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Millets for Food and Nutritional Security for Small and Marginal Farmers of North West India in the Context of Climate Change: A Review

Himanshu Tiwari [a,b++*], R. K. Naresh [a], Lalit Kumar [c], S. K. Kataria [d], Sumit Tewari [e‡], Ankit Saini [f#], Rakesh Kumar Yadav [g†] and Ruchi Asati [g†]

[a] *Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India.*
[b] *School of Agriculture, University of Engineering and Technology, Roorkee, India.*
[c] *Krishi Vigyan Kendra Moradabad, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India.*
[d] *Department of Agronomy, Gochar Mahavidyalay Rampur Maniharan, C.C.S. University Meerut, Saharanpur, Uttar Pradesh, India.*
[e] *School of Agriculture, Lovely Professional University, India.*
[f] *Department of RS and GIS, CSIR-IHBT, Palampur (HP)-176061, India.*
[g] *Department of Genetics & Plant Breeding, College of Agriculture, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior-474002, M.P., India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

In India, 600 million people are dependent on the agricultural sector, the majority of them are small farmers with up to 2 hectares of land holding. Rain-fed is two thirds of the net sown area. About 40 million hectares of this land being flood-prone and about two thirds of it is drought-prone. Geographically, the poorest people typically reside in more exposed or marginal areas, such as on

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[++] *Assistant Professor;*
[#] *Project Associate;*
[†] *Ph.D. Scholar (Genetics & Plant Breeding);*
[‡] *B.Sc. Agriculture 2nd Year;*
**Corresponding author: E-mail: himanshu1996nduat@gmail.com;*

nutrient-deficient soils or flood plains. Due to limited human and financial resources, the poor are also less able to respond and have very limited capacity to cope with the effects of climate change and adapt to a changing hazard burden. The great majority of the world's population is feeds through the current food system, which also supports for the livelihoods of over 1 billion people. Since 1961, The amount of food supply per capita has increased by more than 30%, accompanied by greater use of nitrogen fertilizers and water resources for irrigation. However, 821 million people are currently undernourished, 613 million women and girls between the ages of 15 to 49 are suffer from iron-deficiency, 151 million children under the age of five are stunted, and 2 billion adults are overweight or obese. Millets have a lower carbon footprint of 3,218 kg than wheat and rice, with 3,968 and 3,401 kg of carbon dioxide equivalent per hectare, respectively, helping to lessen the consequences of climate change. Because they are less demanding to external inputs, drought-tolerant, and register a comparatively lower carbon footprint than other cereals. Millets have also attracted the attention of growers and policy-makers in the current implications of adverse effects of climate change. After the institutional neglect for a few decades, millets made a comeback because to these beneficial effects. Millets are suitable staples when focusing on the food and nutritional security of the common people. However, the successful millet harvest warrants an integration of proven and climate-smart technologies to meet the future needs of the ever-growing population. In terms of marginal growing conditions and high nutritional value, millets outperform other grains like wheat and rice as climate change complaint crops.

Keywords: Food security; millets; food diversity; climate change; agricultural productivity.

1. INTRODUCTION

"One of the biggest challenges facing in the modern world is feeding the world population on the planet. The deficiencies of micro- and macronutrients, shortage in food production that leading to supply-demand imbalances, and conflicts that destabilize various regions of the world are all factors that contribute to this problem. The threat of climate change and global warming still lingers, although some of these triggers for hunger can be addressed, resulting in a slight reduction in the population suffering from hunger and malnutrition from about one billion in 1990–1992 to 850 million in 2010–2012" [1]. "According to estimations, 2-3 billion people may suffer from hunger, food and nutritional insecurity by 2050 as a result of declining food production rates along with the additional pressure of feeding a population above 9 billion" [2,3]. "Crop yields, crop production, and the overall sustainability of our food systems are reported to be directly impacted by climate change and rising global average temperatures. A few regions could benefit from climate change due to increased yields and productivity, according to some estimates, but this won't be enough to feed the higher number of inhabitants globally" [4]. Furthermore, the most of scientists agrees that crop production would be significantly decreased by the current rates of global warming and greenhouse gas emissions. Therefore, ensuring food security depends on reducing the emissions of greenhouse gas to control global temperatures. However, one of the primary sources of greenhouse gases such as methane in the atmosphere is the agriculture sector. Intensive farming practices, which are practiced in various parts of the world, typically result in higher emissions [5].

Food is predominantly produced on land, from terrestrial production in 2013, accounted for 83% of the average annual food consumption per person of 697 kg, 93% of the daily energy intake of 2884 kcal, and 80% of the daily protein intake of 81 g [6]. "Over the past 50 years, with increases in crop yields and production the overall supply of food has been increasing. Growth in food production from animal-sourced is driving crop use for livestock feed" [7]. "Between 1961 and 2013, global trade of crop and animal-sourced food has increased by about five times" [6]. "Global food availability has increased from 2200 kcal/cap/day to 2884 kcal/cap/day during this period, shifting the world's food status from food deficit to a food surplus situation" [8].

"The availability of cereals, animal products, oil crops, and fruits and vegetables has mainly grown reflecting shifts towards more affluent diets. This, in general, has resulted in a decrease in prevalence of underweight and an increase in prevalence of overweight and obesity among adults" [9]. During the period 1961–2016, anthropogenic GHG emissions associated with agricultural production has grown from 3.1 $GtCO_2$-eq yr^{-1} to 5.8 $GtCO_2$-eq yr^{-1}. "The increase in emissions is mainly from the livestock sector and use of synthetic fertilizer, and rice cultivation" [6]. Millets possess immense potential in our battles against climate change and poverty, and provide food, nutrition, fodder and livelihood security. Being hardy crops, they can withstand extreme temperatures, floods and droughts. They also help mitigate the effects of climate change through their low carbon footprint of 3,218-kilogram equivalent of carbon dioxide per hectare, as compared to wheat and rice, with 3,968kg and 3,401kg, respectively, on the same measure. *In the past, millets were a poor farmers insurance against the vagaries of the Indian monsoon. In the future, millets can be our insurance in times of climate change.*

"In India, millets are cultivated in an area of 15.48 million hectare producing 17.2 million tonnes with a yield of 1111 kg/ha" (Directorate of Economics and Statistics, 2015). "Maharashtra, Rajasthan and Karnataka are the top most states of millets cultivation in India. Contribution of millets in total food grain production of India reduced from 22.17% to 6.94% over the last six decades from 1950-51 to 2011-12. In spite of all the extraordinary qualities and capacities of millet farming systems, the area under millet production has been shrinking over the last five decades and rapidly, since the Green Revolution period due to relentless promotion of other crops such as rice and wheat for intensive farming in select few resource rich areas under irrigated conditions (MINI) [10]. Another major threat that millets facing in the country in the form of an unnatural promotion of maize, which is resulting in maize invasion in various parts of the country owing to the corporate-induced demand for bio-fuels and poultry feed" [11]. Numerous farmer associations have been established over time to aid small and marginal farmers in overcoming obstacles to millet production and sale. Market instability is a common occurrence, thus policies that safeguard farmers' livelihoods are necessary. Incentivizing the adoption of inter-cropping and providing crop insurance and support for storage facilities will foster income and food security.

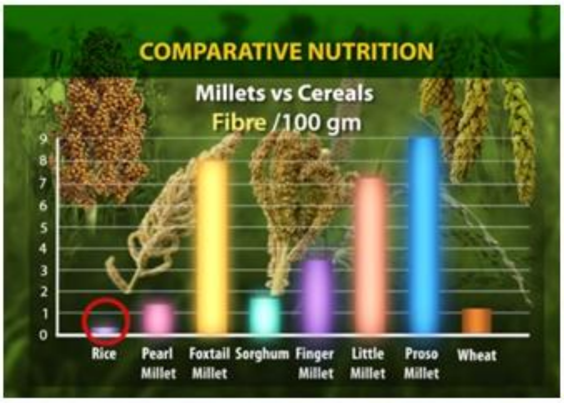
The implications of climate change are what have given the previously unidentified millets a considerable amount of attention. Millets farming is being promoted by international organizations under the theory that it minimizes the carbon impact of agriculture while assuring food and nutritional security. A rising number of farmers are converting to millets farming in India and other regions of the world. The CGIAR has proposed that millets be the way forward for nations like India where food security and nutrient security are important issues and as water-guzzlers like wheat and paddy would face difficult challenges when temperatures rise owing to global warming. According to CGIAR predictions, climate change might cause a 13–20% decline in the world's production of wheat, rice, and maize in the ensuing decades. While productivity must increase by an estimated 70% to feed the 9 billion people by 2050, global agriculture will have to fight against this loss. In that context, it is noteworthy to mention that against a fluctuating productivity trend in case of major food crops, millets have shown exceptional increase in productivity over the last five decades. As India's agriculture suffer hugely from the vagaries of monsoon, millets which are also known as "famine reserves" for their prolonged and easy storability under ordinary are of great relevance. They are most suitable for mixed and intercropping, thus offer sustainable resources use, food and livelihood security to farmers. Millets, which are grown for both food and fodder, increase farming's economic efficiency and enhance the safety of food and livelihood for millions of households, especially small and marginal farmers and people living in remote tribal areas with limited access to water. According to research, a 1% increase in production might cut poverty by 0.65%. As rain-fed areas are 30% less productive than irrigated areas, increasing production is especially crucial in these areas. Millets appear to hold the key to fighting poverty, malnutrition, and climate change.

Since millets have so many advantages, both our farmers and we consumers should strive to raise more of them. We should also include millets in our daily food baskets. In today's age of modernization, industrialization, and urbanization, we need to adequately process the millets in order to produce a variety of nutritious products with added value that correspond to the taste, texture, and flavor of the consumers. This is in addition to increasing production and consumption. In this review paper an attempt has been made with a specific objective to attempt has been made to highlight the utility of millet production and the relative contribution of food and nutritional security. It is hoped that the study will assist the policy makers in formulating necessary strategies and policies to increase the production of millets to meet their demand during the changing times to fulfill the nutritional requirements of people.

Millets show us the way out of our food, fodder, nutrition, and water crises because they are sturdy enough to grow on the poorest lands of the poorest people. They are the only plants that can withstand the harshest of climates in arid and semi-arid regions while still providing food and fodder security for vast populations. Because much of millet farming is ecological, it produces a unique phenomenon known as 'uncultivated foods,' which helps the poor with food and nutritional security. The recent analysis of millets of farming systems has come to the amazing conclusion that millet farming saves nearly six million litres of water per acre, a bonanza for the water starved times we are living in. They can stand up to the most modern crisis of them all, the climate change. Seen from any angle, millets shine forth as miracle grains.

Rigorous efforts are needed to mainstream millet farming to improve the ecological balance and the health system of the population, using the 'super grain' as health foods. Incentives should be provided to people growing and procuring nutri-cereals, besides enhancing domestic consumption by creating awareness among the consumers. Farmers should be educated about millet-growing techniques and their process ability. They have many nutraceutical and health-promoting properties and have three times more calcium as compared to rice; they are also rich in antioxidants and score over rice and wheat.

The glycemic index of millet-based products is lower, which ensures slower release of carbohydrates and control of the blood sugar level. Thus, millets are a very good source of nutrition for diabetic people. Millets are gluten-free and can be a substitute for wheat or gluten-containing grains for coeliac patients.



Nutritive values for 100 g of Cereals and Millets

Name	Minerals Gm	Fibre Gm	Energy	Calcium Mg	Phos-phorus Mg	Iron Mg	Carotine	B1 Mg	B2 Mg	Niacin Mg
Rice	0.6	0.2	345	10	160	3.1	0	0.06	0.06	1.9
Pearl Millet	2.3	1.2	361	42	296	5.0	132	0.33	0.25	2.3
Foxtail Millet	3.3	8.0	331	31	290	12.9	32	0.59	0.11	3.2
Sorg-hum	1.6	1.6	349	25	222	5.8	47	0.37	0.13	3.1
Finger Millet	2.7	3.6	328	344	283	6.4	42	0.42	0.19	1.1
Little Millet	1.5	7.6	341	17	220	10.0	0	0.30	0.09	3.2
Proso Millet	2.6	9.0	309	27	188	5.2	0	0.33	0.09	2.0
Wheat	1.5	1.2	346	41	306	4.9	64	0.45	0.17	5.5

Image 1. Comparative assessment of nutrition

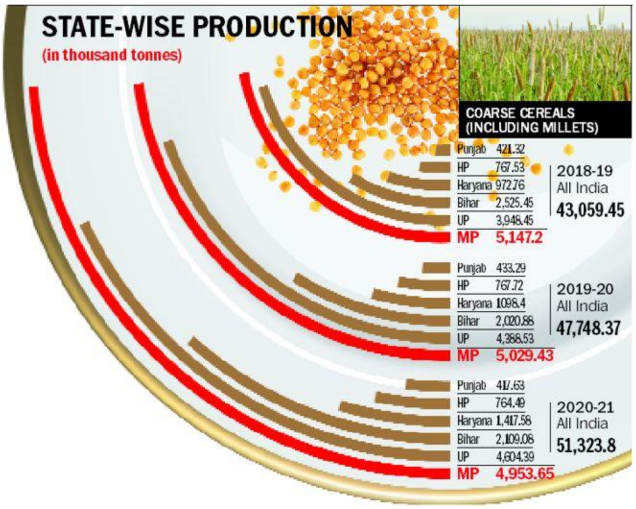


Image 2. State wise production of cereals

2. MILLETS OFFER A SUSTAINABLE ALTERNATIVE TO MAJOR STAPLE CROPS

“Millets are a group of diverse small-grain cereal crops grown in marginal soil and under stressed conditions. They comprise about a dozen crop species originated in Asia and Africa, primarily in the third world countries” [12]. “India is the largest producer of millets producing nearly 40 percent of the world’s millets despite much negative pressure from competing crops in terms of policies and production supports. The millets’ ability to adapt to adverse climatic conditions, requirement of minimal inputs, and superior nutritional qualities are among the specific characteristics of millets rarely found in other common cereals. Millets possess specific molecular, biochemical, and morpho-physiological characteristics that allow them to withstand adverse environmental conditions–drought and poor soil conditions” [13]. “Their shorter lifecycle, short stature, and small leaf area may also offer an added advantage. Considering their adaptability to high light, high temperature, and dry weather as C_4 photosynthetic capacity, millets are more efficient than common cereal crops. These mechanisms allow millets to have enhanced photosynthetic rates and lower photorespiration rates, as well as water and nitrogen use efficiency under warm conditions” [13,14].

“Millets are important sources of nutrients and can play a significant role in improving nutritional security and preventing diseases caused by imbalanced nutrition. They are gluten-free and contain as much protein as wheat does. In terms of macronutrients, millets are either similar or superior to major cereals” [15]. “They also contain several micronutrients, vitamins, insoluble dietary fiber, and phenolic compounds, which are essential for health benefits. They are thought to have several health benefits including the ability to address diabetes, aging, cancer, celiac disease, and cardio-vascular disease” [16]. Millet-based health food items are common and exhibit longer storage life. Durairaj et al. [17] observed “a significant increase in height, weight, and hemoglobin level of the school children who regularly consumed millet-based health food”.

“Millets are also rich in micro- and macro-nutrients, total protein, fiber, and resistant starch. For instance, finger millet is rich in calcium (~364 mg per 100 g) and potassium (~320 mg per 100 g), and little millet and barnyard millet have high iron contents (~10–18 mg per 100 g). The total protein is high in foxtail millet and barnyard millet (>10%), and crude fiber is rich in barnyard millet, little millet, foxtail millet, and fonio ~7–14%” [18]. In terms of agro-ecological traits, millets have better water-use and nitrogen-use efficiencies that enable them to withstand water-limiting conditions. For example, foxtail millet requires ~250 g of water to produce 1 g of dry biomass, whereas wheat and maize require ~450 and 500 g, respectively.

“Compared to major cereals, millets are capable of meeting the immediate need for food security in at least five important ways. (i) Millets ensure subsistence and income to the marginal population because yield loss or the influence of other external factors (i.e., climate, rainfall, and disease) that impact on productivity is minimal compared to major cereals. Although the area of production and yield of millets are significantly less than for major cereals, millets could provide a better gross return, net return, and benefit–cost ratio. (ii) The sustainability of agriculture can be ensured by cultivating millets because they have reduced dependence on synthetic fertilizers, pesticides, weedicides, and insecticides. The global warming potential (GWP) and carbon equivalent emission (CEE) of rice and wheat are the highest among the cereals. The GWP (CO_2 eq/ha) of wheat and rice are 4 and 3.4 tons, respectively, and their CEEs (kg C/ha) are 1000 and 956, respectively” [19]. “However, the carbon footprints of millets could be comparatively lower than those of major cereals” [20,21], although exact values are not available to date. (iii) Millet cultivation and use decrease the over-reliance on the major cereals that are limited in number. Of note, the majority of the global population relies on rice and wheat as their staple food, and the intervention of millets could reduce this dependence. (iv) “Another advantage is the food quality, where millets are established to be highly nutritious with no compromise in taste and texture that are considered to be essential traits for consumer preference. (v) Millets can contribute to ensuring diversity in food. Of the tens of thousands of plant species known on Earth, ~7000 species are edible, among which only 20% cater for 90% of global food requirements” [22]. Rice, wheat, and maize make up 60% of all staple crops, resulting in a monotonous diet.

Image 3. Characteristic features of millets

Image 4. Millet map of India

"In addition to small millets, underutilized tubers and legumes could add to food and dietary diversification. Among tubers, cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), and taro (*Colocasia esculenta*) are cultivated in African countries, where the tubers, corms, and leaves of these species are consumed as food by economically deprived classes. Arrowroot (*Maranta arundinacea*), Indian shot (*Canna indica*), gonala (*Dioscorea spicata*), purple yam (*D. alata*), air potato (*D. bulbifera*), and elephant foot (*Amorphophallus paeoniifolius*) are a few notable tuber crops that are cultivated in arid- and semi-arid regions" [23]. "In the case of legumes, bambara groundnut (*Vigna subterranea*), cowpea (*V. unguiculata*), rice bean (*V. umbellata*), adzuki beans (*V. angularis*), winged bean (*Psophocarpus tetragonolobus*), jack bean (*Canavalia ensiformis*), kidney bean (*Phaseolus vulgaris*), lima bean (*P. lunatus*), faba bean (*Vicia faba*), horsegram (*Macrotyloma uniflorum*), and velvet bean (*Mucuna pruriens*) are meagerly produced in hunger-prone regions" [24] and these legumes have the potential to develop food self-sufficiency among the population. Therefore, while underscoring the importance of millets in solving hunger and related issues, the collective role of these tubers and legumes as well as millets in ensuring food and nutritional security should not be overlooked.

3. WHY MILLETS ARE THE FUTURE CROPS

Due to their diversity and ability to adapt to various climatic conditions and farming techniques, millets make a compelling case for both enhancing biodiversity and diversifying the world's supply of food grains. Millets are the most reliable food crops for humans under a scenario of climate change, especially for the resource-poor dry-land farmers of the world because they are climate change resistant and ensure sustainable grain production with minimal inputs [25]. Maintaining millets is similar to supporting the dry-land agricultural ecology, which accounts for 40% of the world's land area and 30% of its people, and is characterized by widespread food insecurity and malnutrition. Eradication of hunger is a major priority in these regions as under nutrition accounts for 11 per cent of the global burden of disease and is considered the number one risk to health worldwide.

Millets crops are ideally adapted for climate change mitigation and contingency crop planning due to their rich diversity. They are adaptable to both apparent early planting and delayed planting, locations with very low and high rainfall, different elevations, and diverse soil regimes thanks to the flexibility they display. These advantageous traits have not been properly appreciated and utilized in the nation. Small millets with a wide range of uses, such as foxtail millet, barnyard millet, proso millet, and little millet, would adapt to any climatic change and protect farmers from a complete crop failure. The farmers who had shifted from millets to other crops are keen to go back to millets in view of the stable harvests ensured, easy crop production, drought resistance, and eco-friendly production, provided the assured market is in place. Enhanced millets production and consumption directly facilitates improving malnourishment and correcting the slow growth in correction of nutritional disorders such as anemia, surging lifestyle disorders such as diabetes, hypertension, metabolic syndrome, gluten intolerance *etc.* Data on scientific evidences for nutritional and health benefit claims of millets are now available for projecting them as superior nutritious cereals beneficial for human health. In addition, millet foods are being made available in ready-to-eat and ready-to-cook forms.

Table 1. Factors contributing to decline in millets consumption and area in India

Demand side factors	Supply side factors
• Rapid urbanization	• Increasing marginalized cultivation
• Changing consumer preferences and tastes due to increasing per capita incomes	• More remunerative crop alternatives in *Kharif* season competing with millets in question
• Government policies that favour other crops such as input subsidies and output price incentives	• More remunerative crop alternatives in *Kharif* season competing with millets in question
• The supply of PDS rice and wheat at a lower price introduced in non-traditional areas of fine cereals.	• Deterioration in quality (as in *Kharif* sorghum because of poor quality of grains due to blackening of grains)
• Their poor social status and inconvenience in their preparation (especially sorghum)	• There aren't enough incentives for millet production.
• Shorter shelf life for milled grains and millets flour	• The development of better irrigation systems and options as in small millets.

4. MILLETS FOR CLIMATE-SMART AGRICULTURE

"The food consumption will rise proportionally with a growing population. While rice, wheat and rice have been adopted as the main staple cereals, millets and ither orphan crops are lagging behind. There is a lesser possibility of crop improvement production as the world is already contending with challenges expansion of dry-lands, soil degradation, and scarcity of groundwater" [26]. According to the NRAA (2020) report, approximately half of the total irrigated land will remain unirrigated after utilizing maximum irrigation potential. "These alarms are forcing us to promote alternatives to major cereal crops. Millets are the best option among orphan crops, and their cultivation can solve this issue as they can be produced on shallow, low fertile soil types with a pH range of 4.5 to 8.0" [27]. "There are numerous varieties of millet, including job's tears, kodo, finger, foxtail, proso, barnyard, little, guinea, browntop, fonio and teff. Millets can be an easy replacement for wheat and rice. Millets like finger and pearl millet can grow up to a soil salinity of 11–12 dS/m, whereas rice has poor growth and productivity on a soil having salinity more than 3 dS/m" [27]. They are considered as a poor man's crop because of their significant contributions to a resource limited population diet offering several opportunities for their cultivation in developing countries (Fig. 1).

Compared to other major cereals, millets encompass numerous morpho-physiological, molecular, and biochemical characteristics that confer them better tolerant to environmental challenges. Numerous processes, including sensing, signaling, transcription, transcript processing, translation, and post-translational protein modifications, which are governed by both genetic and epigenetic factors, are involved in the molecular mechanisms underlying the plants responses to abiotic stresses (Fig. 2).

Among the major abiotic stresses, increased heat and drought due to climate change adversely impact on present crop production and alone result in higher annual losses. "According to climate change models predict that drought stress will remain a significant abiotic constraint on food production" [28]. "Many reports studies indirect associations between drought and the rising malnutrition rates, poor health, hunger, starvation, and food and water insecurity" [29].

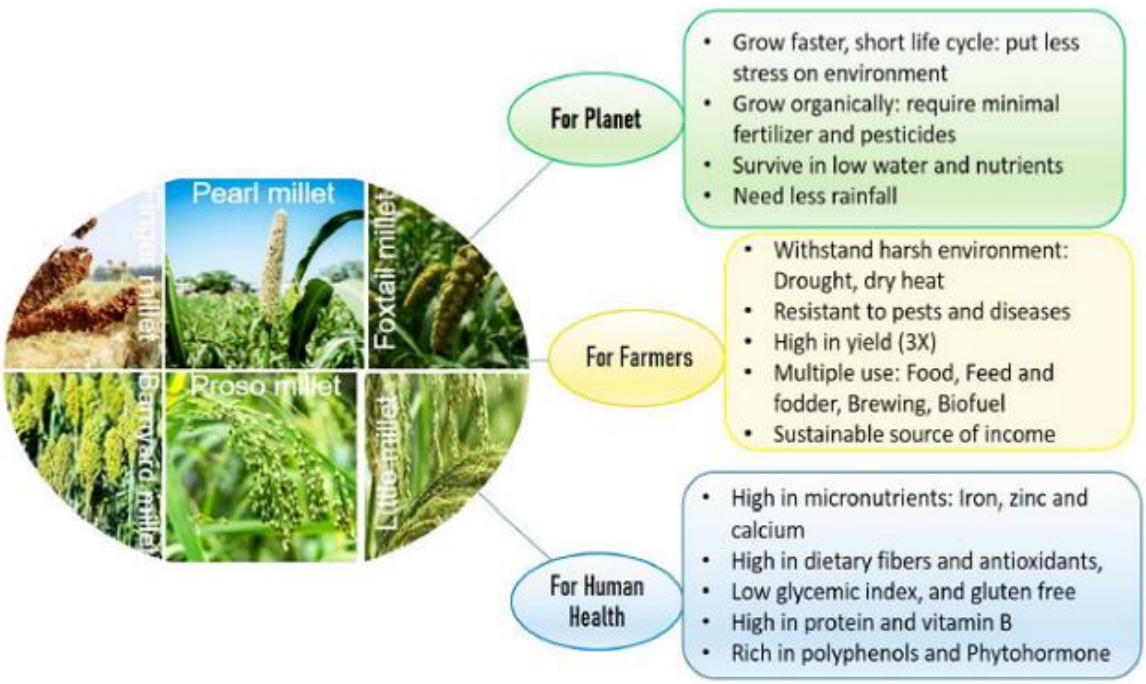


Fig. 1. Millets unique properties for climate-smart agriculture to ensuring human health, food security and nutritional security

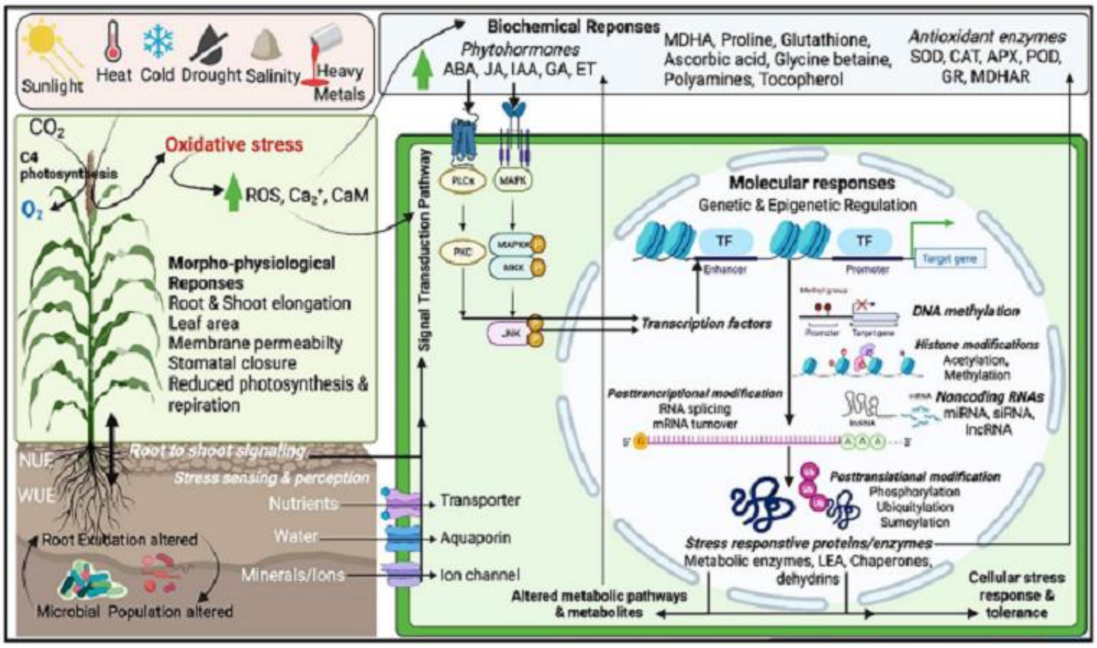


Fig. 2. Sensing, signaling and regulation of the abiotic stress response in millet cells

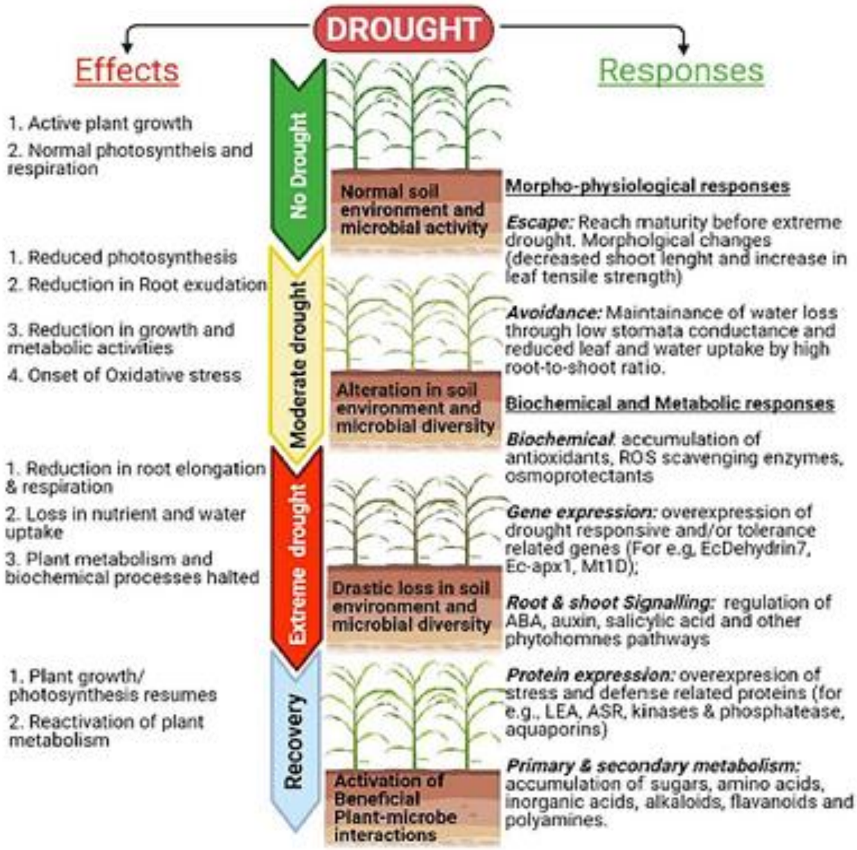


Fig. 3. Drought responses and adaptive strategies linked to numerous morpho-physiological, molecular and biochemical processes that confer more tolerance to environmental stresses in millets compared to major cereals

"Millets are the best alternative in semi-arid and dry regions since they are naturally drought tolerant. Compared to major cereals, millets encompass numerous morpho-physiological, biochemical and molecular characteristics that confer superior adaptation to drought (Fig. 3). For example, rice requires more than 120-140 cm of rainfall, but the rainfall requirement for pearl and proso millet is 20 cm" [15]. "The short life cycle of millets (10 to 12 weeks) as compared to other major crops (20 to 24 weeks) also supports them in stress mitigation. Additionally, they have a C_4 (Hatch and Slack Pathway) photosynthetic system that allows them to endure high temperatures and low humidity. The Calvin cycle and light-dependent reactions are physically apart in the C_4 system. Thus, the C_4 mechanism which increases the concentration of CO_2 in the bundle sheath, which overpowers photorespiration and plants can keep their stomata closed during the day to avoiding water loss" [30]. "Millets have increased photosynthetic rates under warm conditions and confer immediate water and nitrogen use efficiency that is ~1.5 to 4 times higher than C_3 plants" [31]. "To produce 1 g of dry biomass, *Setaria italica* requires just 257 g of water, whereas maize and wheat requires 470 and 510 g, respectively" [32]. "Additionally, C_4 photosynthesis provides other advantages to millets, such as improved ecological performance in warm climates, enhanced flexible biomass allocation patterns, and decreased hydraulic conductivity per unit leaf area" [30]. In the context of a changing climate scenario, these examples offer opportunities for the promotion of these crops to a higher level of production.

5. CONCLUSIONS

Climate change has already had obvious consequences on the environment and put challenges for the agricultural sector globally. Millets have been referred to as 'nutri-cereals' or 'smart foods' due to they are better adapted to diverse environmental conditions through nitrogen-use efficiencies and water-use efficiencies, tolerance to insect, pests and diseases, and resistance to environmental stresses. The climate-resilient features and nutritional profiles of small millets have been widely studied, indicating that millets could be the staple crops of choice in hunger-stricken areas. These regions are heavily affected by under nutrition, malnutrition, and premature deaths owing to the non-availability of food in abnormal situations. Millets, the yesteryear staple diet of a majority of people in the semi-arid regions of Asia, particularly India, could be the climate-resilient future crop. Millets can counter many of the adverse consequences of climate change better than most other food crops. They grow in almost any type of soil, whether it is sandy or with varying levels of acidity. They hardly ever require irrigation or fertilizers.

Millets are nutrients rich, while the iron content of barnyard millet is 15.2 mg that of rice is 0.7 mg. Rice has a 10 mg calcium concentration, compared to 31 mg in foxtail millet. While the proportion of nutrients varies with each variety of millet, in general they are richer in iron, calcium, beta-carotene and other nutrients than wheat and rice. Millets are rich in dietary fibred, which is negligible in rice. With low glycaemic index and no gluten, the millet diet is excellent for those persons with diabetes and celiac diseases. Suitable for mixed and intercropping, crops like maize and broad bean; grown with millets, provide farmers food security and livelihood security. Millets have the potential to be a miracle crop, providing food, nutrition and livelihood security, beating the adverse effects of climate change.

Millets can support sustainable food systems under climate change. Their resilient nature and outstanding potential to survive under low water availability and stressful environments serves as best alternative to staple cereal crops. Therefore, there is an argument to promote them to sustainably address issues such as nutrition and food insecurity, increasing drought and heat, environmental degradation. The success of efforts to promote rural economies to ensure food and nutrition security and poverty eradication depend on creating supportive agriculture policies, the development of climate change resilience in agricultural systems and innovations in smallholder farming practices, as well as the widespread adoption of science and technology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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