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(Review Article)

Nutritional value and health benefits of millets

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Abstract

Millets are nutritionally advantageous, consisting of carbohydrates, antioxidants, and biologically active compounds such as flavonoids, carotenoids, phenolic acids, minerals, and vitamins. They are rich sources of essential macronutrients, micronutrients, dietary fibers, essential amino acids, minerals, antioxidants, trace elements, proteins, lipids, and carbohydrates. Incorporating millets into a balanced diet can help to control and prevent diseases such as cardiovascular disease, diabetes, inflammation, and malnutrition due to their enriched vital nutrients, low glycemic index, and gluten-free nature. Due to their climate resilient characteristics and superior nutrient profile, millets are aptly termed as "miracle grains. The low gluten content and favorable glycaemic index position make millet a healthy choice for combating lifestyle-related ailments such as diabetes and obesity. Rajasthan is the highest producer of millet grains in India, contributing roughly 27% to 30% of the total, and over 40% of the country's pearl millet (bajra) production. Karnataka state is a leading producer of millet grains in India, including finger millet (Ragi), sorghum (jowar), and pearl millet (Bajra). The main millets include, 1) Pearl millet (Bajra) (*Pennisetum glaucum* L.), 2) Foxtail millet (*Setaria italica* L. subsp. *italica*), 3) Finger millet (Ragi) (*Eleusine coracana* L.), 4) Barnyard millet (*Echinochloa esculenta* A.), 5) Proso millet (*Panicum miliaceum* L. subsp. *miliaceum*), 7) Kodo millet (*Paspalum scrobiculatum* L.), 8) Little millet (*Panicum sumatrense* Roth.), and 9) *Sorghum bicolar* which are cultivated widely throughout the world. However, despite being nutrient-rich and climate-resilient, these crops face declining acreage due to competition with cash crops and low market support, though they remain vital for nutritional security.

Keywords: Barnyard millet; Finger millet (Ragi); India; Little millet; Pearl Millet; Proso millet; *Sorghum bicolar*

1. Introduction

Millets are multipurpose crops that can grow in diverse climatic conditions and have high nutritional value [1-50]. Millets are grasses that have been cultivated since ancient times[1-46]. Millets come under the *Poaceae* family and are considered future food crops that can grow in various agro-climatic conditions[1-48]. Millets are a group of small, drought-resistant grains that have been grown for more than thousands of years[1-50]. They are highly nutritious, rich in essential vitamins, minerals, protein, fat, fiber, and have gained attention in recent years due to their potential to address global food security and environmental challenges [1-55-140]. They are rich sources of essential macronutrients, micronutrients, dietary fibers, essential amino acids, minerals, antioxidants, trace elements, proteins, lipids, and carbohydrates[1-53-140]. Due to their climate resilient characteristics and superior nutrient profile, millets are aptly termed as "miracle grains" [1-55-60-140-174]. The UN declared 2023 as "the International Year of Millets" due to their potential to solve concerns of nutrition, food security, and climate change in a sustainable manner [1-3,4-24].

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Millets are easily adaptable and can be intercropped with other cropping systems by considering the varieties of short crop durations[1-50-100]. The low gluten content and favorable glycaemic index position make millet a healthy choice for combating lifestyle-related ailments such as diabetes and obesity [1-59-140]. Even though millets have a greater nutritional potential and are more resilient to extreme climate events they are underutilized compared to rice, wheat, and maize [1-65-98-174]. These crops possess superior nutritional profiles compared to traditional staple cereals and demonstrate exceptional resilience to harsh environmental conditions. They can grow with minimal irrigation and thrive on poor-quality soils[1-65-141-174]. This makes millets ideal for sustainable agriculture in challenging environments[1-45-141-174]. Millets are **C4 plants** characterized by high levels of photosynthetic efficiency, a short lifespan, superior dry matter production, and exceptional heat and drought tolerance[1-65-140]. Consequently, they offer more consistent yields compared to other staple crops in low rainfall locations[1-75-110-174]. The main millets include sorghum, finger millet, pearl millet, foxtail millet, and proso millet, which have been cultivated for thousands of years in diverse regions of the world, especially in Asia and Africa[1-2-63-141-174]. Traditionally considered as "poor man's food," millets are now recognized as a vital source of nutrition, particularly in the context of food security and sustainable agriculture[1-3-70-140-174].

Most of the millets originated from Africa and later domesticated in other parts of the world [1-55-140-174]. Millets are thought to be among the ancient cultivated crops of the world and have been found to be staple food material in parts of Central and Eastern Asia, European countries, Russia, China, India, and parts of Africa. Karnataka state is a leading producer of millet grains in India, including finger millet (Ragi), sorghum (jowar), and pearl millet (Bajra) [1-65-140-174]. Karnataka millet grains (ragi, jowar, bajra, navane) are high-fiber, gluten-free, and nutrient-dense, offering significant health benefits like diabetes management, improved cardiovascular health, and weight loss[1-55-140]. Research indicates these millet grains have a low glycemic index, rich antioxidants (polyphenols), and essential minerals (calcium, iron) [1-59-141-174]. However, despite being nutrient-rich and climate-resilient, these crops face declining acreage due to competition with cash crops and low market support, though they remain vital for nutritional security[1-55-141-173]. Although the production of millet is showing increasing trends, and the nutritional value of millet is high, there is a challenge in cultivating millet as food security [1-45-141-174].

2. Millet Production in India

India is the largest producer of millets in the world according to APEDA [141-174]. India contributes close to 38.4 percent of global production[141-174]. India produces about 15.38 million tones of millets every year. Millets of India includes pearl millet, sorghum, finger millet, foxtail millet, barnyard millet, kodo millet and little millet. These grains have higher protein, fiber and minerals compared to rice and wheat. They grow in dry soils and tolerate heat better[141-174]. This strengthens India's food system. India has grown millets for many years. Demand for millet foods increased due to health awareness[141-174]. Government of India supported improved production of millets[141-173]. Many Indian states focused on improving yields, building processing units and creating export opportunities[141-174]. Millets producing states in India now include regions that earlier depended on rice and wheat[141-174]. This shift supports nutrition and climate resilience. **Rajasthan** is the highest producer of millet grains in India, contributing roughly 27% to 30% of the total, and over 40% of the country's pearl millet (bajra) production [141-174]. It leads in both total acreage and overall production, primarily growing bajra, followed by Maharashtra and Karnataka[141-174].

3. Millet Classification

There are 14 species of millets classified under 10 different genera, including 1) Pearl millet (*Pennisetum glaucum* L.), 2) Foxtail millet (*Setaria italica* L. subsp. italica), 3) Finger millet (*Eleusine coracana* L.), 4) Barnyard millet (*Echinochloa esculenta* A.), 5) Proso millet (*Panicum miliaceum* L. subsp. miliaceum), 7) Kodo millet (*Paspalum scrobiculatum* L.), 8) *Sorghum bicolar*, and 9) little millet (*Panicum sumatrense* Roth.) which are cultivated widely throughout the world[1-55-140]. Literature on millets, however, can be very difficult to study since the same species of millets has different common names and vernacular names[1-55-141-174].

4. Millets: Nutritional value

Mukherjee et al., (2025) [3] reviewed that millets are considered as primary food in many places, especially in India and Africa [3-43-140-174]. Millets, known for their drought resistance amidst environmental adversities, serve as a nutritional powerhouse, offering a rich array of both macro and micronutrients[1-3-60]. They are recognized for their nutraceutical benefits, including anti-diabetic and anti-hypertensive properties[1-3-54-140-174]. Typically, the composition of millet grains includes 65-75% carbohydrates, 6- 8% proteins, 1-1.7% fats, 18%-20% dietary fibers, and 2-2.5% minerals, enriched further with essential vitamins and bioactive compounds such as phytates, tannins, and polyphenols [1-30-140-174] This nutritional profile positions millets as nutritionally superior to major cereals like wheat, rice, and maize[1-65-140-174]. The endosperm of millet grains is notably concentrated in starch, proteins, fats, and a modest amount of fibers, underscoring their value in a balanced diet [1-39-70-140]. The germ consists of protein, fats and minerals while the peripheral layer comprises. dietary fibers, minerals and phenolic compounds[1-55-140]. **Kaur** et al., (2024) [1], Mohanan et al., (2025) [2] and Mukherjee et al., (2025) [3] are of the opinion that among micronutrients various trace elements, vitamins and carotenoids are the important constituents in millets[1-3-43]. Because of wide range of its nutritional composition, millets are termed as nutricereals[1-3-140]. Millets are rich in carbohydrates, primarily in the form of starch, which provides energy[1-55-140]. Carbohydrates in millets range from 64%-79% with sorghum having 72.6% carbohydrates. Major fractions of carbohydrates consist of amylopectin (72%-84%) and amylose (16%-28%) [1-55-65-140]. Among the free sugars i.e. glucose, fructose, raffinose, maltose and sucrose, sucrose is the major sugar present in millets, ranging from 0.3% to 1.2%, while the others range from 1% to 1.4%. An approximate of 1.4-2% total sugars is found in small millets[1-55-65-140]. Millets contain significant amounts of protein, which are of good quality with essential amino acids. Protein content in millets varies from 7.7% to 11.8%[1-55-75-140]. The three important fractions of protein present in millets are: i) globulin and albumin ii) prolamin like and true prolamin and iii) glutelin like and true glutelin of which glutelin comprises the highest fraction (45- 55%) of total protein followed by prolamin (15%-30%) and albumin and globulin (8.5%-16.26%)[1-55-140]. Millets are rich in sulphur containing amino acids like cysteine and methionine especially methionine which is generally deficient in cereals [1-55-140-174].

Like in most cereals, millets are poor in tryptophan and lysine contents[1-65]. Leucine (12-22.3%) and glutamic acid (16-23%) make up the prolamin fraction of protein in millets[1-45-140]. Millets generally have low-fat content, but the fats they contain are mostly unsaturated and considered healthy[1-55-140]. Pearl millet has globulins plus albumins of 18%-26%, prolamins of 33%-49.5% and glutelins of 30%-45%[1-45-140]. Millets are rich in dietary fiber, which aids in digestion and helps maintain gut health. Millets have higher content of dietary fibers as compared to other cereals [1-75-140]. Dietary fibers are of two types; insoluble dietary fibre (IDF) and soluble dietary fiber (SDF) [1-55-98]. Millets serve as abundant sources of micronutrients, typically ranging from 1.7 to 4.3 mg per 100 grams, significantly surpassing the levels found in wheat (1.5%) and rice (0.6%)[1-55-120]. Millets contain various vitamins, each contributing to their nutritional value. Millets are particularly rich in B vitamins such as niacin (B3), thiamine (B1), riboflavin (B2), and vitamin B6[1-55-140]. Millets also contain vitamin E, which acts as an antioxidant, protecting cells from damage caused by free radicals[1-55-61-140]. Niacin content is found to be highest in pearl millet among other cereals[1-55]. B complex vitamins are found in relatively higher amount in sorghum than other cereals[1-55-140]. Kodo millet is a good source of niacin, folic acid and B complex vitamins[1-55-64-140]. The average values of carotenoids in various millets range from 1.99 mg/kg to 3.66 mg/kg, showing variability across different types [1-55-140-174]. The predominant components of carotenoids present in millets are b-carotene, cryptoxanthin, zeaxanthin and trans- or cis-luteine[1-35-140]. In proso millet, lutein (5-15 mg/kg) and zeaxanthin (16-17 mg/kg) are major component of carotenoids whereas β-carotene is a minor component in foxtail, pearl and finger millet[1-65-140]. Millets are rich in phytochemicals[1-65-140]. These include compounds like phenolic acid, lignans, anthocyanins, b-glucans, phytosterols, tocopherols, flavonoids etc. which are quite abundant in millets[1-55-140]. Polyphenols are complex mixture of benzoic acid and cinnamic acid derivatives most of which are found in seed coat of millets, which are found to be reduced after milling[1-55-71-140]. Generally, catechin/ epicatechin, apigenin, glycoside, kaempferol, phloroglucinol, catechin gallates, trans-feruloyl-malic acid and daidzein are the polyphenolic compounds that are found to be present in the seed coat of millets[1-55-62-140-174]. Among the common flavonoids present in millets' leaves are orientin, isoorientin, violanthin, vitexin, isovitexin, violanthin, saponarin, tricin etc[1-55-140-174]. Millets exhibit higher antioxidant activities due to presence of flavonoids, condensed tannins, and polyphenols compared to cereals and fruits[1-55-60-140]. Millets contain various antioxidants such as phenolic compounds and flavonoids, which have potential health benefits [1-55-63-174]. Compounds like phytates, tannins, oxalates and phenols act as anti-nutrients due to their metal chelating and enzyme inhibitory nature[1-55-63-140]. These compounds generally form complexes with mineral ions of zinc, calcium, iron etc. rendering them unavailable biologically to human beings[1-55-135]. Some millet processing methods like soaking, decortication, fermentation, malting, cooking etc. reduce the concentrations of anti-nutrients, which make millets more digestible and the minerals more available to human beings[1-55-140-174].

Millets have some anti-nutrient factors or chemicals[1-55-140]. Anti-nutrients are phytochemical compounds that are being produced by plants for their defense, and millets have more concentration of tannins, phytates, oxalates, trypsin, and chymotrypsin inhibitors compared to wheat and rice[1-28-140]. These chemicals reduce nutrient bioavailability by inhibiting nutrient absorption[1-29-140]. If these are consumed uncooked, they result in nutritional deficiency, micronutrient malnutrition, and bloating[1-55-140]. For the elimination of anti-nutrients, their processing is needed[1-55-140].

Finger millet (Ragi) has the highest carbohydrate level, it is primarily of slowly digestible starch, dietary fiber, and resistant starch [1-24-120]. Around 7% protein is present in finger millet, which is less as compared to other millets[1-24-140]. It contains various micronutrients such as calcium, potassium, magnesium, iron, and zinc, as well as B vitamins, especially B6, niacin, and folic acid, which are abundantly present[1-24-140]. In little millet, there is availability of around 8.7% of protein and amino acids (cysteine and methionine)[1-25-140]. The little millet also contains various micronutrients. (iron, niacin, phosphorous, zinc) and also the proteins [1-8-140].

According to **Kaur** et al., (2024) [1], Proso millet contains a very high level of minerals and dietary fiber [1-8-140]. It is a rich source of various minerals and vitamins. It contains potassium, iron, phosphorus, calcium, magnesium, zinc, vitamin B-complex, niacin, and folic acid[1-8-140]. Pearl millet has less amount of carbohydrates as compared to other staple cereals, and it is mainly composed of starch and insoluble dietary fiber. It is gluten-free and high in omega-3 fatty acids; the amino acid score is also good [1-22,23-140]. Further it contains fatty acids (alpha-linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid), other micronutrients (iron, zinc, copper, potassium, magnesium, phosphorous, manganese), and B vitamins [1-22-124]. **Kaur** et al., (2024) [1] reported that Kodo millet provides gluten-free protein[1-22-124]. It contains B-complex vitamins such as B6, niacin, and folic acid and minerals including magnesium, iron, potassium, calcium, and zinc [1-22-124-174]. Moreover, it is highly digestible[1-22-124]. Foxtail millet contains vitamins, minerals, high dietary fiber content, resistant starch, and essential amino acids [1-22-124].

The cultivation and consumption of millets have socioeconomic implications, particularly in rural areas of developing countries[1-33-140]. Millet production can provide livelihood opportunities for smallholder farmers, empower women in agriculture, and improve food security at the local level[1-34-140]. Furthermore, the growing global demand for millets presents export opportunities and income generation potential for farmers in producing regions[1-2-140-174].

5. Health Benefits of Millets

According to **Kaur** et al., (2024) [1] millets have gained renewed interest in recent years due to their exceptional nutritional value, low resource requirements, and their potential to address food security challenges while mitigating the environmental impact of agriculture[1-140]. Most of the millets are grown in India, and it is the leading cultivator of millets [1-20]. Millets are helpful in reducing the incidence of malnutrition and well as metabolic disorders[1-140]. Furthermore, it helps to provide nutrition and improves food security and availability in the country. Millets are an excellent source of protein as well as some amino acids(i.e., methionine and cysteine) [1-5,6-140]. Millets contain a large amount of various vitamins like E and B and minerals, such as calcium, manganese, potassium, phosphorus, magnesium, and iron[1-5,6-140]. Jacob et al., (2024) [172] and Mohanan et al. (2025) [2] reviewed that millets have numerous health benefits, such as reducing the incidence of cancer, obesity and diabetes, cardiovascular diseases, gastrointestinal problems, migraine, and asthma, hyperglycemia [1-5,6-140-174]. Kaur et al., (2024) [1] reported that these wonder grains play a vital role in day-to-day diet as an essential nutrient, especially in underdeveloped and developing countries[1-16]. Some of the health benefits of millets are diabetes and glycemic Control [1-5,6-140-172]. Jacob et al., (2024) [172], Kaur et al., (2024) [1], Mohanan et al., (2025) [2] and Mukherjee et al., (2025) [3] reported that high dietary fibre and slow-release carbohydrates (lente carbohydrates) make millets ideal for reducing blood sugar levels, managing diabetes, and improving insulin sensitivity[1-5,6-140-172]. Jacob et al., (2024) [172] mentioned that millets also plays an important role in controlling Cardiovascular health and Obesity[1-5,6-140-172]. Regular consumption of millets helps to reduce BMI, lower cholesterol, and improve overall heart health due to high fiber and antioxidants that counteract oxidative stress[1-5,6-140-174]. Millets contains high nutritional content, of Calcium[1-5,6-140]. Ragi (Finger millet), heavily consumed in Karnataka, is an exceptional source of calcium, crucial for bone health [1-5,6-140]. Millets are also rich in iron and minerals which indicates that millets (specifically sorghum/jowar) provide significant iron, zinc, and magnesium[1-5,6-140]. Consumption of millets has showed and improved digestion gluten-Free[1-5,6-140]. Their high dietary fibre aids in digestion, prevents constipation, and supports a diverse gut microbiome [1-5,6-140]. They are a natural, safe alternative for celiac patients[1-5,6-140]. Jacob et al., (2024) [172] reviewed that millets also showed anti-inflammatory and anti-aging properties[1-5,6-140-172]. According to Jacob et al., (2024) [172], the phenolic compounds, flavonoids, and antioxidants in millet grains, exhibit strong anti-inflammatory properties, lowering the risk of degenerative[1-5,6-140-174].

According to Jacob et al., (2024) [172] and Kaur et al., (2024) [1] consuming millets has been associated with numerous health benefits[1-5,6-140-172]. Their high dietary fiber content aids in digestion, reduces the risk of colon cancer, and helps manage diabetes by regulating blood sugar levels [1-5,6-140-172]. Jacob et al., (2024) [172] also reported that the presence of antioxidants in millets combats oxidative stress and lowers the risk of chronic diseases[1-19-140-172]. In addition, millets contain phytochemicals that exhibit anti-inflammatory properties, contributing to overall well-being[1-18-172]. Including millets in the diet has been linked to weight management, cardiovascular health, and improved bone health due to its mineral content[1-20]. Millets are a rich source of nutrients and offer several health benefits[1-5,6-140]. They are free from gluten, hence suitable for persons suffering from celiac disease or gluten sensitivity[1-5,6-140]. Millets are rich in protein, dietary fiber, and essential minerals such as magnesium, iron, and phosphorus[1-3-98]. They also contain antioxidants, which may help protect against chronic diseases[1-20-135]. Furthermore, millets have a low glycemic index, making them an excellent choice for managing blood sugar levels[1-26-140]. Jacob et al., (2024) [172], and Kaur et al., (2024) [1] reviewed that the millets have antioxidant activity, anti-hyperglycemic effects, anti-cholesterol effects, anti-hypertensive effects, and anthropometric effects[1-20, 172-174].

Kaur et al., (2024) [1], Mohanan et al., (2025) [2] and Mukherjee et al., (2025) [3] reported that the nutritional index of millets is comparable to major cereals such as rice, wheat, and maize since they are an abundant source of carbohydrates, dietary fiber, protein, vitamins, micronutrients, and phytochemicals.[1-17-140] Millets are rich in essential nutrients, making them a valuable addition to diets. They are gluten-free and have a lower glycemic index compared to rice and wheat[1-18-130-173]. Millets are abundant in dietary fiber, vitamins(especially B-complex vitamins), minerals(iron, calcium, magnesium), and antioxidants.[1-19-136]. These grains also offer an excellent source of plant-based protein, with variations among different millet types.[1-20-140]. Millets' nutritional profile makes them particularly suitable for addressing malnutrition and lifestyle-related diseases[1, 2, 3].

Jacob et al., (2024) [172], Mohanan et al., (2025) [2] and Mukherjee et al., (2025) [3] reported that millets have the potential to combat malnutrition, especially in regions where staple grains lack essential nutrients [1-3, 172]. Their high protein, iron, and zinc content can help address nutrient deficiencies, particularly among vulnerable populations like children and pregnant women [1-33-140-174]. Integrating millets into government nutrition programs and school meal initiatives could contribute to improved public health[1-33-140-174].

6. Millets: Dry land Agriculture

Mohanan et al., (2025) [2] reviewed that millets exhibit remarkable resilience to harsh environmental conditions such as drought, with some wild varieties even thriving in flooded fields and marshy environments[1-22-124-140]. These contain gluten free protein, low glycemic index carbohydrates, and a wealth of minerals, vitamins, and antioxidants[1-140]. These exceptional qualities make them nutrient-dense and resistant to climate change crops[1-22-140]. Challenges such as the presence of anti-nutritional components and limited sensory acceptance of millet-based products must be addressed through scientific interventions [1-22-124]. Mohanan et al., (2025) [2] are of the opinion that integrating millets into processed and packaged foods can incentivize farmers to cultivate them and unlock new economic opportunities[1-22-124-140]. The current nutrient deficits of protein, calcium, and iron in poor nations can be addressed by the inclusion of millet-based foods in international, national, and state-level fee programmers[1-22-124]. Kaur et al., (2024) [1] reported that the inherent climate resilience and superior nutritional profile of small millets position them as crucial components of sustainable food systems, surpassing traditional staples like rice and wheat[1-22-124-140]. Therefore, crop diversity is crucial in the current environment to achieve food and nutritional security[1-22-124-140-174]. The agricultural community has intensified its focus on small millet improvement to attain food, nutrition, and economic security considering the current threatening climate conditions and rising hunger[1-22-124-140-174].

7. Conclusion

Millets are gaining global attention for their immense potential to address major challenges such as hunger and malnutrition, and the climatic risks on agricultural production. They belong to the *Poaceae* family and are known for their resilience to adverse environmental conditions, making them an essential crop in regions with limited water resources and variable climates. Millets represent a diverse and nutritionally rich group of crops and have superior nutritional profiles of protein, fat, fiber, and essential minerals. Therefore, incorporating millet-based foods can alleviate nutrient deficiencies in poor countries. Despite these benefits, millets remain marginalized in global agriculture, often labeled as "orphan cereal crops" due to the dominance of major cereals such as wheat, rice and maize. Karnataka state in India ranks highly in national millet production, but area and production have declined significantly, from 1.02 million hectares in 2001 to 0.64 million hectares in 2020, even as yield per hectare has shown slight growth. Major millets grown include jowar (sorghum) in North Karnataka and Ragi (finger millet) in South Karnataka, which are vital for food security in these regions. Studies in Karnataka confirmed that millets (specifically finger millet) are rich in calcium, iron, and fiber, with strong anti-diabetic and antioxidant properties. Research highlights that, despite the potential for high returns, farmers often shift away from millets due to low profitability and lack of modern technology adoption in the supply chain.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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