with triglycerides being the major lipid components. These lipids are reported to reduce the risk of duodenal ulcers. The predominant fatty acids present in finger millet include oleic acid (49%), linoleic acid (25%), and palmitic acid (25%). Neutral lipids make up nearly 72% of the total lipid fraction, while glycolipids and phospholipids contribute approximately 13% and 6%, respectively.

3.4 Vitamins and Minerals

Finger millet contains both water-soluble and lipid-soluble vitamins. The water-soluble B-complex vitamins, along with lipid-soluble vitamins present in the germ, are mainly concentrated in the aleurone layer of the grain. Compared to other cereals, finger millet has higher ash content, indicating its rich mineral composition. It is particularly rich in calcium and iron, which are essential for bone development and prevention of anemia, respectively (Shobana *et al.*, 2013) ^[19]. The ash content of finger millet typically ranges from 2.1% to 2.7%, and minerals are mainly located in the germ, aleurone layer, and pericarp. However, the bioavailability of divalent metal ions may be limited by the presence of antinutritional factors such as phytic acid, oxalic acid, and tannins.

4. Processing of Finger Millet

To make finger millet grains suitable for consumption, both traditional and modern processing methods are used. Over time, these methods have been developed to improve the flavor, texture, appearance, and overall quality of the final products. The most common ways to process finger millet include soaking, germination, malting, popping, and milling. Soaking involves placing the grains in distilled water for several hours, usually overnight or for 8-12 hours at temperatures between 30 and 60 °C. When finger millet is soaked in water or NaOH solution for 8 hours, tannin content is reduced and phytic acid can decrease by 24-39%. Soaking for 1-2 days at room temperature has also been reported to reduce anti-nutritional factors and improve mineral bioavailability (Hotz and Gibson, 2007) ^[6]. Additionally, phytate and trypsin inhibitor activity decrease by around 13%

after soaking, and 48-hour soaking reduces phytic acid by 15-18% (Shigihalli *et al.*, 2018) ^[18].

4.1 Germination

Germination is a traditional method in which grains are first soaked in water, then spread on a moist cloth or kept at about 30 °C, and allowed to sprout for one to two days. It needs water, air, and the right warmth to make the grains healthier and more useful. While they sprout, the grains gain more protein, fiber, and minerals, and at the same time, the things that block nutrient absorption, like phytic acid, tannins, and polyphenols, get reduced. Germination also softens the grains and improves their overall nutrition.

4.2 Malting

Malting is a process that combines soaking, germination, and drying. It is very common in Africa, where malted finger millet is considered better than malted sorghum or maize (Sarkar *et al.*, 2015) ^[17]. During malting, the grain becomes richer in fat, fiber, vitamins B and C, and minerals like calcium, phosphorus, sodium, and magnesium (Sakamma *et al.*, 2017) ^[16]. The process also activates enzymes, causes chemical changes, and softens the grain, making it easier to dissolve in water and less thick (Jagati *et al.*, 2021) ^[7]. At the same time, substances that reduce nutrition, such as phytate, phosphorus, and tannins, decrease, and the total phenol content can drop by about 25%, which is linked to antioxidant activity.

4.3 Popping

Popping, also called puffing, is a traditional way to make ready-to-eat millet products that last longer. In this method, the grains are first mixed with a little water, about 3-5%, for a few hours to increase moisture. Then they are exposed to high heat for a short time, which makes the starch inside swell and gelatinize (Premavalli *et al.*, 2003) ^[23]. During popping, a reaction happens between sugars and amino acids in the grain, giving it a nice aroma. The process also dries the grains down to about 3-5% moisture, which helps them stay fresh longer. Popped finger millet can be ground and mixed with protein-rich ingredients to make healthy foods. Modern air-puffing machines now allow mass production, improving the color, taste, and texture of the grains.

4.4 Milling

Milling is the most common way to turn finger millet into flour. First, the grains are cleaned to remove stones, stalks, and other debris. Then they are dehulled and ground using different types of mills like stone, hammer, or ball mills. Milling removes the tough husk and bran, which improves iron absorption, while the flour still retains fiber and other nutrients. About 10% water is sometimes added to make it easier to remove the husk. The flour is then used to make traditional foods like roti, thin porridge (ambali), and dumplings (mudde).

5. Bioactive Compound of Finger Millet: Finger millet contains several bioactive compounds that are nutritionally important, as shown by many research studies. These compounds, which include dietary fiber and polyphenols, demonstrate potential nutraceutical properties by participating in various biological processes. Another study indicated that phenolic compounds are found in all types of millets and are often linked to different components of the

cell wall, such as arabinoxylans and proteins, through glycosidic bonds. However, in finger millet, these bioactive phenolics are mostly absent in the seed coat wall-bound form.

5.1 Polyphenols

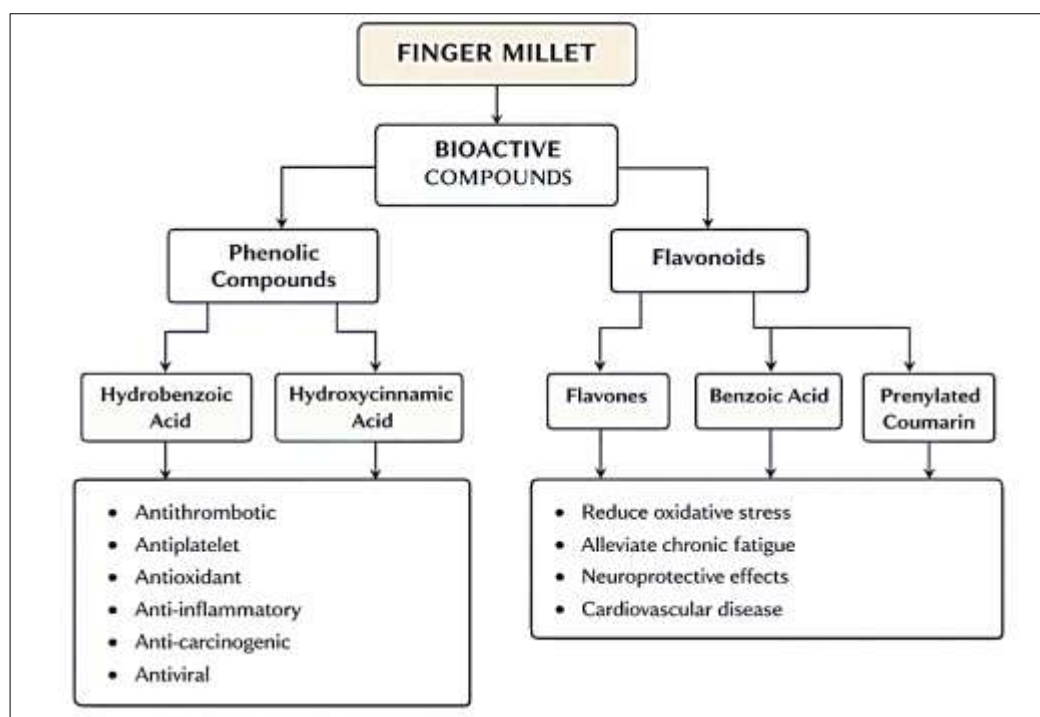


Diagram 1: Bioactive components of finger millet

Studies have shown that natural compounds called bioactive phytochemicals provide many health benefits. Polyphenols, which are found in plants, act as antioxidants that protect the body from harmful molecules and reduce the risk of diseases like heart problems, chronic fatigue, and sickle cell anemia. They also support brain and nerve health and help prevent illnesses. Including finger millet in the diet can further boost health by lowering the risk of cancer, diabetes, high blood pressure, high cholesterol, inflammation, metabolic disorders, and Parkinson's disease. Finger millet *also* has antibacterial properties, aids in wound healing, protects DNA, and supports digestive health.

5.2 Flavonoids

Flavonoid compounds are abundant in finger millet. When compared to other millets, finger millet flavonoids are mostly found in soluble form and in higher concentrations (2100 g/g). Millet flavonoids include quercetin, catechin, gallicocatechin, epicatechin, and epigallocatechin.

6. Value Added Products Using Finger Millet

6.1 Weaning food

Finger millet is a versatile grain and can be used as a substitute for rice and other starchy cereals. It is widely used in the preparation of value-added foods, which helps increase the consumption of this millet. Since ancient times, finger millet malt has been commonly used as a weaning food for infants. It is also used to prepare malt drinks by mixing it with lukewarm water or milk. Finger millet is a rich source of calcium and sulfur-containing amino acids, which are important for infant growth. Composite malt flour made from finger millet *along* with Bengal gram and green gram is often

used to prepare weaning foods, as this combination provides high amounts of protein and calcium. (Gopaldas *et al.*, 1982) ^[26].

To prepare weaning food, the composite grains are first soaked in water at room temperature (about 25 °C) for 48 hours, while in summer soaking for around 38 hours is sufficient. After soaking, the grains are dried either under sunlight or in a dryer to stop further germination, making sure the temperature remains low, as high temperature can reduce malt quality by hardening or partially cooking the grains. Once dried, the malted grains are evenly roasted at 70-80 °C using a pan or gentle heating, which helps develop a pleasant aroma and improves product quality. The roasted malt is then ground into a fine powder using suitable grinding equipment. The ground malt is sieved to separate the fine flour from the husk. The final malt flour can be used directly or mixed with sugar, sweeteners, and whole or skim milk powder to prepare milk-based weaning beverages.

6.2 Fermented foods

Finger Millet is widely used as a main ingredient in many fermented food products because it improves taste and increases the nutritional value of foods. Fermentation of finger millet helps increase fiber, calcium, and protein content by reducing antinutritional factors. Fermented foods can be prepared using malted or sprouted finger millet grains, depending on consumer preference and desired flavor. Study (Mugocha *et al.*, 2000) ^[30] developed a fermented powder gruel using skim milk and finger millet by adding different proportions of finger millet ranging from 0% to 100% and incubating the mixture at temperatures between 30 °C and 45 °C. The results showed that a thick, yoghurt-like product was obtained at an incubation temperature of 45 °C and storage

temperature of 7 °C, even when finger millet gruel was used up to 50%. Another study (Mythrayee & Pavithra, 2017) ^[27] reported that products containing finger millet flour had a longer shelf life, which was attributed to reduced gluten and moisture content due to the addition of finger millet.

6.3 Bakery products

Finger millet is commonly used as a major ingredient in bakery products such as bread, nankhatai, biscuits, and muffins to standardize formulations and maintain product quality. The seed coat of finger millet, which is obtained as a by-product during decortication, milling, and malting, is rich in dietary fiber, phytochemicals, and minerals. Study (Gopaldas *et al.*, 1982) ^[26] reported that cakes prepared using malted finger millet showed improved nutritional quality, particularly higher mineral and fiber content. In addition, composite flours made by blending finger millet with other cereals such as wheat, proso millet, and barnyard millet are widely used in bread making to enhance both nutritional value and product acceptability (Sudha *et al.*, 1998) ^[29].

6.4 Extruded products

Extrusion technology is a frequently employed innovative method for converting components into high-value products. The principle of extrusion cooking involves applying high pressure, temperature, and shear force simultaneously to alter the characteristics of starch. Finger millet flour exhibits favorable properties for extrusion. Because of its porous, crunchy, and smooth surface texture, finger millet flour with 16-18% M.C. may extrude well in a barrel at temperatures between 100 and 120 °C and have an outstanding expansion index. It is acknowledged that pasta and noodles are convenience foods made with cold extrusion technology. A number of studies on the use of finger millet in pasta and noodle recipes have already been completed. (Gopaldas *et al.*, 1982) ^[26] has reported using various combinations of prepared noodles, such as finger millet flour combined with soy and wheat flour in a ratio of 1:4:5, or finger millet flour combined with wheat flour in a ratio of 1:1. In order to prepare noodles while keeping the nutritional worth of the components and customer accessibility in mind, a variety of other mix combinations might be investigated. Because finger millets have a lower glycaemic reaction than controls, it has been claimed that adding 30-50% wheat flour to them before making noodles can help diabetes patients. Pasta cooked with 20% finger millet added was found to have a better dietary fiber, mineral, and antioxidant profile.

7. Health Benefits of Finger

7.1 Glycaemic Regulation and Anti-Diabetic Potential

Finger millet is highly regarded for its low Glycemic Index (GI), making it a critical dietary intervention for Type-2 Diabetes Mellitus. The primary mechanism involves the high concentration of polyphenols and dietary fiber (specifically non-starchy polysaccharides). These compounds act as competitive inhibitors of alpha-amylase and alpha-glucosidase, the two primary enzymes responsible for carbohydrate breakdown. By slowing the rate of glucose release into the bloodstream, finger millet prevents postprandial hyperglycemia. Furthermore, the magnesium content in the grain enhances insulin sensitivity, further stabilizing metabolic health (Kaur *et al.*, 2024) ^[9].

7.2 Bone Mineralization and Osteoporosis Prevention

Among all cereal crops, finger millet possesses the highest concentration of calcium, ranging between 344 and 364

mg/100 g. This exceeds the calcium content of milk and other major staples like rice or wheat by several folds. The bioactive profile includes phytases which, when activated through processing techniques like germination, degrade phytic acid an antinutrient that typically inhibits mineral absorption. Consequently, the bioavailable calcium contributes significantly to bone accretion in adolescent populations and serves as a preventative measure against osteoporosis in geriatric and postmenopausal demographics (Malleshi *et al.*, 2025) ^[10].

7.3 Cardio protective and Anti-Hyperlipidaemia Effects

The heart-healthy profile of finger millet is attributed to its rich supply of essential amino acids, particularly Lecithin and Methionine. These amino acids facilitate the removal of excess fat from the liver and reduce total serum cholesterol levels. Additionally, the presence of soluble and insoluble fibers aids in the excretion of bile acids, which directly correlates with a reduction in Low-Density Lipoprotein (LDL) cholesterol. Recent studies also highlight the role of magnesium in finger millet as a vasodilator, helping to manage hypertension and reduce the risk of myocardial infarction (Singh *et al.*, 2024) ^[21].

7.4 Management of Iron Deficiency Anemia

Finger millet is an essential "nutri-cereal" for combating micronutrient deficiencies, particularly iron deficiency anemia. It contains approximately 3.9 to 4.6 mg/100 g of iron. When consumed in fermented or sprouted forms, the bioavailability of this iron increases significantly. Research indicates that the high levels of sulfur-containing amino acids (cysteine and methionine) further assist in the absorption and utilization of iron within the body, making it a sustainable dietary solution for maternal and child health in developing regions (Tripathi *et al.*, 2024) ^[24].

7.5 Neuroprotection and Psychological Well-being

Emerging research has identified a link between finger millet consumption and mental health. The grain is a rare cereal source of Tryptophan, an essential amino acid that serves as the biochemical precursor to Serotonin (the "feel-good" neurotransmitter). By regulating serotonin levels, finger millet bioactive may assist in managing conditions such as clinical anxiety, depression, and insomnia. Moreover, the antioxidants found in the seed coat provide neuroprotective effects by reducing oxidative stress in brain tissues, potentially delaying the onset of neurodegenerative diseases like Parkinson's (Nayak *et al.*, 2024) ^[12].

Conclusion

Finger millet is a highly nutritious, versatile, and gluten-free cereal rich in calcium, fiber, essential amino acids, vitamins, and minerals like iron, magnesium, and zinc. It contains bioactive compounds such as polyphenols and antioxidants, which help protect against chronic diseases like diabetes, cardiovascular disorders, and cancer. Regular consumption supports bone health, immunity, digestion, blood sugar control, and overall metabolic well-being. Processing methods like soaking, germination, malting, and milling improve nutrient availability and digestibility. Its adaptability for traditional and modern foods makes finger millet a valuable, sustainable ingredient with both nutritional and therapeutic benefits for diverse populations.

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