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REVIEW ARTICLE

Augmentation of nutritional security through millets in Second Green Revolution

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Abstract

Millets are highly resilient crops that can thrive in diverse climatic conditions and marginal lands with minimal water and input requirements. As the world faces the challenges of climate change, population growth and food insecurity. Millets have emerged as promising crops for sustainable agriculture and a potential crop of the Second Green Revolution, which focuses on rainfed agriculture. These crops offer several advantages firstly, their ability to withstand climate fluctuations and suitability for rainfed conditions make them a climate-smart solution for crop production in the face of prolonged droughts and changing weather patterns. Secondly millets are nutritionally rich containing essential micronutrients and dietary fibres which can help address the prevalent issue of malnutrition in many parts of the world. However, the mainstream adoption of millets faces several challenges including limited research and development inadequate infrastructure and insufficient market integration. To unlock the full potential of millets in the Second Green Revolution a comprehensive approach is required encompassing research, policy support, market development and consumer awareness. By harnessing the unique features of millets, the agricultural sector can move towards a more sustainable, resilient and inclusive future contributing significantly to global food security and nutrition goals. These crops offer a promising solution to address the challenges posed by climate change and population growth while promoting sustainable and nutritious food production.

Keywords: food security; millets; nutrition; Second Green Revolution

Introduction

The global hunger and feeding the world population is rapidly rising an immense to challenge requiring sustainable agriculture, reduced food waste and enhanced accessibility to nutrition and many factors contribute to this issue including a deficiency in vital nutrients a decline in food production that causes an imbalance between supply and demand and conflicts that destabilize different parts of the world (1). The people were suffering the hunger and malnutrition was 850 million in 2010-2012 but the climate change and global warming is still a concern (2). The 21st century presents enormous challenges to the global food system, including population increase, climate change, malnutrition and the rise in non-communicable disease prevalence (3).

Millets are classified as cereal grains with small seeds that belongs to the Poaceae (or Gramineae) family. They stand out for being resilient and able to grow well in adverse conditions while most other crops fail (4). Millets can be grown minor agricultural input in a variety of soil types, climates and challenging conditions. Yields can be significantly increased with only small interventions. Most smallholder and tribal farmers cultivate millets in rainfed environments. Traditionally, they had been grown in semi-arid tropical climate, where they have adapted to drought and low fertility (5). The major millets include sorghum, pearl millet and finger millet, while minor millets include Foxtail millet, Proso millet, Kodo millet, Barnyard millet and little millet (6). By comparing with major cereals such as rice, wheat, etc. Small millets are high in nutrition and minerals, protein and vitamins to improve the poor peoples around the Asia-Pacific region (7) (Fig. 1).

The existing research highlights the diverse nutritional and health benefits related to the consumption of millet. Compared to staple crops like wheat and rice, millets provide substantially higher levels of calcium (0.344 %) (found in finger millet), phosphorus (0.28-0.34 %), zinc (0.0037 %), magnesium (0.083 %) (found in barnyard millet), iron (0.017 %) (found in pearl millet), dietary fibre (15-20 %), niacin (12 %) and folic acid (9). Consuming millet has been believed to be reducing aging and aiding in the treatment of metabolic disorders (10). Although, Pseudo cereal is widely recognized as a healthy substitute ingredient in Western nations (11).

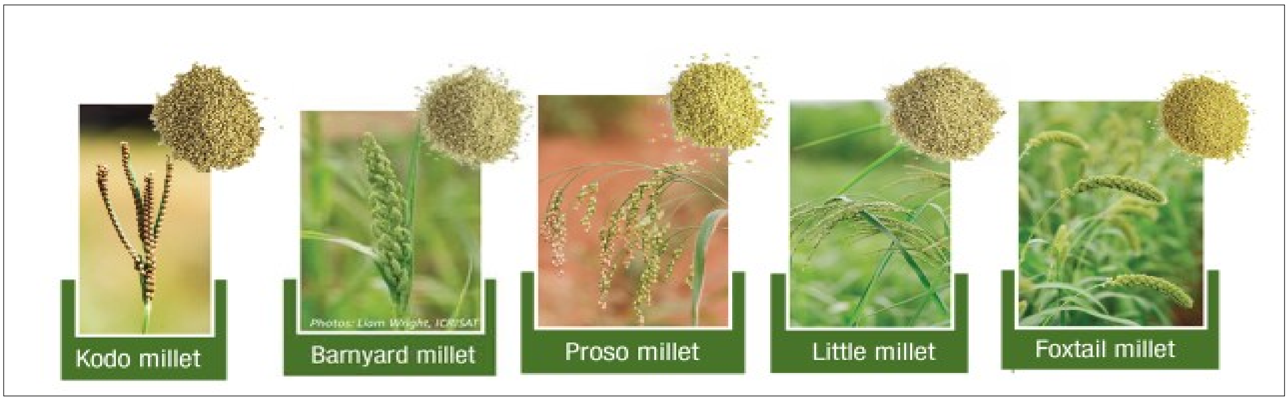

Fig. 1. Crop maturation stage and grains of small millets (8).

Worldwide, the COVID-19 pandemic has changed how people live their daily lives. According to a sequential mixed-methods survey was conducted in Puducherry for six months (January 2021 to June 2021), younger people restricted their intake of unhealthy meals while increasing their consumption of nutritious ones. In India, Total millets are cultivated over an area of 126.98 lakh ha with total production of about 173.21 lakh tonnes and productivity of 1364 kg/ha during the year 2022-23. (APEDA - Agricultural and Processed Food Products Export Development Authority). In Tamil Nadu, Total millets are cultivated over an area of 4.90 lakh ha with total production of about 6.30 lakh tonnes and productivity of 1287 kg/ha during the year 2022-23 (APEDA) (Table 1).

Table 1. Area, production and productivity of different crops in world

Crop	Area (million ha)	Production (million tonnes)	Productivity (tonnes/ha)
Rice	160	780	4.9
Wheat	220	780	3.5
Maize	210	1200	5.7
Millets	30	28	0.9
Pulses	90	90	1.0
Oilseeds	250	600	2.4
Sugarcane	25	1900	76.0
Cotton	33	25	0.75

As a result of the UN General Assembly's recognition of millets ability to address current global issues, 2023 has been declared as the International Year of Millets. The goal of this worldwide effort is to enhance action to increase millets production, consumption and use as well as educating people about their benefits for health. Millets offer age-specific benefits: for infants (6 months-2 years), they aid digestion and growth; children (3-12 years) gain energy and immunity; teens (13-19 years) benefit from hormonal balance and stress relief; adults (20-50 years) manage weight and diabetes; pregnant women get iron and folic acid; elders (More than 60 years) improve bone and heart health. Gluten-free and nutrient-rich, millets support sustainable health for all ages (12).

Green Revolution and its impact

India faced a food scarcity during 1960's. In response to this scenario, the Indian government implemented the Green Revolution in the latter part of the second five-year plan with the aim of increasing agricultural production as well as productivity and the Green Revolution in India is mainly attributed to the states of Punjab, Haryana and Western Uttar Pradesh (13). It's an approach that allows farmers to use less land to produce more food and agricultural goods. This revolution includes development of High yielding variety (HYV) cereal grain seeds, irrigation systems, technique modernization and the distribution of synthetic fertilizers and pesticides to farmers (14).

The Green Revolution proved to be a significant success, leading to increased agricultural production in many countries. India, previously reliant on importing food grains to meet its population's needs, transitioned into a food grain exporter. However, while the Green Revolution had positive outcomes, it also brought about negative effects like loss of biodiversity, land degradation, impact on health, etc (15). In India, 75 % of traditional rice varieties were lost between 1960 and 2000 due to the dominance of HYVs (Food and Agriculture Organization), A 37 % decline in pollinator populations was reported in agricultural areas (16), World Health Organization estimates 385 million cases of pesticide poisoning annually, with 11000 deaths (17), In Haryana and Punjab, 70 % of groundwater samples exceeded WHO nitrate limits (18).

Need of 2nd Green Revolution

The focus of the Second Green Revolution on rainfed agriculture in response to the persistent drought conditions experienced over several years, aiming to enhance the resilience and productivity of crops in regions reliant on rainfall as the primary water source (19). India requires 360 million tonnes of food grains by 2027 to feed its population (1.48 billion), who need healthy diet (20). In the current globalized economy, India's agricultural export potential is enormous and total Agri-Exports (2023-24) are 53.1 billion, Top Export Products are Basmati Rice: $5.4 billion (2023-24), Non-Basmati Rice: $6.3 billion, Sugar: $5.8 billion, Spices: $4.25 billion, Marine Products: $7.4 billion (India is the 2nd-largest fish exporter globally) and Key Markets are USA, UAE, China, Bangladesh, Vietnam and Saudi Arabia. Government Target to $100 billion in agri-exports by 2030 (PM-Mitra scheme, PLI for food processing) (14).

Major driving forces for 2nd Green Revolution includes urgent need for increasing the food production and scarcity of water (21). To tackle the above two issues production of millets and their utilization proves way of food security and millets require ~300-400 mm of water per crop cycle, compared to 1500-2000 mm for rice (FAO). They have a low water footprint: 1 kg of millets uses 650-1200 L of water, whereas rice requires 2500-5000 L (Water Footprint Network) and Millets tolerate heat, drought and poor soils, reducing crop failure risks (ICAR). They grow with minimal fertilizers/ pesticides, cutting farmer expenses. India (largest producer -

12 MMT/year) and Africa are scaling millet cultivation to enhance food security (FAOSTAT). Modify farmers' perspectives to enable them to recognize that the range of their responsibilities can expand. Motivate farmers to cultivate crops in areas where they possess a natural advantage and to transform Indian agriculture, farmers must shift from traditional practices to diversified, climate-smart farming by leveraging regional strengths Punjab/Haryana should grow maize and pulses instead of water-intensive rice, Himalayan states should focus on horticulture, coastal zones on aquaculture and arid regions like Rajasthan on drought-resistant millets, solar farming and agroforestry (khejri, neem). Rajasthan's vast uncultivated land can be revived through drip irrigation (PMKSY), millet cultivation (Rajasthan Millet Mission) and solar-powered farming (KUSUM Scheme), supported by policies like Soil Health Cards and National Agroforestry Policy, ensuring sustainable growth while combating water scarcity and soil degradation (22).

International Year of Millets - 2023: a global recognition of nutri-cereals

The United Nations declared 2023 as the International Year of Millets, following a proposal by the Government of India that was supported by over 70 countries. This global initiative aimed to raise awareness about the nutritional and environmental benefits of millets, promote their cultivation and improve global food security. Millets such as sorghum, pearl millet, finger millet, foxtail millet, barnyard millet and others are traditional grains known for their high nutritional value, climate resilience and low water requirement. They are rich in protein, fibre, essential vitamins and minerals, making them an ideal solution to combat malnutrition and lifestyle diseases. The International Year of Millets highlighted the importance of these crops in diversifying agriculture, supporting small-scale farmers and sustainable farming systems, particularly in arid and semi-arid regions. It also encouraged innovation in millet-based products, value chain development and greater market access for millet farmers. India, as the largest producer of millets, led global celebrations through policy support, millet-based food festivals, research collaborations and promotion of millets in school meals and public distribution systems (12).

Why substitution of millets over other crops in rainfed agriculture?

Rainfed agriculture is prevalent worldwide and contributes to approximately 70 % of the global staple food grain production. Specifically, around 45-50 % 55 of rice, 10-15 % of wheat, 60-65 % of Maize, 20-25 % Sugar crops, 80-85 % 91 of millets, 70-75 % 90 of pulses, 65-79 % 85 of oilseeds and 60-65 % of cotton are cultivated in rainfed conditions (23). Millets and similar coarse grains can thrive with an annual rainfall of less than 350 mm, whereas other cereal crops struggle to grow without sufficient water and are sensitive to climate fluctuations (24).

Rainfed agriculture is prevalent in India and contributes to approximately 40 % of the total staple food grain production. Specifically, around 50-55 % 53 of rice, 25-30 % of wheat, 60-65 % of Maize, 20-25 % Sugar crops, 85 90 % 95 of millets, 75-80 % 91 of pulses, 65-70 % 80 of oilseeds and 50-55 % 60 of cotton are cultivated in rainfed conditions (23). Globally, the percentage of crops grown under rainfed conditions differs when considering cultivated area versus production due to yield gaps. Rainfed cultivation covers 50-55 % of rice area but contributes only 30-40 % of production, as irrigated rice yields far more. Similarly, 65-70 % of maize area is rainfed, but it accounts for just 50-55 % of output, while drought-resilient crops like millets (85-90 % area, 80-85 % production) and pulses (75-80 % area, 70-75 % production) show smaller gaps. Cash crops like sugarcane (25-30 % rainfed area, 15-20 % production) and cotton (55-60 % area, 40-45 % production) rely heavily on irrigation for higher yields. Oilseeds (70-75 % rainfed area, 60-65 % production) also reflect this trend. Rainfed farming dominates in arid regions but lags in productivity, highlighting the need for improved drought-resistant techniques to bridge the yield gap (Fig. 2).

As reported that global population may increase from 7.4 to 9.1 billion by 2050 (25), which lead to a greater demand for food, animal feed and fibre. Consequently, there is a need to ramp up production to meet the rising demand for nutritious foods (26). Changes in dietary preferences and habits, along with the ongoing challenges of climate change and water scarcity, have compounded this global issue (27).

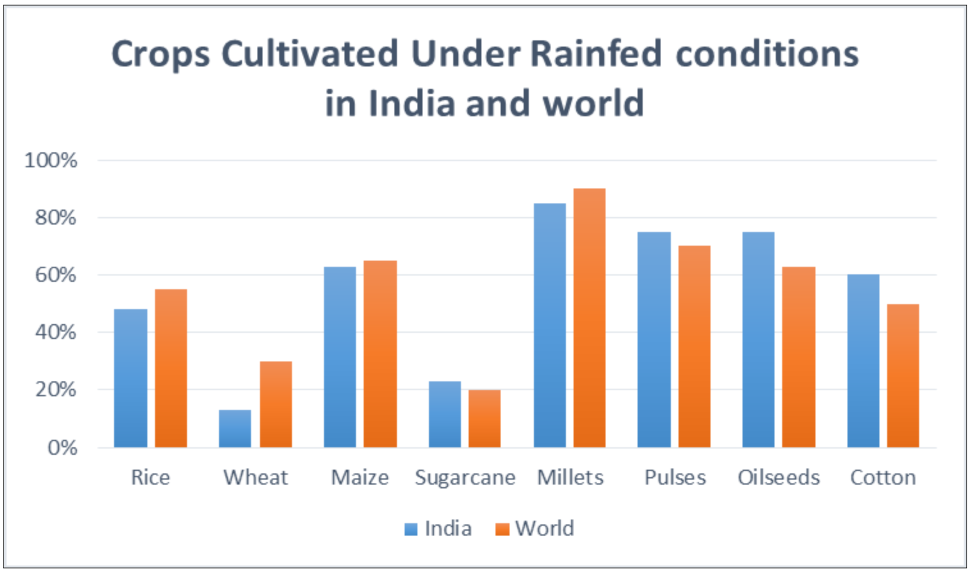

Fig. 2. Crops cultivated under rainfed condition in Worldwide and India (23).

In the upcoming days, agriculture is set to face numerous environmental changes such as increased temperatures, erratic rainfall patterns, variation in CO_2 and greenhouse gas emissions and a rise in unpredictable natural disasters (26). The past five years (2019-2023) the warmest years on record, with 2023 being the hottest year ever recorded (1.2 °C above pre-industrial levels). Heatwaves intensified, affecting crop yields (e.g., 2022 European heatwave reduced wheat production by 4–5 %) and 2020-2023 saw extreme rainfall variability, Floods in China (2020, 2023) disrupted rice production, Horn of Africa faced worst drought in 40 years (2021-2023), killing livestock and crops, U.S. Midwest (2019, 2023) experienced both floods and droughts, affecting corn/soybean yields and CO_2 levels rose from 410 ppm (2019) to 420 ppm (2023) (National Oceanic and Atmospheric Administration), Methane (CH_4) emissions surged due to agriculture (livestock and rice paddies) and fossil fuels, Nitrous Oxide (N_2O) from fertilizers increased, worsening climate feedback loops. In response to these challenges, there is a need for the implementation of climate-resilient agricultural practices, with a focus on cultivating climate-smart crops like millets as a key strategy (28).

Millets serve as an alternative crop suited to conflict the challenges of climate change. They possess characteristics making them resilient to adverse climatic conditions, allowing them to thrive in a broader range of agricultural environments (29). Millet has short duration crops allowing them to avoid potential environmental challenges when planted either early or late in the season (30). Millets have a small leaf surface area with thick cell walls and denser fibrous root system, enhancing their ability to withstand environmental stress. Millets are disease-tolerant due to their hardy genetics, adaptability to harsh conditions and natural resistance to pathogens. Unlike wheat or rice, they face fewer severe diseases and thrive in dry, low-fertility soils, reducing pathogen susceptibility. Their short growth cycle and minimal need for pesticides further enhance resilience, making them a sustainable, low-input crop (31).

Millets has a highly nutritious and resilient crop, capable of thriving even in challenging climate conditions (24). It has essential nutrients and minerals, millets offer a promising solution for ensuring both food security and livelihoods, particularly amidst a growing global population. Their versatility in adverse conditions makes them a smart choice for sustainable agriculture. Despite Rajasthan's above-average 2024 monsoon rainfall (+12 % in Jaipur), millets like bajra and jowar demonstrate remarkable resilience, thriving in both drought and heavy rain conditions due to their deep roots and short growth cycles. Historical data shows millet yields increased by 9 % during 2019's 135 % excess rainfall, outperforming waterlogged crops. Farmers can optimize millet cultivation through proper drainage, intercropping with legumes and post-rain sowing, supported by Rajasthan's Millet Mission and PM-FASAL insurance. These nutrient-rich crops remain Rajasthan's most reliable option for food security amid climate variability, proving adaptable to extreme weather fluctuations while maintaining stable productivity (31).

Millet production and cultivation worldwide

Millets are grown in 93 countries worldwide, although only 7 countries have more than 1 million hectares area under millet cultivation. Generally speaking, developing countries produce and consume millets to a greater extent than 97 %. It was predicted that between 1961 and 2018, the area cultivated with millets decreased by about 25.71 % on all continents (32). According to FAO 2020, global millet production was delivered to reach 28.33 million metric tonnes in 2019 and 30.08 million metric tonnes in 2021. As per 2021, India is the first and largest producer of millets, holding a total of 41 % of the world's total production. Niger comes in 2nd having 12 %, followed by China having 8 %. Despite this, India holds 12th ranks among the countries that produce high yields of millets (8).

While the area under millet cultivation has decreased in throughout Asia, the production trend has been gradually increasing, which has improved productivity. In the case of India, millet output peaked in the 1980s and then steadily declined as a result of an enormous decrease in the area under cultivation (8) (Fig. 3). India contributes 37.5 % of world millet production which leads the world's millet producers, followed by Nigeria and Sudan (29). The world produces about 30 million tonnes of millet a year as of 2023; most of that is produced in developing nations (33).

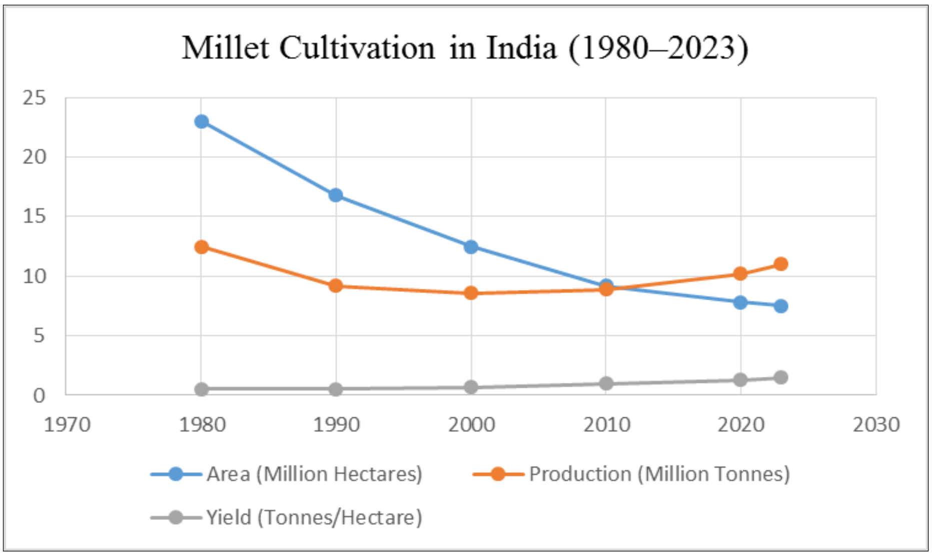

Fig. 3. Millet cultivation in India (1980-2023) (FAO).

The resurgence of millets

Millets as smart crop

Compared to traditional crops, millets have a remarkably low water requirement and may grow in semi-arid environments. A factor in agricultural resilience is their capacity to thrive in a variety of climates (34). When compared to other crops, millets are more sustainable in a number of ways. Rice requires more water to cultivate than millet when the two are compared. Rice is dominant role in food security, where it is the primary caloric source. However, millets being climate-resilient, nutrient-dense and less water-intensive present a viable substitute, particularly in drought-prone areas. Future work will incorporate millets to assess their economic and agronomic feasibility. From an economic perspective, while millets have lower yields compared to high-yielding rice varieties, their lower input costs (water, fertilizers) and rising market demand for nutritious grains could enhance farmer profitability. Policy support and consumer awareness are crucial to scaling millet production as a sustainable alternative (35). A rice plant needs around 2.5 times as much water as a single millet plant, based to a study (5).

Millets can be grown with minimal chemical inputs, which minimizes its impact on the environment. Against growing concerns about water scarcity and environmental sustainability in agriculture, millets are a viable option because of their natural adaptability and ecologically friendly farming (34). Millets exhibit climate change resilience because they can adapt to a wide range of environmental situations. Millet is a more reliable crop for farmers in heavy rainfall regions due to its adaptability, short growth cycle and resistance to waterlogging and diseases. While excessive rain can still harm any crop, millets outperform traditional staples like rice and wheat under such conditions, providing better yield security. Thus, promoting millet cultivation can enhance farmers' resilience in areas prone to heavy rainfall. These resilient crops are renowned for their ability to resist heat waves, droughts and poor soil conditions (pH - 5-6.5 and EC - 0.8 and 1.8 dS/m) (36). Because of their low water needs and capacity to flourish in harsh environments, millets are an essential tool for maintaining agricultural sustainability and food security in the face of shifting climatic patterns and millets boost climate resilience by thriving in droughts, high temperatures and poor soils with minimal water. Their low carbon footprint and adaptability to erratic rainfall make them ideal for climate-smart agriculture, ensuring food security while reducing ecological stress (35) (Table 2).

With climate change becoming more obvious there's a pressing need for crops that can survive tough conditions (39). Millets, recognized for their ability to endure drought and thrive in poor soil, provide a practical solution (40). They withstand drought well because of their strong roots and ability to slow down metabolism when water is scarce and millet root penetration depth varies significantly with soil type: in sandy soils, roots can reach 60-90 cm due to low mechanical resistance, while loamy soils, being optimal, allow depths of 45-75 cm. Clayey soils restrict growth to 30-50 cm because of compaction and shallow or rocky soils limit penetration to 20-40 cm, though millets adapt by spreading laterally in such conditions (41). This renders millets essential in dry and semi-arid areas impacted by climate change because it enables them to survive and yield grains even under conditions of limited rainfall (42). Compared to most other staple grains, millets can tolerate higher temperatures. They can survive in temperature as high as 46 to 50 °C, which is far higher than rice, wheat and maize can tolerate (43). A climate-resilient substitute for conventional staples, millets come into their own as global temperature continue to increase.

Strengthening communities and developing sustainability

According to cooperative efforts, millets are becoming more and more prevalent as a healthy and sustainable substitute, both in traditional tribal communities and in urban regions (44). The success of these community initiatives showed the transformative capacity of millet farming, stressing the significance of farmer cooperatives in promoting constructive transformation (45). Local communities such as Gonds community, Tribal communities in Chhattisgarh, Tribal communities in the North Coastal areas and parts of Rayalaseema, Andhra Pradesh, Farmer communities in various states, etc have taken the lead in promoting millet growing in a number of places as a way to accomplish both economic sustainability and food security (46).

Table 2. Millets and its special features and nutritional benefits

Sno.	Crop name	Scientific name	Special features	Health benefit	References
1.	Finger millet	*Eleusine coracana*	Moderately resistant to heat, drought and humidity, adapted to wide altitude range	Rich source of calcium	(40)
2.	Foxtail millet	*Setaria italica*	Adapted to low rainfall, high altitude, short duration, tolerant to low fertility and drought	Energy diluents to formulate low calorie diets	(38)
3.	Proso millet	*Panicum miliaceum*	Short duration, well adopted to low rainfall and high altitude area, tolerant to drought and heat	Reduced bioavailability of Ca, Mg, Zn, Fe	(19)
4.	Kodo millet	*Paspalum scrobiculatum*	Long duration, needs little rainfall, grow well in very poor soils, shallow and deep soil, good response to improved management	No gluten content, rich in fibre, Management of certain type of diabetes	(33)
5.	Barnyard millet	*Echinochloa frumentacea*	Very short duration (Fastest growing crops), best fodder, not limited by moisture, high altitude adapted	Rich in linoleic acid, Reduced risk of inflammatory bowel disease	(28, 37)
6.	Little millet	*Panicum sumatrense*	Short duration, adapted to low rainfall and poor soils and act as famine food, withstand waterlogging	Hypocholestero-laemic activity and reducing the risk of cardiovascular diseases	(6)

Millets are important for sustainable farming, which focuses on soil health, ecological balance and human welfare (44). This approach emphasizes cultivating land and growing crops to maintain soil vitality and overall well-being. It's crucial to recognize the significance of millets for our health and the environment, integrating them into both farming practices and daily meals (47) (Table 3).

Collaboration of farmers, non-governmental organizations (NGOs) and government agencies is common in programs such as National Millets Mission (NMM), Price Support Scheme (PSS) and encouraging value-added millet products, National Food Security Act (NFSA) 2013 and the National Nutrition Strategy (NNS), Sub-Mission on Nutri-cereals, International Year of Millets (IYM) 2023, Rainfed Area Development Project (RADP) support millet production. A noteworthy instance is the "Millet Mission' in India, which endeavours to encourage the cultivation and consumption of millet by means of awareness campaigns, training initiatives and monetary rewards (45). Promoting the consumption of millet intake is an essential aspect of effective millet community projects. Communities conduct culinary demonstrations and awareness campaigns that emphasize the variety of foods that can be made with millets (48). These initiatives not only promote better eating habits but also generate demand for products made from millet (45).

In Karnataka, Bhooja Thota Millet Growers' Cooperative works mainly to encourage of small-scale farmers to cultivate millet. The cooperative offers instruction in sustainable agriculture, organic farming methods and water conservation. Members are benefited by spending low input costs for seeds and equipment by pooling their resources (45).

Enhancing food security and nutrition

Millets, as a result, are a vital crop in assisting food security for a large number of under-resourced countries within the global culturist climate. Millets are high in a variety of essential vitamins and a vital element in the fight against malnutrition. Millets provide energy, protein and dietary fibre to the body (49).

In comparison, people's diets frequently lack essential elements including iron, zinc and B vitamin all of which are abundant in millet (50). Their low glycemic index leads to better blood sugar regulation and diabetes (Type-2) control. Additionally, they don't contain gluten, so those who have celiac disease or gluten sensitivity can safely consume them without adverse reactions (48). Millets are well-suited for small and marginal farmers because they don't need much investment. Growing millets helps small and marginal farmers feed their families consistently and independently, reducing reliance on external factors (52).

Nutrition is a key factor that determines the functionality and activity of the immune system. Due to the highly nutritious composition, millets could be vital in promoting immunity (53). The presence of antioxidants, such as phenolic acids, enhances immunity by preventing oxidative damage to immune cells (54). Zinc in millets also improves the activity of the immune system, influencing the growth and maturation of various immune cells (55). Fibre in millets enhances gut health, which is crucial to the activity of the immune system. A healthy gut bacterium plays a critical role in maintaining the function of the immune system (56). However, this malnutrition can be reduced if we take millets in sufficient amount in our diet (38).

Emerging opportunities

Millets can survive in unfavourable soil conditions, require little water and are resistant to drought, making them an excellent choice for food crops in drought-prone locations (57). Millets have a good amount of protein, fibre, vitamins and minerals (58). Since millets are naturally gluten-free, anyone with celiac disease or gluten intolerance can safely consume them (59). Millets are a flexible crop option for farmers, as they can be grown in a variety of climates and soil conditions (60). India has a wide variety of millets, including hybrids that are farmed utilizing traditional farming practices that are both environmentally friendly and sustainable (61).

Consumption challenges for millet

Millets have difficulties with perception and demand, despite their resilience and nutritional value. The perception of millets as "famine food" or "food for the poor" in many areas hinders the middle and higher classes from consuming it (62). To increase the demand for millets, this perception needs to be modified. Many consumers find millets less preference than wheat or rice because of their slightly bitter flavour that is caused by the presence of phenolic chemicals (63). Moreover, millets have extensive cooking times and rough texture prevent their widespread consumption (64). Due to inadequate processing methods and inadequate storage facilities, millets frequently experience significant post-harvest losses (65). A significant challenge in dehulling millets is their hard seed coat and small size. Additionally, processing

Table 3. Age-wise digestibility of staple foods versus millets (44)

Age group	Digestive capacity	Staple foods (e.g., rice, wheat)	Millets	Justification
Infants (0-2 years)	Very low; immature digestive enzymes and gut lining	Easily digestible when cooked as porridge or gruel	Difficult to digest; high fibre and anti-nutrients	Millets may cause bloating; not ideal unless specially processed (e.g., fermented)
Toddlers (2-5 years)	Developing digestive system; sensitive to heavy foods	Soft chapatis and khichdi are suitable	Still relatively hard to digest	Limited inclusion possible in soft, fermented forms
Children (6-12 years)	Moderate digestive capacity	Easily digestible, common in daily diet	Can be included in small amounts	Millets can be used in porridge or dosa form with proper cooking
Adolescents (13-18 years)	Fully functional digestive system	Well tolerated	Can be included more regularly	Can handle more fibre and complex carbs
Adults (19-59 years)	Strong digestive capacity (in healthy individuals)	Easily digestible, staple food	Highly suitable, if properly prepared	Best time to include millets regularly for health benefits
Elderly (60+ years)	Slower digestion; weaker gut function	Still easy to digest, especially in soft form	May cause discomfort if not cooked well	Should be consumed in softer, fermented forms for ease

can lead to nutrient loss, especially if not done carefully and the proper solution to milling machineries and technologies are Improved Pre-Treatment Methods (Hydrothermal Treatment and rubber roller shellers), Advanced Milling Technologies such as Impact Hullers (Centrifugal Dehullers), CFTRI (Central Food Technological Research Institute, India) Millet Dehuller, Friction-Based Dehullers (Modified Emery Rollers) and Satake's Abrasive Dehullers and Nutrient-Preserving Techniques such as cryogenic milling and Fractionation Technology (66).

Policy support and market opportunities

In India, small and marginal farmers produce 60 % of total millet production, hence to support the farmers Government of India implemented the policy for millets promotion. In World, small and marginal farmers produce 94 % of total millet production. This policy addressing the threats of climate change and ensuring food and nutritional security. The Indian government, state governments and research organizations have launched a number of programs and initiatives to increase millet production and consumption (8).

Nutri cereals under National Food Security Mission (NFSM)

As part of the National Food Security Mission (NFSM), the Department of Agriculture and Farmers Welfare (DA & FW) conducted a submission on Nutri-cereals (millets) in the years 2018 to 2019. The main goal of the submission was increasing the millets cultivation area, total production and productivity (44). The aim of the mission was to develop a market-oriented strategy to tackle production, demand and research-related concerns. The objective of this plan was to enhance productivity and expand the cultivation area through sustainable methods, hence increasing the production of Nutri-Cereal in certain districts of the country (67). The Nutri-Cereal (Millets) Mission has made moderate progress in expanding cultivation, enhancing productivity and boosting demand through sustainable methods, particularly in states like Rajasthan, Karnataka and Odisha. Initiatives such as high-yielding seed distribution, FPO support and the 2023 International Year of Millets have improved market linkages and consumer awareness. However, challenges like low MSP adoption, supply chain gaps and uneven farmer participation persist. While productivity and area under cultivation have increased in targeted districts, sustained efforts are needed to fully realize the mission's potential.

PLI scheme on millet

The "Production Linked Incentive (PLI) Scheme for Food Processing Industry," a central sector initiative with a budget of Rs. 10900 crores, was approved by the government on March 31, 2021. The plan was implemented over a seven-year period, starting in the academic year 2021-2022 and ended in the 2026-2027 academic year (68). The principal aims of this initiative was to cultivate world-class leaders in the food manufacturing industry and to increase the awareness and identification of Indian food product brands in global markets (44).

Promoting millets in Public Distribution System (PDS)

To improve millets' affordability and accessibility, the Indian government has indeed taken steps to promote millets (such as jowar, bajra, ragi, etc.) by including them in the Public Distribution System (PDS) in the year of 2013-14 to enhance affordability and accessibility. Additionally, the government has revised the rules governing the interstate transportation of surplus millet production to quicker the movement of millets (69). Transporting excess millets across state boundaries is one of the ways that the Food Corporation of India (FCI) is meeting the pre-procurement needs of the consuming State (68). Public awareness campaigns can promote the nutritional and environmental benefits of millets, encouraging consumer demand and Government-Led Awareness Campaigns such as 2018 - "Year of Millets" (declared by Govt. of India to promote nutri-cereals), 2019-2020 - "Eat Right India" campaign by FSSAI included millet promotion, 2021 - "POSHAN Abhiyaan" integrated millets for better nutrition, 2023 - "International Year of Millets" (UN, led by India) with nationwide campaigns, food festivals and global promotions, 2023 - "Millets Shakti" (Women's Self-Help Groups promoted millet-based products) and 2023-24 - "Millet Mahotsavs" (food fairs and exhibitions across states) (44). Moreover, value addition and market linkages can enhance the economic viability of millet farming, ensuring fair prices for farmers and access to nutritious millet-based products for consumers and the Minimum Support Price (MSP) for the 2022-23 for millets has seen a significant hike. Ragi (Finger Millet) now has an MSP of ₹4290 per quintal, marking a rise from the previous year. Other millets also have revised MSPs are Jowar (Hybrid) - ₹3371 per quintal, Maldandi Jowar - ₹3421 per quintal, Bajra (Pearl Millet) - ₹2625 per quintal (33). Some of the policy and institutional barriers such as MSP & Procurement Bias, Limited Research & Development (R&D), Weak Market Linkages & Supply Chains, Trade & Export Challenges and Low Institutional Support for Farmers to the promotion and consumption of millets include: millets are less prioritized in terms of their focus and attention in agricultural policies and research in comparison to other cereals such as rice and wheat (70).

A plan called the Initiative for Nutrition Security through Intensive Millets Promotion has been created to put into action the announcement. The goal of this plan is to show the effectiveness of better farming and post-harvest methods in a combined way to encourage more millet production in the nation (53). Apart from boosting millet production, the plan aims to create consumer interest in millet-based food products by using processing and adding value techniques (71). This lack of policy direction could lead to low productivity as well and low demand by the farmers growing the cereal. There is little research focus on enhancing millet varieties and farming techniques to help improve yields as well as millets exhibit strong natural resistance to pests and diseases due to their biochemical and structural defenses including silica-rich leaves, phenolic compounds and hard seed coats. Their genetic diversity and adaptation to harsh environments further enhance resilience. Unlike major cereals, millets attract fewer pests and some varieties release repellent volatile compounds or support natural predators. They are less prone to devastating fungal and viral diseases, though exceptions like pearl millet downy mildew and finger millet blast exist. Agronomic practices like intercropping and crop rotation reduce pest pressure, while their short growth cycle and drought tolerance help avoid peak infestations. Though generally hardy, some pests (e.g., shoot fly) and storage weevils remain challenges. Overall, millets' low susceptibility to pests and diseases makes them a sustainable, low-input crop, ideal for eco-friendly farming and food security (72). They further note that there is little involvement to develop markets for millets and product development, which includes value addition to make it attractive for consumption by consumers and fetching the farmer a lucrative return (73).

Conclusion

Millets have the potential to play a pivotal role in achieving nutritional security and promoting sustainable agriculture in the context of the Second Green Revolution. These hardy and nutrient-rich crops offer a range of benefits that can address the challenges of malnutrition, climate change and environmental degradation. By promoting the cultivation and consumption of millets, can diversify our food systems and ensure a more balanced and nutritious diet for populations worldwide, particularly in regions prone to food insecurity. Millets are rich in essential nutrients, such as proteins, vitamins and minerals making them an excellent source of nourishment for vulnerable communities. Moreover, millets are well-adapted to thrive in harsh environments including drought-prone areas and marginal land making them a resilient choice in the face of climate change. Their low water and input requirements, coupled with their ability to grow in poor soil conditions and make them an environmentally sustainable option for smallholder farmers. To fully harness the potential of millets concerted efforts are needed from various stakeholders including policymakers, researchers, extension services and farmers. Investments in research and development, capacity building and market linkages can facilitate the widespread adoption of millet cultivation and consumption. By embracing millets as a key component of the Second Green Revolution it can enhance nutritional security, promote sustainable agriculture and contribute to the overall well-being of communities worldwide fostering a more resilient and equitable food system for generations to come. As it navigate the challenges of the 21st century, millets can serve as the cornerstone of a more resilient and inclusive food system.

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Authors' contributions

GG collected the literature and drafted the manuscript, while SV provided overall guidance for corrections and improvements. TR, SR, SS and KP assisted with literature collection and formatting. All authors contributed equally to revising the manuscript and approved the final draft.

Compliance with ethical standards

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