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Review Article

Millets: Nutritional, Functional, Health and Sustainability Perspectives—A Review

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Abstract
Millets are a diverse group of small-seeded cereal grains that have traditionally served as staple foods in many parts of Asia and Africa. In recent years, they have attracted renewed scientific and public interest because of their nutritional density, bioactive compounds, adaptability to harsh agroclimatic conditions, and potential contribution to sustainable food systems. Commonly consumed millets include pearl millet, finger millet, foxtail millet, little millet, kodo millet, barnyard millet and proso millet. They provide carbohydrates, protein, dietary fibre, unsaturated fatty acids, vitamins, minerals and numerous phytochemicals, including phenolic acids, flavonoids and tannins. Finger millet is particularly notable for its calcium content, whereas pearl millet provides appreciable amounts of iron, zinc, protein and lipid. The dietary fibre, slowly digestible starch, resistant starch and polyphenolic constituents of millets may contribute to favourable glycaemic and lipid responses. A systematic review and meta-analysis published in 2021 found that millet-based diets generally produced lower glycaemic responses than commonly consumed refined cereal staples and were associated with improvements in several measures of glycaemic control. Another meta-analysis reported reductions in total cholesterol, triacylglycerol, LDL cholesterol and VLDL cholesterol following millet consumption. Processing methods such as dehulling, soaking, germination, fermentation, milling and cooking substantially influence nutrient availability, digestibility and antinutritional factors. Beyond nutrition, millets are drought tolerant and can perform under relatively low-water and high-temperature conditions, making them valuable crops for climate-resilient agriculture and food security. Nevertheless, evidence for some proposed therapeutic effects remains limited, and human clinical trials are still needed. This review summarizes the nutritional composition, bioactive components, health effects, processing, food applications and sustainability relevance of millets and discusses their future potential as components of healthy and resilient food systems.
Keywords: Millets, Pearl Millet, Finger Millet, Nutrition, Dietary Fibre, Polyphenols, Diabetes, Cardiovascular Health, Food Security, Climate Resilience.

1. Introduction

Millets are ancient cereal crops belonging to the family Poaceae. They include several species that have been cultivated for thousands of years, particularly in regions characterized by low rainfall, high temperatures and marginal soils. Important food millets include pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), barnyard millet (*Echinochloa* spp.), proso millet (*Panicum miliaceum*) and other regionally important species [1, 2].

Although millets historically formed an important component of traditional diets, their consumption declined in many areas with the expansion of rice, wheat and highly processed foods. Renewed interest in millets has resulted from growing concerns regarding malnutrition, non-communicable diseases, biodiversity loss, water scarcity and climate change. Their ability to grow under relatively harsh environmental conditions makes them attractive from both nutritional and agricultural perspectives [2, 8]. Millets should not, however, be regarded as a single nutritionally uniform group. Their nutrient composition varies considerably according to species, genotype, cultivation conditions, grain structure and processing method. Therefore, the health and nutritional characteristics of a particular millet should be interpreted in relation to the specific grain and food preparation used [1, 3, 7].

2. Nutritional Composition of Millets

Millets are primarily carbohydrate-rich foods, but unlike highly refined cereal products, whole millet grains can provide substantial amounts of dietary fibre, protein, minerals, vitamins and phytochemicals [1–3]. The carbohydrate fraction consists predominantly of starch, with variable proportions of amylose, amylopectin, resistant starch and slowly digestible starch. These characteristics can influence starch digestion and postprandial glycaemic responses [3, 5].

Protein content generally ranges from approximately 7% to 13%, although substantial variation exists among species and varieties. Millet proteins also contain several essential amino acids, while finger millet is particularly recognized for its relatively favourable amino-acid composition among cereal grains [1,3]. Nevertheless, as with most cereals, the amino acid profile is not fully balanced for all essential amino acids, and dietary diversification remains important. Millets provide dietary fibre in both soluble and insoluble forms. Fibre contributes to satiety, intestinal function and modulation of carbohydrate and lipid metabolism. Finger millet is especially notable for its high fibre content and substantial concentration of polyphenolic compounds [9].

Mineral composition is another important characteristic. Finger millet is particularly rich in calcium, while pearl millet can provide useful quantities of iron, zinc, phosphorus and magnesium [1, 9]. These characteristics make millets potentially valuable in populations where micronutrient inadequacy is common. However, the absolute nutritional benefit depends on bioavailability, because minerals can be bound by antinutritional compounds such as phytic acid. Millets also contain B-group vitamins and varying quantities of lipids. Pearl millet generally contains more fat than several other millet species, with a considerable proportion of unsaturated fatty acids [2, 3]. Thus, replacing highly refined cereal products with minimally processed millet foods can increase dietary diversity and nutrient density.

MILLET CONSUMPTION

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Nutritional components

Carbohydrates • Protein • Dietary fibre • Minerals • Vitamins • Unsaturated fatty acids

↓

Bioactive components

Phenolic acids • Flavonoids • Tannins • Other phytochemicals

↓

Physiological effects

↓

Improved carbohydrate metabolism → Lower postprandial glycaemic response

↓

Improved lipid metabolism → Possible reductions in total and LDL cholesterol

↓

Improved satiety and gastrointestinal function → Potential support for weight management

↓

Micronutrient contribution → Calcium, iron, zinc and magnesium intake

↓

Overall potential health benefits

Glycaemic control • Cardiovascular health • Nutritional adequacy • Dietary diversity

↓

Agricultural and environmental benefits

Drought tolerance • Lower water requirement • Climate resilience • Crop diversification

↓

Millet-based healthier and more resilient food system

Figure 1. Schematic representation of the nutritional composition, bioactive constituents and potential health and sustainability benefits of millets. The magnitude of these effects varies according to millet species, variety, processing method and dietary context [1–8].

Table 1. Nutritional and functional characteristics of commonly consumed millets.

Millet	Important nutritional characteristics	Major bioactive/ functional components	Potential health relevance
Pearl millet (*Pennisetum glaucum*)	Relatively rich in protein, iron, zinc, magnesium and lipids	Phenolic compounds, flavonoids	May support micronutrient intake, glycaemic control and cardiovascular health [1–4]
Finger millet (*Eleusine coracana*)	Particularly rich in calcium and dietary fibre	Phenolic acids, flavonoids, tannins	May contribute to bone health, antioxidant activity and glycaemic control [3, 9, 10]
Foxtail millet (*Setaria italica*)	Provides carbohydrates, protein, dietary fibre and minerals	Polyphenols and flavonoids	May have favourable effects on glycaemic and lipid metabolism [2–5]
Little millet (*Panicum sumatrense*)	Provides dietary fibre, protein and minerals	Phenolic compounds	May contribute to dietary fibre intake and antioxidant activity [2, 4]
Kodo millet (*Paspalum scrobiculatum*)	Provides dietary fibre, protein and minerals	Polyphenols and other phytochemicals	May provide antioxidant and metabolic health benefits [2–4]
Barnyard millet (*Echinochloa* spp.)	Relatively rich in dietary fibre and minerals	Phenolic compounds	May be useful for glycaemic management and dietary diversification [2–5]
Proso millet (*Panicum miliaceum*)	Provides protein, carbohydrates, dietary fibre and minerals	Phenolic compounds	Provides a nutrient-dense cereal option and contributes to dietary diversity [2–4]
Note: Nutrient composition varies considerably with genotype, cultivation conditions, dehulling, milling and other processing methods. Potential health effects should not be interpreted as therapeutic claims [1–7].			

3. Bioactive Compounds and Antioxidant Potential

The nutritional importance of millets extends beyond their macronutrient and mineral composition. They contain phenolic acids, flavonoids, tannins and other phytochemicals with antioxidant activity [1, 3, 9]. Phenolic compounds are often concentrated in the outer layers of the grain; consequently, excessive polishing or dehulling may reduce certain bioactive components.

Finger millet has received particular attention because of its diverse phenolic profile. Compounds such as phenolic acids and flavonoids may contribute to antioxidant activity and have been investigated for possible antidiabetic, antimicrobial and cardioprotective effects [9]. These findings provide a biological rationale for the health-promoting potential of millet-based diets.

However, antioxidant activity demonstrated in chemical assays or experimental models should not automatically be interpreted as evidence of clinical disease prevention. Bioavailability, metabolism and physiological concentrations of individual phytochemicals differ substantially between laboratory and human conditions. Therefore, the strongest evidence currently supports millets as nutrient-rich whole-grain foods rather than as medicines.

4. Millets and Glycaemic Control

The effect of millets on glycaemic control has become one of the most extensively investigated areas of millet research. Their relatively high fibre content, resistant starch, slowly digestible starch and polyphenols may delay carbohydrate digestion and absorption [3, 5].

A systematic review and meta-analysis published in 2021 evaluated 65 studies and found that the mean glycaemic index of the millets examined was approximately 52.7, lower than the reported values for milled rice and refined wheat. Long-term millet consumption was also associated with reductions in fasting and postprandial blood glucose in people with diabetes and with improvements in HbA1c among prediabetic participants [5]. These findings suggest that replacing refined cereal staples with appropriately prepared millet foods may be useful as part of dietary management of glycaemic disorders.

Nevertheless, the glycaemic index of millet is not fixed. It can be affected by grain variety, milling, particle size, cooking, fermentation and other processing methods [5,7]. For example, a highly processed millet product may produce a considerably different glycaemic response from an intact or minimally processed grain. Therefore, the phrase "millets are low-GI foods" should be used cautiously.

5. Cardiovascular Health, Lipids and Obesity

Millets may also have favourable effects on cardiovascular risk factors. Their dietary fibre, unsaturated fatty acids, phytochemicals and slowly digestible carbohydrates may contribute to improved lipid metabolism and satiety [2, 3].

A 2021 systematic review and meta-analysis involving 19 studies reported that millet consumption was associated with reductions in total cholesterol, triacylglycerol, LDL cholesterol and VLDL cholesterol. The analysis also reported improvements in HDL cholesterol and reductions in blood pressure and body mass index in some studies [6]. These findings are promising because dyslipidaemia, hypertension and excess body weight are major modifiable cardiovascular risk factors.

The evidence should nevertheless be interpreted carefully. The included studies differed in millet type, dose, duration, food form and participant characteristics. Consequently, millets should be considered a component of an overall heart-healthy dietary pattern rather than a standalone treatment for hyperlipidaemia or obesity.

6. Micronutrient and Public Health Importance

Millets may have an important role in addressing micronutrient deficiencies. Finger millet is a particularly important dietary source of calcium, while pearl millet provides useful quantities of iron and zinc [1,9]. Their nutritional value can be especially relevant in populations dependent on cereal-based diets.

At the same time, the presence of minerals in a food does not necessarily mean that all of those minerals are readily absorbed. Phytate and other antinutritional factors can reduce mineral bioavailability. Traditional processing techniques, including soaking, germination and fermentation, can alter these compounds and improve nutrient accessibility [7].

The incorporation of millets into complementary foods, porridges, baked products and other culturally acceptable foods may therefore offer an opportunity to increase dietary diversity. However, successful nutrition interventions require attention to affordability, acceptability, preparation time, food safety and local dietary preferences.

7. Processing and Its Influence on Nutritional Quality

Processing is central to the utilization of millets because it affects digestibility, texture, flavour, shelf life and nutrient availability. Common processes include dehulling, decortication, milling, soaking, germination, malting, fermentation, roasting, popping and cooking [7].

Dehulling and polishing can improve palatability and reduce some antinutritional factors, but excessive removal of the outer grain layers may also decrease dietary fibre and phenolic compounds. Germination and fermentation can modify starch and protein digestibility and may improve the availability of some nutrients. Fermentation may additionally contribute desirable sensory characteristics and extend the range of millet-based foods [7].

Cooking is essential for many millet products, but thermal processing can alter starch structure and consequently influence glycaemic response. Therefore, processing should not simply be viewed as either beneficial or detrimental. The objective should be to develop processing methods that maximize nutrient bioavailability while retaining desirable fibre and bioactive components.

8. Food Applications and Functional Foods

Millets have considerable versatility in food production. Traditional preparations include porridges, flatbreads, steamed foods, fermented products and beverages. Modern food technology has expanded their use into breakfast cereals, biscuits, bakery products, pasta, noodles, extruded snacks and ready-to-eat foods [2, 7].

Finger millet has been incorporated into malted beverages, complementary foods and bakery products, while pearl millet is widely used as flour and in traditional flatbreads. Minor millets have potential for use in gluten-free products, although product formulation is technically challenging because millet lacks the gluten network responsible for the structure of conventional wheat bread [9].

The development of millet-based functional foods should emphasize whole-grain or minimally processed formulations rather than relying on highly refined products that may lose some of the nutritional advantages of the original grain. Product development should also consider taste, texture, affordability and consumer acceptance.

9. Millets, Gluten-Free Diets and Celiac Disease

Millets are naturally gluten-free and can therefore contribute to dietary variety for individuals who need to avoid gluten. However, gluten-free does not automatically mean nutritionally superior. Some commercial gluten-free foods are highly refined and may contain substantial quantities of sugar, fat or sodium.

For individuals with celiac disease, the use of millet requires attention to cross-contact with gluten-containing cereals during cultivation, processing, storage and preparation. Certified gluten-free products and appropriate food-handling practices are therefore important where strict gluten avoidance is medically required.

10. Antinutritional Factors and Potential Limitations

Despite their nutritional benefits, millets contain compounds that may reduce nutrient utilization. Phytic acid can bind minerals such as iron, zinc and calcium, while tannins and other phenolic compounds can interact with proteins and digestive enzymes [1, 7]. These compounds are not necessarily undesirable because many also possess antioxidant properties, but their concentration and bioavailability need to be considered.

Goitrogenic compounds have also been discussed particularly in relation to pearl millet, although the clinical importance depends on dietary pattern, iodine status, quantity consumed and processing. Thus, claims that millets universally improve or impair thyroid function are not justified by the available evidence.

Another limitation is the variability among millet species and products. Nutritional quality cannot be predicted solely from the word "millet" on a package. Whole grains, polished grains, flour-based products and highly processed snacks may have markedly different nutritional profiles.

11. Environmental Sustainability and Food Security

The renewed interest in millets is not based solely on nutrition. Millets are generally adapted to environments where water availability is limited and temperatures can be high. Their resilience makes them attractive crops for diversification of food systems in regions vulnerable to climate variability [8]. A greater role for millets could reduce excessive dependence on a small number of staple crops and contribute to agricultural biodiversity. Pearl millet, for example, is widely cultivated in arid and semi-arid regions of Asia and Africa and is considered a climate-resilient crop with potential to support food and nutritional security [8].

However, the sustainability of millets should be evaluated across the entire food system. Production practices, yields, transportation, processing, storage, consumer demand and market access all influence environmental and socioeconomic outcomes. Increased millet cultivation alone will not solve food insecurity, but diversification with resilient crops can form an important part of a broader strategy.

12. Evidence Gaps and Future Research

Although the scientific literature on millets has expanded substantially, several important gaps remain. Much of the evidence for antioxidant, anti-inflammatory, anticancer and other therapeutic effects originates from in vitro experiments or animal studies [3, 9]. More well-designed human trials are needed to determine whether these biological activities translate into clinically meaningful outcomes. Future studies should compare different millet species and processing methods using standardized nutritional and clinical endpoints. Long-term randomized controlled trials are particularly needed for diabetes, cardiovascular disease, obesity and micronutrient deficiency. Research should also investigate the effects of whole millet grains compared with refined millet flour and highly processed millet-based foods. Another priority is the development of standardized databases describing nutrient composition, glycaemic index, bioactive compounds and antinutritional factors across millet varieties. Such information would improve dietary guidance and facilitate evidence-based food product development.

13. Conclusion

Millets represent nutritionally valuable and agriculturally resilient cereal grains with considerable potential for improving dietary diversity and supporting sustainable food systems. They provide carbohydrates, protein, dietary fibre, minerals, vitamins, unsaturated fatty acids and bioactive compounds such as phenolic acids and flavonoids [1–4]. Evidence from systematic reviews indicates that appropriate millet consumption may improve glycaemic control and lipid profiles, although the magnitude of benefit depends on millet type, processing method, dietary context and individual characteristics [5, 6].

The greatest potential of millets lies not in portraying them as "superfoods" or medicines, but in their integration into balanced, diverse diets. Improved processing technologies, consumer education, product innovation, agricultural support and high-quality clinical research are needed to realize this potential. Given the combined nutritional, agricultural and environmental attributes of these grains, millets can make an important contribution to healthier and more resilient food systems.

Declarations

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