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Millets: A Future of Sustainable Development and Food Security

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Abstract: Extreme climatic conditions are increasingly threatening staple crop yields and jeopardizing global food security. In response, there is a growing emphasis on optimizing natural resource utilization to adapt to a changing climate. Millets have emerged as vital resilient crops capable of thriving in less fertile soils and harsh environments, making them essential for sustainable food systems. Varieties such as sorghum, pearl millet, finger millet, foxtail millet, barnyard millet, and pseudo-cereals like amaranth and quinoa are cultivated across arid, semi-arid, and cold semi-arid regions of India. Their ancient origins and rich nutritional profile position millets as key players in addressing the global hunger crisis and shaping the food industry. Millets are highly nutritious, offering substantial amounts of protein, dietary fiber, calcium, essential amino acids, and vitamins, while their low water requirements and compatibility with organic farming align with Sustainable Development Goals (SDGs) such as SDG-1, SDG-2, SDG-3, SDG-8, SDG-12, SDG-13, and SDG-15. Beyond their nutritional benefits, millets contribute to health by preventing conditions like type II diabetes, malnutrition, celiac disease, cancer, cardiovascular diseases, and obesity. Traditional mixed cropping systems, such as India's Barahnaja-where twelve or more crops including millets, pulses, legumes, and oilseeds are cultivated together during the Kharif season-highlight the integral role of millets in sustainable agriculture. Similar systems are practiced in other resource-limited regions of India, including arid Rajasthan. This review emphasizes the critical role of millets in promoting sustainable development and ensuring food security amidst climate challenges.

Key words: Millets, resilience, food security, health benefits, sustainable development goals.

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Food and nutrition insecurity remains a critical challenge worldwide driven by high poverty, climate change, natural resource degradation, poor agricultural practices and

insufficient organizational support, etc. In this context, millets have garnered attention for their numerous benefits, including sustainability and their role in enhancing food security. Millets are ancient crops widely grown in India followed by China, Niger, Nigeria, and Africa (Tripathi and Vyas, 2023). Furthermore, India emerged as the highest millet-producing country in 2022 (Singh *et al.*, 2024). In 2023, the country celebrated the 'International Year of Millets' to raise awareness about the numerous benefits of millets (Gupta *et al.*, 2023). Millets are also referred as "*Mota Annaj*, *Shree Ann*, Nutri-Cereal, and Cereal of the Poor". A state-wise graphical representation of millet-producing states of India is shown in Fig. 1, where Rajasthan is the highest millet-producing state followed by Uttar Pradesh, Karnataka, Madhya Pradesh, Haryana, Tamil Nadu, Gujarat, Andhra Pradesh, and Uttarakhand.

The major millets, include pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor* L.), and small millets including finger millet (*Eleusine corocana*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), proso millet (*Panicum miliaceum*), and barnyard millet (*Echinochloa esculenta*) and are grown in arid, semi-arid, and cold semi-arid regions (Prasad *et al.*, 2021). Before the Green Revolution, millets were a staple in human diets. However, following the Green Revolution, dietary preferences shifted towards high yielding rice, wheat, and maize (Ayele and Tarekegn, 2020). But climate change is now threatening the high yield of these crops. To overcome these challenges, millets should be promoted worldwide because of their climate-resilient properties and their potential to flourish in poor soil quality, varying temperature conditions, less water consumption state, and survival in drought conditions (Baduni *et al.*, 2024).

Further, millets also grow in high altitudes (2000 to 3000 m) with Uttarakhand being the leading millet-producing state in the Indian Himalayan Region (IHR). For thousands of years, millets played a significant role in culture and tradition, and became a popular crop of IHR like Uttarakhand, Himachal Pradesh, Nagaland, Assam, Arunachal Pradesh, and other states. In Uttarakhand, the production of finger millet has increased by 15% from 2019 to 2023 (Anonymous 2019). However, some of the crops have become extinct from many villages in the past few decades, like foxtail millet, which was majorly cultivated about 20 years ago and has almost disappeared from Uttarakhand. Meanwhile, finger millet and barnyard millet have become popular crops in Uttarakhand in the past three years. Within the past less than a decade, some of the crops cultivated previously have become locally extinct in many villages (Bhat *et al.*, 2019).

Changes in climate conditions and various biotic and abiotic stresses have led to the losses of a large amount of agricultural production and yield. In semi-arid and arid regions, extreme temperatures, drought, salinity, flooding, etc. are the main factors that decrease its production (Balakrishnan and Schneider, 2022). Millets

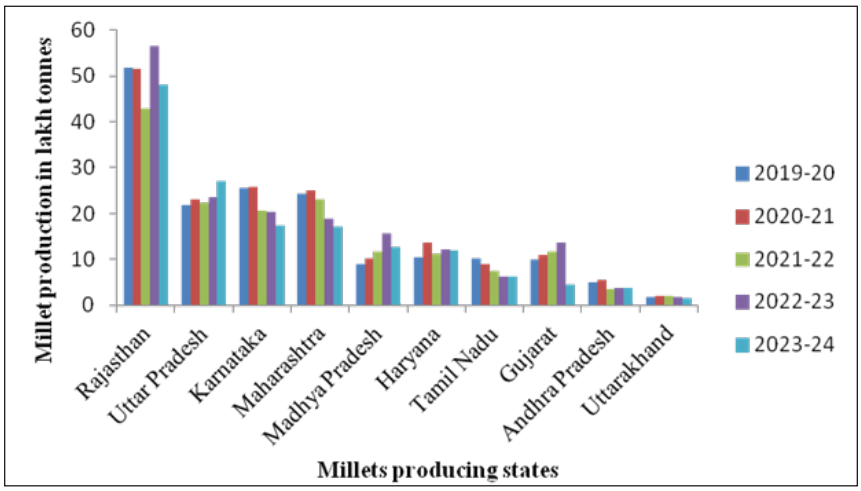

Fig. 1. Graphical representation of millet producing states from year 2020-2024. (Source: Anonymous 2024).

possess various morphological, biochemical, physiological, and molecular traits that give them strength to grow under these stressful conditions with increased production and yield (Karthikeyan *et al.,* 2022; Vardhan *et al.*, 2025). Millets contain very proficient photosynthetic systems resembling wheat, maize, and rice; hence are considered C_4 plants (Hariprasanna *et al.,* 2014). They make a group of small-seeded annual grasses belonging to the family Poaceae and are primarily cultivated on marginal lands and in harsh environmental conditions. Millets are equally important for both human health and the environment. Rich in nutritive and bioactive compounds such as proteins, vitamins, polyphenols, flavonoids, and phytosterols, they help prevent degenerative diseases, including inflammation, cancer, arthritis, osteomalacia, and arteriosclerosis. Compared to staple grains like wheat, rice, and maize, millets offer superior nutritional value and serve as a more sustainable cereal option by conserving natural resources. Additionally, promoting and expanding the use of millets and their by-products-such as *chapati, idli, chilla,* desserts, and other recipes-enhances their health benefits for human consumption.

Nutritional and Medicinal value of Millets

Millets offer a diverse range of nutritional benefits, being rich in proteins, minerals, fiber, healthy fats, fatty acids, vitamins, and essential amino acids (Table 1). They are also abundant in antioxidants, polyphenols, phytosterols, and flavonoids (Prasad *et al.*, 2019). This nutrition has a direct impact on human health; for example, it reduces blood sugar levels, malnutrition, and cancer probability, and is highly recommended for type II diabetics. During COVID-19 pandemic, people started replacing their diet with millets which included finger millet, barnyard millet, pearl millet, etc., to boost their immune response which would help in speedy recovery (Babele *et al.,* 2022). Furthermore, calcium plays a vital role in overall health of pregnant women and nursing mothers as well as the toddlers and adults those need to prevent malnutrition (Dayakar *et al.,* 2017). By consumption of finger millets, problems like weak bones or bone density loss can be cured. Other than the benefits of micronutrients, millets also have a significant role in various aspects that provide energy and promote good health. Moreover, millets reduce the risk of cancer and high blood pressure,

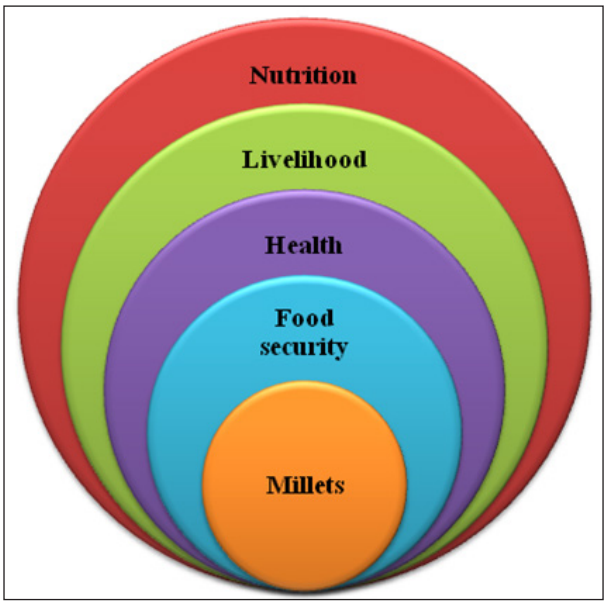

Fig. 2. Various functions of millets with respect to sustainable agriculture.

and enhance the immunity in the human body through the presence of tannins, polyphenols, phytosterols, and polycains (Bravo, 1998). Furthermore, millets have additional properties such as antioxidant and detoxifying system that decrease the possibility of degenerative diseases (Prasad *et al.,* 2020). Due to these numerous beneficial properties, millets offer the suitable solution for sustainable agriculture (Fig. 2).

Significance of millets in view of sustainable development goals (SDGs)

The United Nations established 17 SDGs in 2015 as a part of the 2030 agenda which remark upon human challenges like poverty, starvation, well-being, and environmental degradation. SDGs aim to eliminate hunger and poverty, protect our planet, and ensure health, wealth, and growth for all while promoting harmony and partnership. Millets offer promising solutions for achieving SDGs as they deal with ecological challenges and promote good health outcomes. Local farmers and villagers rely on the millets as a good source of food and income. Millets contribute to several sustainable development goals (SDGs) mainly No Poverty (SDG-1), Zero Hunger (SDG-2), Good Health and Well-being (SDG-3), and Climate Action (SDG-13) (Patil *et al.,* 2023). The relation between SDGs and millets is shown in Fig. 3. Role of millets concerning to various SDGs is described in the following paras.

Fig. 3. Relationship between SDGs and millets.

No Poverty (SDG-1)

Cultivation of millet crops contribute significantly to achieving SDG-1 which helps to end poverty globally and provides farmers a constant source of income. Due to unstable income and limited funds, local farmers struggle to cultivate high-maintenance crops. In these conditions, millets offer the best option for cultivation as they do not require the external sources, and are comparatively cost-effective short duration crops. Further, they require less amount of water for growth. In many developing countries, millets are affordable and considered as good source of high nutritious food. As compared to other crops, millets require very less amount of investment, time, and resources making these crops ideal for small farmers. Moreover, in Sub-Saharan African and Asian countries more than 90 million populations consume millets as a major component of their diet (Manimalathi, 2023).

Zero Hunger (SDG-2)

This goal targets to promote agricultural practices to look after food security, enhance nutrition quality, and develop a source of income for farmers while shielding the environment. Moreover, it also focuses on increasing productivity, supporting local farmers, and encouraging a sustainable/ resilient farming system. In addition, it upgrades soil health and reduces the use of pesticides and chemical fertilizers. Millets are climate resilient/smart crops under drought, heat, and other environmental stresses due to the involvement of a range of mechanisms such as osmotic adjustment (Shrestha *et al.,* 2023), stomatal conductance (Ghatak *et al.,* 2016), antioxidant defense and ROS interception capacity (Murali *et al.,* 2021), and flowering plasticity (Shrestha *et al.,* 2023). In fact, millets contribute to a balanced environment along with mitigation and supporting local farmers. In addition, millets have been known to be limited to bird/animal fed; however, their rich source of nutrition (calcium, iron, phosphorus, and zinc) has retrieved importance towards human consumption and eco-safety addressing various challenges like malnutrition, diabetes, and other health aspects. If these matters have been addressed, this goal will continue for good health and wellness (Patil *et al.,* 2023).

Good Health and Well-being (SDG-3)

This goal encourages a healthy lifestyle for human beings of all age groups. It contains various targets such as mortality rates, reduction of morbidity, and addressing the influence on health by environmental factors. Their contribution to this SDG plays a vital role in numerous health benefits (Patil *et al.,* 2023). Millets are gluten-free grains that make a great choice out of other grains for people who have restrictions for gluten intolerance. Besides, they also possess a low glycemic index (GI) and, therefore, are highly recommended for type II diabetes (Ugare *et al.,* 2014). During COVID-19 pandemic, people included millets in their diet and observed the benefits of millets due to their richness in starch resistance and antioxidants. It showed a great tendency to reduce blood sugar levels and maintain blood pressure (Nyasha *et al.,* 2023). The potential of bioactive components in millets to enhance health and combat various diseases has been well-documented. Their antioxidant, antimicrobial, anti-cancer, and anti-inflammatory properties have also been reported (Jayawardana *et al.,* 2021). Pearl millet has been reported to be rich in iron and zinc, fiber content, and low GI index which reduce malnutrition, anaemia, and hunger issues (Nyasha *et al.,* 2023).

Decent Work and Economic Growth (SDG-8)

Millets play a vital role in increasing the economy of various rural areas of India (Padulosi *et al.,* 2015). In rural areas, the production of millets creates a larger scope for livelihood by

providing employment and generating a source of income for them. The objective of SDG-8 is to establish farmer-producer organizations and cooperatives to strengthen the market system, bargaining strategies, and access to finance the local farmers.

Responsible Consumption and Production (SDG-12)

Millets are environment friendly crops that play significant role in sustainable development and have a lesser carbon footprint than other grains. SDG-12 promotes a healthy diet and decreases the burden on natural resources. This goal encourages organic farming to use efficient resources, reduce waste, and minimize the harsh impact on the environment by the production of millets. For example, in IHR, the local farmers do not use any kind of fertilizers or pesticides in millet cultivation. Hence, millets remain favorable crops concerning health, as compared to wheat, rice, and corn.

Climate Action (SDG-13)

Being resilient towards the harsh environment, millets play important role in SDG-13. This goal encourages mechanisms for enhancing effective environmental factors such as strategies and management in developing countries (Ceasar and Maharajan, 2022). Millets grow in arid, semi-arid, and cold semi-arid regions. They are C_4 crops that require less water for cultivation and can be grown under drought conditions. Given these qualities, millets become the preferred crops for climate-variable and water-deficient regions. Further, millets play an important role in climate action as they have low carbon footprint, suitable for reducing greenhouse emissions. Also, they supply higher carbon sequestration as compared to other crops. In addition, the cultivation of millet crops may also improve nutrient cycling and soil health, reduce use of fertilizers, and enhance organic matter content (Gupta *et al.,* 2022).

Life on Land (SDG-15)

Millets play a vital role in sustaining land ecosystems and biodiversity. The traditional and genetic traits of millets make them sustainable in agro-climatic scenarios that further promote the use of lands for agricultural practices (Rani *et al*., 2024). By improving soil health such as fertility, structure, controlled erosion, quality, and water infiltration, millets provide a sustainable ecosystem. Millet cultivation also helps in promoting sustainability, protecting land use, forest management, and combating desertification. Furthermore, the ecological functioning of the agro-ecosystem will advance by encompassing millets into a cropping system. Additionally, the cultivation of millets provides shelter and resources to vertebrates, invertebrates, and other wildlife (Patil *et al.,* 2023).

Mixed cropping system (MCS) for small millet crops in IHR

Barahnaja-Conventional system of Mixed cropping in IHR: The conventional method of mixed cropping system (MCS), referred as *Barahnaja*, is an old method, used in various regions of central Himalaya. The components, distribution, benefits, and future scope of *Barahnaja* along with its various scientific aspects are discussed in the following paras.

Components of MCS: Agricultural practices are a key focus of the IHR, which is also recognized as a hotspot for agro-biodiversity. Approximately 75% of the population is engaged in agriculture, allied activities, or traditional farming, highlighting the region's deep reliance on agrarian livelihoods. However, *Barahnaja* is commonly followed by those who are completely devoted to the traditional farming systems in the hilly regions of Uttarakhand (Gururani *et al.,* 2021). In this system, generally 12 crops are cultivated; however, in some regions cultivation of 12-20 crops is also seen depending upon the habitat, eating habits, culture, and geographical conditions. The Barahnaja system is a scientifically grounded and sustainable approach, where diverse crops mature at different times throughout the year, ensuring food security, enhancing overall yield, and improving drought resilience. This conventional method also provides nutritional security because different crops that are grown in the system are rich sources of macro and micronutrients. For example, millets are rich source of calcium, iron, phosphorus, and vitamins while legumes are rich in proteins. Besides these qualities, the system also supports the relationship between agriculture and animal farming by utilizing fodder for the animals (Misra *et al.,* 2008; Misra, 2019).

Applications of MCS: To cope with the impulsive changes in climate conditions and another risk during the cultivation, the local farmers introduced MCS/*Barahnaja*. This system is a safeguard for the Garhwal region of IHR under the crop rotation practice. The system maintains field fertility, controls pests and herbs, and enhances productivity without chemicals. Other than that, the system provides synergism between soil microbiota and various crops. The rhizospheric region, mainly roots engages through their signalling mechanisms and interacts with soil such as physicochemicals and microorganisms that give nutrition to the whole plant body, and develop and activate defense mechanisms. *Barahnaja* gives higher productivity per unit area by applying two or more different crops cultivated at the same time (Ghosh and Dhyani, 2004). The method generally depends on the combination of leaf type, plant height, root morphology, and grain quality. The diverse root structure of mixed crops, fed at different soil depths, makes good companionship (Zhardhari, 2000). Further, the cultivation of foxtail millet and maize, the early maturing crops, provides great nutrition and growth to paddy crops by reducing competition. Similarly, finger millet, oil seed, and pulses have a great ability of pest and disease resistance (Finckh and Mundt, 1992). Sorghum and pearl millet (major millets) play a significant role in cropping systems in rainfed areas as they are short-period crops. Mixing sorghum with a red gram ratio of 2:1/2:2 or sorghum with a soybean ratio of 2:4/3:6 enhances productivity and also improves soil health which links with food security and gives benefits to rural people of semi-arid regions. However, crop diversification can improve productivity, profitability, resource utilization, and also climate resilience (Dutta and Bandyopadhyay, 2006). Intercropping of finger millet and black gram enhances the yield where black gram fixes atmospheric nitrogen and provides availability to finger millet for prevention from moisture and weed suppression (Dass and Sudhishri, 2010). It has been reported that finger millet with a pigeon pea ratio of 8:2 gives higher grain yield (45%) and economic profitability as compared to single crop cultivation of finger millet (Sukanya *et al.,* 2024). In the Garhwal region of Uttarakhand, mixed cropping of finger millet with soybean (9:1) and lupine with finger millet (5:10/75:10) is cost effective and has greater yield than sole cropping (Singh and Arya, 1999).

Benefits of MCS: IHR farmers have small and fragmented lands. Adopting MCS with respect to millets minimizes land use, resulting in optimized consumption of soil and water, increased nutrients, productivity, and profit under unpredictable rainfall conditions. In the MCS system, if one crop fails to be cultivated others will ensure and grow. The MCS makes it easier to meet current requirements without sacrificing the next generation's needs. Further, applying MCS in millet cultivation fulfils food security and also provides nutraceutical benefits to local people. Mixed cropping of millets such as finger millet, foxtail millet, sorghum, and barnyard millet along with soybean, oil seed, legumes, and black gram on the same land provides a variety of food choices and decreases crop failure by undesirable conditions or natural disasters. Generally hardy, drought-resistant, pest-resistant, and nutritionally superior crops are produced in MCS. Crops, especially millets and pseudo-cereals, cultivated in MCS are termed nutri-grains by their outstanding nutritional values (Gururani *et al.,* 2021).

Food Security

By 2050, world's population will reach 9 billion, and almost 2-3 billion people will be experiencing hunger and malnutrition. The ongoing scenario has been concerned with how to address food demand for the future population (Passot *et al.,* 2016). In a recent study, millets have been reported for high amounts of protein, fat, fiber, minerals, macro and micronutrients, amino acids, and vitamins (Table 1). Moreover, finger Millets are rich in calcium and phosphorus i.e. 348 and 293 mg 100 g^{-1} (Jacob *et al.,* 2024) which gives benefits to the defense mechanism of the body against free radicals and improves bone and muscle health (Saleh *et al.,* 2013). As compared to other grains, millets possess high amount of vitamins (thiamine and riboflavin) which are advantageous to metabolism, brain function, and healthy skin (Dayakar Rao *et al.,* 2017). These value-added small grain nutri-cereals offer innumerable health benefits. In the present changing climate scenario, rising temperature, greenhouse gas emissions, and global warming are alarming to show our attention towards food security and agriculture sustainability

Table 1. Proximate composition of various millets

Millet	Protein (g)	Fat (g)	Crude fiber (g)	Carbohydrate (g)	Calcium (mg)	Phosphorus (mg)	Thiamine (mg)	Riboflavin (mg)
Sorghum	10.4	1.9	1.6	70.7	35.2	266	0.28	0.15
Pearl millet	1.6	5	1.2	67	35	339	0.30	1.4
Finger millet	7.3	1.3	3.6	72.6	34.8	250	0.40	0.6
Barnyard millet	6.2	2.2	9.8	55	18.3	280	0.33	4.2
Foxtail millet	12.3	4.3	8	63.2	31	300	0.60	1.6
Kodo millet	8.3	1.4	9	66.6	32.3	300	0.15	2.0
Proso millet	12.6	1.1	2.2	63.8	10	200	0.41	0.2
Little millet	7.7	4.7	7.6	60.9	17	220	0.3	0.09

Source: Kumar *et al*. (2024); Gowda *et al*., 2022; Sendhil *et al*. (2023).

which impacts directly on our crops and results in low yield and production. Small millets are eco-friendly and resistant to biotic and abiotic stresses. These crops produce nutritionally rich grains on less fertile soil which has the potential to lower the carbon emission compared to other grain crops (Singh *et al*., 2024). Moreover, foxtail millet has a highly efficient photosynthetic system which reaches its maturity stage early. A traditional cropping system has been followed for the cultivation of multiple crops from a single land during a year by just one pre-sowing precipitation. In addition, they possess high nutritional values and excellent pest/disease resistance (Dwivedi *et al*., 2012). These characteristics highlight the qualities of small millet and reveal how they are important for sustained agriculture and food security.

Challenges in millet production

The decline of millets in favor of wheat and rice over the years can be attributed to policy biases from the Green Revolution, shifting consumer preferences, increased irrigation facilities, and inadequate market support. While millets were once staple crops due to their resilience, they lost significance as government subsidies, research efforts, and procurement policies favored wheat and rice. Additionally, changing dietary habits and processing challenges further contributed to their reduced cultivation. However, with growing awareness of their nutritional and climate-resilient benefits, recent initiatives are working to revive millet production and consumption in India. But, millets cannot entirely replace wheat, maize, or paddy due to entrenched consumption patterns and existing agricultural systems. On average, a millet farmer reaps a measly 33% and 42% of what a wheat or a paddy farmer gets for their crops. Cultivators of pearl millet, sorghum, and finger millet receive 33%, 32%, and 8.7% of an average wheat farmer. The net margin over paid-out costs of farmers cultivating millets plummeted in the new millennium (NM) by 30% over the paid-out costs, relative to the previous two-decade average. Cultivating millets increased farmer income by a modest 1.7% per annum compared to a relatively better growth of 2.2% in the case of wheat (Nuthalapati *et al*., 2024). However, in hilly and arid terrains, a partial or significant shift towards millet cultivation is feasible, particularly where water scarcity and degraded soils limit conventional cereal production. However, even in these regions, the optimal cropping system-mixed or sole-would depend on depends on environmental constraints, resource availability, and specific cultivation goals. In hilly terrains, where soils are often shallow, eroded, and nutrient-poor, mixed cropping systems are typically advantageous. Integrating millets with legumes such as cowpea or horse gram enhances soil fertility through biological nitrogen fixation, reduces soil erosion, and improves overall resilience against climatic stresses. This approach also promotes biodiversity and stabilizes yields in fragile ecosystems. In arid zones, water availability is the key factor influencing cropping decisions. When water resources are limited, mixed cropping with drought-resistant legumes like clusterbean (guar) or moth bean supports moisture conservation, soil stabilization, and nitrogen enrichment, thereby improving crop resilience under water-stressed conditions. Conversely, in areas with reliable irrigation or seasonal rainfall, sole cropping-particularly of drought-

tolerant millets like pearl millet-may yield higher productivity and economic returns, while also simplifying management practices. Strategic policy measures, supported by research-driven innovations, can play a crucial role in promoting millet cultivation across large parts of India

Conclusions

Production of millets is essential for improving food security, health outcomes, and sustainable agriculture practices. For future aspects, the government and stakeholders must work together to ensure the supply and availability of millets worldwide and also promote the health benefits to incorporate their diet for a healthy lifestyle. Millets possess various therapeutic and nutraceutical supremacy and are a good source of nutrition with gluten-free properties and low glycaemic index and they are high in calcium, iron, phosphorus, protein, vitamins, amino acids, and fiber as compared to cereals. The present review analyzed the potential of millets in addressing food security along with its role in SDGs. In addition, various biotechnology techniques such as plant growth promoting and CRISPR/Cas9, plant microbiome, and genetic/molecular variation are to be used for enhancing the productivity and yield of millets. While farmers should be enthusiastic about millet production, the subsidies provided by the government for improving agricultural practices should promote farmers to grow good quality and nutritious grains. In addition, by addressing food security, climate issues, and general awareness of millets for their sustainability, nutritional quality, and food security should be promoted as they are climate resilient and drought tolerant crops with numerous health benefits. This can reduce the risk of diseases like cardiovascular, cancer, celiac, and help in maintaining blood sugar levels in diabetic patients.

Conflict of interest

Authors declare no conflict of interest in this study.

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References

Anonymous 2019. https://www.millet.res.in/pub/2019/Millet_Indian_Himalaya.pdf

Anonymous 2024. https://apeda.gov.in/milletportal/files/Statewise_Millet_Production.pdf

Ayele, A. and Tarekegn, K. 2020. The impact of urbanization expansion on agricultural land in Ethiopia: A review. *Environmental and Socio-economic Studies* 8(4): 73-80.

Babele, P.K., Kudapa, H., Singh, Y., Varshney, R.K. and Kumar, A. 2022. Mainstreaming orphan millet for advancing climate smart agriculture to secure nutrition and health. *Frontiers in Plant Science* 13: 902536.

Baduni, P., Maikhuri, R.K., Bhatt, G.C., Rawat, H., Singh, R., Semwal, C.P. and Meena, A.K. 2024. Contribution of millets in food and nutritional security to human being: Current status and future perspectives. *Natural Resources Conservation and Research* 7(1): 5479.

Balakrishnan, G. and Schneider, R.G. 2022. The role of amaranth, quinoa, and millet for the development of healthy, sustainable food products-A concise review. *Foods* 11(16): 2442.

Bhat, B.V., Arunachalam, A., Kumar, D., Tonapi, V.A. and Mohapatra, T. 2019. *Millets in the Indian Himalaya*. Indian Council of Agricultural Research, New Delhi. 84 p.

Bravo, L. 1998. Polyphenols: Chemistry, dietary sources, metabolism, and nutritional significance. *Nutrition Reviews* 56(11): 317-333.

Ceasar, A.S. and Maharajan, T. 2022. The role of millet in attaining United Nation's sustainable developmental goals. *Plants People Planet* 4(4): 345-349.

Dass, A. and Sudhishri, S. 2010. Intercropping in finger millet (*Eleusine coracana*) with pulses for enhanced productivity, resource conservation and soil fertility in uplands of southern Orissa. *Indian Journal of Agronomy* 55(2): 89-94.

Dayakar Rao, B., Bhaskarachary, K., Arlene Christina, G.D., Sudha Devi, G., Vilas, A.T. and Tonapi, A. 2017. Nutritional and health benefits of millet. *ICAR-Indian Institute of Millet Research (IIMR) Rajendranagar, Hyderabad* 2: 112.

Dutta, D. and Bandyopadhyay, P. 2006. Production potential of intercropping of groundnut (*Arachis hypogaea*) with pigeon pea (*Cajanus cajan*) and maize (*Zea mays*) under various row proportions in rainfed Alfisols of West Bengal. *Indian Journal of Agronomy* 51(2): 103-106.

Dwivedi, S.L., Upadhyaya, H.D., Senthilvel, S., Hash, C.T., Fukunaga, K., Diao, X. and Prasad,

M. 2012. Millet: genetic and genomic resources. *Plant Breeding Reviews* 35: 47-375.

Finckh, M.R. and Mundt, C.C. 1992. Stripe rust, yield, and plant competition in wheat cultivar mixtures. *Phytopathology* 82(9): 905-913.

Ghatak, A., Chaturvedi, P., Nagler, M., Roustan, V., Lyon, D., Bachmann, G. and Weckwerth, W. 2016. Comprehensive tissue-specific proteome analysis of drought stress responses in *Pennisetum glaucum* (L.) R. Br. (Pearl millet). *Journal of Proteomics* 143: 122-135.

Ghosh, P. and Dhyani, P. 2004. Baranaaja: The traditional mixed cropping system of the central Himalaya. *Outlook on Agriculture* 33(4): 261-266.

Gowda, N.A.N., Siliveru, K., Prasad, P.V.V., Bhatt, Y., Netravati, B. P. and Gurikar, C. 2022. Modern processing of Indian millets: A perspective on changes in nutritional properties. *Foods* 11: 499. https://doi.org/10.3390/foods11040499

Gupta, M., Asfaha, D.M. and Ponnaiah, G. 2023. Millet: a nutritional powerhouse with anti-cancer potential. *Cureus* 15(10): 47769.

Gupta, R., Singh, M. and Khan, B.R. 2022. Photosynthetic electron transport rate and root dynamics of finger millet in response to *Trichoderma harzianum*. *Plant Signaling and Behavior* 17(1): 2146373.

Gururani, K., Sood, S., Kumar, A., Joshi, D.C., Pandey, D. and Sharma, A.R. 2021. Mainstreaming Barahnaja cultivation for food and nutritional security in the Himalayan region. *Biodiversity and Conservation* 30(3): 551-574.

Hariprasanna, K., Gomashe, S., Ganapathy, K.N. and Patil, J.V. 2014. Millet for ensuring nutritional security. *Popular Kheti* 2(3): 170-175.

Jacob, J., Krishnan, V., Antony, C., Bhavyasri, M., Aruna, C., Mishra, K. and Visarada, K.B. 2024. The nutrition and therapeutic potential of millet: an updated narrative review. *Frontiers in Nutrition* 11: 1346869.

Jayawardana, S.A.S., Samarasekera, J.K.R.R., Hettiarachchi, G.H.C.M., Gooneratne, J., Choudhary, M.I. and Jabeen, A. 2021. Anti-inflammatory and antioxidant properties of finger millet (*Eleusine coracana* (L.) Gaertn) varieties cultivated in Sri Lanka. *Biomed Research International* 1-10.

Karthikeyan, A., Renganathan, V. G. and Senthil, N. 2022. Role of proteomics in understanding the abiotic stress tolerance in minor millet. *Omics of climate resilient small millet*, *Springer*, 125-139. http://dx.doi.org/10.1007/978-981-19-3907-5_7

Kumar, V., Yadav, M., Awala, S.K., Valombola, J.S., Saxena, M.S., Ahmad, F. and Saxena, S.C. 2024. Millet: A nutritional powerhouse for ensuring food security. *Planta* 260(4): 101.

Manimalathi, P. 2023. Role of millet in sustainable development. *Structural and Institutional Dimensions of Sustainable Development Goals (SDGs) in India: A Narrative*, 215.

Misra, A.K. 2019. Fodder production and utilization strategies for sustainable livestock development in India. *Annals of Arid Zone* 58(1&2): 1-11

Misra, S., Maikhuri, R. K. and Dhyani, D. 2008. Indigenous soil management to revive below ground biodiversity-case of Garhwal. *Leisa India*, 13.

Murali, M., Singh, S.B., Gowtham, H.G., Shilpa, N., Prasad, M., Aiyaz, M. and Amruthesh, K.N. 2021. Induction of drought tolerance in *Pennisetum glaucum* by ACC deaminase producing PGPR-*Bacillus amyloliquefaciens* through antioxidant defense system. *Microbiological Research* 253: 126891.

Nuthalapati, C.S., Kumar A., Sonkar, V.K., Susanto K. Beero, S.K. and Areef, M. 2024. Indian Millet Cultivation Plagued by Low Yields, Prices, and Profits. https://tci.cornell.edu/?blog=indian-millet-cultivation-plagued-by-low-yields-prices-and-profits#:~:text=Profitability%20of%20millet%20cultivation%20compared,of%20an%20average%20wheat%20farmer. Assessed on 02-09-2025

Nyasha, S., Kugedera, T.A., Makuvara, Z., Chipunza, N., Nhara, R.B. and Marumure, J. 2023. Contributions of small grains grown in Zimbabwe's dryland regions in boosting immunity and combating COVID-19. *Springer*, 59-75. Cham. https://doi.org/10.1007/978-3-031-21472-1_5

Padulosi, S., Mal, B., King, O.I. and Gotor, E. 2015. Minor millet as a central element for sustainably enhanced incomes, empowerment, and nutrition in rural India. *Sustainability* 7(7): 8904-8933.

Passot, S., Gnacko, F., Moukouanga, D., Lucas, M., Guyomarc'h, S., Ortega, B. M. and Laplaze, L. 2016. Characterization of pearl millet root architecture and anatomy reveals three types of lateral roots. *Frontiers in Plant Science* 7: 829: 1-11.

Patil, P.B., Goudar, G., Preethi, K., Rao, J.S. and Acharya, R. 2023. Millet: Empowering the society with nutrient-rich superfoods to achieve sustainable development goals. *Journal of Drug Research in Ayurvedic Sciences* 8(1): S100-S114.

Prasad, M.E., Arunachalam, A. and Gautam, P. 2020. Millet: A nutraceutical grain that promises nutritional security. *Ecology, Environment and Conservation* 26: S1-6.

Prasad, M.E., Joshi, I., Kumar, N., Gautam, P. and Chhabra, J. 2019. Proximate composition of minor millet from cold semi-Arid regions. *International Journal of Innovative Technology and Exploring Engineering* (*IJITEE)* 12S3(8): 86-93.

Prasad, M.E., Kumar, N., Arunachalam, A., Rawat, B.S. and Gautam, P. 2021. Millet of Cold Semi-Arid Regions: Vital Facts in Starch Content and Composition. *International Journal of Current Research and Review* 13(11): 92.

Rani R, Khandelwal, V., Jhunjhadia, S., Ambawat, S., Bhanwariya, S., Singh, A. and Kumar, V. 2024. Quantifying genetic diversity based on morphological and molecular analysis in pearl millet [*Pennisetum glaucum* (L.) R. Br.] inbred lines. *Annals of Arid Zone* 63(3): 105 110.

Saleh, A.S., Zhang, Q., Chen, J. and Shen, Q. 2013. Millet grains: nutritional quality, processing, and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety* 12(3): 281-295.

Sendhil, R., Joseph, J. Akhilraj, M., Devi, T.S., Swaminathan, N. and Pouchepparadjou, A. 2023. Status of millets in India: Trends and prospects. In: *Sensitizing the Millet Farming, Consumption and Nutritional Security - Challenges and Opportunities* (Eds. A. Pouchepparadjou, V. Krishnan, N. Swaminathan, R. Sendhil, L. Umamaheshwari, T. Sivasakhti Devi; S. Parthasarthi, V. Vengadessan and M. Umamaheshwari). Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Pudduchery

Shrestha, N., Hu, H., Shrestha, K. and Doust, A.N. 2023. Pearl millet response to drought: A review. *Frontiers in Plant Science* 14: 1059574.

Singh, H., Vani, S.R.D., Datha, M.S. and Kumari, S. 2024. A review on problem and prospects of millet production in India. *International Journal of Advanced Biochemistry Research* 8(7): 25-34.

Singh, R.V. and Arya, M.P.S. 1999. Nitrogen requirement of finger millet (*Eleusine coracana*) + pulse intercropping system. *Indian Journal of Agronomy* 44(1): 44_1-44_1.

Tripathi, T. and Vyas, S. 2023. From ancient grains to modern solutions: A history of millet and their significance in agriculture and food security. *International Journal of Home Science* 9: 72-78.

Ugare, R., Chimmad, B., Naik, R., Bharati, P. and Itagi, S. 2014. Glycemic index and significance of barnyard millet (*Echinochloa frumentacae*) in type II diabetics. *Journal of Food Science and Technology* 51: 392-395.

Vardhan, B.H., Narasimhulu, R., Priya, M.S. and Sekhar, A.C. 2025. Association analysis for morpho-physiological and yield-attributing traits in foxtail millet (*Setaria Italica* L. Beauv.). *Annals of Arid Zone* 64(1): 129-134.

Zhardhari, V. 2000. Barah Anaaj-Twelve food grains: traditional mixed farming system. *Leisa India* 2(1): 25-26.

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