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Millets: A Scientific Perspective on Their Nutritional and Health Relevance

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This work was carried out in collaboration among all authors. Author RCA did the conceptualization, writing and editing. Authors LR, PY, DC and AS did the contributed on subtopics by collecting the review articles. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Millets are resilient crops with the ability to endure various climatic conditions, making them sustainable and drought-resistant. Over the past few decades, their production has increased to meet the nutritional needs of the growing global population. These grains are rich in essential nutrients, including proteins, carbohydrates, fats, minerals (iron, zinc, magnesium, calcium and phosphorus), vitamins (niacin, thiamine, riboflavin, folate and vitamin E) and bioactive compounds. Millets are recognized for their high-energy content, addressing malnutrition effectively. They serve as a valuable source of medicinal and nutraceutical properties, offering antioxidants that play a role in preventing health issues such as high blood pressure, heart disease, obesity, cancer, cardiovascular diseases, and diabetes. Additionally, millets contribute to a decrease in tumour cases. Due to their nutritional composition and bioactive components, millets are considered a long-

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term and sustainable solution for ensuring a stable supply of food and feed materials. This review aims to emphasize the scientific aspects of millets, focusing on their nutritional content, biologically active compounds, and pharmaceutical properties

Keywords: Diseases; health; millets; malnutrition; nutrients.

1. INTRODUCTION

Globally, there has been a noteworthy surge in cereal grain production, reaching unprecedented levels, and cereals are vital for human nutrition as a primary energy source. The total cereal production in 2023 reached a record of 2840 million tonnes [1]. However, contemporary challenges such as a growing population, climate fluctuations, high food costs, limited water resources, environmental pollution, and socio-economic impacts could hinder local agricultural progress, leading to a decline in cereal output. This, in turn, may result in elevated food prices and significant global food security concerns [2,3]. To address challenges in on-field production, collaboration between nutrition and technology experts is crucial. Identifying suitable cereal crops for use as a food source is essential [4,5,6]. Additionally, there is a need for sustainable crop alternatives to meet food requirements and improve the economic status of farmers [7]. In this context, millet emerges as a promising and nutritious alternative to meet the dietary needs of a growing population [8].

"Millets, encompassing both major and minor varieties, constitute a vital global food crop with substantial economic implications for developing nations. These small-seeded grasses, classified under the Poaceae family, exhibit resilience to drought and pests, making them particularly advantageous for cultivation in tropical and subtropical regions [9]. Predominantly found in India, China, Malaysia, Sri Lanka, and Australia, these grains contribute significantly to the economies of developing countries, with 97% of millet production occurring in these regions [10]. The Poaceae family, to which millets belong, holds considerable importance in both agricultural practices and environmental sustenance [11]. Millets are favoured for their ability to thrive in arid, high-temperature conditions with short growing seasons, making them efficient crop yielders. Their popularity is rooted in their historical role in human diets, particularly in Asia and Africa. Millets have been cultivated in East Asia for the past 10,000 years [10]. The major types of millets include Pearl millet (*Pennisetum glaucum*), Foxtail millet (*Setaria italica*), Proso millet or white millet (*Panicum miliaceum*), and Finger Millet (*Eleusine coracana*). Additionally, there are minor millets such as Barnyard millet (*Echinochloa* spp.), Kodo millet (*Paspalum scrobiculatum*) and Little millet (*Panicum sumatrense*) [7,12,13,14,15].

In recent years, there has been a growing public interest in the functional roles of food beyond mere nutritional content, particularly in its potential for disease prevention. Millet, a cereal rich in essential macro and micro nutrients, distinct mineral profiles, and essential amino acids, stands out in comparison to major cereals like wheat and rice [9,10,16,17]. Millet grains are gaining global attention, particularly in developing nations, for their use as a staple food, and in developed countries, for their promising applications in biofilm and bioethanol production [18]. Furthermore, millet grains exhibit nutraceutical properties, providing health benefits such as cancer prevention, reduced tumour incidence, and addressing various cardiovascular concerns including low blood pressure, cholesterol issues, and heart disease. Additionally, millets contribute to improved fat absorption rates, alleviate gastric problems, and offer gastrointestinal bulk supply [18,19,20]. This multifaceted nutritional profile underscores the potential of millet as a valuable component in promoting health and preventing a range of diseases.

At a fundamental level, current food systems fall short in delivering adequate and nutritious food to a significant portion of the global population. This deficiency has led to widespread issues of hunger and malnutrition. In 2022, approximately 735 million people experienced hunger, and more than 3.1 billion could not afford nutritionally rich diets [21]. Developing countries, in particular, grapple with insufficient food access, resulting in widespread illnesses and fatalities [22]. Millets emerge as a promising solution due to their status as high-energy, nutritious foods, capable of addressing malnutrition and hunger-related challenges. Recognized by various global health organizations, the promotion of plant-based foods, including millets, is advocated to enhance health and prevent chronic diseases [23]. Focusing on the nutritional quality and cultivation of millets could serve as a comprehensive solution to the prevailing issues of hunger and malnutrition. Embracing millet consumption aligns with the United Nations' goal to eradicate malnutrition by 2030 [24].

Millets play a crucial role in the agricultural and food security systems of impoverished farmers in Sub-Saharan Africa and Asia [25]. These versatile grains can be processed and consumed in various traditional forms, including balls, parboiled dishes, popping meals, porridges, chapati, dosa, pastas, bread, and biscuits [26,27,28,29]. In many African countries, millet-based foods and beverages constitute a significant portion of the daily diet [30]. To enhance the nutritional quality and edibility of millets, the Food and Agriculture Organization (FAO) recommends employing traditional food processing methods such as decortications, milling, germination, fermentation, malting, and roasting [26]. These methods serve to mitigate antinutritional properties and enhance the overall quality of millet-based products.

In light of the abundant availability of nutrients and energy sources in millets, there is a growing focus from scientists, agricultural industries, and food security policies on millet production and processing to address hidden hunger globally. Recent reviews in this field underscore the significance of millets and emphasize the need for their optimal utilization. This review aims to consolidate the latest scientific research, offering crucial updates, particularly on the comprehensive nutritional composition, functions, and their associated benefits for human health. The primary objective is to furnish a concise yet comprehensive overview, shedding light on millets and their potential maximization to enhance food and nutritional security.

2. ORIGIN AND DISTRIBUTION

Millets, comprising varieties such as Pearl millet, Finger millet, Foxtail millet, Kodo millet, Proso millet, Barnyard millet, and Little millet, have been cultivated globally for millennia as a vital food source [9,10]. These grains exhibit extensive diversity in colour, shape, size, and cultivation regions (Table 1), with historical roots in Asia, Africa, and parts of Europe, now thriving in tropical and subtropical areas worldwide [7]. As the earliest known cereal grain domesticated by humans, millets possess unique qualities, including adaptability to infertile soil, resistance to drought and pests, and a short growth cycle of 45–60 days [31]. Presently, millets serve as a staple food for millions in developing countries of Africa and Asia, owing to their resilience and nutritional value. India stands out as the leading global producer of millets, playing a significant role in both productivity and marketability [10]. For an extended period, millet crops have been esteemed for their nutritional and edible attributes [32]. The enduring popularity and cultivation of millets underscore their importance in addressing food security challenges, particularly in regions facing adverse agricultural conditions.

Pearl millet, commonly found in dry tropical regions like India, plays a crucial role as a staple food and feed crop, especially in arid and semi-arid environments [10,30]. Finger millet, also known as Small millet, is a salt-tolerant plant and a significant cereal, ranking after maize. It is a staple food in East and Central Africa, India, and Uganda. Finger millet grains are highly nutritious, easily digestible, and versatile, commonly used for rice-like dishes, porridge, flour, and cakes. Sprouted grains are recommended for infants and the elderly [10,33]. Foxtail millet is the world's second-largest millet crop, cultivated for centuries. It is known for its drought and high salt tolerance, mainly grown in China as a food and feed source for arid and semi-arid areas [9,34,35]. Proso millet has a history dating back to at least 2000 B.C., with cultivation in Central Europe. It is the primary millet crop in the Pacific Northwest USA, Northern China, Eastern Asia, Mongolia, Manchuria, Japan, India, Eastern and Central Russia. Drought resistance, high temperature tolerance, and disease resistance are notable characteristics of this crop [10,36]. Kodo millet is an indigenous cereal in India, known for its drought resistance and cultivation in poor soils. It is prevalent in arid and semi-arid regions [37]. Barnyard millet is a rapidly growing crop thriving in unfavourable conditions, commonly cultivated in Egypt. It serves as a multipurpose crop for both food and fodder [38]. Little millet is cultivated throughout India, featuring smaller seeds than common millet. It is well-suited for sandy loam, slightly acidic, and saline soils. Little millet is an early, resilient catch crop, displaying resistance to adverse agro-climatic conditions [39].

Table 1. Different characteristics of millet [10,40]

Millet	Scientific Name	Colour	Shape	Origin
Pearl millet	*Pennisetum glaucum*	White, grey, pale yellow, brown, or purple.	Ovoid	Tropical West Africa (Sahel)
Finger millet	*Eleusine coracana*	Light brown to dark brown.	Spherica	East Central Africa (Uganda)
Foxtail millet	*Setaria italica*	Pale yellow to orange	Ovoid	China
Little millet	*Panicum sumatrense*	Grey to straw white	Elliptical to oval	Southeast Asia
Kodo millet	*Paspalum scrobiculatum*	Blackish brown to dark brown	Elliptical to oval	Mainly in India also in west Africa
Barnyard millet	*Echinochloa crusgalli*	White	Tiny round	Mainly in Japan and India
Proso millet	*Panicum miliaceum*	White cream, yellow, orange	Spherical to oval	Central and eastern Asia

3. NUTRITIONAL IMPORTANCE

Nutrition plays a crucial role in human health, impacting physiological functions at the molecular level. Essential nutrients derived from food are vital for sustaining bodily processes, supporting immune function, and facilitating cellular repair. The quality of our diet is a fundamental aspect of maintaining overall physical well-being, as it serves as a sustainable force for health, development, and the optimization of human genetic potential.

Addressing the persistent issues of food insecurity and malnutrition requires careful consideration of dietary quality [41]. In addition to their agricultural advantages, millets offer high nutritive value comparable to major cereals like wheat and rice [7]. Millet crops have long been esteemed as part of a nourishing diet, recognized for their richness in phytoconstituents, vitamins, minerals, and non-starch polysaccharides essential for normal growth, diabetes control, and overall nutritional well-being [42,43]. The consumption of millets is associated with various health benefits, primarily attributed to the presence of bioactive phytochemicals in these cereals, including lignans, flavonoids, phenolics, beta-glucan, sterols, inulin, pigments, dietary fiber, and phytate [44,45,46]. Table 2 provides the proximate composition of different millet varieties, highlighting their nutritional content in a clear and concise manner.

3.1 Carbohydrates in Millets

Millet carbs come in three main types: starch (60–75%), non-starchy polysaccharides (15–20%), and free sugars (2–3%) [47]. The carbohydrate levels in millets vary (50% to 88%) based on factors like type, species, climate, and farming methods. Millets also pack dietary fiber, including arabinoxylans, cellulose, hemicellulose, lignin, and b-glucan [48]. Notably, pearl millet, Kodo millet, and finger millet have more starch. Barnyard millet leads in fiber, with 6.1–10.5% insoluble and 3.5–4.6% soluble fibers [49]. Foxtail, proso, and kodo millets also boast high total dietary fiber. In millets, insoluble fiber, containing lignin and cellulose, dominates, while soluble fiber may include glucoarabinoxylans, b-glucan, and certain hemicellulose types. The main chunk of dietary fiber, the insoluble part, sparks antioxidant activity, guarding against issues like gastrointestinal disorders, cancers, and neurological concerns. A higher fiber intake reduces gut transit time, produces short-chain fatty acids through colonic fermentation, and slows down sugar release into the blood [50].

3.2 Protein in Millets

Millets, diverse in protein content across species, showcase a protein range of 10% to 15%, notably higher than many cereal grains. Proso and little millet stand out with their robust protein levels, making them comparable to other high-protein grains. This abundance positions millets as promising candidates for crafting nutritious food products aimed at addressing malnutrition. While protein quantity is vital, the amino acid composition plays a crucial role in determining the grains' potential. Unlike many cereals that lack in lysine, millets like finger millet and kodo millet boast 2.2–5.5 g lysine/100 g of proteins, and pearl millet can even reach 6.5 g/100 g protein. Studies confirm the high lysine content in pearl millet and finger millet, attributed to their albumin, glutelin, or globulin fractions rich in lysine [56]. Notably, foxtail and proso millet, with higher prolamin concentration, tend to have lower lysine content but compensate with elevated leucine levels. The albumin and globulin composition of millet proteins suggests superior amino acid profiles and protein quality compared to other cereals [57].

3.3 Lipid in Millets

Millets boast a low lipid content, a key factor enhancing their shelf life. This is because most of the fat is concentrated in the germ, which is removed during processing [58]. The lipid levels in millets typically range from 1% to 6%, although some types may have higher amounts, potentially impacting shelf stability. For instance, pearl millet contains 5.06% total lipids, with 77.22% being mono or polyunsaturated fat, notably rich in linoleic acid (47.5%) and lower in linolenic acid (2.15%) [59]. Similar concentrations of linoleic acid (41–71%) and linolenic acid (1.1–4.1%) are found in other millets, with palmitoleic acid content consistently below 1% [48]. An exception is finger millet, where oleic acid dominates, constituting 47.5% of total lipids, followed by palmitic and linoleic acid [60].

3.4 Mineral Profile of Millets

Mineral deficiency is a serious concern because it can greatly affect metabolic processes and tissue structure, leading to severe and chronic disorders [61]. The mineral content of crops, particularly millets, depends on factors like soil fertility, climate, farming practices, and geographical conditions. Among millets, potassium and phosphorus are consistently prominent, while major minerals include calcium, sodium, and magnesium [52]. Looking at Table 3, pearl millet stands out for being rich in potassium and phosphorus, with significant amounts of iron, zinc, and manganese. Kodo millet, on the other hand, is exceptionally loaded with trace minerals like iron, copper, zinc, and manganese. Calcium and sodium content are relatively consistent across all millets, ranging between 0.1 and 0.7 g/kg. Little millet takes the lead in zinc content, followed by proso, barnyard, finger, and foxtail millet. Polyphenols in cereals and legumes can bind to minerals like calcium, iron, and zinc, impacting their absorption [62]. The phosphorus in millets often exists as phytic acid, limiting its bioavailability [63]. While milling reduces mineral concentration, it also lowers antinutrient levels, making minerals more available [64]. Processing treatments like germination, fermentation, soaking, and enzymatic treatment (phytase) help reduce phytic acid content, releasing chelated minerals and improving absorption [65,66]. To address mineral deficiency, various nutritional interventions such as biofortification and enrichment have been employed. Millets emerge as promising candidates for delivering essential nutrients to combat malnutrition [67].

3.5 Vitamins Profile of Millets

Millets play a crucial role in our diet, providing a wealth of B vitamins, with the exception of B12, which is mainly found in yeast and animal products. The goodness of vitamins is concentrated in the bran, pericarp, and aleurone layers of millets [63]. When it comes to thiamine and riboflavin, millets boast content ranging from 0.25 to 0.57 and 0.05 to 0.23 mg/100 g, respectively. Tocopherols and tocotrienols in minor millet fractions [70]. The total tocopherol concentration in minor millets ranges from 1.2 to 4.1 mg/100 g, with finger millet leading the pack followed by proso millet (3.6 mg/100 g). Notably, pearl millet packs a punch with carotenes at a concentration of 5.4 mg/kg of flour [71].

4. PHYTOCHEMICALS IN MILLETS

The increasing public focus on nutrition and health research supports the idea that phytochemicals have promising health benefits [72]. Millets, a type of grain, also contain various active compounds like polyphenolic compounds, phenolic acids, tannins, and flavonoids, with flavonoids being a key player [73]. These compounds, known as aromatic plant metabolites, not only contribute to the colour (grey, yellow, green, and creamy white) and sensory qualities of millets but also offer nutritional benefits [9]. They act as antioxidants, supporting the immune system and helping prevent chronic and degenerative disorders [19,74,75,76]. Found mainly in the outer bran layers of millets, alongside minerals, vitamins, and fibers, these phytochemicals play a crucial role in promoting overall health [77].

Table 2. Compositional profile of whole grain millets [9,47,48,51,52,53,54,55].

Millets	Carbohydrate (%)	Protein (%)	Fat (%)	Ash (%)	Crude fibre (%)
Pearl millet	63.0–78.0	8.6–19.4	1.5–6.5	2.7–3.6	1.4–11.0
Finger millet	85.0–88.0	7.7–10.9	1.3–1.4	2.9–3.3	3.7–3.9
Foxtail millet	60.9–75.2	11.3–12.9	3.6–3.9	3.0–3.2	4.5–8.0
Little millet	69.7–78.5	10.2–13.4	3.7–4.1	3.0–3.4	4.0–8.0
Kodo millet	66.0–72.0	6.2–13.1	3.2–4.9	3.0–4.1	8.4–11.0
Barnyard millet	51.5–65.0	11.2–12.7	2.5–6.3	4.7–5.0	13.9–14.7
Proso millet	65.82–78.59	10.65–14.7	1.54-3.77	2.0–4.0	2.0–9.0

Table 3. Mineral composition of millets [47,48,52,55,68,69].

Millets	Major minerals (g/kg)					Trace minerals (mg/kg)			
	Ca	P	K	Na	Mg	Fe	Cu	Zn	Mn
Pearl millet	0.29–0.42	2.40–3.72	3.90–4.42	0.10–0.12	1.30–1.37	50–110	6–10.6	29–31	11.5–18
Finger millet	0.90–3.44	2.83–5.84	4.08–11.23	0.11–0.68	1.37–3.74	377–695	4.7–13	23–93	54.9–165
Foxtail millet	0.19–0.31	2.90–7.15	3.64–9.23	0.02–0.62	1.43–3.02	208–386	5.9–15	35–84	11.6–39
Little millet	0.17–0.24	2.20–6.98	1.26–5.04	0.07–0.72	2.33–3.44	457–515	9.0–12	37–161	26–33
Kodo millet	0.22–0.35	1.80–4.73	1.41–6.40	0.61–0.65	2.10–3.01	1082–1413	17–20	59–76	47–89
Barnyard millet	0.20–0.22	2.80–6.17	7.34–7.92	0.68–0.69	2.40–3.08	301–381	10–11	60–103	36–42
Proso millet	0.15–0.22	2.06–5.54	1.95–5.32	0.57–0.60	1.97–2.97	423–550	14–18	74–91	21–45

4.1 Phenolic Acids in Millets

Approximately 60% of phenolic acids in millets exist in conjugated forms, with the rest being either free or extractable [15,78]. The distribution of these compounds varies among millet types and within different parts of the seeds [79]. The total phenolic content in millets to range from 146 to 1157 µmol ferulic acid equivalents (FAE) per gram of phenolic extract, with kodo millet showing the highest content [80]. Pearl millet varieties also exhibited variations, with total phenols ranging from 72.08 to 136.25 mg gallic acid equivalents (GAE) per gram [81]. Phenolic concentrations in different millets, such as finger millet (107.8 mg FAE/100 g), barnyard millet (129.5 mg FAE/100 g), and finger millet (136.3 mg FAE/100 g) [82]. In foxtail millet, free and bound fractions of phenolic compounds at 161.86 and 224.47 mg FAE per kg [83]. Meanwhile, for finger millet, phenolic concentrations ranging from 148.55 to 589.12 mg FAE/100 g [84]. The phenolic composition of foxtail, proso, and finger millet, noting that bound phenolics in hulls and whole grains were higher than their soluble counterparts [85]. These millet polyphenols are known for various bioactivities, including free radical scavenging, anticancer, antimicrobial, and anti-osteogenic properties [79,86].

4.2 Flavonoids in Millets

Flavonoids, vibrant polyphenolic compounds, are the secret behind the beautiful hues of blue, red, and purple in various foods. Structurally, they boast aromatic rings linked through a unique three-carbon heterocyclic ring [73]. Abundant in many plants, flavonoids not only contribute to visual appeal but also offer health benefits, surpassing vitamins C and E in antioxidant power [87]. Millets stand out as rich sources of flavonoids, spanning anthocyanins, flavones, flavanols, flavonols, and proanthocyanidins. The total flavonoid content in millets varies, with kodo millet taking the lead, followed by finger millet and proso millet [80]. Foxtail and little millet, unveiling noteworthy flavonoid levels in both bound and soluble fractions [88]. Exploring finger millet varieties, uncovered a colourful spectrum-red boasting the highest flavonoid concentration, followed by brown, reddish, and the least in white seed coat finger millet [89]. The mix, reporting flavonoid content in barnyard and finger millet. Beyond their visual allure, millet flavonoids wield a therapeutic arsenal, showcasing anti-inflammatory, anti-hypertensive, diuretic, analgesic, anticancer, and hypolipidemic effects [82,90,91,92,93]. These tiny grains pack a powerful punch in promoting both visual delight and holistic health.

4.3 Dietary Fibre in Millets

Plant-based foods, like fruits and vegetables, contain essential components known as fibers, distinct from those found in meat. Fiber plays a crucial role in promoting gut health [94]. It is a non-absorbable complex carbohydrate originating from plant cell walls, with two types: soluble and insoluble fibers. While not chemically broken down by the body, fiber aids digestion, helps lower cholesterol, and constitutes low-calorie, animal fat-free food [95]. Research work underscores the connection between dietary fiber intake and conditions like constipation, obesity, cardiovascular diseases, colon cancer, and diabetes mellitus [96]. Fiber, possessing physicochemical properties such as water and oil-holding capacities, organic molecule absorption, bacterial degradation, cation-exchange capacity, and antioxidant activity, influences these physiological actions [97]. Millet seed coats, rich in pectin, cellulose, and hemicelluloses, resist digestive enzyme breakdown, making them a valuable source of dietary fiber [98]. This fiber-rich seed coat, known for its resilience to digestive processes, serves dual purposes. Not only does it contribute to nutritional well-being by acting as a source of dietary fiber, but it also generates significant by-products, particularly useful in creating composite flour for baking biscuits [99,100].

5. PHARMACOLOGIC ROLES OF MILLETS ON HUMAN HEALTH

Consuming plant-rich diets has been linked to protection against various degenerative diseases like cancer, cardiovascular issues, diabetes, metabolic syndrome, and Parkinson's disease, according to studies [101,102,103]. Whole-grain cereals have also shown protective effects against age-related ailments such as diabetes, cardiovascular diseases, and certain cancers [104]. While traditional belief attributed these health benefits to vitamins, minerals, essential fatty acids, and fiber in whole grains, recent research suggests that a combination of bioactive substances contributes to their positive effects. These include resistant starch, oligosaccharides, lipids, antioxidants, phenolic acids, flavonoids, lignans, phytosterols, phytic acid, and tannins [95,105]. Millets, too, are gaining recognition as functional foods and nutraceuticals due to their rich content of dietary fibers, proteins, energy, minerals, vitamins, and antioxidants essential for human health. Millets have been associated with various health benefits, including cancer prevention, cardiovascular disease reduction, decreased tumor incidence, lower blood pressure, decreased heart disease risk, cholesterol reduction, slowed fat absorption, delayed gastric emptying, and providing gastrointestinal bulk [19,106]. The diverse health advantages of different millet varieties are summarized in Table 4.

5.1 Diabetes Mellitus

Diabetes mellitus, a persistent metabolic condition marked by elevated blood sugar levels and disruptions in carbohydrate, protein, and lipid metabolism, stands as a prevalent endocrine disorder. It manifests through insufficient insulin production (type 1) or a combination of insulin resistance and impaired insulin secretion (type 2). Encouragingly, the consumption of whole grain foods, particularly millets, emerges as a beneficial approach for diabetes prevention and management. Epidemiological data highlights lower diabetes rates in populations that include millets in their diets [120,121,122]. For instance, diets based on finger millet lead to significantly lower blood glucose levels compared to rice and wheat, thanks to the higher fiber content in finger millet. The lower glycemic response of finger millet-based diets may also be attributed to antinutritional factors that hinder starch digestion and absorption [123]. Barnyard millet, with its low glycemic index, has shown benefits for type 2 diabetics [124]. Even foxtail millet flour incorporated noodles have proven to be nutritious with a hypoglycemic effect [125]. Phenolic compounds found in millet grains exhibit potential antidiabetic effects by inhibiting enzymes like α-glucosidase and pancreatic amylase [121]. However, foxtail millet and proso millet do not show inhibitory effects on these enzymes [122]. Additionally, millet consumption contributes to antioxidant levels, with diabetic animals experiencing significant reductions in enzymatic and nonenzymatic antioxidants restored to normal levels in millet-fed groups [126]. Finger millet, in particular, has demonstrated efficient control of blood glucose levels in diabetic patients [127]. This suggests that millet grains possess the potential to prevent and aid in the treatment of diabetes. Nevertheless, further research, involving both animal models and human subjects, is crucial to substantiate the antidiabetic properties of millet grains and their derivatives.

5.2 Cardiovascular Disease

Unhealthy lifestyle choices like obesity, smoking, poor diet, and lack of exercise significantly raise the risk of heart attacks and strokes. Unfortunately, many countries worldwide are grappling with high andincreasing rates of cardiovascular disease. Research

Table 4. Promising health benefits of different types of millets

Millet	Health benefits/bio-functional properties	References
Pearl millet	Antioxidant and anti-inflammatory properties, good heart health, slower glucose release, reduction in inflammation disorders	[9,10, 59]
Finger millet	Prevent cardiovascular diseases, inhibition of cataractogenesis, antioxidant potential and prevention of diabetes mellitus	[107,108,109]
Foxtail millet	Hypolipidemic and hypoglycaemic behaviour, healthy digestive system, cholesterol management	[78,110,111]
Little millet	Lowers blood glucose and cholesterol levels, prevention of diabetes mellitus, antioxidant potential	[9,112]
Kodo millet	Hypoglycaemic activity, higher radical quenching ability, cholesterol and lipid management	[113,114,115]
Barnyard millet	Lowers blood glucose level, triglycerides and serum cholesterol, reduced risk of cancer	[116,117]
Proso millet	Prevent cardiovascular diseases, reduction in blood glucose level, antiproliferative properties against cancer	[108,118,119]

has shown promising results regarding the impact of different millets on health. Rats fed a diet primarily consisting of barnyard millet starch, both in its natural form and after undergoing certain treatments, demonstrated notably lower levels of blood glucose, serum cholesterol, and triglycerides compared to those fed with rice and other minor millets [116]. Additionally, when mice with genetic obesity and type-2 diabetes were subjected to a high-fat diet, those given proso millet protein experienced positive effects. This included improved levels of adiponectin and high-density lipoprotein (HDL) cholesterol, both crucial for cardiovascular health [128]. Furthermore, kodo millet has been found to have antioxidant properties, inhibiting lipid peroxidation, which is a process linked to cardiovascular issues [80].These findings highlight the potential of incorporating specific millets into diets as a means of promoting heart health.

5.3 Cancer

Millets, packed with phenolic acids, tannins, and phytates, are often labelled as "antinutrients." Surprisingly, these compounds, while having that label, actually play a protective role against colon and breast cancer in animals. Studies indicate that millet phenolics exhibit potential in thwarting the initiation and progression of cancer in laboratory settings [80]. Intriguingly, populations that include millet in their diets show lower rates of oesophageal cancer compared to those relying on wheat or maize [129]. This implies that millets might be wielding some cancer-fighting magic, even though they're often associated with antinutrients.

5.4 Celiac Disease

Celiac disease, an immune-related condition triggered by gluten intake in genetically susceptible individuals, was once thought to be rare, mostly affecting European children. However, recent studies reveal it as one of the most common lifelong disorders worldwide [130]. Instead of wheat, barley, and rye, those on a gluten-free diet turn to grains like rice, corn, sorghum, millet, amaranth, buckwheat, quinoa, wild rice, and oats [131]. Millets, being gluten-free, show promise in creating foods and drinks suitable for those with celiac disease [80,132,133]. This makes millet grains and their parts potential contributors to cancer prevention and the production of celiac-friendly food products.

5.5 Anti-Ageing

The interaction between the sugars found in millet grains and proteins, known as nonenzymatic glycosylation, plays a significant role in diabetes-related complications and aging [93]. Millet grains are packed with antioxidants and phenolics, but it's important to note that compounds like phytates, phenols, and tannins in millets contribute to their beneficial antioxidant effects, which are crucial for health, aging, and metabolic syndrome [7]. Interestingly, studies reveal that methanolic extracts from finger millet and kodo millet can actually inhibit the glycation and cross-linking of collagen, suggesting that millets might have potential in protecting against aging [134].

5.6 Antioxidant Activity

Oxidative stress, identified as a primary driver of degenerative and chronic diseases, results from an imbalance between the increased production of free radicals and inadequate antioxidant defences [74]. Millet grains contain phenolics and flavonoids, acting as antioxidants by binding to metal ions, shielding cells from free radical damage, preventing radical formation, and enhancing the body's natural antioxidant system [105]. Various millet types, such as kodo, finger, little, foxtail, barnyard, and great millet, along with their white varieties, exhibit noteworthy antioxidant properties, measured through DPPH reduction and Ferric reducing antioxidant potential [72,135,136]. The antioxidant capabilities and phenolic content in millet grains may serve as an anti-aging solution and safeguard cells from metabolic syndrome [137].

5.7 Antimicrobial Activity

Scientists found that extracts from several types of millets have antimicrobial characteristics. *In vitro* tests were conducted to determine the potential of seed protein extracts from pearl millet, sorghum, Japanese barnyard millet, foxtail millet, and finger millet to suppress the development of *Rhizoctonia solani, Macrophomina phaseolina*, and *Fusarium oxysporum*. The antibacterial activity of finger millet seed coat extract was shown to be greater than that of whole wheat extract against

Bacillus cereus and *Aspergillus flavus*. This implies that it may be used as a natural antioxidant and food preservative [136]. These results demonstrate the potential of phenolic acids and other bioactive elements found in millet extracts as natural substitutes for food preservatives and possible medicinal uses. To completely investigate and establish their antimicrobial activities, more research is necessary [138].

6. CONCLUSION

Millets, traditional cereals, have been utilized since ancient times for their nutritional richness and unique bioactive compounds with various health benefits. This review focuses on the nutritional aspects and pharmaceutical potential of different millet varieties. Millets serve as a staple food, supplying essential nutrients such as proteins, carbohydrates, fats, vitamins, and minerals. In developing countries, malnutrition and health issues like obesity, diabetes, cardiovascular diseases, skin problems, cancer, and celiac disease prevail due to insufficient nutritional intake. This is often attributed to the underutilization of certain crops as food sources and lack of awareness. Millets are a rich source of major and minor nutrients, including carbohydrates, high-quality proteins, fats, dietary fiber, vitamins, minerals, antioxidants, and phytochemicals. Recognizing the nutritional needs of the global population, this study advocates for millets as a crucial food source. The aim is to promote millets as nutritious foods that can address malnutrition and health problems effectively. The study underscores the nutraceutical properties of millets and their application as alternative cereals in the development of therapeutic food products. These include protein and energy-rich diets, diabetes-friendly diets, gluten-free diets, and those beneficial for cardiovascular health. Ultimately, the study positions millets as a form of "food medicine," highlighting their potential in addressing nutritional deficiencies and promoting overall health.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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