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Millet production, challenges, and opportunities in the Asia-pacific region: a comprehensive review

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Global warming, water scarcity, population growth, rising food prices, urbanization, and other socio-economic factors pose significant threats to agriculture and food security in the 21st century. This situation is particularly grave for low-income individuals in the Asia-Pacific region. To tackle this challenge and eradicate hunger and poverty, it is imperative for scientists to explore alternative food sources, covering all stages from production through processing to consumption. Cereal grains serve as a crucial food source and hold substantial importance in human diets. Therefore, revamping the food system becomes crucial to achieve food and nutritional security. A pragmatic approach toward reaching this goal involves ensuring universal access to affordable, wholesome, and nourishing food through the utilization of millets—nutrient-dense grains (often referred to as Nutri-cereals) that offer a rich array of vital macronutrients, micronutrients, carbohydrates, protein, dietary fiber, lipids, and phytochemicals. Leveraging these grains holds the potential to significantly alleviate the challenges of food insecurity and malnutrition. Millet, a drought-resistant grain, constitutes a primary source of carbohydrates and proteins for populations residing in semi-arid regions of Africa and Asia. Given its crucial contribution to national food security and potential health advantages, there is a growing focus among food scientists. Additionally, the United Nations designated 2023 as the International Year of Millet, underscoring its importance. This article delves into various methods of production and processing, highlighting opportunities to enhance the production and nutritional qualities of millet. We attribute millets to inadequate rainfall distribution, poor crop management high prices of farm inputs such as fertilizer and pesticides and low adoption of improved varieties by the farmers. It also outlines the constraints, challenges, and future prospects associated with promoting millet as a viable food source for the burgeoning population. Despite the promise that millets hold, they have not received adequate research attention. Therefore, increased research efforts on integrating genomics in genome-wide marker-trait association are imperative, encompassing germplasm collection, protection, evaluation, consumption patterns, development of high-yielding cultivars, processing techniques, and policy interventions. Such initiatives are necessary to bolster the cultivation of millets and harness their potential to address the escalating global food challenge.

KEYWORDS

food security, nutrition, agriculture, global challenges, sustainability

Introduction

One of the biggest challenges facing the world today is tackling hunger and feeding the world's expanding population. This problem is caused by numerous factors such as a lack of essential nutrients, a decrease in food production that results in an imbalance between supply and demand, and conflicts that destabilize various regions around the globe (Nithiyanantham et al., 2019). The number of people experiencing hunger and malnutrition has decreased from about one billion in 1990–1992 to 850 million in 2010–2012, but the threat posed by climate change and global warming is still a concern (Food and Agricultural Organisation–FAO, 2016; Hu et al., 2023). Millet has many nutritional and medical functions (Gopalan et al., 2009) and rich in health-promoting phytochemicals and considered functional foods. Millets have potential health benefits and epidemiological studies have showed that consumption of millets reduces risk of heart disease, protects from diabetes, improves digestive system, lowers the risk of cancer, detoxifies the body, increases immunity in respiratory health, increases energy levels and improves muscular and neural systems and are protective against several degenerative diseases such as metabolic syndrome and Parkinson's disease (Chandrasekara and Shahidi, 2011). The important nutrients present in millets include resistant starch, oligosaccharides, lipids, antioxidants such as phenolic acids, avenanthramides, flavonoids, lignans and phytosterols which are believed to be responsible for many health benefits (Taylor et al., 2006; Dutta et al., 2019) It is estimated that 2–3 billion people may experience hunger, food insecurity, and malnutrition by 2050 as a result of declining rates of food production and the additional strain of feeding a population that will surpass 9 billion (Godfray et al., 2010; Wheeler and Von Braun, 2013).

In India, for centuries, millets were the staple crops, but gradually they were replaced by high-yielding varieties of wheat and rice in the identified green revolution regions, which led to their marginalization. Millets are types of small-grained cereals that are considered staples in arid and semi-arid regions of Asia, Africa, and parts of Europe. Among the small millets are finger millet (*Eleusine coracana L.*), foxtail millet (*Panicum italicum* L.), kodo millet (*Paspalum scorbiculatum* L.), proso millet (*Panicum miliaceum* L.), little millet (*Panicum sumatrense* L.), and barnyard millet (*Echinochloa frumentacea* L.; Figure 1). Compared to rice and wheat, small millets are superior in nutrition and offer inexpensive minerals, protein, and vitamins to improve the poor communities around the Asia-Pacific region (Huang et al., 2023). Additionally, they are almost free of grain storage pests and have alonger storage life (Leder, 2004; Panghal et al., 2006; Saleh et al., 2013). Due to their untapped potential grain yield and nutritional benefits, millets have the potential to become important future food crops, especially in the more challenging rainfed areas (Arendt et al., 2008; Gupta et al., 2009; Yang et al., 2012).

Millets are grown in diverse soils, climates, and adverse environments with minimal Agri inputs. By making minimal interventions, it is possible to substantially increase yields. Providing good quality seeds is an important intervention in millet cultivation. The majority of smallholder and tribal farmers grow millets, which are coarse cereals, in rainfed environments (Mariac et al., 2006; ICRISAT, 2007). Millets are distributed in the Asian and African continents and some parts of Europe. They are among the oldest cultivated crops in India. The Ministry of Agriculture and Farmers Welfare India has recognized the importance of millets and declared major millets, comprising sorghum, pearl millet, minor millets, such as finger millet, foxtail millet, proso millet, kodomillet, barnyard millet, little millet, and brown top millet, and two pseudo millets (buckwheat and amaranth) as "Nutri-cereals" for production, consumption, and trade. Small millets possess qualities that make them an ideal crop for promoting agricultural sustainability in resource-poor and fragile ecological conditions (Lu et al., 2009; Sharma and Gujral, 2019). These crops offer advantages to the cropping system, such as increased sequestration, improved agro diversity, prevention of erosion in arid areas, and the production of grains and fodder. Despite the adverse impacts of global warming and climate change, small millets can survive due to their hardiness and resilience to climate change. Millets are often referred to as "yesterday's coarse grains and today's nutri-cereals" and are considered to be the "future crops" as they are resistant to most pests and diseases and can adapt well to the harsh conditions of the arid and semi-arid regions of Asia and Africa (Rao et al., 2011).

Nutri-cereals are making a strong comeback in the Indian cereal production segment after decades of negligence. India dominates global millet production with a share of about 40.6% and an estimated production of 10.91 million tonnes during 2018–2019. India ranks first in nutri-rich millet production and second in rice and pulses worldwide. However, India also ranks second in child malnutrition incidences, with more than one-third of the world's malnourished children living in the country. Furthermore, India has become a hub for diabetic and overweight people, which puts the country under the double burden of malnutrition. According to the United Nations (UN) report titled "State of Food Security and Nutrition 2022," the number of undernourished people in India has decreased from 247.8 million in 2004–06 to around 224 million in 2019–21. However, the count of anemic children and women, as well as overweight people, remains disquietingly high. The evaluation of different processing methods on the nutritional properties of minor millets has shown that over half of the children and women suffer from anemia, while the incidence of obesity is on the rise among both men and women. However, regular consumption of millet can improve hemoglobin levels and reduce anemia-causing iron deficiency, besides fulfilling most of the daily nutritional requirements of an average person (Doggett, 1989; Edge et al., 2005; Dutta et al., 2019).

Millets are considered functional and superfoods, as they contain bioactive ingredients that are beneficial for the physiological well-being of humans and can combat chronic diseases. Millets are highly nutritious crops, containing considerable amounts of vitamins and minerals, and are a good source of energy, dietary fiber, slowly digestible starch, and resistant starch, providing sustained release of glucose and satiety. Compared to cereals, millets are a better source of protein and amino acids (methionine and cysteine) and have a better fatty acid profile (Anitha et al., 2020; Zhang et al., 2023). Millets are known for their high nutritional value and are sometimes referred to as super grains. They contain a variety of essential vitamins and minerals, including vitamin E, vitamin B, calcium, phosphorus, magnesium, manganese, potassium, and iron. However, they do contain a limited amount of lysine and tryptophan, which can vary depending on the cultivar. According to a previous study (Shobana et al., 2009), people who eat millets have a lower incidence of diabetes. Additionally, the high fiber content in millets may help reduce harmful cholesterol levels while boosting valuable cholesterol. It also prevents the secretion of bile acids that cause gallstones in the body. Furthermore, since millets take longer to move from the stomach to

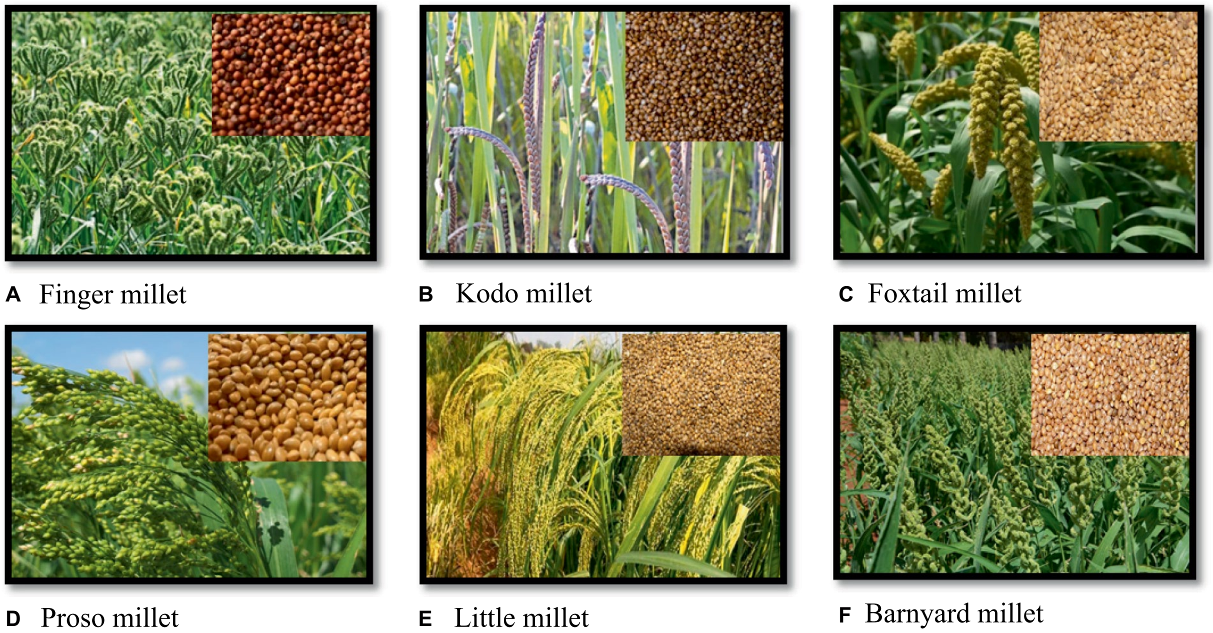

FIGURE 1
Crop maturation stage with seed grains of small millets.

the intestines, they lead to longer food intervals, which prevent obesity. Given their high nutritional value, millets are even more relevant globally in the aftermath of the COVID-19 pandemic (Hu et al., 2024).

The Indian government has highlighted the benefits of millet. In 2018, the Indian government declared it as the "National Year of Millets." The same year, millets were also recognized as Nutri-cereals and included under the '*Poshan Abhiyan*' and '*National Nutrition Mission*'. To create domestic and global demand and to provide nutritional food to the people, Government of India had proposed to the United Nations for declaring 2023 as International Year of Millets (IYoM-2023). The proposal of India was supported by 72 countries and United Nation's General Assembly (UNGA) declared 2023 as International Year of Millets on 5th March, 2021. This led to the Hon'ble Union Finance Minister making a Budget announcement on 1st February 2022: "2023 has been announced as the International Year of Millets. Support will be provided for post-harvest value addition, enhancing domestic consumption and branding of millet products nationally and internationally. and India is the largest producer of millets in the world, accounting for 20% of global production and 80% of Asia's production (Amadou et al., 2013; Saleh et al., 2013; Shivran, 2016). Governments and policy makers are requested to prioritize sustainable production and consumption of millets as a way to fight hunger, build resilience to climate change, increase biodiversity, and promote a diverse diet. FAO encourages them to take policy and legislative actions that promote the cultivation of millets and support research and development, including innovative methods for harvest and post-harvest processes. The private sector is also called to facilitate access to credit or other financial support, millet-specific training, farming equipment, and new technologies that improve the handling (harvest and post-harvest processing) of millets and thus their quality. We will take the opportunity of IYM2023 to take stock of the millets production and consumption around the world, identifying gaps and opportunities for research and development. To encourage consumption of millets, FAO launched a Global Chefs Challenge on social media, where chefs and hobby cooks can share millets-based recipes with the global audience. Selected recipes featured in a Millets Cook/Recipe Book (approved by IYM Steering Committee, with official launch in pdf and html version in all UN languages for 18 October 2023 during WFF event). A background document on millets and their current challenges and opportunities: "Unleashing the Potential of Millets" includes a synopsis of the current status of millets around the world and was created to inspire policymakers, farmers, civil society, opinion leaders, research and development agents and the general public to reconsider the role of millets in diversified and nutritious diets. The document to be published in all UN languages and announced with press release on 1 September. The IYM2023 Secretariat is supporting various national, regional and international celebrations of the IYM all around the world providing communication and technical expertise. To raise awareness of the benefits of millets within specialized audience and as legacy of IYM, the Secretariat is organizing a Global Webinar Series. Moreover, FAO will launch an IYM Photo contest inviting people to submit their best photos of millets. Which are phytochemical compounds that plants produce naturally, for their defense, as secondary metabolites to protect themselves against adverse conditions (Panghal et al., 2006; Saleh et al., 2013; Chandel et al., 2014; Pontieri et al., 2014).

Millet production

According to FAO, in 2020, global millet production was projected to reach 28.33 million metric tonnes in 2019 and 30.08 million metric tonnes in 2021. As of 2021, India is the largest producer of millet, accounting for a total of 41% of the world's production. Niger comes in second with 12%, followed by China with 8%. Despite this, India still ranks 12th among the countries that produce high yields of millets (Figures 2, 3). Millets have been an essential part of the human diet for centuries due to their numerous health benefits. They require low water and input requirements for production, making them an environmentally-friendly option. According to the Ministry of Agriculture and Farmers Welfare, India's millet production increased from 14.52 million tonnes in 2015–16 to 17.96 million metric tonnes in 2020–21. In the Asia-Pacific region, India produces 12,490 metric tonnes and occupies the first position with a share of 80% followed by China with 2,300 metric tonnes (Figure 4; Tonapi et al., 2015; Ashoka et al., 2020; Anonymous, 2022). India holds the largest share in the millet market with a CAGR of 4.4%. In order to meet the increasing demand from manufacturers of beverages, dairy, frozen desserts, confectionery, and baked goods, the millet companies in this region are constantly improving their overall business processes and product portfolio. The Asia-Pacific region is home to many domestic and foreign businesses. The region primarily encourages the expansion of the millet market through an effective food manufacturing sector and accommodating trade laws. With Asia-pacific growing malnutrition problem, both under-nutrition (vitamin, mineral, and protein deficiencies) and over-nutrition (obesity, metabolic syndrome, and lifestyle diseases), there is a growing awareness of the need to move to healthier, more accessible, and inexpensive diets that include millets. In addition to being naturally gluten-free and nutrient-dense, millets are also a rich source of protein, essential fatty acids, dietary fiber, and vitamin B. The consistent demand for millets production in Asia-Pacific countries is fueled by constant demand for millets from retailers and an efficient supply chain (Verma and Patel, 2013; Kalaisekar et al., 2016). Growing consumers' preferences for flavored food and beverages have also been contributing to the steady demand for millet (Asia Pacific Wind Turbine Condition Monitoring Market Forecast to 2028, 2022). The brief quality seed production activities and genetic and agronomic principles of millet seed production are described in Tables 1, 2 (Bhaskaran and Vanangamudi, 2002; Indian Minimum Seed Certification Standards, 2013; Kannan, 2013; ICAR-IIMR India, 2020; Figure 5).

Nutritional and health benefits of millets

Cereal grains are an important source of food worldwide and play a significant role in the human diet. Millets, in particular, are rich in micronutrients and phytochemicals. They are non-glutinous and non-acidic, making them easy to digest and considered one of the least allergenic grains. Millets are also high in quality protein, fiber, and B-complex vitamins, as well as vitamins A and E (Gupta et al., 2012; Devi et al., 2014; Ramashia, 2018). Millets have the potential as a natural source of antioxidants and as a nutraceutical and functional food ingredient to promote health and reduce disease risk. Additionally, millets are rich sources of non-nutritional components such as phenols and flavonoids, which can be used as antioxidants and as a source of beneficial phytochemicals in the pharmaceutical and food industries (Rao et al., 2011).

Millets are functional food for weight reduction due to the high content of fiber and proteins which provide the satiety. Millets are also rich in iron, magnesium, and calcium as well as B vitamins, apart from polyphenols and flavonoids (Kumar et al., 2016; Puranik et al., 2017). Calcium and magnesium are important essential macromineral that are required in relatively large quantities in the diet for maintaining cellular function and overall health. Young children, pregnant and nursing women, as well as elderly populations in marginalized and poorest regions of the world are at highest risk of calcium malnutrition (Puranik et al., 2017). In the elderly population calcium deficiency manifests in the form of osteoporosis and osteopenia and improved dietary intake of calcium may be the most cost-effective way to meet such deficiencies. Finger millet [*Eleusine coracana* (L.) Gaertn.], a crop with inherently higher calcium content in its grain, is an excellent candidate for understanding genetic mechanisms associated with calcium accumulation in grain crops. Millets can be developed as food-based nutraceuticals in the form of highly personalized medicine or therapeutic agents due to the high content of minerals and flavonoids and amino acids (Kumar et al., 2016; Joint FAO/WHO Food Standards Programme Codex Committee, 2017; Puranik et al., 2017). Finger millet is a crop with a potentially tremendous but

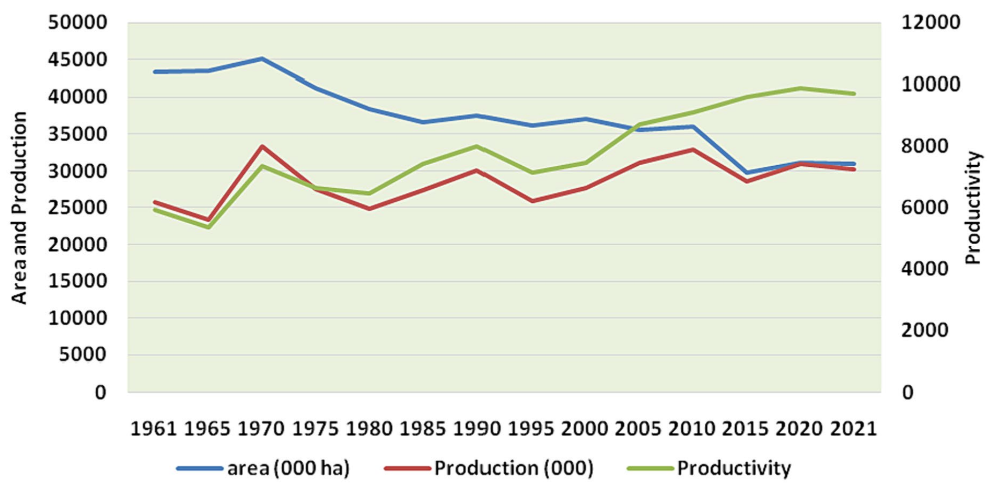

FIGURE 2
Global trends in area, production, and productivity of millets, 1961–2021 (FAOSTAT, 2022).

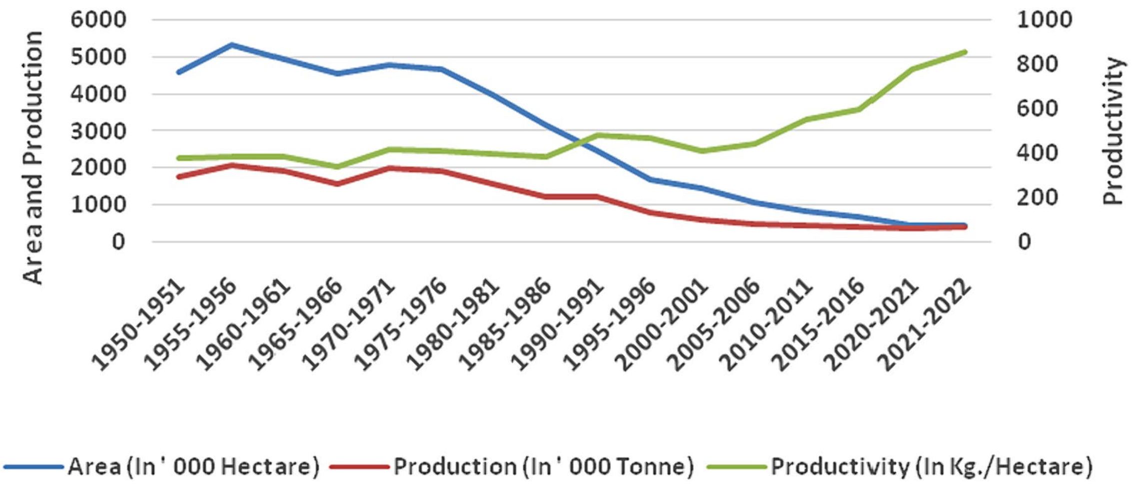

FIGURE 3
Indian trends in area, production, and productivity of millets, 1950–2022 (Anonymous, 2022).

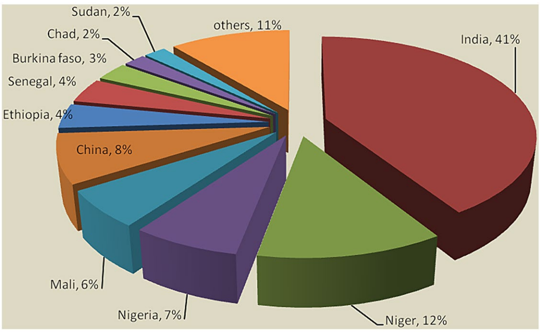

FIGURE 4
Country-wise production share of different millets (FAOSTAT, 2022).

underexplored source of nutraceutical properties as compared to other regularly consumed cereals. According to the 2017 agenda of the FAO and WHO in the era of growing divide and drawback of food security via food diversity, these characteristics of millets should be harnessed to develop finger millet as a novel functional food Millets could be mixed in cakes, biscuits, cookies, bread, and pastries to provide proteins and the abovementioned micronutrients which may convert modern foods into functional foods (FAO of the UNO, 2017; Joint FAO/WHO Food Standards Programme Codex Committee, 2017) As a result, millet grains are gaining attention for their potential as a food source in developing countries as well as for their use in manufacturing bioethanol and biofilm in some developed countries (Rathore et al., 2016). Determination of nutritional composition acts as a key factor as it could help solve food insecurity problems and may help overcome malnutrition in developing countries (Singh and Raghuvanshi, 2012).

Carbohydrates: Milled millet grains possess different proportions of nutrients, such as starch (60–75%) followed by non-starchy polysaccharides (15–20%) and sugars (2–3%) (Himashu Chauhan et al., 2018). The sugar profile of millets indicates the presence of glucose, sucrose, and fructose in significant proportions. The non-starchy part includes dietary fibers such as hemicelluloses, cellulose, and pectinacious part. Starch is one of the industrially important nutrients that occupy the major carbohydrate proportion in millet grains. General features, rheological, and pasting properties of specific millet starch illustrate their behavior under a specific set of conditions which ultimately demonstrates their use in different food products (Punia et al., 2019; Siroha et al., 2019; Punia et al., 2020). Starch could be used in the preparation of various food products as well as biodegradable packing materials (Sandhu et al., 2020). Kumari and Thayumanavan (1998) studied the starch present in different millet types and observed that the characteristic shape and size of starch granules vary with the type of millet. The shape of proso millet starch was small spherical; large spherical (rare) polygonal with specific size ranging from 1.3–8.0 μm. Foxtail millet is a small spherical, small polygonal large pentagonal with a size of 0.8–9.6 μm. In barnyard millet, the shape of starch granules is small spherical, large spherical, and large polygonal with a size range of 1.2–10 μm. In Kodo millet the shape of starch granules was large polygonal; rarely small spherical and polygonal with a size range of 1.2–9.5 μm. In little millet, the shape of starch granules observed was small spherical and large spherical with a size range of 1.0–9.0 μm. The amount of amylose content in millets may vary with their type. For instance, the amount of amylose content reported for pearl millet was 13.6–18.1 g/100 g followed by finger millet (30–32.4 g/100 g); proso millet (1.2–21.5 g/100 g); barnyard millet (18–31 g/100 g); foxtail millet (3.3–25.21 g/100 g) and kodo millet (18–19.61 g/100 g; Kim et al., 2009; Liu et al., 2010; Balasubramanian et al., 2011; Annor et al., 2014; Wu et al., 2014; Singh and Adedeji, 2016; Sandhu and Siroha, 2017; Bean et al., 2019).

Protein and amino acids: Scientific reports indicate the presence of a significant amount of protein in millets. Specific fractions of proteins include prolamin, glutelin, globulin, and albumin. The content of glutelin fractions and prolamin dominates over other protein types such as albumins and globulins. The amount of protein may vary with cultivar type and type of millets. For instance, out of the total protein content, the amount of prolamin was observed to be high in foxtail millet (47.6–63.4%); finger millet (24.6–36%) and pearl millet (23–31%; Indira and Naik, 1971; Singh et al., 1987;

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TABLE 1 Detail of the cultivation practices, including agronomic requirements, planting techniques, and seed production of major/neutral millet species.

Crop	Pearl millet	Sorghum	Finger millet	Proso millet
Land requirement	Land should be free from other crop plants, volunteer plants and other varieties of the same crop	In the previous season, no sorghum crop was grown. Avoid the field with a previous crop disease history	the same kind or variety should not be grown in the previous season	Ideal soil types are loam/sandy loam with lots of organic matter. Devoid of volunteer plants.
Isolation distance	400 m for FS 200 m for CS	300 m –FS, 200 m CS for hybrids, presence of Johnson grass 400 m FS and CS, presence of forage sorghum 400 m- FS and 200 m –CS	It is a self-pollinated crop. 3 m for both FS and CS.	Self-pollinated crop, raised crop maintains 3 m isolation distance for FS and CS.
Brief cultural practices	a. Preparation of land: One to two ploughings followed by leveling. b. Time of sowing: Kharif- Second fortnight of July. Rabi- Mid-October to mid-December c. Source of seed: Obtain seed from Certification Agency d. Method of sowing: Line sowing e. Spacing: 15 cm between rows. f. Seed rate: 3.5–5 kg/ha, g. Fertilization: 50–50-50 kg/ha of NPK as basal dose. Later another 50 kg N in two installments (first after 25–30 days, second 40–45 days).	a. Preparation of land: Should be plow followed by harrowing b. Time of sowing: For Kharif 2nd fortnight of July, For rabi mid of October. For summer 1st or 2nd fortnight of January c. Source of seed: Seed from foundation/certified which is authorized by seed certification agency d. Method of sowing: direct sowing (Line sowing) or transplanting e. Field preparation: Ridges and furrows f. Spacing: 45 × 15 cm g. Planting ratio: 4:2 or 6:2 h. Seed rate: 8 kg/ha for A line and 4 kg/ha for R line i. Fertilization: 7.5 t/ha of FYM add 2–3 weeks before sowing. 100:50:50 kg/ha of NPK	a. Preparation of the land: Land is plowed 2 to 3 times to get fine tilth. b. Time of sowing: Dec to Jan c. Source of seed: Seed from foundation/certified which is authorized by seed certification agency d. Method of sowing: Direct sowing, Broadcasting, Line sowing, Drilling in rows Transplanting (3 to 4 week seedlings) e. Spacing For line sowing 22.5 to 30 cm between the lines 8 to 10 cm within the line. For transplanting(Early Kharif and Rabi 25 × 10 cm) (Late Kharif 30 × 10 cm) f. Fertilization For irrigated N:P:K Kg/ha – 50:20:20	a. Preparation of land: The land is harrowed and leveled 2–3 times to make it to a fine tilth and to form ridges and furrows. b. Time of sowing: June–July and Feb -Mar. c. Source of seed: Obtain BS/FS from a source approved by a certification agency. d. Method of sowing: Broadcast manually or by Seed driller in furrows at 3–4 cm depth. e. Spacing: 30×10cm f. Seed rate: 10 kg/ha g. Fertilization: Irrigated condition - N- 40-60 kg/ha, P-30 kg/ha and K- 20 kg/ha. Half of the N and the whole of P and K are applied as basal doses. The remaining half is applied at the time of 1st irrigation.
Special techniques	Jerking: This activity is done 20–25 days after transplanting or 30–40 days after direct sowing.	Nitrogen application to get synchronization of flowering in late parents, staggered sowing, application of MH at 100–200 ppm	Contact method	Roughing
Irrigation	If rains are not adequate, 1–2 irrigations are needed. Adequate moisture is ensured at the tillering and flowering stage.	Irrigation should be provided once in 8 days in case of light textured soil whereas, once in 15 days in case of heavy textured soil.	First irrigation is given on the third day in case of red soil to soften the hard crust. Subsequent irrigation adjusts according to soil type.	1st irrigation - 25-30 days after sowing. 2nd irrigation - 40-45 days after sowing. Summer crop-2-4 irrigation. Rainy season - draining is necessary.
Rouging	It should be done before flowering. All rogues, volunteers, and off-types should be removed.	Undesirable plants should be removed completely from the field before they cause contamination.	To remove off types, volunteer, and diseased plants. Rogue up-to flowering stage	To remove off types, volunteer, and diseased plants. Rogue up-to flowering stage. Max off types at final inspection is 0.05% for FS and 0.10% for CS.
Harvesting	Harvest male rows first and keep their heads separate. After that, the female rows should be harvested.	Duration —40-45 days after 50% flowering Formation of drunken layer on seeds. Male rows are harvested first and the seed parental rows.	First harvest – 50% of the ear heads of the crop turn brown Second harvest – 7 days after the first harvest	Ready to harvest in 65–75 days after sowing. Harvested when 2/3rd of the seeds are ripe.
Yield	1.5tonnes/ha	1.5–2.0 tonnes/ha	1.2–2.5 tonnes/ha	2.0–2.3 tonnes/ha

N, Nitrogen; P, Phosphorus; K, Potassium; MH, Maleic hydrazide; SCA, Seed certification agency.

Geervani and andEggum O., 1989; Himashu Chauhan et al., 2018). Glutelin percentage in different millets was documented as 40–52% in kodo millet, 13–30% in pearl millet, 12–28% in finger millet, and 5–18% in foxtail millet (Subramanian et al., 1990; Vivas et al., 1992; Serna-Saldivar and Rooney, 1995; Kumar and Paramswaran, 1998; Adebowale et al., 2011; Cremer et al., 2014).

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TABLE 2 Detail the cultivation practices, including agronomic requirements, planting techniques, and growing conditions, specific to minor/ positive millet species.

Crop.	Little millet	Kodo millet	Barnyard millet	Foxtail millet
Land requirement	Land should be devoid of volunteer plants. The previous crop should not be the same variety or other varieties of the same crop.	Land should be devoid of volunteer plants. The land should be fertile with a good drainage facility	Land must be fertile and free from disease-borne organisms	The land selected for seed production must be fertile, free from weeds, and volunteer plants from previous crop.
Isolation distance	3 m for both FS and CS production	3 m for FS and CS production	FS-3 m CS-3 m	FS:3 m CS:3 m
Brief cultural practices	a. Preparation of land:. Loam soils with good drainage or sandy loam soils with lots of organic matter are good for farming. b. Time of sowing: typically in June to July. For summer crops, the optimal sowing time is from February to March. c. Source of seed: Seeds must be taken from certified seed agencies and institutes. d. Method of sowing: Seeds are sown manually or using a seed driller into furrows, with a recommended depth of 3 to 4 cm. e. Spacing: Row to Row 22.5 cm Plant to Plant 8-10 cm. f. Seed rate: The recommended seed rate is 4 kg/acre (10 kg/ha). g. Fertilization:40:20:22 kg NPK /ha	a. Preparation of land: At the onset of monsoon field should be plowed 2–3 times to make it a fine tilth followed by ridges and furrows. b. Time of sowing: sowing should be done in mid-June to mid-Julyan in South India during September – December c. Source of seed: Seeds must be taken from certified seed agencies and institutes. d. Method of sowing: Seeds are broadcast manually or seeds can be sown in ridges or line sowing e. Spacing: 30×10 cm f. Seed rate: The recommended seed rate is 4 kg/acre (10 kg/ha). g. Fertilization: FYM @ 5 tonnes /acre (12.5 tonnes/ha) and incorporate into the soil.40:20:20NPK kg/ha should applied at the time of sowing	a. Preparation of land: Two ploughings with local plough or harrowing followed by planking b. Time of sowing: Barnyard millet can be sown in the first fortnight of July with the onset of monsoon rains c. Source of seed: purchases seeds from any authorized agency d. Method of sowing: line sowing e. Spacing:30×10 f. Seed rate: 8 to 10 kg /ha g. Fertilization: FYM 5 to 10 tonnes/ha 30:40:50 NPK	a. Preparation of land: With the onset of the monsoon, the field should be harrowed or plowed with a local plow twice. B. Time of sowing July to August c. Source of seed Any authorized source like NSC, SSC any other private sector d. Method of sowing The seeds can be sown with a local seed drill 30 cm apart e. Spacing 25-30 cm(row to row) 8-10 cm(plant to plant) f. Seed rate: 8-10 kg/ha g. Fertilizer application 40:20:20 kg NPK/ha
Irrigation	The initial irrigation should be applied 25 to 30 days after sowing, For summer crops, the number of irrigations, ranging from 2 to 4, depends on the soil type and prevailing climatic conditions.	The Kharif season crop is predominantly rainfed and generally does not necessitate irrigation. However, in the absence of sufficient rainfall, one or two irrigations may be applied.	One irrigation must be given at the time of the panicle initiation stage	Flood the land depth of 2.5 cm At sowing and for summer 2 irrigation required at flowering and seed filling stage
Roguing	Roguing should be done before flowering to remove the off-types, volunteer plants and diseased plants from the seed production fields to maintain the genetic purity.	Maximum percentage of off-types permitted at the final inspection is 0.05% for FS and 0.10% for CS production.	1 or 2 roguings are required before flowering to get maximum genetic purity	Rogue out the plants of maintainer line and off type plants before flowering
Harvesting	the crop is typically ready for harvest around 80 to 85 days after sowing, with approximately two-thirds of the seeds being fully ripe.	When the earheads reach physiological maturity and attain their maximum dry weight, the crop is prepared for harvesting within 100 days.	. It is cut from the ground level with the help of sickles and stacked in the field	Harvest of male rows first to avoid chances of mechanical admixture.
Yield	1.5 tonnes/ha	1.5 tonnes/ha	0.7 tonnes/ha	1.0–1.2 tonnes/ha

NS, Nucleus seed; BS, Breeder seed; CS, Certified seed; FYM, Farm yard manure; NSC, National seed corporation.

Lipids: Lipids are also important from a nutritional point of view as they help in various reactions in the biological system. Millets grains have a fat content in the range of 1–5%, with their maximum distribution in bran and endosperm (Himashu Chauhan et al., 2018). A major proportion of fat (24%) is present in millet grains embryos. The fatty acid profile of millets indicates the presence of both types of

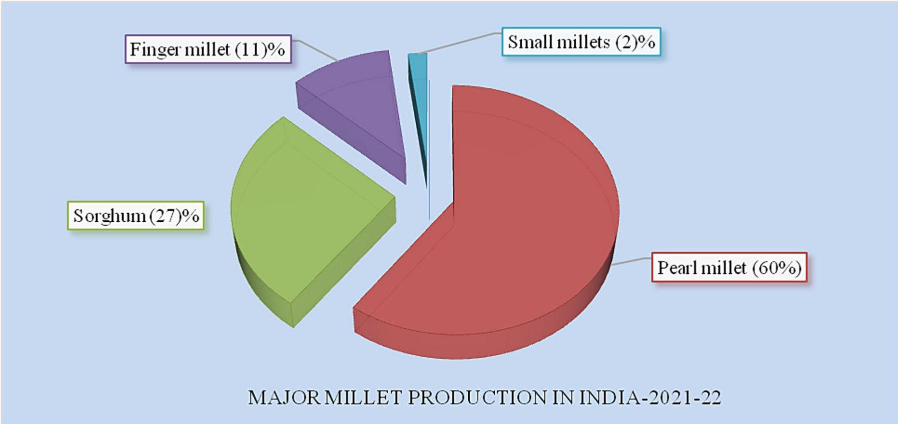

FIGURE 5
Major millet production in India-2021-22 (Anonymous, 2022).

fatty acids (saturated and unsaturated). Maximum proportion in millet grains is unsaturated fatty acids, which range from 78 to 82%, followed by saturated fatty acids (17.9–21.6%).

Minerals and vitamins: Minerals and vitamins are specific nutrients that are present in natural resources and required for sustaining normal metabolic reactions in the body. The human body is not capable of synthesizing all the essential nutrients; therefore, it becomes necessary to provide them through specific food materials. It is important to add nutrient-rich food sources to the daily dietary menu to stay healthy and disease-free. Each mineral performs specific functions for the welfare of the body for example: calcium is necessary for the maintenance of teeth and bones and helps to regulate neural functioning and blood pressure. Iron is an essential mineral as it regulates enzymatic activation, and helps in the synthesis of myoglobin, hemoglobin, hormones, and neurotransmitters. The inclusion of zinc in the diet helps to boost the immune system, wound healing, and regulate cellular division. For instance, out of total protein content, the amount of prolamin was observed high in foxtail millet (47.6–63.4%); finger millet (24.6–36%), and pearl millet (23–31%; Indira and Naik, 1971; Singh et al., 1987; Geervani and andEggum O., 1989; Himashu Chauhan et al., 2018). Glutelin percentage in different millets was documented as Kodo millet (40–52%); pearl millet (13–30%); finger millet (12–28%) and foxtail millet (5–18%). The type and amount of amino acids may vary in different types of millet. The amino acid profile demonstrated that pearl millet protein is rich in leucine (80–251 $g kg^{-1}$), lysine (17-65 $g kg^{-1}$), tryptophan (11-28 $g kg^{-1}$), aspartic acid (49-103 $g kg^{-1}$) and proline (59-142 $g kg^{-1}$) whereas foxtail millet protein is rich in arginine (27-95 $g kg^{-1}$). Similarly finger millet is rich in phenylalanine (32-84 $g kg^{-1}$); isoleucine (37-85 $g kg^{-1}$); methionine (13-43 $g kg^{-1}$); threonine (27-58 $g kg^{-1}$); valine (58-104 $g kg^{-1}$); Glutamic acid (203-378 $g kg^{-1}$); cysteine (7-29 $g kg^{-1}$); glycine (33-59 $g kg^{-1}$); serine (51-87 $g kg^{-1}$) and tyrosine (20-56 $g kg^{-1}$) Table 3. Protein isolated from proso millet is rich in histidine (18-29 $g kg^{-1}$) and 39-122 $g kg^{-1}$of alanine (Kalaisekar et al., 2016; Kumar et al., 2018; Kaur et al., 2019; Anonymous, 2022).

Fibers: Fibers are one of the essential health-benefiting non-starchy carbohydrates required to maintain a healthy lifestyle. Two different terms are used for the fibers (1) Dietary fibers and (2) Functional fibers. The dilatory fibers refer to those naturally present in the food material. While functioning fibers are artificially added to food materials for health benefits based on solubility, fibers can be categorized into two types (i) soluble fibers and (ii) insoluble fibers. Soluble fibers are typically founding significant amounts in oats, fruits, and legumes and they have the potential to reduce low-density lipoprotein levels and manage blood sugar. Insoluble fibers are commonly found in cereal grains, bran, and vegetables and play an important role in maintaining appetite, reducing the incidence of type-2 diabetes, and preventing constipation. The fiber profile of millets indicates their presence in varies millets such as pearl millet (20.8%) and finger millet (18.6%; Kamath and Belavady, 1980). Scientific studies have demonstrated that pearl millet is a good source of both soluble and insoluble fibers with amounts varying from 2 to 4.5% (Ali et al., 2003; Ragaee et al., 2006). Kodo millet and little millet were observed to contain significant amounts of dietary fibers (37–38%; Malleshi and Hadimani, 1993; Hegde and Chandra, 2005).

Finger millet grains are said to contain essential minerals such as calcium and phosphorus. Compared to other millet species, the grains have the highest concentration of calcium, ranging from 162.0 to 358.0 mg/100 g (Roopa and Premavalli, 2008; Manjula and Visvanathan, 2014; Himashu Chauhan et al., 2018). It is important for growing children, pregnant women, the elderly, and those with obesity, diabetes, and malnutrition (Towo et al., 2006). Phosphorus, another mineral found in millets, contributes to the development of body tissue and energy metabolism (Vanithasri et al., 2012; Joint FAO/WHO Food Standards Programme Codex Committee, 2017), with the concentration of P in millets ranging from 130.0–283.0 mg/g. The iron content of finger millet grains ranges from 3 to 20% (Rajiv et al., 2011; Upadhyaya et al., 2011; Shobana et al., 2013; Shukla and Srivastava, 2014; Dlamini and Siwela, 2015; Puranik et al., 2017), with higher mineral content and amino acid concentration (Table 4), and germinated millet seeds have been found to contain more nutrients and minerals than un germinated seeds (Figure 6), despite the grain being extremely ignored and underutilized (Roopa and Premavalli, 2008; Nithyashree, 2022).

Health benefits of millets

Millets are rich in nutraceutical properties that canhelp prevent varies health problems including high blood pressure, heart disease, cancer, and cardiovascular diseases. They can also reduce the

TABLE 3 Type and concentration of amino acid in different types of millet.

Amino acid	Pearl millet	Foxtail millet	Finger millet	Proso millet	Kodo millet	Reference
Phenylalanine ($g\,kg^{-1}$)	44–56	43–67	32–84	43–56	56–60	McDonough et al. (2000); Waniska and Rooney (2000); Bean et al. (2019)
Histidine ($g\,kg^{-1}$)	18–26	17–40	3–40	18–29	15–22	
Isoleucine ($g\,kg^{-1}$)	36–59	39–76	37–85	31–65	30–77	
Leucine ($g\,kg^{-1}$)	80–251	114–136	64–162	106–154	67–127	
Lysine ($g\,kg^{-1}$)	17–65	16–18	22–55	14–43	30–35	
Methionine ($g\,kg^{-1}$)	15–29	16–31	13–43	13–26	15–18	
Threonine ($g\,kg^{-1}$)	12–49	36–37	27–58	23–45	27–31	
Valine ($g\,kg^{-1}$)	48–70	38–69	58–104	40–65	38–72	
Tryptophan ($g\,kg^{-1}$)	11–28	4–19	10–17	6–17	5–10	
Aspartic acid ($g\,kg^{-1}$)	49–103	64–77	57–100	37–63	61–64	
Glutamic acid ($g\,kg^{-1}$)	123–254	176–199	203–378	149–223	122–339	
Alanine ($g\,kg^{-1}$)	75–105	86–93	59–89	39–122	53–60	
Arginine ($g\,kg^{-1}$)	32–81	27–95	34–82	27–91	36–50	
Cysteine ($g\,kg^{-1}$)	7–28	5–15	7–29	5–28	7–10	
Glycine ($g\,kg^{-1}$)	28–58	28–31	33–59	17–25	30–47	
Proline ($g\,kg^{-1}$)	59–142	105–107	42–101	53–104	53–92	
Serine ($g\,kg^{-1}$)	37–56	46–59	51–87	48–69	40–42	
Tyrosine ($g\,kg^{-1}$)	17–48	22–32	20–56	18–40	34–42	

TABLE 4 Nutritional and mineral composition of millets (per 100 gram edible portion).

Crop	CHO (g)	Protein (g)	Fat (g)	Crude fiber (g)	Ash (g)	Ca (mg)	P (mg)	Fe (mg)	Zn (mg)	Mg (mg)	Reference
Finger millet	72.6	7.7	1.5	3.6	2.7	344	250	6.3	2.3	130	Becker and Lorenz (1978)
Foxtail millet	60.9	12.3	4.3	8	3.3	31	290	2.8	2.4	81	
Proso millet	60.9	12.5	1.1	5.2	1.9	14	206	0.8	1.4	81	
Barnyard millet	65.5	6.2	4.4	13.6	2.2	20	280	8	3	137	Dey et al. (2022)
Little millet	65.6	10.4	1.3	7.6	1.3	16.1	220	1.3	3.7	133	Subramanian and Jambunathan (1980); Subramanian et al. (1981)
Kodo millet	66.2	8.9	2.6	5.2	1.7	15.3	188	2.3	0.7	147	Geervani and and Eggum (1989)
Pearl millet	70.0	8.5	2.7	2.6	2.0	50.0	450	7.5	3.1	137	Gopalan et al. (2009)
Sorghum	70.7	10.4	3.1	2.0	1.8	25	520	5.4	1.7	165	Murty et al. (1985)

occurrence of tumors, improve gastric emptying time, and provide roughage to the gastro intestinal system (FAO of the UNO, 2017). Due to their digestive enzymes, millets are considered alkaline-forming foods that are often recommended for achieving optimal health. Their alkaline properties help maintain the body's proper pH balance, which is essential for preventing illnesses (Obilana and Manyasa, 2002; Liu, 2007; Shobana et al., 2013).

- **Diabetes**: Populations that include millet in their diet have lower incidences of diabetes. Millet phenolics have been found to inhibit enzymes like alpha-glucosidase and pancreatic amylase, reducing postprandial hyperglycemia by partially inhibiting the enzymatic hydrolysis of complex carbohydrates. Inhibitors like aldose reductase prevent the accumulation of sorbitol, reducing the risk of diabetes-induced cataract diseases (Rani et al., 2014). Consumption of finger millet helps control blood glucose levels, improves antioxidant status, and accelerates the dermal wound healing process in diabetic rats. Proper dietary choices and correlations with diabetes severity/risk can help minimize the risk of diabetes symptoms (Greenwood et al., 2013; Sharma and Niranjan, 2018). Along with medication, the selection of suitable food materials and lifestyle changes can help diabetic individuals

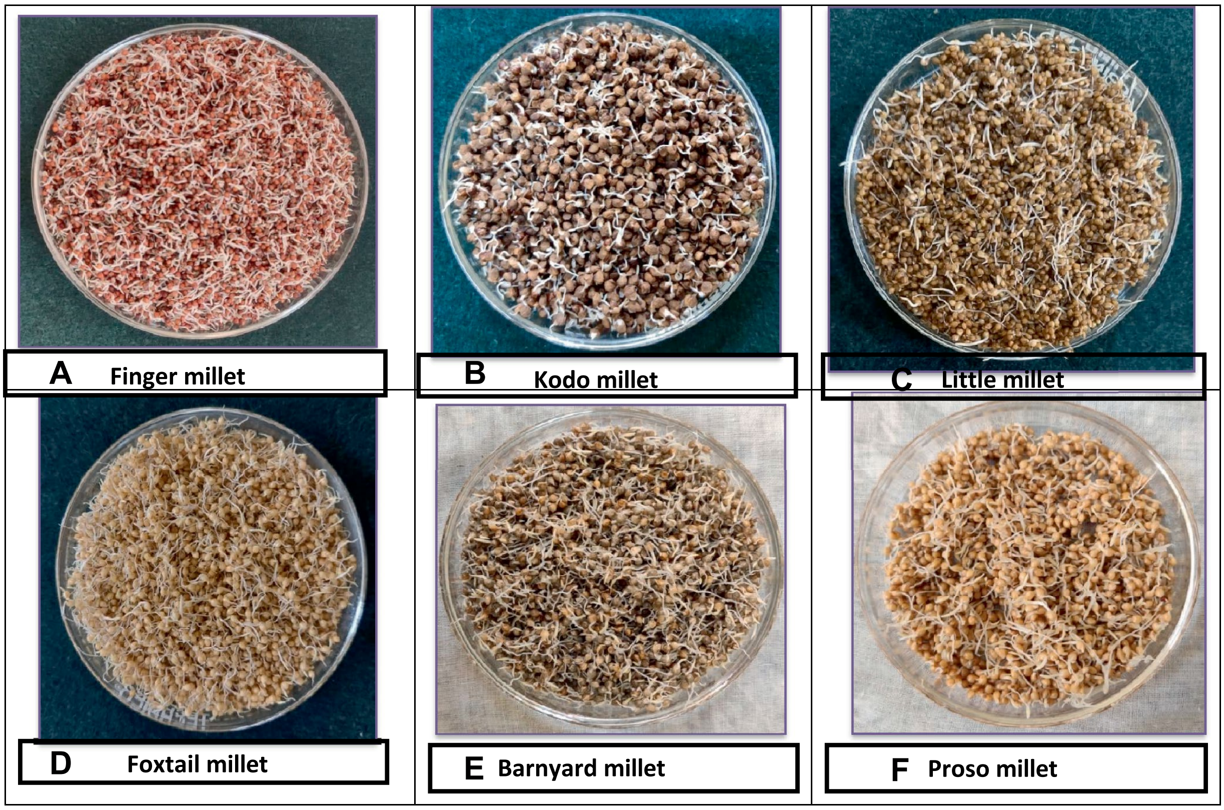

FIGURE 6
Germinated micro greens of small millets (Nithyashree, 2022).

survive. The risk of diabetes symptoms can be minimized by adopting a suitable diet and considering the severity/risk factors (Bangoura et al., 2013). Dietary fibers are essential for boosting gastrointestinal functionality and reducing serum glucose spikes. Studies on millets have demonstrated significant cholesterol level management with regular consumption (Anderson et al., 2009; Bangoura et al., 2013; Sharma and Niranjan, 2018). Bangoura et al. (2013) reported that insoluble fibers in foxtail millet may delay glucose diffusion and promote absorption in the intestinal tract. The consumption of millet and millet-based food products inhibits the activity of α-amylase, affecting carbohydrate digestibility and slowing the release of glucose. Millets and their products are ideal for improving insulin sensitivity during diabetes mellitus (Ju-Sung et al., 2011). In addition to managing insulin and glucose levels, millets help manage elevated cholesterol levels and reduce the risk of cardiovascular disorders (Anderson et al., 2009; Lee et al., 2010; Sireesha et al., 2011). A study (Kumari and Sumathi, 2002) on *dosa* (a south Indian dish) prepared from finger millet found that its consumption resulted in a significant decrease in plasma glucose levels with less peak rise. During diabetic conditions, the body's capacity to heal wounds decreases significantly. The abnormal physiological response is due to damages caused by free radicals in cells, leading to necrosis and deeper wounds (King, 2001). Including antioxidant-rich foods in the diet increases the body's potential for wound healing (Rajasekaran et al., 2004). A study on the effect of finger millet consumption in diabetic rats for nerve growth factor production and wound healing showed that including finger millet in the diet enhances wound healing capability. The regular consumption of millet, especially finger millet, is associated with a lower risk of diabetes and gastrointestinal disorders (Tovey, 1994). Sireesha et al. (Sireesha et al., 2011) reported the anti-hyperglycemic potential of foxtail millet aqueous extracts in streptozotocin-induced diabetic rats, showing a significant decrease (70%) in blood glucose levels with a specific extract dose (300 mg/kg). Choi et al. (Choi et al., 2005) demonstrated that foxtail millet can manage cholesterol and insulin levels (Kumari and Sumathi, 2002). observed that the consumption of millet regulates protein concentration (C-reactive) and lipid levels with a decrease in triglyceride levels. Millet grains are well-documented for their health-benefiting phenolic compounds, tannins, and antioxidant potential (Chandrasekara and Shahidi, 2010; Lee et al., 2010; Chandrasekara and Shahidi, 2011; Chandrasekara and Shahidi, 2012; Salar et al., 2016; Siroha et al., 2016; Salar and Purewal, 2017; Purewal et al., 2020; Sandhu et al., 2020). The consumption of millet is reported to decrease the chances of cancer initiation, especially esophageal cancer (Van Rensburg, 1981). One of the main reasons for the increasing popularity of millets is their gluten-free nature. Millet-based products are becoming more popular worldwide because they are both tasty and beneficial for health. Celiac disease is a significant issue faced by people worldwide (Chandrasekara and Shahidi, 2011). This autoimmune disorder is triggered by gluten consumption and causes damage to the small intestine. The gluten-free nature of millet-based products can be a boon for patients suffering from celiac disease (Taylor et al., 2006; Taylor and Emmambux, 2008).

- **Cardio vascular Disease**: Millets are excellent sources of magnesium, which is known to reduce the risk of migraine and heart attacks. Millets are also rich in phytochemicals that contain phytic acid, which helps lower cholesterol levels (Coulibaly et al., 2011). Additionally, finger millet has been found to prevent cardiovascular disease by reducing plasma triglycerides in hyperlipidemic rats (Miller, 2001; Edge et al., 2005; Lee et al., 2010).
- **Celiac Disease**: Celiac disease is an immune-mediated enteropathy triggered by gluten consumption in genetically susceptible individuals. For those with celiac disease or gluten sensitivity, millets can serve as an excellent alternative, as they are gluten-free. Unlike wheat and other commonly used cereal grains, millets do not contain gluten, making them an excellent choice for individuals sensitive to gluten, who may experience irritation from the gluten content in other grains (Catassi and Fasano, 2008; Saleh et al., 2013).
- **Cancer**: Millets are known for their high levels of phenolic acids, tannins, and phytate, which are often referred to as "anti-nutrients" due to their potential to interfere with nutrient absorption. However, these anti-nutrients may also have positive health benefits. Studies have shown that they can reduce the risk of colon and breast cancer in animals. Additionally, research has demonstrated that millet phenolics may be effective in preventing the initiation and progression of cancer cells in laboratory studies (Siroha et al., 2016).
- **Antimicrobial potential**: Antimicrobial agents have the potential to control or kill microbial strains, including fungi and bacteria (Rani et al., 2014). The antimicrobial potential of natural resources can be evaluated based on the zone of inhibition against microbial strains. During antimicrobial assays, a suitable amount of extract (e.g., 100 μL or 150 μL) is added to a slot created using a cork borer in the nutrient media. The nutrient media provide favorable conditions for the growth of microorganisms, and the extract plays a role in inhibiting their growth. The results are easily observed by the naked eye in the form of a zone of inhibition (an area where microorganisms fail to grow). Fractions of millet and extracts prepared from them are well-documented for their antimicrobial potential. Taylor and Emmambux (2008) demonstrated that extracts prepared from seed coat have significant antimicrobial potential against *B. cereus* and *A. flavus*. Their findings support the idea that adding finger millet to the diet can be beneficial for health. Bisht et al. (Bisht et al., 2016) studied proso millet and finger millet for their antimicrobial potential, finding that finger millet had greater antimicrobial potential (22.6 mm) compared to proso millet (15.6 mm) against gram-positive bacteria. Amadou et al. (Van Rensburg, 1981; Viswanath et al., 2009) studied the antimicrobial potential of finger millet extracts against *E. coli, S. typhi*, and *S. aureus*, observing zone of inhibition during the antimicrobial assay against *E. coli* (18.4 mm), followed by *S. aureus* (17.3 mm) and *S. typhi* (17 mm). Ogbeba (Ogbeba, 2019; Purewal et al., 2019) reported antimicrobial activity of finger millet extracts against *P. aeruginosa, E. coli*, and *S. aureus*. The study showed that different concentrations of finger millet extracts at 100 mg/mL resulted in a zone of inhibition against *P. aeruginosa* (8 mm), followed by *S. aureus* (5 mm) and *E. coli* (4 mm).
- **Anti-Inflammatory Activity**: Ferulic acid, an extremely potent antioxidant with anti-inflammatory properties, can scavenge free radicals. Antioxidants can effectively prevent tissue damage and promote the wound-healing process. Studies have shown that finger millet has good antioxidant effects on the dermal wound healing process in rats with diabetes-induced oxidative stress-mediated inflammation (Rajasekaran et al., 2004).
- **Aging**: The non-enzymatic glycosylation process, involving the interaction of proteins' amino groups with reducing sugars' aldehyde groups, is a major cause of diabetes complications and aging. Millets are rich in antioxidants and phenolics, including tannins, phenols, and phytates. These substances may enhance antioxidant activity, crucial for maintaining good health, and delaying the onset of metabolic syndrome, and aging (Hegde and Chandra, 2005).
- **Other health benefits**: The mineral profile of millets shows that they are a good source of minerals, especially potassium and magnesium, which play a role in maintaining blood pressure and reducing the risk of strokes and heart attacks. Antioxidant properties in millets help combat cancer, diabetes, and chronic disorders. The fibers, minerals, and other important nutrients in millets help the body eliminate toxic compounds. The fibrous nature of millet grains reduces the formation of gallstones and aids in maintaining body weight.

Challenges in millet production

1. Decline in the area under millet cultivation: Previously, millets were cultivated across an area of 35 million hectares of land. However, due to low yields, time-consuming and laborious processing methods, primarily undertaken by women, and minimal marketing and processing into value-added products, they are now being grown in only 15 million hectares of land. In the 2019–20 period, the total off-take of cereals through the Public Distribution System (PDS), Integrated Child Development Scheme (ICDS), and school meals amounted to approximately 54 million tonnes. If 20% of rice and wheat were to be replaced by millet, the state would have to procure 10.8 million tonnes of millet.
2. Low productivity of millets: In the past decade, sorghum production has dwindled, pearl millet output has plateaued, and other millets, such as finger millet, have either remained stagnant or experienced a decline.
3. Lack of awareness: Many people in India are not aware of the health benefits of millet, leading to low demand.
4. High cost: Millets often come with a higher price tag compared to traditional cereals, posing accessibility challenges for low-income consumers.
5. Limited availability: Millets are not widely available in traditional and modern (e-commerce) retail markets, making it difficult for consumers to purchase them.
6. Perceived taste: Millets face limited presence in both traditional and modern retail markets (e-commerce), creating obstacles for consumers seeking to purchase them.

7 Agricultural hurdles: Millet cultivation is frequently associated with low yield and limited profitability, discouraging farmers from cultivating them.
8 Competition with rice and wheat: Rice and wheat, as staple foods in India, enjoy widespread availability, presenting a formidable challenge for millets to establish a competitive presence in the market.
9 Insufficient government support: The lack of substantial government backing in India has hindered the promotion of millet cultivation and consumption, impeding their overall growth.
10 Decentralized processing: Processing millets poses several challenges, mainly due to the differences in size among various millet types and the low shelf life of processed millets. The grains vary in shape, grain surface nature, hardness, and husk-grain bonding. Additionally, there can be variations within the same small millet crop due to differences in varieties, cultivation practices, and microclimate across production regions.
11 Marketing and market linkages: The millet supply chain is facing challenges due to inconsistent supply and demand, which is hampering its commercial viability. Low crop productivity is a result of the lack of access to high-yielding (HYV) seeds, while limited awareness about the nutritional benefits of millets has contributed to their low adoption as a ready-to-cook cereal. Furthermore, sub-optimal reach, lower price realization, and wastage are the consequences of limited distribution and market knowledge.
12 Shelf life augmentation: Millets are highly nutritious foods that have been proven to have numerous health benefits. However, millets have a poor shelf life once they are processed due to their intrinsic enzyme activity, which causes rapid rancidity and bitterness, as well as lipid oxidation. Millet products are also prone to moisture and water activity, which can further reduce their quality. Therefore, ensuring the quality assurance of millet products greatly depends on different pre-treatments and storage conditions.

Emerging opportunities

1 Climate-resilient staple food crops: Millets are a suitable food crop for drought-prone areas due to their drought-resistant nature, low water requirement, and ability to grow in poor soil conditions (Hu et al., 2022; Jiang et al., 2023).
2 Rich in nutrients: Millets contain a good amount of fiber, protein, vitamins, and minerals (Chandrasekara and Shahidi, 2010; Amadou et al., 2011; Chandrasekara and Shahidi, 2012).
3 Gluten-free: Millets are inherently gluten-free, making them appropriate for individuals with celiac disease or gluten intolerance.
4 Adaptable: Cultivable in diverse soils and climates, millets emerge as a versatile crop choice for farmers.
5 Sustainable: Millets are often grown using sustainable and environmentally friendly traditional farming methods, and India has a vast range of varieties and hybrids available.

Promoting millet cultivation

The Millets Export Promotion Program has been launched following India's proposal endorsed by the United Nations General Assembly (UNGA) to declare 2023 as the International Year of Millets (IYM). In a recent development, the Indian government proposed to the United Nations to declare 2023 as the International Year of Millets (IYM). This proposal garnered support from 72 countries, following which the United Nations General Assembly (UNGA) declared 2023 as the International Year of Millets. As part of this declaration, India will celebrate IYM 2023 as a People's Movement to showcase Indian millets, recipes, and value-added products on a global platform.

Measures for the promotion of millets

The Indian government is planning to help exporters, traders, and farmers participate in 16 international trade expos and Buyer Seller Meets (BSMs). To promote Indian millets, Indian missions abroad will be involved in branding and publicity efforts, while Ambassadors of Foreign missions in India will be invited to showcase various millet-based products to potential importers from targeted countries.

Promotional activities: India's Agricultural and Processed Food Products Export Development Authority (APEDA) has announced plans to promote millets in various countries around the world. Promotional activities will take place in South Africa, Dubai, Japan, South Korea, Indonesia, Saudi Arabia, Sydney, Belgium, Germany, the United Kingdom, and the United States of America. Indian millets will also be showcased on global food platforms, including Gulfood 2023, Foodex, Seoul Food & Hotel Show, Saudi Agro Food, Belgium's Food & Beverages Show, Fine Food Show in Sydney, Germany's BioFach and Anuga Food Fair, and San Francisco's Winter Fancy Food Show. To familiarize consumers with millet products, APEDA will organize food sampling and tasting at the retail level and in key local bazaars in the targeted countries. Additionally, the Indian government is supporting startups in the exports of value-added products in the 'Ready to Eat' and 'Ready to Serve' categories, such as noodles, pasta, breakfast cereals mix, biscuits, cookies, snacks, sweets, etc.

Other measures: Identifying international chefs and potential buyers, such as departmental stores, supermarkets, and hypermarkets, for communication and tie-ups. India is one of the world's largest millet producers, accounting for about 41% in 2020. India's millet production growth was 27% in 2021–22 compared to last year's millet production. The share of millet exports is almost 1% of the total millet production. Exports of millet value-added products from India are small. Major importers of Indian millet include the United Arab Emirates, Nepal, Saudi Arabia, Libya, Oman, Egypt, Tunisia, Yemen, Great Britain, and the United States.

Research and innovation

Globally, millets have received very limited research on the development of plant varieties to improve yield traits and resistance to biotic and abiotic stress (Yi et al., 2022; du et al., 2024). Most of the varieties that have reached the market worldwide have been produced by land breeding through pure line selection. In India, the All India

Coordinated Small Millet Research Project (AICRP-Small Millet) was launched in 1986. The AICRP-Small Millet research project is implemented through a network of 13 centers located in State Agricultural Universities, ICAR Institute, and 22 cooperative centers. AICRP-Small Millet is responsible for planning, coordinating, and implementing research programs to increase the production and productivity of all large and small millets. The research focus of the project is on developing agricultural production technology appropriate to national/regional needs to maximize production/productivity. Yield improvement with institutes Small Millet resulted in the development of high-yield cultivars resistant to blast disease, high-quality nutrition, early and mid-maturing varieties, and white and bright-seeded finger millet, resistance to collaring and indecisiveness in domestic millet, and resistance to shoot flies in both proso and small millets. A total of 250 varieties in six small millets have been released in India so far.

Conclusion

Millets are a precious gift from nature to humanity. They contain a wealth of micronutrients, such as B-complex vitamins and minerals, deficiencies of which are rampant in India. Non-communicable diseases are increasing globally, but millets can help counter these issues due to their high fiber content and health-promoting phytochemicals, which function as antioxidants and immune stimulants. Therefore, millet can be considered as important functional food. However, some of these phytochemicals, such as polyphenols, phytates, and tannins, can interfere with the bioavailability of micronutrients, especially minerals. Awareness can be raised through training programs on the beneficial effects of processing methods on millets for the general population. More research is needed to develop high-yielding varieties and processing and utilization technologies, as well as policy interventions to promote millet cultivation and diversify dietary patterns to ensure healthy lives and face the threats of global malnutrition and climate change. Being gluten-free, millets could be recommended for a majority of people who are suffering from celiac disease. To meet the increasing demand for health-benefiting food products, millets could serve as a suitable substrate. Millet grains are easily available in the market at affordable prices, so they could be industrially used for the preparation of various processed product formulations. The presence of specific compounds with antioxidant properties makes millet an important cereal grain that is pharmacologically important. Regular consumption of millet helps to eradicate the occurrence of diseased conditions. Every age group could use millet and millet-based bakery products to sustain a healthy life.

Author contributions

MH: Conceptualization, Funding acquisition, Investigation, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AB: Conceptualization, Investigation, Project administration, Supervision, Visualization, Writing – review & editing. BC: Funding acquisition, Investigation, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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