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Diksha Bhatt
Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Munavirul Fairos
Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Ayushi Mazumdar
Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India,

Corresponding Author
Diksha Bhatt
Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Millets: Nutritional composition, production and significance: A review

Diksha Bhatt, Munavirul Fairos and Ayushi Mazumdar

Abstract
Millets are minor cereals crops belonging to the Poceaea family and are drought resistant and can survive various climatic conditions. They are rich in protein and, most importantly gluten-free. They are a rich source of phytochemicals with medicinal properties in the form of antioxidant activities, which helps lower many health diseases. Millets are a staple food for many African and Asian countries, providing food security worldwide. They are categorized as major and minor millets, including sorghum, pearl and finger millet, while proso, barnyard, kodo, little and foxtail millets come under minor millets. This review focuses on the different varieties of millets, their global production, their nutritional composition, and their bioactive compounds. The paper describes millets' nutritional value, promoting the requirement of research on the nutritional properties and functional capabilities of various millet varieties.

Keywords: Millet, sorghum, pearl, finger, kodo, proso, foxtail, barnyard, global millet production

1. Introduction
Millets belong to minor cereals in the grass family Poaceae. Millets are cereal crops grasses with small-seeded structures planted in diverse tropical and desert climates with the capacity to thrive in less rich soil (Shobana *et al*., 2013) [45]. Millets are the world's sixth most important cereal grain, providing nourishment and energy to millions of people in India, Africa, and China, particularly in dry and semiarid areas (Das *et al*., 2019) [9]. They are higher in nutrients than other main grains and are frequently referred to as "Nutri-Cereals" due to their higher nutritional content than commonly manufactured major cereals (FAO, 2018) [14]. According to the Indian Council of Agricultural Research and the Indian Institute of Millets Research (ICAR-IIMR), Nutri-cereals are extremely nutritious grains with the same amount of nutrients as frequently eaten cereal foods (Saini *et al*., 2021) [37]. Millets are an essential source of nutrition for millions of people worldwide, notably in hot and dry climates (Amadou *et al*., 2013) [1]. Millets are the world's sixth most important crop, feeding one-third of the global population (Saleh *et al*. 2013) [38]. They are annual small-seeded grain crops farmed worldwide for food, feed, fodder, and oil and come in over 20 different varieties (Das *et al*., 2019) [9]. They include Sorghum (*Sorghum bicolor* L.), Pearl millet (*Pennisetum glaucum*), Finger millet (*Eleusine coracana*), Kodo millet (*Paspalum setaceum*), Proso millet (*Penicum miliaceum*), Foxtail millet (*Setaria italic*), Little millet (*Panicum sumatrense*), and Barnyard millet (*Echinochloa species*) (Saleh *et al*., 2013) [38]. Millets are mainly categorized into two categories: Major millets and minor millets. Sorghum, pearl and finger millet or ragi are major millets, while kodo, barnyard, proso, tiny, and foxtail millet are minor millets (Banerjee and Maitra, 2020) [4]. Compared to many other crops, millets can produce much higher yields on minimal soils with low fertility and low input farming techniques and have the potency to be a saviour for the world's increasing population, hunger, and food shortages (Das *et al*., 2019) [9].

2. Types of millet
2.1 Pearl millet
Pearl millet (*Pennisetum glaucum* L.) is the sixth most important grain in the world and the principal source of food in Asia and Africa's semiarid regions (Pattanashetti *et al*., 2016) [50]. Pearl millet was cultivated at least 3000 years ago on the borders of the Sahara Desert when the current drying era caused a transition from Mediterranean cereals to other species better suited to shifting weather patterns and rising aridity (Bidinger and Hash, 2004) [4]. Pearl millet (*Pennisetum typhoides*), a resistant cereal crop compared to wheat and rice, is cultivated in places with deficient rainfall (Jain and Bal, 1996) [21]. Among all millet types, pearl millet covers more than 29 million hectares of land, despite its geographical distribution being

restricted to Africa (15 million) and Asia (11 million), where it is the largest producer (Rathore *et al*., 2016) [34]. More than 95 percent of pearl millets are grown in developing countries, with India leading the way with 9.8 million hectares of total world production (Rani *et al*., 2017) [33]. (Rathore *et al*., 2016) [34]. It is the fourth most important tropical cereal after rice, maize, and sorghum (Bidinger and Hash, 2004) [4]. The principal producers of this crop include Ethiopia, Malawi, Sudan, Zimbabwe, Kenya, Tanzania, Uganda, Zambia, Somalia, Botswana, India, and others (Jain and Bal, 1996) [21]. Because of its versatility, pearl millets are often produced in marginal, arid, and semiarid tropical and subtropical settings; its two primary cultivation zones are arid to semiarid (Bidinger and Hash, 2004) [4]. Because of its high oil content (4-9%), pearl millet may be readily kept at low temperatures and moisture levels. It also contains considerable amount of folate, copper, zinc, iron, magnesium, calcium, vitamin B complex, and unsaturated fatty acids (Saini *et al*., 2021) [37].

2.2 Sorghum

Sorghum (*Sorghum bicolor* L.) is an African cereal crop domesticated between 3,000 and 5,000 years ago (Cardoso *et al*., 2015) [11]. Sorghum is the world's fifth most important cereal crop, capable of being grown in a range of climates and widely cultivated as a grain, sweet, forage, low-lignin, and biomass crop (Stamenkovic *et al*., 2020). Most sorghum varieties can withstand drought and are heat-tolerant, which is significant in arid climates (Ratnavathi and Komala, 2016) [35]. Sorghum output in 2021 was predicted to be about 3.5 million tonnes, 32% less than the previous year (2020) and 28% less than the five-year average (FAO, 2021) [15]. Sorghum is one of the most significant cereal crops among all millets, and it is more nutritious than other cereals such as rice and wheat (Ratnavathi and Komala, 2016) [35]. Cultivable sorghum has developed from its original form into five main major species (*bicolor, guinea, caudatum, kafir, and durra*) and 10 intermediate races, all of which are hybrids of major races based on panicle structure and spikelets (Wang *et al*., 2016) [52]. *S. bicolor* is a worldwide grown crop used for food, fodder, alcoholic beverages, and biofuels (Ratnavathi and Komala, 2016) [35].

2.3 Finger millet

Finger millet (*Eleusine coracana* L.) is an allotetraploid crop that originated from the *crop E. coracana* subsp. *Africana*. The *Eleusine* genus has around ten species, including annuals and perennials variants (Vetriventhan *et al*., 2016) [50]. Finger millet is a grain crop used for food in Africa and Southern Asia, particularly in India (Dida and Devos, 2006) [13]. It is known as *Koracan* in Sri Lanka and other names in Africa and has historically played a key role in staple diets, particularly in eastern and central Africa, as well as in India (Shobana *et al*., 2013) [45]. Farming of finger millet most likely started approximately 5000 years ago in Western Uganda and the Ethiopian highlands, and the crop spread to India's Western Ghats around 3000 BC (Vetriventhan *et al*., 2016) [50]. Each year, 3834,021 tonnes of finger millet grains are produced globally and the worldwide production area of finger millet is projected to account for around 12.5 percent of millet output (Gebreyohannes *et al*., 2021) [16]. Finger millet grows well in various tropical soils, including red lateritic, sandy loams, and heavy black vertisols, and may be grown as a drought crop in areas with as little as 500 mm of annual rainfall (Dida and Devos, 2006) [13]. Finger millet is high in nutrients, including calcium, iron, phosphorus, zinc, potassium, other minerals, and fibre, as well as various phenolic compounds that could have health benefits (Singh *et al*., 2016) [34].

2.4 Foxtail millet

The foxtail millet (*Setaria italica* L.) is an essential old dry land crop that has been grown in China for over 10,500 years and belongs to the Panicoideae subfamily and the Paniceae tribe (Vetriventhan *et al*., 2016) [50]. It is a cereal grain that belongs to the Setaria genus of the Poaceae family and subfamily Panicoideae (Sharma and Niranjan, 2018) [42]. Foxtail millet is one of the world's oldest cultivated crops and is commonly produced in semi-arid parts of Asia and Africa, as well as some other industrialized nations, for use as bird feed (Sharma and Niranjan, 2018) [42]. After pearl millet, foxtail millet is the second most significant millet crop. Foxtail millet is widely grown for grain and fodder throughout Asia, Europe, North America, Australia, and North Africa, and it is a staple food in China, India, Korea, and Japan (Vetriventhan *et al*., 2016) [50]. It is an annual grass plant that produces seeds with health-promoting benefits due to its unique protein composition, which has a high concentration of essential amino acids (Sachdev *et al*., 2020) [36]. This millet has 12.3% crude protein and 3.33% minerals (Pawar and Machewad, 2006) [31]. Except in a few commercial situations where processing equipment is now accessible, foxtail millet has traditionally been cultivated for local use, and applications are limited to grazing, fodder, or silage (Sachdev *et al*., 2020) [36].

2.5 Proso millet

Proso millet (*Panicum miliaceum* L.) is an annual herbaceous plant of the Panicum genus (Upadhyaya *et al*., 2016) [30]. With a growing season of about 10-11 weeks, proso is the oldest summer grain used by humans, apart from wheat and barley (Kalinova and Moudry, 2006) [23]. Proso millet, also known as broomcorn millet, common millet, hog millet, and Russian millet, is a grain that is widely grown in Asia, Australia, North America, Europe, and Africa. It is used for animal feed in industrialized nations and food in certain Asian areas (Upadhyaya *et al*., 2016) [30]. Proso millet is extensively farmed in India, China, Nepal, Africa, Russia, Ukraine, Belarus, the Middle East, Turkey, and Romania and is one of the most delicate crops for rainfed agricultural systems with an annual rainfall of less than or equal to 100mm (Das *et al*., 2019) [9]. Proso millet, as well as barnyard, kodo, tiny, finger, and foxtail millets, is used as a substantial nutritional component in a range of traditional dishes and drinks, such as bread, porridges, and snack foods, while grains given to animals such as pigs, fowls, and cage birds (Upadhyaya *et al*., 2016) [30]. Despite providing one-third of protein and energy in developing countries, proso millet is underused, with birdseed companies holding most of the market share (Das *et al*., 2019) [9].

2.6 Kodo millet

The kodo millet (*Paspalum scrobiculatum*) is a popular crop in India, Pakistan, the Philippines, Indonesia, Vietnam, Thailand, and West Africa (Deshpande *et al*., 2015) [12]. Kodo millet originated in India, produced on poor soils, and dispersed widely in arid and semi-arid parts of India and African countries (Bunkar *et al*., 2021) [6]. Kodo millet is also known as cow grass, rice grass, ditch millet, Native Paspalum,

or Indian Crown Grass, and is commonly farmed by tribal people in tiny regions across India under different names (kodo, khoddi, arugu, varagu), mandal in Pakistan (Upadhyaya *et al*., 2016) [30]. Kodo millet is high in vitamins, minerals, and sulfur-containing phytochemicals, as well as essential amino acids such as lysine, threonine, valine, and sulfur-containing amino acids (Bunkar *et al*., 2021) [6]. Because of their high fibre content, polyphenols, and protein composition may significantly contribute to the nutritional security of a vast portion of the population (Sharma *et al*., 2017) [44]. Kodo millet has the highest dietary fibre concentration of any millet, making it an ideal food for diabetic patients. It also has a high protein content, a low fat content, a significant amount of vitamins like folic acid (B9), niacin (B3), pyridoxine (B6), and some minerals like calcium, iron, magnesium, potassium, and zinc (Saini *et al*., 2021) [37].

2.7 Barnyard millet

Barnyard millet (*Echinochloa species*) is the oldest millet crop used in tropical and temperate climates across Asia, including India, China, Japan, and Korea (Madhusudhana *et al*., 2018) [26]. Barnyard millet is also known as Japanese barnyard millet (*Echinochloa crus-galli*), Indian barnyard millet (*Echinochloa colona*), cockspur grass, Korean native millet, prickly millet, sawa millet, and watergrass (Upadhyaya *et al*., 2016) [30]. Barnyard millet is an ancient millet grown in warm and temperate climates, primarily in India, China, Japan, and Korea (Madhusudhana *et al*., 2018) [26]. Echinochloa has about 250 annual and perennial species commonly farmed in all agro-climatic zones across the globe (Bajwa *et al*., 2015) [3]. Barnyard millet is a fast-growing millet crop typically harvested in 6 weeks and is also known as Swank or Shyama (Saini *et al*., 2021) [37]. Barnyard millet is considered a functional food crop due to its high vitamin content and antioxidant properties, and millet grains are gluten-free, providing strong potential for their usage as health foods (Sood *et al*., 2015) [47].

3. Global production of millets

Millets are produced in 93 countries worldwide, with just seven countries having more than one million hectares of millet land while developing countries account for more than 97 percent of millet production and consumption. It is predicted that between 1961 and 2018, 25.71 percent of the land under millets cultivation dropped throughout the continents. However, worldwide millet production has improved by 36% since 1961, from 575 kg/ha in 1961 to 900 kg/ha in 2018. (Meena *et al*., 2021) [27]. According to USDA 2016-17 data, Africa and Asia account for approximately 96.89 percent of total millet production, estimated at 27,572,961 tonnes, followed by the European Union (1.81 percent) with a total production of approximately 514,248 tonnes and America (1.18 percent) with 335, 698 tonnes. In contrast, countries of the Australian subcontinent contribute only 36,112 tonnes, i.e., only 0.127 percent of total global production. With 15 million tonnes, pearl millet accounts for about half of worldwide millet output, followed by foxtail millet (5 million tonnes), proso millet (4 million tonnes), and finger millet (around 3 million tonnes) (Chandra *et al*., 2021) [7]. According to FAO Stat 2021 [15], the worldwide average yield of millets is 1229 kg/ha, whereas India's average yield is (1239 kg/ha). India produces more than 170 lakh tonnes of millets, accounting for 80% of Asia's and 20% of global output (Ministry of Agriculture & Farmers Welfare, 2022) [28]. According to FAO STAT 2021 [15], Africa produces millet in the largest region of 489 lakh ha with the cultivation of 423 lakh tonnes in 2019, followed by America, Asia, Europe, Australia, and New Zealand (Figure 1) with a total area of 138 lakh ha and a production of 863 lakh tonnes (Ministry of Agriculture & Farmers Welfare, 2022) [28].

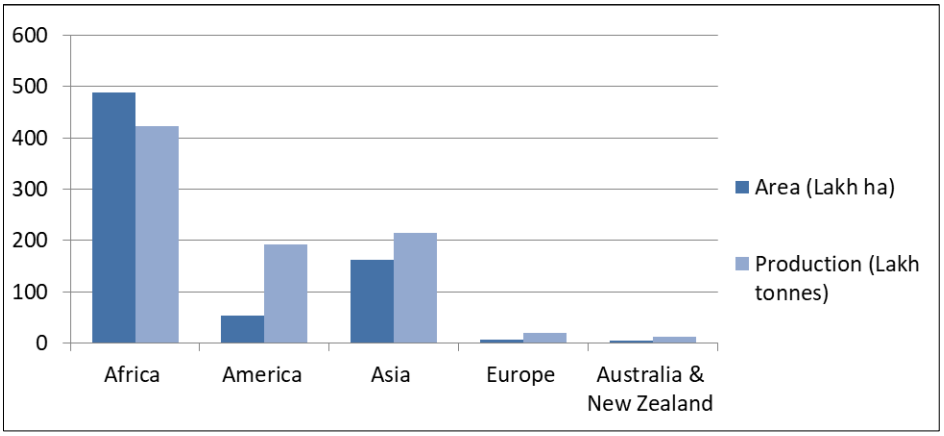

Fig 1: Global millet production based on area and production (Source: Ministry of Agriculture & Farmers Welfare, 2022) [28]

4. Nutritional composition of millets

Millets are essential in maintaining nutritional security for people all over the globe by offering calories and protein (Serna-Saldivar *et al*., 2016) [41]. Millets are distinguished from cereals by their high calcium levels, dietary fibre, polyphenols, and protein (Amadou *et al*., 2013) [1]. Millets are a nutrient-dense food that contains 60-70 percent dietary carbs, 6-19 percent protein, 1.5-5 percent fat, 12-20 percent dietary fibre, 2-4 percent minerals, and various additional phytochemicals (Haldimani *et al*. 1995). They are high in vitamin B, magnesium, and antioxidants (Sarita and Singh, 2016) [34]. Millets are high in macronutrients and micronutrients, and their mineral and essential amino acid content is higher than wheat and rice (Sharma *et al*., 2021) [32]. Among all millets, finger millet has the most excellent carbohydrate content at 72.05 g/100g, followed by proso millet at 70.4 g/100g, barnyard millet at 68.8 g/100g, pearl millet at 67.0 g/100g, kodo millet at 66.6 g/100g, and small millet at 65.55 g/100g. Foxtail millet has the lowest carb (Table 1). Proso millet has the most effective protein content at roughly 12.5 g/100gm, followed by pearl, foxtail, barnyard, kodo, tiny, and finger millet at 11.8 g/100gm, 11.2 g/100gm, 10.5 g/100gm, 9.8 g/100gm, and 7.3 g/100gm, respectively (Table 1). Proso millet has the most fibre, with around 14.2

g/100g. Micronutrients are vitamins and minerals, and millets have high mineral content, including phosphorus, calcium, iron, zinc, magnesium, potassium, sodium, manganese, and copper (Table 2). Millets are also high in vitamins, including thiamine (0.55 mg/100g in proso millet), riboflavin (2 mg/100g in kodo millet), and niacin (5.11 mg/100g in proso millet). Phytochemicals are non-nutritive compounds that provide a variety of health advantages. Kodo millet has a moderately high total phenol and flavonoid content, with 19.7 mg gallic acid equivalent/g and 11.1 mg catechin equivalent/g. Pearl millet has the greatest phytosterol content, with 58 mg/100g.

Table 1: Nutritional composition of Millets (mg/100 g)

Millets	Carbohydrates	Protein	Fat	Minerals	Fibre	References
Pearl millet	67.0	11.8	4.8	2.2	2.3	(Muthamilarasan *et al*., 2016) [29]
Finger millet	72.05	7.3	1.3	2.7	11.5	(Shobana *et al*., 2013) [45]
Foxtail millet	63.2	11.2	4.0	3.3	6.7	(Jaybhaye *et al*., 2014) [22]
Kodo millet	66.6	9.8	3.6	3.3	5.2	(Saleh *et al*., 2013) [38]
Proso millet	70.4	12.5	3.1	1.9	14.2	(Habiyaremye *et al*., 2017) [17]
Little millet	65.55	8.92	2.55	1.72	6.39	(Dayakar Rao *et al*., 2017) [10]
Barnyard millet	68.8	10.5	3.6	2.0	12.6	(Ugare *et al*., 2011) [49]

Table 2: Mineral nutritional composition of Millets (mg/100 g)

Millets	Ca	P	Fe	Mg	K	Na	Mn	Cu	Zn	References
Pearl millet	46	379	8.0	137	442	12.0	1.8	1.06	3.1	(Himanshu *et al*., 2018) [20]
Finger millet	137.33	158.43	1.46	6.38	35.19	3.70	2.85	0.06	0.48	(Sanusi *et al*., 2019) [39]
Foxtail millet	23	310	3.2	130	270	10	2.2	0.9	2.1	(Serna-Saldivar *et al*., 2019) [41]
Kodo millet	32.33	300	3.17	110	141	4.8	1.10	1.60	32.7	(Kumar *et al*., 2018; Chandra *et al*., 2016) [24, 8]
Proso millet	10	200	2.2	120	210	10	1.8	0.8	1.7	(Kumar *et al*., 2018; (Serna-Saldivar *et al*., 2019) [24, 41]
Little millet	30	260	20	133	370	8.1	20	4	11	(Himanshu *et al*., 2018) [20]
Barnyard millet	22	280	18.6	82			0.96	0.60	3	(Chandra *et al*., 2016) [8]

5. Significance of Millets

Millets are rich in minerals and phytic content, are a staple diet in many African and Asian countries. Millet has the lowest agricultural production cost of any grain (Hasan *et al*. 2021). Previous therapeutical investigations on millets have shown their nutritional qualities regarding the antioxidant activity. Millets contain bioactive substances that have the potential to lower the risk of various illnesses, including cardiovascular disease, diabetes, high blood pressure, and cancer (Sharma *et al*., 2021) [32]. Millets include antioxidants such as phenols, tannins, and flavanoids in addition to their nutritional benefits (Liang and Liang, 2019) [25]. Millets may decrease -glucosidase and pancreatic amylase levels, lowering postprandial hyperglycemia by reducing carbohydrate complexes through enzymatic hydrolysis. Furthermore, because of the presence of magnesium, millets can potentially reduce Type II diabetes. Magnesium is an essential element that helps insulin and glucose receptors operate by releasing enzymes that break down carbs and influences insulin activity (Ambati and Sucharitha, 2019) [2].

It has been found that soluble- and insoluble-bound phenolic extracts of numerous millet whole grains (kodo, finger, foxtail, proso, pearl, and little millets) are high in phenolic compounds and have antioxidant, metal chelating, and reducing properties (Saleh *et al*., 2013) [38]. Fermented millet products are a natural probiotic therapy for diarrhoea in young children, and millet's whole grain has prebiotic action, which helps boost the population of friendly bacteria, which is vital for digestion (Sarita and Singh, 2016) [34]. Consumption of whole-grain meals has been considered advantageous for preventing and controlling diabetes mellitus, and millet-consuming communities had an epidemiologically reduced incidence of diabetes (Saleh *et al*., 2013) [38]. Celiac disease is an immune-mediated enteropathy caused by gluten consumption in genetically sensitive people. Millets are gluten-free, making them an ideal choice for people with celiac disease and gluten-sensitive individuals (Sarita and Singh, 2016) [34]. Millet grains are high in antioxidants and phenolics; nevertheless, it has been shown that phytates, phenols, and tannins may all contribute to antioxidant activity, which is significant in health, aging, and metabolic syndrome (Saleh *et al*., 2013) [38]. As a fundamental component and other vital ingredients, Millet has established a tradition of producing numerous healthy food items (Yousaf *et al*., 2021) [53]. Because of its high iron content, barnyard millet is an excellent choice for commercial diets for people with diabetes, newborns, and pregnant women. Barnyard millet is also an important source of fodder in the Himalayan area. Barnyard millet leaves are wide, and the plant grows quickly, producing a large amount of feed (Sood *et al*., 2015) [47].

6. Conclusion

This article presents the recent research carried out to date on the production and nutritional quality of millet grains and their significance. Based on the results studied, it is concluded that millets are considered a staple food for many African and Asian countries as they are rich in nutrients involving macro and micronutrients; mineral and essential amino acid contents are superior to that of wheat and rice. Bioactive compounds present in millets can potentially reduce several diseases such as cardiovascular, diabetes, high blood pressure and cancers. Millets are also substituting major cereals due to their gluten-free, celiac properties providing the patients and health-conscious population a better solution. They can potentially be used for bio-fortification, improving their nutrient content. Future research is required to gather more basic information about millets and their properties. For further future research and development of millets, a shift in consumer preference from major cereals to minor cereals for a sustainable food supply and nutritional security.

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