Millets as food and nutrition in the period of Climate Resilient Agriculture: A Review

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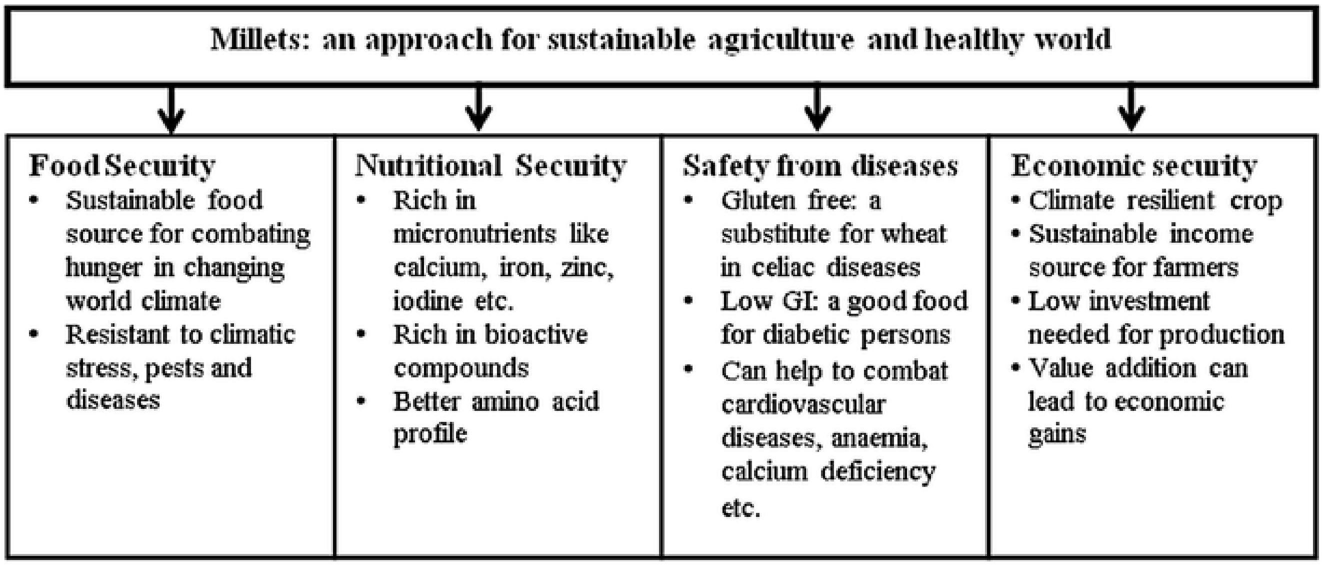
ABSTRACT: World is facing agrarian as well as nutritional challenges. Agricultural lands with irrigation facilities have been exploited to maximum, and hence we need to focus on dry lands to further increase grain production. Owing to low fertility, utilization of dry lands to produce sufficient quality grains is a big challenge. Millets as climate change compliant crops score highly over other grains like wheat and rice in terms of marginal growing conditions and high nutritional value. Sustainable food systems aim to provide sufficient and nutritious food, while maximizing climate resilience and minimizing resource demands as well as negative environmental impacts. We perform a series of optimizations to maximize nutrient production (i.e., protein and iron), minimize greenhouse gas (GHG) emissions and re-source use (i.e., water and energy), or maximize resilience to climate extremes. We find that increasing the area under coarse cereals (i.e., millets, sorghum) improves nutritional supply (on average, +1% to+5% protein and +5% to +49% iron), increases climate resilience (1% to 13% fewer calories lost during an extreme dry year), and reduces GHGs (−2% to −13%) and demand for irrigation water (−3%to −21%) and energy (−2% to −12%) while maintaining calorie production and cropped area. The extent of these benefits partly depends on the feasibility of switching cropped area from rice to coarse cereals. Millets are climate-resilient crops which are considered as a "Miracle grains adaptable to wide variety of ecological conditions requiring less water for irrigation with better growth and productivity in low nutrient soils. They require low artificial fertilizers application and show minimal vulnerability to environmental stresses. There is need to revive the importance of millet groups as health foods to enhance food and nutritional security and can help in alleviating malnutrition. Two main groups of millets are great millets (Sorghum and Pearl millet) and Small millets (Finger millet, Foxtail millet, Little millet, Proso millet, Barnyard millet, Kodo millet and Brown top millet) classified based on the grain size. Both great and small millets have traditionally been the main components of the food basket of the poor people in India. India stands first in area of millets with 90.94 lakh Hectare followed by Niger with 69.99 lakh Hectare. Millets area of the entire world accounts for 312.44 lakh Hectare. India also stands first in production of millets with 115.6 lakh tonnes followed by Niger with 37.9 lakh tonnes. Millets Production of the entire world accounts for 284.59 lakh tonnes. Uzbekistan stands first in yield of millets with 7563 kg per ha followed by Switzerland with 4236 kg per Hectare, yield of the entire world accounts for 910 kg per ha (Food and Agricultural Organization, 2017). Millets contain high amounts of proteins, fiber, niacin, thiamine and riboflavin, methionine, lecithin and little of vitamin E. They are rich in minerals like iron, magnesium, calcium and potassium also. Millets due to their nutritive value have potential health benefits to prevent cancers, decrease the occurrence of cardiovascular diseases, reduce tumor proliferation, lower blood pressure, risk of heart diseases, cholesterol content, rate of fat absorption, delayed gastric emptying and increased gastrointestinal bulk. Value-addition to millet grains as ready-to-eat and ready-to-cook items offers good opportunity to farmers for enhanced income generation, promotes production and marketing leading to nutritional security, employment and revenue generation. However, the successful harvest of small millets warrants integration of proven and climate-smart technologies for the fulfillment of the future needs of the ever-growing population. The review paper focused on all these aspects. Moreover, the research scope mentioned in the review paper implies future directions for enhancing millet-based agriculture viable in diversifying food baskets and achieving food and nutritional security in a hunger-free society.

***Keywords*: Millets, Food security, Nutritional value,**

Introduction

Tackling hunger and feeding the world population are two of the biggest challenges of the modern world. Reasons contributing to this issue range from deficiencies in the supply of micro- and macro-nutrients, shortage in production of foods leading to supply–demand imbalances, and conflicts destabilize various parts of the world. Although several of these triggers for hunger can be addressed leading to a slight reduction in the population suffering from hunger and malnutrition from almost one billion in 1990–1992 to 850 million in 2010–2012, the threat of climate change and global warming still lingers (FAO, 2012). Estimates show that the reduction in food production rates along with the added pressure of feeding a population exceeding 9 billion by 2050 could lead to 2–3 billion people suffering from hunger, food and nutritional insecurities (Godfray et al., 2010; Wheeler and Braun, 2013). Millets are multipurpose: They consume 70 percent less water than rice; grow in half the time of wheat; and require 40 percent less energy in processing. They are one-stop solution in the wake of climate change, water scarcity, and drought conditions along with high nutritive value to provide sustainable food security (Fig.1).



Sustainable diets are protective of bio diversity and ecosystems with low environment impact, which contributes to food and nutrition security. Diversifying crop production by including more coarse cereals like millets can build food supply, reduce Green House Gas (GHG) emissions, and enhance climate resilience without compromising on nutritive value. A quantitative assessment of altering monsoon cereal production in India, found millets as a viable option for food security and environmental resilience. The Figure 2 indicates the contribution to calories from monsoon cereals with maximum supply of protein and iron, maximum savings in water, energy, green house gases, and climate resilience.

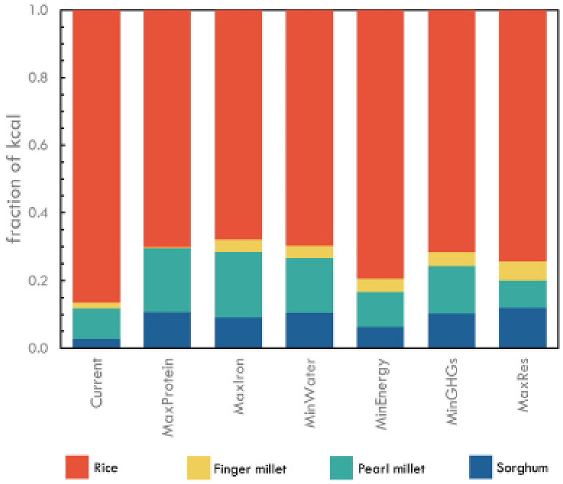


Fig. 1: Current and optimized shares of monsoon cereal production [Source: Davis et al., 2019]

Millets are a smart food: they are good for your health, good for the environment as they survive with less water and have a low-carbon footprint, and good for the farmer as they are more resilient and climate-smart. More than 90 million people in Africa and Asia depend on millets. In comparison, wheat, rice, and maize are staple foods for 4 billion people. These three major cereals provide 51% of the world's calorie intake. 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. Millets are resilient to extreme conditions including high temperatures and drought. They can grow in the harshest, most arid regions. Currently, around 55% of millets are grown in arid regions of Africa, 40% in Asia, and 3% in Europe. In India, the demand for millets has grown by 140% but the production is less than 50%.

A farmer gets just 600 kilograms of millet per hectare with 400 millimeters of rain. Currently, the yield of rice in India is 2.7 metric tons per hectare and wheat is 3.5 metric tons. In China, this is 4.9 and 5.6 metric tons respectively but with investments in input technology, such as high-quality seeds and irrigation, per hectare yield of small millets can reach 4.5 tons, and pearl millet and sorghum can touch 9 tons. Millets have a diverse genetic makeup and require few cultivation inputs. They are also more nutrient-dense than traditional grains (Banerjee and Maitra, 2020). Millets, which are grown for both food and fodder, provide food and livelihood stability to millions of people while also assisting in efficient farming especially for small/marginal farmers of rain-fed areas (Reynolds *et al*.,2015). Malnutrition is pervasive in many developing nations; for example, India is one of many countries where child malnutrition is severe (Pasricha and Biggs, 2010). Minor millets are essential food group that has been missing from the food basket in recent years. Minor millets are well-known for their health advantages.

Millets offer nutritional security and there is a need for promoting millets as they are highly nutritious. These have been important food staples in human history, particularly in Asia and Africa. Sorghum and other millets consumption usage as direct food have significantly declined over the past three decades. The decline in demand has led to the decline in millets production considerably in India. Production of sorghum in India has come down from 7 million tonnes during 2010-11 to 4.2 million tonnes during 2015-16; bajra production was reduced from 10.4 million tonnes to 8.1 million tonnes, production of ragi reduced to 2.2 million tonnes to 1.8 million tonnes and small millets production came down to 0.39 million tonnes from 0.44 million tonnes during the same period.

Davis et al. (2019) also found that the potential for substantial increases in iron supply, modest improvements in protein supply, reductions in water and energy demands and GHG emissions, and enhancements of climate resilience (Fig. 2) all while maintaining calorie production from cereals within each state. National iron supply from cereals could increase by 49% on average (+737 tons annually). Changes in protein supply were relatively modest in comparison (+5%) due to the overall similarity in protein content between cereals. Reductions in total water demand were also modest (−8%), while monsoon irrigation water demand could be reduced by 16 km^3 H_2O on average (or −21%) and in many places that currently experience declining groundwater tables. Energy demand reduced by an average 12% and GHG emissions were reduced by an average 21 M tonne CO_2eq (−13%). Further, by increasing areas cultivating coarse cereals, the loss of calories under an extremely dry year would reduce by 13% on average.

These estimated changes are in large part a reflection of the nutritional and environmental characteristics of rice in comparison to coarse grains [i.e., comparable protein content; lower iron content; less efficient intensities of water use energy use, and GHG emissions (Rao et al., 2019), and higher climate sensitivity (Davis et al., 2019).

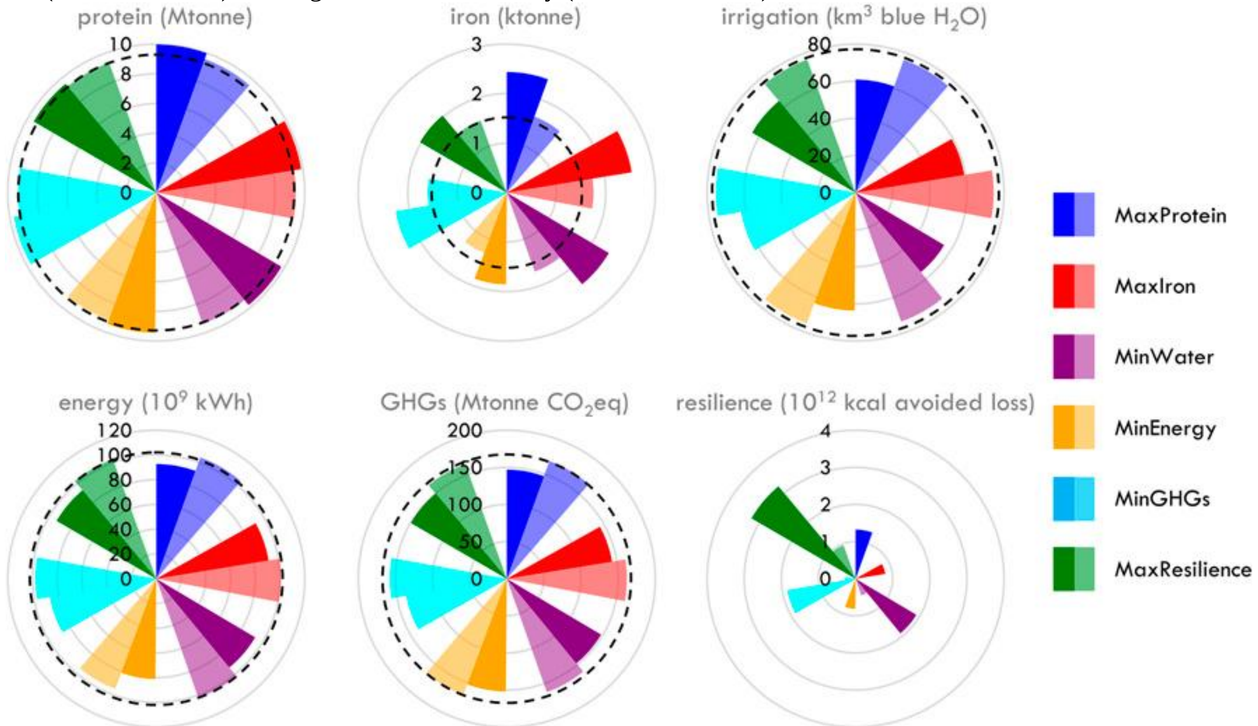


Fig. 2: Outcomes of optimizations for nutrient supply, environment, and climate resilience [Source: Davis et al., 2019]

There is a big shortfall between the amount of food we produce today and the amount needed to feed everyone in 2050. There will be nearly 10 billion people on Earth by 2050—about 3 billion more mouths to feed than there were in 2010.

Feeding 10 billion people *sustainably* by 2050, then, requires closing three gaps:

- **A 56 percent food gap** between crop calories produced in 2010 and those needed in 2050 under "business as usual" growth;
- **A 593 million-hectare land gap** (an area nearly twice the size of India) between global agricultural land area in 2010 and expected agricultural expansion by 2050; and
- **An 11-gigaton GHG mitigation gap** between expected agricultural emissions in 2050 and the target level needed to hold global warming below 2ºC (3.6°F), the level necessary for preventing the worst climate impacts.

In general millets are rich source of fibre, minerals and B-complex vitamins. High fibre content and presence of some anti-nutritional factors like phytates and tannins in millets affect bioavailability of minerals. Millets are also rich in health promoting phytochemicals like polyphenols, lignans, phytosterols, phyto-oestrogens, phytocyanins. These function as antioxidants, immune modulators, detoxifying agents etc. and hence protect against age-related degenerative diseases like cardiovascular diseases (CVD), diabetes, cancer etc. (Rao *et al.*, 2011). Some of the known nutrients vitamins, minerals, essential fatty acids also have benefits in terms of prevention of degenerative diseases besides their known functions of preventing nutritional deficiency diseases. Being non-glutinous, millets are safe for people suffering from gluten allergy and celiac disease. They are non-acid forming, easy to digest and non-allergenic (Saleh *et al.,* 2013). Millets have potential for protection against age-onset degenerative diseases. Consumption of millets reduces risk of heart disease, protects from diabetes, improves digestive system, lowers the risk of cancer, detoxifies the body, increases immunity in respiratory health, increases energy levels and improves muscular and neural systems and are protective against several degenerative diseases such as metabolic syndrome and Parkinson's disease (Chandrasekara and Shahidi, 2012). The important nutrients present in millets include resistant starch, oligosaccharides, lipids, antioxidants such as phenolic acids, avenanthramides, flavonoids, lignans and phytosterols which are believed to be responsible for many health benefits (Edge *et al.*, 2005).

Among these, millets are known for their climate-resilient features including adaptation to a wide range of ecological conditions, less irrigational requirements, better growth and productivity in low nutrient input conditions, less reliance on synthetic fertilizers, and minimum vulnerability to environmental stresses. o achieve inclusive and fair growth and development in our country, the second green revolution must focus primarily on nutrition, which was overlooked in the first green revolution, which was focused on production (Negin et al., 2009). In our country, inner invisible hunger (micronutrient insufficiency) is a major issue. Eradication of extreme poverty and hunger is the first of the Millennium Development Goals (MGDs) proposed by the United Nations in the year 2000. India is far away from achieving this goal (Patwari, 2013). Further, cultivation of millets addresses some of the Sustainable Development Goals (SDG) such as SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and wellbeing) and SDG 15 (life on land) (UN, 2021). Tackling these challenges necessitates a paradigm shift from the existing incremental adaptation strategies toward transformative substitutes that emphasize human health, nutrition, and environmental sustainability. The current natural disasters make it even more imperative to shift toward a climate-resilient agriculture system (Bisoffi et al., 2021; Rasul, 2021).

Millets for nutritional importance

World is in the clinch of several health disorders and chronical diseases. A nutrient imbalanced diet is responsible for most of these diseases. According to the estimates of United Nations Food and Agriculture Organization, about 795 million people (10.9% of world population in 2015) were reported undernourished. While on the other hand more than 1.9 billion (39% of world's population) adults ≥ 18 years of age were over -weight and further 13% were reported to be obese (FAO, 2015). India is the home of world's largest undernourished population. About 194.6 million people, i.e. 15.2% of total population of India, are undernourished. According to the 2017 Global Hunger Index report, India ranked 100^{th} among 119 countries. The score of India is even poorer than Nepal, Sri Lanka and Bangladesh (Von Grebmer et al., 2017). Protein energy malnutrition (PEM) was reported to result in 4, 69,000 deaths with 84,000 deaths from the deficiency of other vital nutrients such as iron, iodine and vitamin A (Lozano et al., 2012). Obesity is also a major health concern in India with the prevalence rate of 11% in men and 15% in women.

60 million children under-weight (highest in world) 30% low birth weight babies75% pre-school children suffer from iron deficiency anaemia 85% districts have endemic iodine deficiency (Gragnolatia et al., 2005) 35.7% of children under five are under weight; 58.4% of children between 6 and 59 months are anaemic; 53% of (non-pregnant) women are anaemic. 51 million people suffer from diabetes which is expected to increase to 79.4 million by 2030 (the increasing consumption of highly polished rice grains and decreasing consumption of coarse cereals contributes to this trend) (Kaveeshvar and Cornwall, 2014) 18.5% children over weight 5.3% children obese.

Choi et al. (2005) studied the effect of dietary protein of Korean fox-tail millet and found its importance in increasing insulin sensitivity and cholesterol metabolism. Lee et al. (2010) investigated the effect of millet consumption on lipid levels and C-reactive protein concentration; it was found that hyperlipidemic rats fed with foxtail millet had decreased levels of triglycerides. Aqueous and ethanolic extracts of kodo millet have been reported to produce adose-dependent fall in fasting blood glucose (Hegde et al., 2002). Further millets are gluten free and might have anti-carcinogenic properties (Dykes and Roone, 2005).

The millets contain as high as13-38% of total dietary fiber that could be considered in the management of disorders like diabetes mellitus, obesity, hyperlipidemia, etc. The glycaemic load lowering effects of barnyard millet is highest among all the millets (Kumari and Thayumanavan 1998). Foxtail millet exhibits antihyperglycaemic and antilipidemic activities. An aqueous extract of 300 mg of foxtail millet per kg body weight of rats exhibited 70% reduction in blood glucose level in streptozotoc in induced diabetic rats (Sireesha et al., 2011). Millets are also a good source of carotenoids (78-366mg/100g) and possess higher antioxidant capacity (Devi, 2014). The antioxidant activity of millets is also attributed to their tocopherol content (Fig. 3).

The barnyard millet grain contains about 49-65% carbohydrates (Sood et al., 2015).The carbohydrates are mainly composed of dietary fibre. The high content of dietary fibre helps in the prevention of constipation, reducing glycaemic load and lowering of blood cholesterol level. It has the highest content of crude fibre (14.7g/100g) and minerals (4.0g/100g) among all the millets. The iron content (18.6 mg/100g) of Barnyard millet is higher among all the millets and protein content is from 11.1% to 13.9%.

Proso millet the fat content is 2^{nd} highest among millets i.e. 4.0g/100g and the predominant fatty acids in the free lipids are linoleic, oleic, and palmitic acids (Amadou *et al.*, 2013). The protein content is10.6 g/100g. The protein of proso millet is gluten free and can be used for foods for people with gluten intolerance or celiac disease.It is also a good source of Vitamin B2, B3 and B9. It is also rich in fibre and minerals i.e. 12g and 2.9 per 100g, respectively. Proso millet is also a god source of dietary fibre and has a lower glycaemic index (Park et al., 2008).

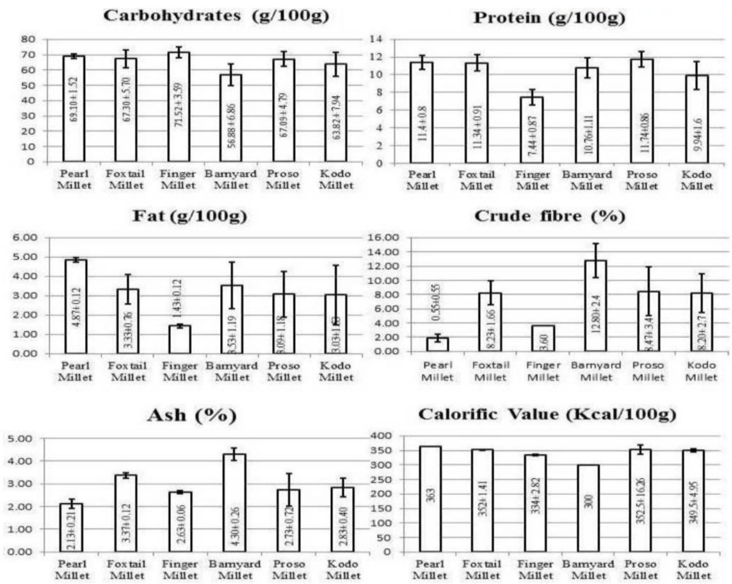


Fig. 3: Nutrient Composition of different millets (Source: Kumar et al., 2108)

About 5-8% of protein is present in finger millet, 65-75% carbohydrates, 15-20% dietary fiber and 2.5-3.5% minerals (Chethan and Malleshi, 2007a). The Naked caryopsis of finger millet with brick red coloured seed coat is generally used in the form of whole meal in the traditional food preparations such as roti, muddle and ambali (thin porridge). Regular consumption of whole grain cereals and their products have shown in epidemiological studies that they can protect against risk of diabetes mellitus, gastrointestinal diseases and cardiovascular risks (McKeown, 2002). The use of millets as whole grain makes the essential nutrients such as dietary fiber, minerals, phenolics and vitamins concentrated in the outer layer of the grain or the seed coat form the part of the food and offer their nutritional and health benefits (Antony *et al.*, 1996).

Sorghum has 11.9 per cent of moisture and about 10.4 per cent of protein and a lower fat content of 1.9 per cent. The fibre and mineral content of grain sorghum is essentially similar, and is 1.6 per cent. It is a good source of energy and provides about 349 K cal and gives 72.6 per cent of carbohydrates (Gopalan *et al.*, 1996). Starch is the major carbohydrate of the grain. The other carbohydrates present are simple sugars, cellulose and hemicellulose. The amylose content of starch varies from 21.28 per cent. Sorghum is also rich in dietary fibre (14.3%). Calcium, phosphorous and iron content of sorghum is 25 mg, 222 mg and 4.1 mg (per 100 g of edible portion), respectively (Hosmani and Chittapur, 1997).

Millets like Jowar has protein content of 10.4g, Bajra 11.6g, the 12.5g of proso millets, 12.3g of foxtail millet, and 11.6 of barnyard millet is equal to wheat's 11.8g and significantly greater than rice's 6.8g. In comparison to wheat and rice, finger millet has lower protein content (7.3g), but it is higher in mineral matter and calcium. Millets in general have more fibre than fine cereals. In compared to wheat 1.2g and rice 0.2g, tiny millets such as barnyard millet 14.7g, kodo millet 9g, little millet 8.6g, and foxtail millet 8.0g are the richest in fibre. As a result, millets are now referred to as "Miracle grains/ Adbhut Anaj and nutria-cereals"(Senthilvel *et al.*, 2008). Finger millet has 16 times the calcium content of maize, and some believe it could eventually replace rice as a staple diet, which is especially important to humans due to the availability of key minerals (Hassan *et al.*, 2021).

Consuming little amounts of millet on a daily basis reduced the chance of developing type 2 diabetes. This happens because whole grains like minor millet are high in magnesium, which serves as a co-factor in a variety of biochemical activities in the body and hence aids glucose and insulin secretion (Saikia and Deka., 2011).

Millets for climate smart agriculture

Future agriculture will face some common environmental changes like enhanced temperature, uncertainties in rainfall, elevated CO_2 and GHGs levels, and more frequency in natural calamities. Under these conditions, climate resilient agriculture should be adopted in which cultivation of climate smart crops will play a pivotal role. There is no doubt that millets are the climate smart crops which can simultaneously mitigate the ill effects of climate change and adapt to the changed and wider agro-climatic conditions (Bandyopadhyay et al. 2017). Millets have some efficient morphological, physiological, molecular and biochemical traits which can withstand abiotic stresses. As millets are short-duration crops, thus completing a cycle within a short time span, they can escape the possibility of environmental stress conditions under early or late sowing conditions. Besides, millets possess less leaf area a thickened cell wall and a dense fibrous root system which facilitates their capability to tolerate abiotic stress (Li and Brutnell 2011). Being C_4 plants, millets can utilize more atmospheric CO_2 and by the process of photosynthesis can produce more assimilates, even under elevated CO_2 levels into the atmosphere (Aubry et al., 2001). Furthermore, water use efficiency (WUE) of millets are higher than major cereals and in the future, under the crucial situation of water deficit in a major portion of the world, millets will automatically be chosen to combat water shortage. For example, foxtail millet needs only 257 g of water to produce 1 g of dry biomass and the water requirement is half that of maize (470 g) and wheat (510 g) to produce the same quantity of dry biomass (Bandhyophyay et al. 2017). Wheat and rice have a global warming potential of around 4 tons CO_2 eq/ha and 3.4 tons CO_2 eq/ha, respectively. Wheat, rice and maize also have high carbon equivalent emissions of 1000, 956 and 935 kg C/ha for wheat, rice and maize, respectively (Jain et al. 2016). The carbon footprint of millets is comparatively less than major cereals and therefore cultivation of millets can reduce the carbon footprint (Saxena et al. 2018). Furthermore, in the process of chemical nitrogen fertilizer production, CO_2 is generated and as per an estimate to fulfill the present requirement of chemical nitrogen fertilizers in the world, annually 300 teragram ($Tg = 10^{12}g$) of CO_2 is released into the atmosphere (Jensen et al. 2012). Millets are less nutrient demanding crops and promotion of millet cultivation will indirectly save the environment.

The demand for food will increase proportionally with a growing population. While maize, rice and wheat have been adopted as the major staple cereals, millets and other orphan crops are lagging behind. There is a lesser possibility of crop improvement production as the world is already facing the challenges of drylands expansion, soil degradation, and groundwater scarcity (Bisoffi et al., 2021). Millets are the best choice among orphan crops and their cultivation can solve this problem as they can be grown on shallow, low fertile soils with a varied (ranging from 4.5 to 8.0) pH (Rathinapriya et al., 2020). There are many small types of millet such as finger, foxtail, proso, barnyard, Kodo, little, guinea, brown top, teff, and fonio. Millets can be an easy replacement for wheat and rice. Further, millets like pearl and finger millet can grow up to a soil salinity of 11–12 dS/m, while rice has poor growth and productivity on a soil having salinity higher than 3 dS/m (Rathinapriya et al., 2020). They are considered as a poor man's crop due to their significant contributions to a resource-limited population diet offering several opportunities for their cultivation in developing countries (Fig. 4).

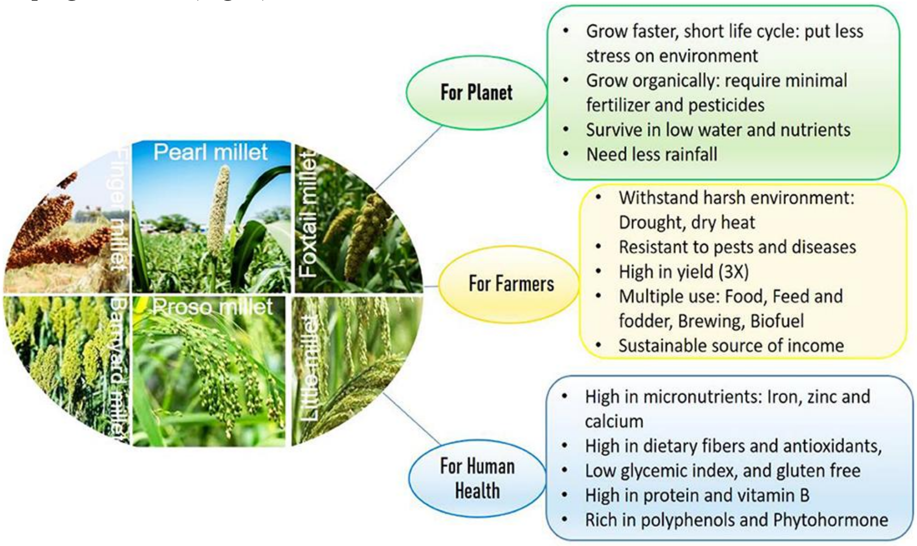


Fig. 4: Unique properties of millets for climate smart agriculture, ensuring human health, food and nutritional security [Source: Rathinapriya et al., 2020]

Drought and millets: Impact and adaptation

Crop productivity is affected by a number of biotic and abiotic stresses. Rapid changes in climate led to major losses of arable land used for crop production and imposing abiotic stresses during critical plant growth and development stages causing yield losses. In semi-arid and arid regions, abiotic stress such as drought, extreme temperature (cold, frost and heat), flooding, salinity etc. are the major yield limiting stressors. Millets encompass numerous morpho-physiological, molecular, and biochemical properties that confer better tolerance to environmental stresses than major cereals. Molecular mechanisms underlying the plants responses to abiotic stresses include multitude of processes including sensing, signaling, transcription, transcript processing, translation and post-translational protein modifications which are governed by both genetic and epigenetic factors (Fig. 5). Among all major abiotic stresses, increased drought and heat due to climate change adversely affect current crop production and alone cause more annual losses. The climate change models predict that drought stress would continue as a major abiotic limitation for food production (Simmons et al., 2020).

Millets encompass numerous morphophysioloical, biochemical and molecular traits that confer superior adaptation to drought than major cereals (Fig. 6). The rainfall requirement of pearl and proso millet is 20 cm, which is many folds lower than rice as they require more than 120–140 cm (Kumar et al., 2018). The short life-cycle of millets (~10–12 weeks) as compared to other major crops (20–24 weeks) also supports them in stress mitigation. Millets have enhanced photosynthetic rates at warm conditions and confer immediate water and nitrogen use efficiency, which is ~1.5- to 4-fold higher than C_3 photosynthesis (Wang et al., 2012). For instance, Setaria italica requires just 257 g of water to produce dry biomass of 1 g, whereas maize and wheat require 470 and 510 g, respectively (Nadeem et al., 2020). Additionally, C_4 photosynthesis provides secondary benefits to millets, including better growth and ecological performer in warm temperatures, enhanced flexible allocation patterns of biomass, and reduced hydraulic conductivity per unit leaf area (Lundgren et al., 2014).

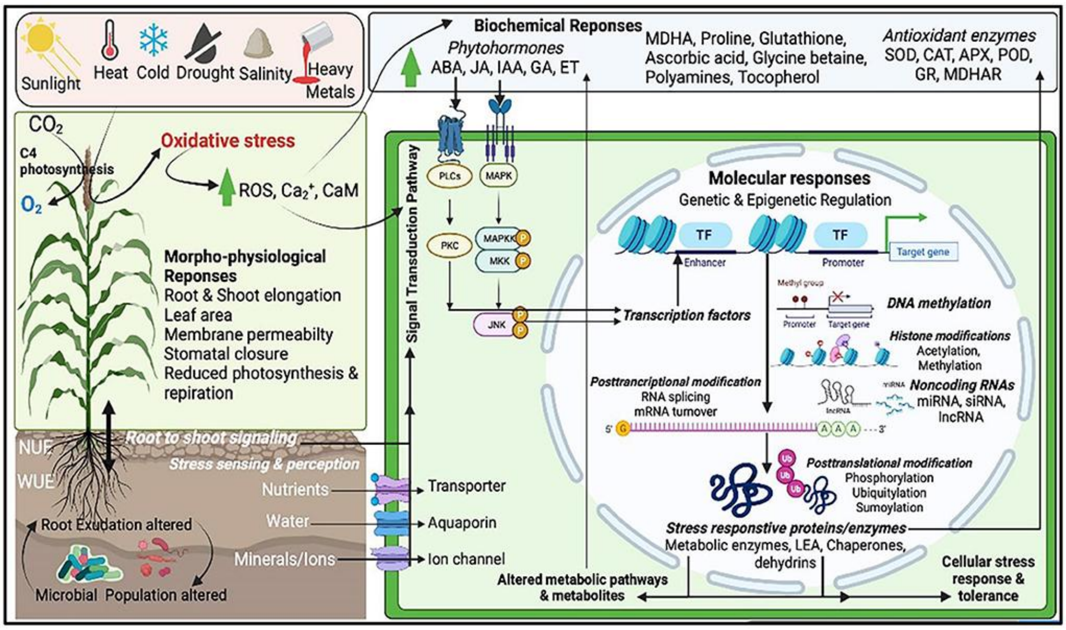


Fig. 5: A schematic framework of abiotic stress response sensing, signaling and regulation in millet cells. Abiotic stresses alter morpho-physiological, biochemical and molecular processes and also by modulating the rhizosphere properties and functions in millets [Source: Simmons et al., 2020]

Compared to maize, pearl millet can modulate their membrane dynamics better for water permeability to attain better water status during osmotic stress (Bandyopadhyay et al., 2017). An increase in leaf tensile strength and root length was reported in teff and little millet under drought (Balsamo et al., 2006). Several biochemical events, e.g., reactive oxygen species (ROS) regulation, enhances ROS scavenging enzymes (catalase and superoxide), and other stress-related proteins. The accumulation of antioxidants and osmolytes has been reported in response to abiotic stresses in millets (Ajithkumar and Panneerselvam, 2014). These qualities of millets make them a suitable model system holding the potential for research to explore the stress-responsive traits and delineate the mechanism of stress at the physiological, biochemical, and molecular levels.

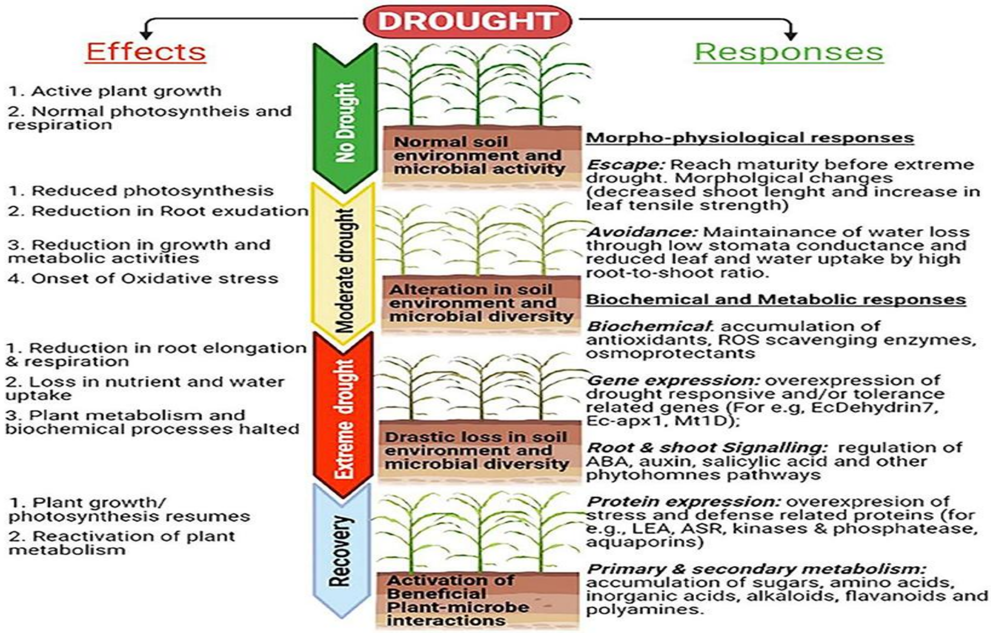
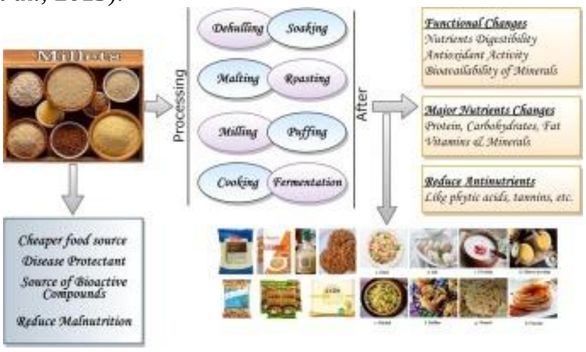


Fig. 6: Drought responses and adaptive strategies linked to numerous morpho-physiological, molecular, and biochemical processes that confer better tolerance to environmental stresses in millets compared to major cereals [Source: Kumar et al., 2018]

Incorporation of millets in Indian food supply chain

- To feed the population we first need to produce then only we can process millets and enjoy its nutritional benefits (Saleh *et al*., 2013). But the scope for enhancement of productivity under irrigated conditions is limited because of over-exploitation of available resources, but there is ample opportunity for boosting yield in dry-lands by adopting suitable crops and cropping systems. The combination of cereal and legume in intercropping can be a major help to the farmers in subsistence farming targeting livelihood security (Maitra, 2020c). They also have numerous advantages, such as increased crop productivity, increased resource efficiency, reduced water run-off and soil conservation in erosion-prone areas, prevention of soil nutrient loss, improved soil health, insurance against crop failure due to unusual weather, and a higher monetary return and benefit-cost ratio (DeVincentis *et al.*,2020; Maitra *et al*., 2022).

- Snacking is becoming a common practice especially in children and adults therefore an attempt to develop some healthy snacks like muffin cakes and biscuits from processed malted finger millet flour to get the maximum advantage of their nutrient content in terms of bioavailability. Malting Finger millet malt (FMM) can be prepared by different methods given by with slight modifications that is by steeping finger millet grains for 18-24 h at room temperature and allowed to sprout for 48-120 h. Grains were dehydrated for 60 min at 60 °C. Further rootlets of grains were removed and powdered to obtain flour for later usage. Also, the above process can be repeated by blanching, pressure cooking or roasting the grains field (Khokhar and Apenten, 2003).
- After fermenting and cooking the ready-made mix to create idli and dosa, germinated powders of minor millets were blended and incorporated with other fundamental traditional components like rice powder and de-husked black gramme powder in defined proportions. In comparison to rice-based idli, high proportions of protein (15-18%), fat (8.5-9.8), and carbohydrate (69-72%) were determined for dosa. In millet based meals, processing stages such as decortication, germination, and fermentation also considerably reduced anti nutrients such phytic acids (69%) and tannin (78%) concentration (Krishnamoorthy *et al.*, 2013).



- A key caveat in achieving the estimated benefits of cereal diversification is the extent to which agronomic characteristics will permit switches between crops. On one hand, historical policy regimes have promoted the widespread cultivation of crops in places that may not have otherwise been agro-ecologically suitable or sustainable (e.g., rice in northern India). On the other hand, certain areas where rice is currently grown may not be able to support the cultivation of coarse cereals. Assessments quantifying the range of biophysical conditions that can support the cultivation of each cereal will therefore be essential for understanding the potential magnitude of co-benefits from increased coarse cereal production (DeFries et al., 2018).
- Increases in coarse cereal production largely occurred in or close to the places where the cultivation of these cereals is currently centered. This is encouraging from a farmer perspective as the local knowledge of effective crop management practices may be more readily available.

CONCLUSIONS

Climate change has already had obvious effects on the environment and put challenges for the agricultural sector globally. These extreme climatic events (temperatures rise, rainfall variation, drought etc) add to pressures on agricultural and food systems. This outbreak has disrupted many agriculture and supply chain activities, compounding food and nutrition security challenges, and sustaining livelihoods. Their impacts have the most negative effects on developing countries by adding resource problems, such as water scarcity, pollution, and soil degradation. There are huge genetic resources in terms of landraces, varieties are available in different millets but not much attention has been given to work the responsiveness of varieties under different soil types.

Millets have low glycaemic index, abode gluten-free protein and are rich in minerals (calcium, iron, copper, magnesium, etc.), B-vitamins and antioxidants. These extraordinary traits make them nutritious and climate change compliant crops. These can not only serve as an income crop for farmers but also improve the health of the community as a whole. Therefore, we advocate using the term "climate smart/resilient" agriculture considering several elements such as: (i) more prominent role for locally produced important millet crops, (ii) increase in production of nutritious food and value addition to help the human immune system, (iii) creation of low-cost farming systems with less dependence on water and chemicals, (iv) leveraging agro-ecology to synthesize the environment with farming, and (v) nudging consumers' demand toward climate-resistant grains, and making farming more feasible for marginal farmers.

In India, diversifying crop production to include more coarse cereals, such as millets and sorghum, can make food supply more nutritious, reduce resource demand and greenhouse gas emissions, and enhance climate resilience without reducing calorie production or requiring more land. Millets can contribute to 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.

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