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REVIEW

Millets: a nutritional powerhouse for ensuring food security

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Abstract

Main conclusion **Millets are important food source to ensure global food and nutritional security and are associated with health benefits.**

Abstract Millets have emerged as a nutritional powerhouse with the potential to address food security challenges worldwide. These ancient grains, which come in various forms, including finger millet, proso millet, and pearl millet, among others, are essential to a balanced diet, since they provide a wide range of nutritional advantages. Millets have a well-rounded nutritional profile with a high protein, dietary fiber, vitamin, and mineral content for optimal health and wellness. In addition to their nutritional advantages, millets exhibit remarkable adaptability and durability to various agroecological conditions, making them a valuable resource for smallholder farmers functioning in resource-poor regions. Promoting the growth and use of millet can lead to several benefits that researchers and development experts may discover, including improved nutrition, increased food security, and sustainable agricultural methods. Therefore, millets are food crops, that are climate smart, nutritional, and food secured to feed the increasing global population, and everyone could have a healthier, more resilient future.

Keywords Traditional crop · Macronutrient · Micronutrient · Nutritional quality · Grain crop · Sustainable crop

Introduction

The millet grain is an ancient one with a long history and unique qualities. These drought-tolerant, small-seeded grains are vital for areas experiencing environmental difficulties, since they can adapt to various climatic circumstances. Because millets are crucial in enhancing food security and nutritional quality, they are becoming increasingly popular as a new and emerging dietary trend worldwide. Cognisant of their complex significance as a whole food, this review considers millets' origins, history, exceptional nutritional value, global production statistics, remarkable resilience to abiotic stress, and many benefits they offer regarding food security. The evolution of human civilization is intimately linked to the history of millets. With a history spanning more than 10,000 years, millets have their roots in Africa and the Indian subcontinent (Korisettar 2020). Around 8000 BC, the first known evidence of millet consumption was found in the Chinese province of Shandong (Liu and Reid 2020), but millet farming extended over Asia, Europe, and Africa. Because millets can tolerate various environmental conditions, they were essential to early agricultural practices.

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Their capacity to flourish in harsh environments, such as drought-prone ones, made them an indispensable staple crop for communities with food scarcity and unpredictable weather. Climate change, water scarcity, population growth, rising food prices, and other socioeconomic effects are predicted to threaten agriculture and global food security in the twenty-first century, particularly for the world's poorest residents of arid and sub-arid countries. Millets come in a wide range of varieties, including pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), kodo millet (*Paspalum setaceum*), proso millet (*Panicum miliaceum*), foxtail millet (*Setaria italic*), little millet (*Panicum sumatrense*), browntop millet (*Brachiaria ramosa),* and barnyard millet (*Echinochloa utilis*). In addition to maize (*Zea mays*), sorghum (*Sorghum bicolor*), oats (*Avena sativa*), and barley (*Hordeum vulgare*), they are referred to as coarse cereals (Bouis 2000; Kaur et al. 2019). Developing nations account for around 97% of global millet production and consumption, while the remaining amount is contributed by the rest of the globe (Meena et al. 2021). The global millet output was expected to reach 28,273,641.59 t, 30,825,051.54 t, and 30,089,625 t in 2019, 2020, and 2021, respectively (Meena et al. 2021).

The remarkable nutritional quality of millet is one of the main characteristics that raise them to the level of being a complete food. Amadou et al. (2013) state that millets are high in nutrients and offer several essential elements. Depending on the variety, millets have a moderate-to-high protein content. Millets are a complete protein source among cereal grains, since they contain all the essential amino acids (Dayakar Rao et al. 2017). Additionally, because millets are high in dietary fiber, they prevent constipation, promote regular bowel movements, and reduce the incidence of gastrointestinal disorders (Nithiyanantham et al. 2019). All these benefits assist in maintaining healthy digestive systems.

Furthermore, according to Rybicka and Gliszczynska-Swiglo (2017), millets are an excellent source of several B vitamins, including riboflavin (vitamin B2), thiamine (vitamin B1), and niacin (vitamin B3). The metabolism of energy, neuron function, and overall health all depend on these vitamins. Millets contain significant amounts of magnesium, phosphorus, and manganese, among other minerals. These minerals are essential for bone health, muscle function, and the body's defense mechanisms against free radicals. Millets are high in antioxidants called carotenoids and phenolic compounds, which support the body's defenses against oxidative stress and damage from free radicals. By assisting in the neutralization of toxic molecules, these antioxidants lower the risk of chronic illnesses and promote general health (Shahidi and Chandrasekara 2013). Millets are also low in fat, with most of their fats being unsaturated, linked to heart health and a lower risk of cardiovascular illnesses (Dayakar Rao et al. 2017).

The innate resistance of millets to abiotic stress, especially drought and high temperatures, is one of their most impressive features. Millets are particularly advantageous because of their ability to withstand unfavorable growing circumstances in a world where climate change is posing an increasing threat to traditional agriculture (Saxena et al. 2018). Compared to many other cereal crops, these resilient grains are more drought-tolerant because of their deep root systems, which enable plants to obtain water and nutrients from deeper soil layers (Nematpour et al. 2019). Although millets have a long and nutritious history, there have been fluctuations in their production across the globe over time. India is the world's largest producer of millets in the twenty-first century, especially finger millet (ragi) and pearl millet (Paschapur et al. 2021). India's commitment to millet farming stems from its culinary and cultural importance. The production of millet is likewise a global endeavor, with Nigeria, Niger, and Sudan being significant contributors. However, translating to more resource-intensive crops like wheat and rice has made millet more challenging to produce. However, there is a growing recognition that to maximize millet's nutritional value and agricultural sustainability, there is a need to revive the crop in domestic and international markets (Rao et al. 2016).

To raise global awareness of the value of millet crops in addressing essential concerns, including food security, nutrition, and sustainability, the UN and FAO have declared 2023 the International Year of Millet (Sahoo and Mahapatra 2023). This global event aims to maximize the potential of millet for strengthening and resilience within the global food chain by promoting its production, consumption, and use. Many significant objectives are highlighted during the International Year of Millet. It aims to advance knowledge of millets' nutritional value, their ability to reduce malnutrition, and their ability to enhance a variety of meals (Srivastava et al. 2023). The initiative also emphasizes how vital millets are to maintaining food security in the face of climate change, improving sustainable agricultural practices, and protecting biodiversity. The UN hopes to inspire governments, organizations, and communities to invest in millet research, production, and consumption by bringing attention to millet through the International Year of Millet (Dwivedi et al. 2023). With coordinated efforts, the full potential of these hardy grains will be realized, ensuring a more nourishing, sustainable, and food-secure future for the world's growing population.

Origin and history of millet

Millets have an exciting story ingrained in agricultural history and human civilization (Kingsbury 2011). Millets have existed for centuries, shaping economies, diets, and

cultures worldwide. Various types of millet are cultivated in different parts of Africa and Asia, where millets originated (Scott 2015). Pearl millet (*Pennisetum glaucum*) is the oldest; it is thought to have been domesticated in West Africa circa 4000 BCE (Rangan et al. 2012). Because of its ability to adapt to arid and semi-arid climates, it was an essential food staple for communities in the Sahel region, where food production was severely hampered by water scarcity and erratic rainfall patterns (Cleasby et al. 2016). Cultivated as early as 7000–6000 BCE, foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) were two of the first millets to be grown in East Asia (Motuzaite-Matuzeviciute et al. 2008). China, Korea, and Japan were the locations where these millets were initially grown. Evidence from early Yangshao culture archaeological sites highlights the importance of foxtail millet, a major crop in Chinese agriculture (Barton et al. 2009). One more notable millet relative, proso millet (*Panicum miliaceum*), is said to have originated in North Africa and has been cultivated for at least 4000 years (Stevens et al. 2021). After that, it traveled to North America, where it was a significant food crop for native Americans, and Europe, where it became a mainstay of the diets of the ancient Romans (Stevens et al. 2021).

Another significant millet variation with African origin is sorghum (*Sorghum bicolor*), an important cereal crop in the continents agriculture, since it was domesticated in Northeastern Africa about 5000–7000 years ago (Taylor 2019). It is a vital food source in desert areas, since it is highly adaptable to different climatic conditions and drought-resistant. The historical significance of millets goes beyond their place of origin and includes their function in prehistoric societies. For instance, finger millet (*Eleusine coracana*), which has been farmed in India for more than 2000 years, is known to have existed throughout the Harappan era (Pokharia et al. 2014). Indian meals rely heavily on millet because of its high nutritional content and ability to withstand drought in areas where they are often found (Saxena et al. 2018). Finger millet, sometimes called "Ragi", has come to be appreciated for its remarkable nutritional value, especially its high iron and calcium content (Rashmi 2014). Foxtail millet was a staple crop in ancient China that was grown alongside other grains such as rice and wheat. It was used to manufacture various culinary items, such as fermented drinks, dumplings, and porridge (Bisht 2022). The importance of millets in Chinese agriculture is demonstrated by the abundance of foxtail millet grains found in the early Neolithic archaeological remains (Lu et al. 2009). Pearl millet was an essential crop in Africa that helped advance ancient civilizations like the Songhai and Mali empires (Champion and Fuller 2018). In addition to being a necessary food item, it represented wealth and authority, since it was frequently used as currency or tribute (Kim 2015). Millets did not grow only in Asia and Africa but were also welcomed by European cultures. The ancient Romans relied heavily on proso millet, which they used to make porridge and bread. It flourished in the harsh environment of the Roman Empire, providing food for the armed forces and the general populace (Kiple 2007). Millets were important even in Eastern Europe; broomcorn millet was a staple crop in places like Ukraine. Indigenous American communities integrated millets into their agricultural systems when they arrived (Das and Rakshit 2016). It is thought that proso millet and foxtail millet were brought to North America around 2000 years ago and that Native American cultures used them as staple foods (Austin 2006). Native American's use of millet in their diet demonstrates how adaptable and versatile they are in a variety of climates. As other staple crops like wheat, rice, and maize were prioritized in modern agriculture, millets saw a recent decrease in cultivation and consumption (Cheng 2018). However, due to worries about nutritional diversity, environmental sustainability, and food security, millets have gained popularity again in recent years.

Potential health benefits of millet crops

In a nutrient powerhouse with many potential health advantages, millets are frequently overlooked in favor of more well-known grains like rice, wheat, and maize (Ali and Bhattacharjee 2023). These small-seeded grains, cultivated for centuries in various regions of the world, include proso millet, foxtail millet, finger millet (Ragi), and pearl millet. We explore several reasons why millet crops, despite their ancient origins, should be given more credit and incorporated into contemporary diets as we investigate their unrealized potential. Above all, millet is highly valued for its extraordinary nutritional value. Vital nutrients, such as dietary fiber, protein, vitamins, and minerals, are abundant in these grains (Oso and Ashafa 2021). Millets have a notable high dietary fiber content, vital for gut health. According to Dayakar et al. (2017), the fiber in millet prevents constipation, lowers the risk of digestive issues, and promotes regular bowel movements. Moreover, it aids in blood sugar regulation, which makes it a dietary option that benefits people with diabetes or those trying to sustain consistent energy levels (Rawat et al. 2023). Furthermore, millet is a rich source of vital vitamins and minerals critical for general health. Millet contains high amounts of B vitamins, including riboflavin, thiamine, and niacin, which support energy metabolism, brain function, and healthy skin (Dayakar Rao et al. 2017). Additionally, essential minerals in millet include magnesium, phosphorus, and manganese, which support the body's defenses against free radicals and maintain the health of muscles and bones (Saleh et al. 2013). When people eat millet, these nutrients improve their health and energy levels (Saleh et al. 2013). Studies have shown that daily millet

eating may help reduce the chance of developing heart disease and diabetes (Saleh et al. 2013). Hassan et al. (2021) claim that millet is a valuable diet for blood sugar regulation because of its low-glycemic index.

For people with diabetes or at risk, including millet in their diet can be pretty advantageous. Additionally, the millet's high dietary fiber content lowers cholesterol, lowering the risk of heart disease (Jideani and Jideani 2011). The unique makeup of millet aids with weight control as well. Because of its high fiber content, it promotes satiety and fullness, which can help regulate appetite and cut back on caloric consumption (Dayakar Rao et al. 2017). Furthermore, millet is an excellent option for people trying to keep their weight in check because of its high nutrient profile and low-fat content (Rai et al. 2008). Millet's entire grains break down slowly, resulting in prolonged energy levels that lessen the chance of energy crashes and harmful snacking (Keys and Plan). As a prebiotic, the fiber in millet feeds the good bacteria in the stomach (Lamothe et al. 2021).

Numerous health benefits, such as better digestion, increased food absorption, and a more robust immune system, are linked to a healthy gut microbiota (Yao et al. 2020). Furthermore, because millet is gluten-free, it is a healthy substitute for wheat and other gluten-containing grains for people with celiac disease or gluten sensitivity (Pandey 2022). For those who want more antioxidants, millet is a great choice. Antioxidants are vital substances that shield the body from the damaging effects of free radicals and oxidative stress. Antioxidants included in millet, such as carotenoids and phenolic compounds, assist in counteracting damaging molecules within the body and lower the chance of developing chronic illnesses (Verma et al. 2023). According to studies, these antioxidants may help maintain skin health and postpone aging (Das et al. 2019). Millet grains, full of vital nutrients, have several benefits, from helping to control weight and lower the risk of chronic diseases to supporting healthy digestion and blood sugar regulation (Saleh et al. 2013). People can use millet's health benefits in various culinary preparations because of its adaptability in the kitchen. Additionally, millet planting can lessen the adverse environmental effects of agriculture and improve world food security. In a time when robust, sustainable, and healthful food supplies are essential, millet is a valuable ally in many ways (Patel et al. 2020).

Besides its remarkable nutritional characteristics, millet is an adaptable ingredient for various culinary applications. Millet's culinary adaptability allows it to be used in various delicious meal alternatives, such as porridges, stews, flatbreads, and salads (Porwal et al. 2023). Thanks to its versatility, people can employ millet's health benefits in ways that best suit their dietary needs and taste preferences. In addition to its health benefits, millet has the potential to enhance environmental sustainability and global food security. Due to their remarkable resilience to unfavorable growing conditions, such as dryness and poor soil quality, these hardy grains are an excellent choice for regions with harsh climates (Chadalavada et al. 2021) (Fig. 1).

Millets in the food industry

Considered the "forgotten grain", millet is slowly making a resurgence in the food sector because of its exceptional nutritional value, extraordinary adaptability, and ability to help solve urgent global concerns, especially those related to food security. As traditional agriculture faces increasing challenges from climate change, water scarcity, and an expanding global population, millets are emerging as a viable solution to these complicated issues (Saxena et al. 2018). Due to its adaptability in the food industry, millets are becoming increasingly popular. These grains can be used in various food products and recipes to satisfy changing

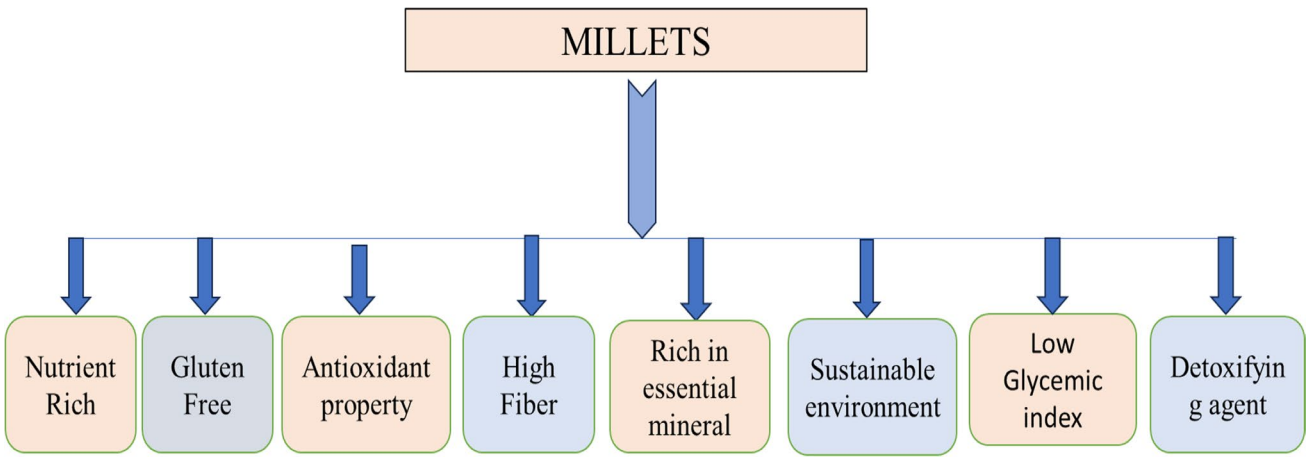

Fig. 1 Benefits of millets

consumer demands for varied, healthier, and more sustainable diets (Balakrishnan and Schneider 2022). Millet's ability to address issues related to food security is one of its most noteworthy features (Gupta et al. 2017). Concerns about climate change, scarce water supplies, and the need to feed a growing population have made food security a global issue. Millets provide answers to these issues because of their unique qualities. First, can millets grow in adverse growth environments (Gupta et al. 2017). They are an excellent crop for places where traditional grains like rice and wheat are difficult to grow, since they can flourish in areas with little rainfall and lousy soil. This adaptability can support populations in obtaining a reliable food supply, even in the face of shifting climatic trends (Zenda et al. 2021). A key component of food security in water-scarce environments is water conservation, which millets help ease the burden on water supplies (Mabhaudhi et al. 2019).

Food security takes into account both the amount and quality of food. Millets are an excellent option for enhancing the nutritional content of diets in areas where food security is a concern, since they are nutrient-dense and abundant in essential nutrients (Sarita and Singh 2016). Millet's high fiber content promotes healthy digestion, lowers blood sugar, and increases feelings of fullness, which can help with weight management (Dayakar Rao et al. 2017). Additionally, millet is an excellent source of plant-based protein, which is necessary for healthy growth, tissue repair, and general wellness (Samtiya et al. 2023). The protein content of millets is complete, with all essential amino acids needed for body activities present, even though it is not as high as legumes or animal proteins (Saleh et al. 2013). Millets offer a healthy and safe substitute for wheat and other gluten-containing grains, so people with dietary limitations can still enjoy a varied and well-balanced diet even as the number of gluten-related illnesses rises (Ahmad et al. 2019). One of the most critical aspects of millets' capacity to address food security challenges is their adaptability in the food sector. Millets can be included in a wide range of culinary items, enhancing the diet with their distinct flavor and advantageous health properties. Millet flour can make gluten-free bread, pasta, and baked products that are safe and nourishing (Hager et al. 2012), demonstrating how millets are a good source of palatable and readily available dietary options and a solution for food security. Products made from millet are enhanced nutritionally and provide health benefits, since they are fortified with extra nutrients. With their fiber, vitamins, minerals, and antioxidants, millets help to create functional foods that can repair the digestive system, lower the risk of chronic diseases, and help control blood sugar levels (Sarita and Singh 2016). In the food industry, millet-based beverages are becoming more and more popular. These drinks satisfy the increasing need for creative and healthful options and add a refreshing and unique flavor to the beverage market's diversity. The ability of millet to combat malnutrition is a significant additional use. Millets are abundant in vital nutrients (Table 1) and can be found where undernutrition is a chronic problem (Banerjee et al. 2020). To improve the nutritional value of staple foods and address micronutrient shortages, food makers and organizations are investigating the possibility of fortifying them with millet flour (Melaku 2022). Such initiatives can significantly impact public health, particularly in places with limited availability of various nutrient-dense foods. Additionally, the food industry's millet use helps to preserve biodiversity (Bunkar et al. 2021). There is a growing need to diversify the raw materials used in food manufacturing as the business accepts a broader range of ingredients (Wilkinson 2002). Including millet can aid in maintaining crop diversity, which is crucial for long-term food security. The food industry contributes to the preservation of the genetic diversity of millet by cultivating and using a range of types, which protects the grain's resilience and adaptation for future generations (Patil 2020).

There are numerous options available when it comes to preparing dishes with millet grains. Food that satisfies various dietary needs and tastes can be made from millet. The following are some culinary creations that may be prepared using millet:

Bread and Baked Goods: Millet flour can make gluten-free bread, muffins, and cookies. These products provide a healthy and safe substitute for those with gluten sensitivity or celiac disease (Rai et al. 2018).

Porridge: Millet porridge, a staple in many cultures, is a nutritious and comfortable breakfast choice. Toppings like honey, almonds, and fruits can be added to customize it (Gaikwad et al. 2023).

Flatbreads: Flatbreads, popular in places like Africa and India, can be made by grinding millet grains into flour. These flatbreads are quite nutritional and delicious (Rai et al. 2018).

Cereals: Millets can be processed into ready-to-eat cereals, frequently supplemented with vitamins and minerals, to give busy consumers a handy and nutritious breakfast choice (Alavi et al. 2019).

Pasta: For people who cannot eat regular wheat pasta, millet-based pasta, which is frequently combined with other gluten-free flour, provides a delightful and nourishing substitute (Asrani et al. 2023).

Beverages: Millet grains can be utilized to make unique-tasting beverages like millet milk and millet beer for people who are lactose intolerant or looking for dairy-free options (Silva et al. 2022).

Functional Foods: Functional foods enhanced with extra nutrients are made from millet to improve their nutritional content. These foods include breakfast cereals, energy bars, and gluten-free snacks (Jideani and Jideani 2011).

Table 1 Nutrient composition of millets

Component	Finger millet	Proso millet	Foxtail millet	Kodo millet	Little millet	Barnyard millet	Sorghum	Pearl millet	Browntop millet
A. Nutritional composition of millets (g/100 g)									
Protein (g)	7.3	12.6	12.3	8.3	7.7	6.2	10.4	11.6	8.98
Fat (g)	1.3	1.1	4.3	1.4	4.7	2.2	1.9	5	1.89
Carbohydrate (g)	72.6	63.8	63.2	66.6	60.9	55	70.7	67	71.32
Crude fiber (g)	3.6	2.2	8	9	7.6	9.8	1.6	1.2	4.92
Minerals (g)	2.1	1.9	3.3	2.6	1.7	4.7	1.6	2.3	4.2
B. Micronutrients content of millets (per 100 g)									
Phosphorus (mg)	250	200	300	300	220	280	266	339	276
Calcium (mg)	34.8	10	31	32.3	17	18.3	35.2	35	28
Iron (mg)	4.2	2.2	3.5	3.1	9.3	17.4	5.2	10.3	7.72
Zinc (mg)	2.3	1.4	2.4	0.7	3.7	3.0	1.6	3.1	NA
Niacin (mg)	0.80	4.54	0.55	0.09	3.2	0.10	5.19	1.11	NA
Riboflavin (mg)	0.60	0.2	1.6	2.0	0.09	4.2	0.15	1.4	NA
Thiamine (mg)	0.40	0.41	0.60	0.15	0.3	0.33	0.28	0.30	NA
C. Essential amino acid composition of millets (mg/100 g)									
Threonine	243	149	193	197	191	231	189	239	NA
Lysine	220	190	140	150	110	106	126	190	NA
Tyrosine	220	NA	244	213	NA	150	167	200	NA
Methionine	210	160	180	180	180	133	87	150	NA
Arginine	300	290	220	270	250	NA	NA	300	NA
Cysteine	140	NA	100	110	90	175	94	110	NA
Trypto-phan	100	50	60	50	60	63	63	110	NA
Isoleucine	400	410	480	360	370	288	245	260	NA
Histidine	130	110	130	120	120	NA	NA	140	NA
Valine	480	410	430	410	350	388	313	330	NA
Phenyl-alanine	310	310	330	430	330	362	306	290	NA
Leucine	696	754	1032	648	763	725	832	748	NA

Source: Nutritive value of Indian foods, NIN (2007), Saleh et al. (2013), Tripathi et al. (2021)

Millet-Based Side Dishes: Millets, frequently prepared with vegetables, herbs, and spices to produce flavorful and satisfying meals, can make a nutritious and hearty base for side dishes (Gaikwad et al. 2023).

Soups and Stews: Incorporating millet grains into soups and stews improves their overall texture and nutritional content (Nout 2009).

Desserts: Millets can be added to puddings, rice cakes, and even ice cream to add a nutritious touch to sweet delights (Bladholm 2016).

Millets for Malnutrition: Millets can be processed into supplemental foods or combined with other ingredients to make nutritionally balanced products used in malnutrition-affected areas to fight undernutrition (Batra et al. 2016).

These numerical statistics, which highlight the carbohydrate, protein, fiber, fat, and mineral content of different millet types, provide a clear picture of the nutritional worth of these variations. Millets provide a comprehensive nutritional profile, making them essential to a balanced and healthy diet. Because of their tolerance to unfavorable growth circumstances, water efficiency, and nutritional richness, millets are a potential strategy to combat hunger, improve dietary diversity, and provide a constant food supply, especially in places with agricultural and environmental issues. By harnessing millet's nutritional potential, Wemay establishes a foundation for a healthier, sustainable, and food-secure future (Fig. 2, Table 2).

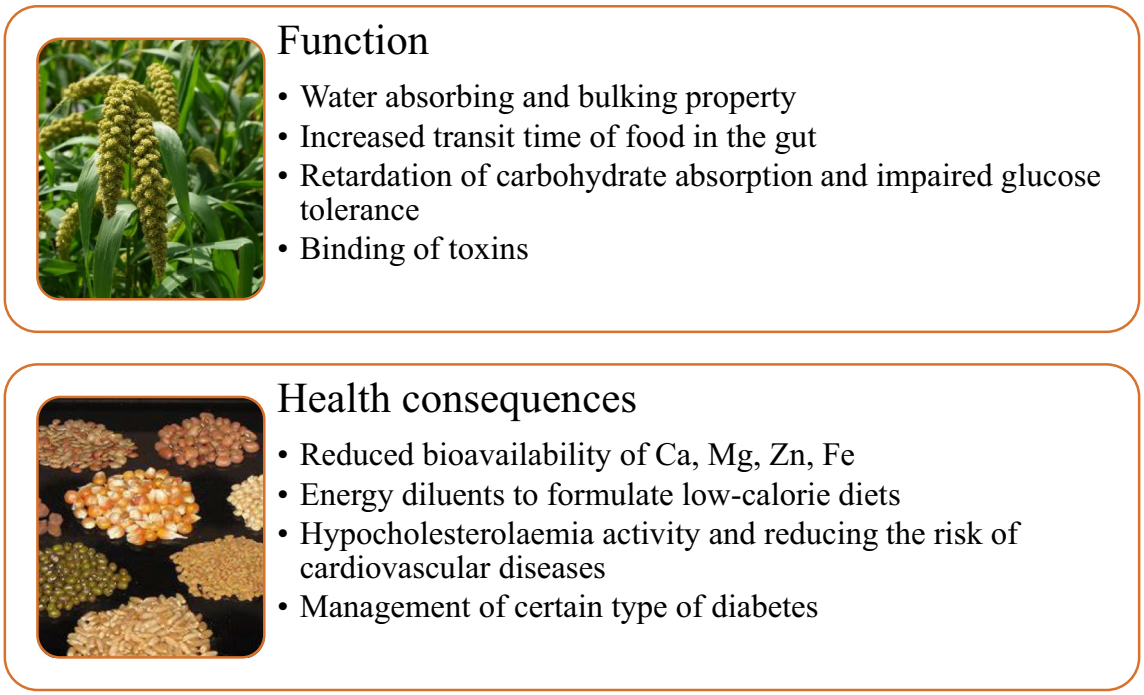

Fig. 2 Function and health composition of millet

Biofortified millets

Millets are leading the way in this nutritional revolution as biofortification has become a viable strategy to combat malnutrition and improve the nutritional value of traditional crops. Millets that have been biofortified and enhanced with vital micronutrients by traditional breeding or biotechnology offer a wide range of varieties (Table 3) specifically designed to address dietary deficits (Vinoth and Ravindhran 2017). Some of the major kinds that have drawn attention for their nutritional benefits are iron-biofortified pearl millet, zinc-biofortified finger millet, and vitamin A-biofortified proso millet. With its higher iron concentration, the iron-biofortified pearl millet has excellent potential to fight iron deficiency anemia. This common malnutrition affects millions of people worldwide, especially in areas with limited resources (Kumar et al. 2022). Iron is required to produce hemoglobin, the protein that carries oxygen throughout the blood, one of the essential micronutrients. Iron-biofortified pearl millet can help populations manage iron deficiency anemia by increasing their intake and reducing its adverse effects, including fatigue, poor cognitive function, and decreased productivity at work (Pompano et al. 2022), which is especially true in areas where millets are a staple food.

Zinc-biofortified finger millet is another significant development in biofortified millets (Bhardwaj et al. 2022). Zinc is necessary for several physiological processes, such as DNA synthesis, wound healing, and immunological function. Insufficient zinc levels are linked to increased infection vulnerability, inhibited growth and development, and weakened reproductive systems (Chasapis et al. 2020). Biofortification activities aim to alleviate zinc deficiency, especially in susceptible groups, including pregnant women, newborns, and young children, by increasing the zinc content of finger millet (Vinoth and Ravindhran 2017). Eating finger millet biofortified with zinc can increase immunity, lower the morbidity rate from infectious diseases, and improve general health and wellbeing.

Proso millet biofortified with vitamin A can address vitamin A deficiency, a widespread public health concern impacting millions worldwide, especially in low- and middle-income nations (Bouis and Saltzman 2017). Vitamin A is essential for general health and development, since it is critical for immunological response, cellular differentiation, and eyesight. A lack of vitamin A can result in blindness, heightened vulnerability to infections, and unfavorable pregnancy outcomes. Biofortification programs fortify proso millet with vitamin A to boost dietary consumption of this essential micronutrient and lower the incidence of vitamin A insufficiency and its related health effects (Shivran 2016). Proso millet biofortified with vitamin A can be added to meals to support healthy growth and development, boost immune systems, and enhance visual health, especially in susceptible groups like children and pregnant women. Agricultural systems can be made more robust and sustainable by encouraging the production and consumption of biofortified

Table 2 Nutritional and health significance of different categories of millet

Types of millets	Nutritional importance	Health significance	Refs
Finger millet	Mineral content is higher in finger millet grains, including dietary fiber (18%), calcium (0.38%), and phenolic compounds (0.03%-3%)	Antibiotic properties, resistance to diabetes and tumor growth inhibition, prevention of atherosclerosis promotion, antimicrobial activity, and antioxidant activity	(Thapliyal and Singh 2015)
Foxtail millet	Foxtail millet is rich in fat (4%) and protein (11%). Glutelins (9.9%), prolamins (39.4%), and albumins and globulins (13%) comprise the protein fractions. Hence, it is suggested as an optimal dietary option for individuals with diabetes. In addition, substantial quantities of potential antioxidants such as phenols, phenolic acids, and carotenoids are present	In foxtail millet, there are significant quantities of protein, fiber, minerals, and phytochemicals. Phytic acid and tannin, antinutrients found in this millet, can be rendered negligible by applying appropriate processing techniques. It has also been reported that millet possesses antioxidant, hypolipidemic, and low-glycemic index properties	(Zhang and Liu 2015)
Proso millet	Proso millet contains (2.3 g crude fiber and 13.09 g protein). Elements including zinc, iron, and copper were detected within the concentration ranges of 3.65–3.78 mg, 5.53–8.82 mg, 12.96–13.33 mg, and 4.45–5.90 mg, respectively	Proso millet contains a high concentration of lecithin, which promotes neural health. It also contains abundant vitamins (folic acid, niacin, B-complex vitamins), minerals (positron, calcium, zinc, and iron), and essential amino acids (methionine and cysteine)	(Das et al. 2019) (Karkannavar et al. 2021)
Kodo millet	Kodo millet has a 66.6% carbohydrate content, 2.4% mineral content, 1.4% fat content, and 2% ash content. Its iron level varies from 25.86 to 39.60 ppm Kodo millets are abundant in vitamins B3, B6, folic acid, and minerals, including calcium, potassium, magnesium, and zinc	Kodo millet can provide significant benefits to postmenopausal women exhibiting cardiovascular symptoms, such as hypertension and hypercholesterolemia Kodo millet is easily digestible and contains a significant amount of lecithin, which is crucial for the wellbeing neurological system's wellbeing	(Singh et al. 2023) (Chandel et al. 2014)
Little millet	This species is a millet with a high dietary fiber and mineral content These micronutrients function as antioxidants, playing a crucial role in the human body	It includes minerals such as magnesium, calcium, manganese, tryptophan, phosphorus, dietary fiber, and B vitamins	(Bunkar et al. 2021)
Barnard millet	Barnyard millet grains are abundant in dietary fiber, iron, zinc, calcium, protein, magnesium, fat, vitamins, and vital amino acids This food is a valuable reservoir of protein, carbs, fiber, and essential micronutrients like iron (Fe) and zinc (Zn)	The desired traits include a high capacity for producing crops, consistent crop production, increased ability to withstand high salt levels in the soil, resistance to pests and diseases, and better nutritional quality, particularly in micronutrient content	(Renganathan et al. 2020)
Pearl millet	Pearl millet has a chemical composition (on a dry basis) that consists of approximately 72.2% carbohydrates, 11.8% proteins, 6.4% lipids, 7.8% dietary fiber, and 1.8% minerals Pearl millet has a high content of iron (Fe), zinc (Zn), and lysine (17–65 mg/g of protein) in comparison to other types of millet	Millet has more energy than sorghum and nearly equals brown rice due to its higher lipid content (3 to 6%). Pearl millet can treat celiac disease, constipation, and other noncommunicable disorders	(Martins Netto and Durães 2005)
Sorghum	Sorghum mainly consists of starch, which digests more slowly than other grains, poor-digestible proteins, and unsaturated fats. It also contains certain minerals and vitamins	Sorghum contains nutrients and bioactive substances, including 3-deoxy anthocyanidins, tannins, and polycosanols, which have been shown to improve noncommunicable disease	(de Morais Cardoso et al. 2017)

Table 3 The list of millet biofortified varieties

Millet	Biofortified varieties	Improved traits
Little millet	CLMV1	Iron and Zinc
Proso millet	–	Vitamin A
Finger millet	CFMV 2	Iron, Zinc, Calcium
	CFMV(Indravati)	Calcium, Iron and Zinc
	VR 929 (Vegavathi)	Iron
Sorghum	ICSR 14001	Iron
	ICSH 14002	
	ICSA 661 X ICSR196	
	ICSA X ICSR 94	
	ICSA 336 X IS 3760	
	12KNICSV(Deko)-188	
	112KNICSV-22(Zabuwa)	
Pearl millet	HHB 299	Iron 73 ppm and Zinc 41 ppm
	AHB 1200fe	Iron 73 ppm
	AHB 1269Fe	Iron 91 ppm and Zinc 43 ppm
	ABV 04	Iron 70 ppm and Zinc 63 ppm
	Phule Mahashakti	Iron 87 ppm and Zinc 41
	RHB 233	Iron 83 ppm and Zinc 46 ppm
	RHB 234	Iron 84 ppm and Zinc 46 ppm
	HHB 311	Iron 83 ppm

Source: Devendra et al. (2020), Bouis and Saltzman, (2017), Kadapa (2023)

millets, especially in areas where shortages of resources and climatic fluctuation are frequent. Compared to major grains like rice and wheat, millets are naturally hardy crops that require less water and fertilizer (Padulosi et al. 2013). Furthermore, millets grow well under various agroecological circumstances, making them a vital resource for smallholder farmers, especially in underserved areas with difficult growing conditions.

Antinutrients in millets

Millets are very nutritious and health-beneficial; however, they contain antinutrients such as tannins, phytic acid, and polyphenols (Sharma 2021), which are unsuitable for human consumption. The antinutrients bind to nutrients and then reduce the bioaccessibility and bioavailability of the minerals, such as iron and zinc, and micronutrients in millet (Sheethal et al. 2022). According to Rehman et al. (2001) and Samtiya et al. (2020), tannins can prevent protein digestion by forming complexes with protein, causing inactivation of digestive enzymes. Phytic acids affect the bioavailability of minerals, by binding to metal ions, such as zinc, iron, magnesium, and calcium to form complexes and reduce their absorption rates (Samtiya, et al. 2020). Ultimately,

Table 4 Antinutrients compound in some millets

Millets	Antinutrients	
	Phytic acids	Tannins
Kodo millet	1.2 – 1.4 $mg.g^{-1}$	1.0 – 1.2 $mg.g^{-1}$
Little millet	–	332.1 – 336.8 $mg.g^{-1}$
Barnyard millet	3.37 – 3.70 $mg.g^{-1}$	–
Proso millet	7.2 $mg.g^{-1}$	–
Finger millet	5.54 – 5.58 $mg.g^{-1}$	3.5 $mg.g^{-1}$
Pearl millet	9.2 $mg.g^{-1}$	2.2 $mg.g^{-1}$

Source: Sharma et al. (2021), Dey et al. (2022)

antinutrients cause micronutrient malnutrition and mineral deficiency in humans (Soni et al. 2022). There are different processing methods used to reduce antinutrient content in millets including milling, fermentation, boiling, decortication, roasting, germination, soaking, microwave heating, and autoclaving to make nutrients available (Soni et al., 2020). Millets have different levels of antinutrient composition, as shown in Table 4.

Future perspective

The prospects for millet's nutritional and health benefits are promising due to the increasing acknowledgement of their nutritional value, sustainability, and potential to address global health concerns. Consumers are placing a growing emphasis on their health and actively seeking food options that are both nutritious and eco-friendly. Millets are highly sought after to create millet-based items due to their plentiful essential elements and absence of gluten. Ongoing research on millet's nutritional composition and health benefits is continuously uncovering new insights. Studies on the bioactive compounds in millets, including antioxidants and polyphenols, have yielded significant knowledge on their capacity to prevent illnesses and enhance overall wellbeing. Millets are known for their resilience under adverse weather conditions, using less water and resources than other cereal crops. Engaging in their cultivation supports the practice of sustainable agriculture and contributes to the mitigation of climate change. Millets possess a nutritional composition that makes them highly effective in addressing malnutrition and dietary insufficiencies, especially in nations with low resources. Millets can make a substantial contribution to achieving food and nutrition security goals. The meticulous emphasis on product development and innovation has led to diverse gourmet goods crafted from millet, catering to a broad spectrum of consumer preferences. The assortment of products includes snacks, cereals, beverages, and bakery items derived from millet (Kumar et al. 2018). Multiple countries recognize millet's significance in improving

nutrition and promoting sustainable agriculture. Millets are the most valuable crops during climate change, and they fit in well with the current conditions of hunger, poverty, nutritional concerns, and marginal farming. Millets are also the most eco-friendly crop. Millets also have a beneficial nutrigenomic role. Millets are highly revered in tribal societies, serving as snacks, bread, puddings, and drinks and having significant cultural significance. Millets are processed multiple times to improve their nutritional bioavailability and sensory properties and minimize anti-nutritional elements. Fermentation is a strategy for increasing millets' nutritional content and bioactive characteristics. It is also used to create a variety of probiotic foods and drinks made from millet. Furthermore, these activities provide a primary source of income for many people, particularly in Africa and Asia, and provide food security for millions (Saleem et al. 2023).

Conclusion

Millets are becoming increasingly valued by the food industry due to their adaptability, sustainability, and capacity to address issues related to food security. These resilient grains are an excellent crop for regions with limited water supply and an environmentally beneficial choice, because they thrive in challenging growth conditions. They are nutrient-rich, because they include vital components like fiber, protein, vitamins, and minerals. In the food sector, millets are used for many things, including creating gluten-free products, treating malnutrition, and producing a wide range of delicious foods. Due to their adaptability, sustainability, and high nutritional content, millets are a valuable part of efforts to offer a steady food supply for the world's expanding population. As such, they can address issues with food security. Furthermore, millets might support biodiversity preservation and the development of a more robust, diverse, and nutrient-rich food chain. Expectedly, millets will play a bigger role in the food industry and tackle some of the world's most pressing problems related to sustainability and food security.

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