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Review article

Millets: The future crops for the tropics - Status, challenges and future prospects

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A R T I C L E I N F O

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A B S T R A C T

Millets are small-grained nutritious minor cereal crops that are resistant to different abiotic stresses resulting from climate change. Despite their many benefits, millets have received limited attention in agricultural research, policies, and markets. Considering the importance of millets, recently the government many tropical countries including India and Bangladesh give more emphasis to millets cultivation and improvement. Moreover, Food and Agricultural Organization of the United Nations (FAO) declared 2023 to be the "International Years of Millets". In these connections, a details and updated review of the pros and cons of millets cultivation and its improvement in this region warrant due attention. The review therefore, examines the potential and main barriers to the adoption and promotion of millet cultivation in this region. These include limited research and development efforts, inadequate infrastructure and inputs, weak market linkages and demand, and insufficient awareness and knowledge about millets' nutritional and environmental benefits. This review also highlighted the prospects and strategies for scaling up millet cultivation in this region especially in Bangladesh. These include increasing public and private investment in research and extension services, strengthening farmers' organizations and market linkages, promoting millet-based value chains and products, and integrating millets into nation's food policy. The review concludes that millets might support equitable and sustainable agricultural growth, which would contribute to global food and nutritional security and could help attain the sustainable development goals (SDGs). However, achieving this potential will require concerted efforts from multiple stakeholders, including farmers, researchers and policymakers. The review emphasizes the need for a multi-disciplinary and multi-stakeholder approach that prioritizes innovation, inclusiveness, and sustainability. Lastly, the review highlights more investigation into the socioeconomic, environmental, and nutritional effects of millet production in this region with special emphasis on Bangladesh in order to support evidence-based policies and practices.

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1. Introduction

Millets are the member of *Poaceae* family that are small-seeded cereals grown extensively in dry and tropical parts of Eurasia and Africa. Millets are among the first crops to be domesticated. Evidence of millet consumption was found dates back to the Indus Valley Civilization (3000 BC). Millets are considered to be the most significant crop of cereal grains worldwide, behind wheat, rice, maize and barley [1]. Relative to other cereals, millets have higher pest and disease resistance [2]. Formerly millets were important food crops but nowadays it is promoted as the important foods of the future due to the detrimental impacts of changing climate which are more pronounced in vulnerable ecosystem [3]. Millets are described as "miracle crops" because of their numerous advantages, including their use as food and food products with added value, forage, contribution to agro-diversity, low nutrient requirements, greater C sequestration (C_4 plants), ability to prevent erosion in arid regions and confirmation of adequate supply of food and nutrition for smallholders who live in harsh environmental condition [4]. Also, millets are the perfect food for people who care about their health because millets are gluten-free [4].

Throughout the world, billions of people regularly eat rice, wheat, maize, and to a lesser amount of millet as their main sources of food. The growth pattern of these crops is influenced by temperature and water availability. While wheat is mostly produced in regions with limited water resources and suitable temperatures, rice and maize are grown in regions with an abundant supply of water. In regions with limited water supplies, millets are farmed. Furthermore, millets are grown in semi-arid and dry areas because of their resistance to biotic and abiotic stressors and their high yield on low-quality soil with little maintenance [5]. An old crop with a durable future, millets are adaptable to dry and semi-arid climates and do well in areas with little rainfall. Since millet seeds are vulnerable to damage from cold weather and frosts, a mild, temperate atmosphere is necessary for their sprouting and germination. The grains are 70% more water-efficient than rice and can tolerate temperatures as high as 42 °C. The fact that millets can tolerate high temperatures makes it an ideal choice for tropical countries which are looking for drought-resilient food solutions. International Crops Research Institute for the Semi-arid Tropics stated that, millets are "usually the last crops standing in droughts" [6]. Recently, the interest in the potential of millets has been increased to contribute to sustainable and inclusive agricultural development, particularly in regions facing adverse impact of climate change and food insecurity. One such area is Bangladesh, where millets can be a potential crop to address a number of issues affecting the agricultural sector, such as climate change, malnutrition, and poverty. The rural *Bengali* tradition is associated with this crop. It was once commonly grown in villages, but due to its inability to compete with other crop kinds, traditional millet is being lost. The majority of the food produced in Bangladesh is made up of three cereals: rice, wheat, and maize. It is reasonable to state that millet production is quite low as a result of human neglect despite the cheap cost, eco-friendly, simple agricultural methods, and water conservation measures. Otherwise, the primary obstacles to growing millets include a lack of better seeds, water stress during crop establishment, high input prices (seeds, fertilizers, and pesticides), and the lack of timely access to agricultural loans. Additionally, crop loss from early flash floods is a common occurrence, particularly in low-lying char regions and waterlogging conditions. The lack of contemporary farming equipment and technology that would shorten the gap between two harvests in a millets-based cropping pattern was also noted to be a barrier to the production of millets. According to a report by the ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), in Bangladesh, millets occupy below 1% land of the overall cultivated area [7]. Their limited widespread cultivation is mostly due to the fact that they are given less attention in research and extension programs than significant cereals like rice, maize, and wheat. Millets are also often grown in soils that are less productive. In addition, compared to other cereals, the crops are naturally less productive and have a reduced production potential. Most farmers cultivated conventional, low-yielding millets. Modern types might boost the production of these minor grains by 50–80%, but their availability and usage were constrained [8]. Their output is further constrained by the shortage of high-yielding cultivars and timely supplies of premium seeds.

Millets have a remarkable rate of return-on-investment while being subject to climate change. Millets' climate-resilient characteristics continue to support sustainable agriculture without requiring chemical fertilizers [9]. Millet cultivation are anticipated to support environmentally sound farming with no harm to the environment since agricultural production might result in serious harm to the environment owing to the careless application of fertilizers and pesticides. Inputs of fertilizer and pesticides are now virtually ever necessary for agriculture output. This is not true for millets. Traditionally, millets have been produced as rain-fed crops with little to no fertilizer input over a period of thousands of years [10]. One of the advantages of millets is that they are less prone to disease and pests and have low water and investment expenses. As a result, millet grains are receiving interest from many developing nations due to their potential for use as food and animal feed. It can also withstand droughts and be preserved for a long period without being harmed by insects. Millets stand out from other cereals due to their abundance in calcium, dietary fiber, polyphenols, and protein [11]. In recent years, millet-based meals have become more and more advocated for a balanced diet and for treating a variety of health conditions [12]. Millets can therefore be viewed as crops of the future that will help agriculture to overcome obstacles. There is a strong need to include "millet" as a staple food in addition to wheat and rice in the current condition of shrinking land, food shortage, and nutritional deficiency. The importance of millets as a crop has been recognized by various organizations and researchers. The Food and Agricultural Organization of the United Nations (FAO) has emphasized millets' potential to support food and nutrition security, particularly in areas with high rates of malnutrition and poverty [13]. In this connection, FAO declared 2023 to be "International Years of Millets".

Over the year, various research has been done on different millets which have been summarized, discussed and presented in this article. We have also reviewed the existing literature on the agronomic, economic, and socio-cultural barriers that hinder the adoption, improvement and promotion of millet cultivation in Bangladesh, as well as the opportunities and strategies for scaling up millet cultivation in the country. The article will provide insights for researchers, policymakers, and development practitioners to promote millet cultivation in the tropics with special emphasis on Bangladesh, with a focus on innovation, inclusiveness, and sustainability.

2. Distribution, types and uses of millets

Millets are a kind of cereal crops that are widely cultivated worldwide. Millets are known for their high nutritional value and adaptability to diverse agro-ecological conditions. About 14 species of millets belonging to 10 genera are cultivated in the world including pearl millet (*Pennisetum glaucum* (L.) R. Br.), finger millet (*Eleusine coracana* (L.) Gaertn.), foxtail millet (*Setaria italica* (L.) P. Beauv), proso millet (*Panicum miliaceum* L. subsp. miliaceum), kodo millet (*Paspalum scrobiculatum* L.), barnyard millet (*Echinocloa esculenta* A. and *Echinocloa colona* L.), and little millet (*Panicum sumatrense* Roth. Ex Roem. & Schuit) [14]. Table 1 lists several important millets that are grown across the world with their origins, total cultivable germplasm, unique traits, and applications.

3. World status of millets cultivation

3.1. Millets producing counties

Millions of people depend on millets as a vital source of food, and they are grown in many parts of the world, including Asia, Africa, and South America [25]. According to FAO, millets are grown in over 100 nations throughout the world, with India, Nigeria, and Niger being the top three producers [26]. In Africa, millets are the second most widely grown cereal and are particularly important in semi-arid regions where they are grown as rainfed crops [27]. Top 10 millet-producing countries in the world are given in Fig. 1.

Table 1
List of millets grown across the world, their origin, including their total cultivable germplasm, unique traits, and uses [14].

Crop name	Total cultivable germplasm	Center of origin	Major countries	Special characteristics	Uses
Major Millets					
Sorghum (*Sorghum bicolor* L. Moench)	168,500	Kassala in eastern Sudan	Nigeria, USA, Sudan, Mexico, Ethiopia, India	Tolerate moisture stress and high temperature better than any other crops [14]	In addition to its conventional usage as food and fodder, it is also recognized for use as cow feed, poultry feed, and drinkable alcohol. Its grain is mostly utilized in the animal feed, starch, and distillery industries.
Finger millet (*Eleusine coracana* (L.) Gaertn.)	36,873	Highlands of Uganda and Ethiopia	Nepal, India Ethiopia, Sri Lanka, Uganda, Burundi, Malawi	Wider adaptability, rich source of calcium [15]	Grown for food grain, beer making, porridge, flatbread, and other traditional foods [16]
Pearl millet (*Pennisetum glaucum* (L.) R. Br.)	20,844	Sahelian zone of Africa occupies western Sudan to Senegal	India and Africa	Tolerate to drought, rich in folic acid [14]	Used to make porridge, bread, and other traditional foods and also as animal feed [17]
Minor millets					
Foxtail millet *(Setaria italica* (L.) P. Beauv.*)*	44,761	China	China, Myanmar, India, Eastern Europe	Short duration, tolerant to low soil fertility and drought [18]	Commonly used to make porridge, rice, and other traditional foods and also as animal feed. It is also used to make biofuels and paper [19]
Proso millet (*Panicum miliaceum* L.)	29,308	Northeast China	The USA, Russia, India, South Korea, Ukraine, Iran, Belarus, France, Kazakhsta	Short duration, tolerant to heat and drought	Commonly used to make porridge, bread, and other traditional foods and also used as animal [20]
Barnyard millet (*Echinocloa esculenta* A.)	7923	Japan	India, Japan, China, Malaysia	Fastest growing, voluminous fodder [21]	Cultivated for both human and animal sustenance [14]
Shama millet (*Echinocloa colona* L.)	707	India	India	–	Cultivated for both human and animal sustenance [14]
Kodo millet (*Paspalum scrobiculatum* L.)	4780	India	India	It is a long duration crop, suitable for both shallow and deep soil, richest source of folic acid [22]	Commonly used to make porridge, rice, and other traditional foods [23]
Little millet (*Panicum sumatrense* Roth. Ex Roem. & Schuit)	3064	Eastern Ghats of India	India	It is a short duration crop, resistance to drought and waterlogging [24]	Cultivated for both human and animal sustenance [14]

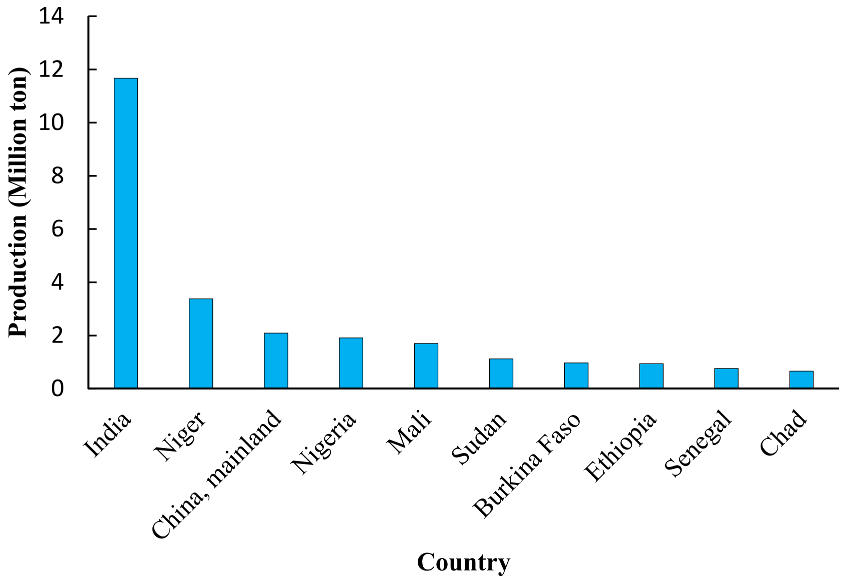

Fig. 1. Top 10 millet-producing countries in the world [26].

3.2. Acreage and production

A total of 30.1 million tons of millet were produced worldwide in 2021, with 41% of the total output coming from India [26]. Niger produced a sizable amount as well. Developing nations, mainly those in Africa and Asia, produce and consume 97% of the world's millets. Fig. 2 shows the world acreage and production of millets from 2010 to 2021 and Fig. 3 shows the average production share by region from 2010 to 2021.

With 26.6% of the global and 83% of the Asian millet producing areas, India is the largest millet producer in the world [26]. The importance of millets in India as food crop is established for centuries, particularly in the drier regions where other crops struggle to grow. In India, roughly 12.7 million acres of land are used to produce a total of 16.9 million tonnes of millets food grain, making up around 6% of the country's total food grain production [28]. Rajasthan, Maharashtra, and Karnataka are the top three states in India for millets cultivation, accounting for 35%, 23%, and 14% of the nation's total millets area, respectively. The most sorghum is grown in Moharashtra and Karnataka, whereas pearl millet is grown more extensively in Rajasthan, Gujarat, Uttar Pradesh, and Maharashtra. Karnataka, Tamil Nadu, and Uttarakhand are the states with the most ragi land. Madhya Pradesh, Uttarakhand, and Chhattisgarh have the most small millets land [28].

Millets are an imperative food crop in Africa, especially in the semi-arid areas. In Africa, Nigeria produces the most millets, following by Niger, Mali, and Burkina Faso [26]. The millet species that are most often grown in Africa are sorghum, pearl millet, finger millet and foxtail millet [29]. Millets have been grown for millennia in China, especially in the country's cold and arid northern areas. The three types of millet that are most often grown in China are foxtail millet), proso millet, and barnyard millet) [30]. Recently, in

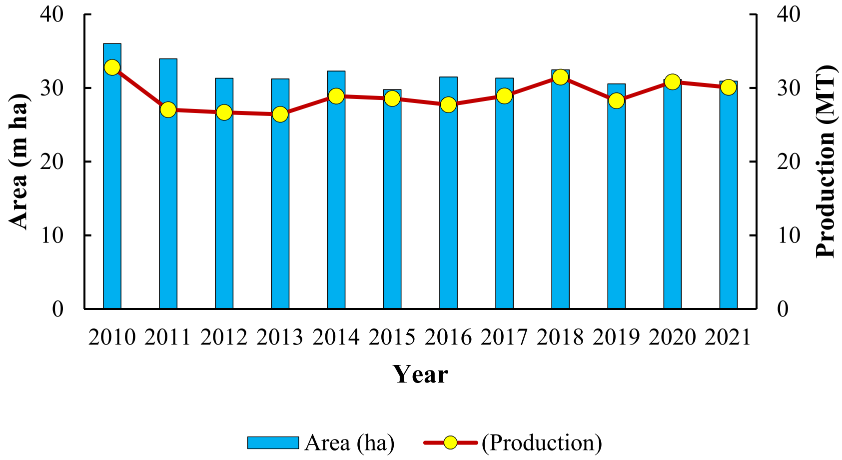

Fig. 2. World acreage and production of millets (2010–2021) [26].

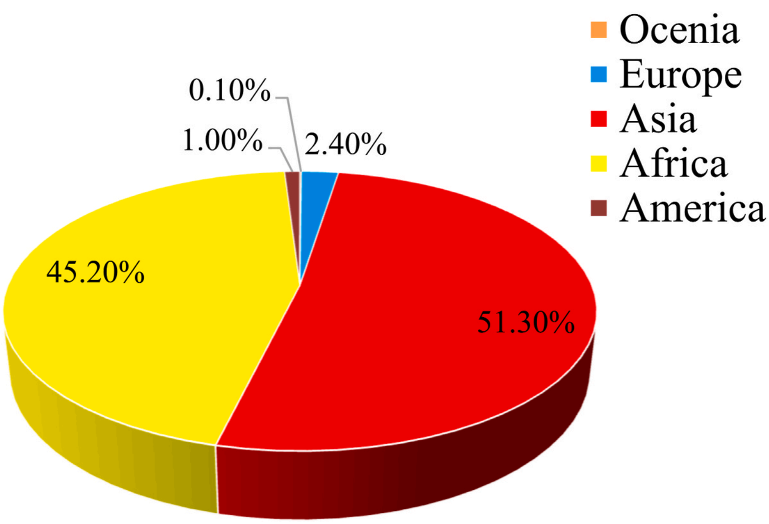

Fig. 3. Region-specific millets production share (Average 2010–2021) [26].

China and Indonesia, millets have been largely replaced by rice and maize [27]. In Latin America, millets are grown primarily in Mexico, and are used primarily for animal feed rather than human consumption [25]. Nevertheless, due to the rising popularity of other cereals like rice and wheat, millets' production and consumption have decreased during the past several decades [27]. Millets are also grown in North America as well. Mainly proso millet is grown there particularly in the great plains of America as a bird feed. Moreover, in the Midwest part of the US, there are many certified proso millets producers.

4. Status of millets cultivation in Bangladesh

4.1. Area and production

Although millets are not a common cereal grain in Bangladesh, they are produced there in some locations, notably those that are prone to drought [31]. Millets are mostly grown in north, north-west, central parts (nearby big rivers) and hilly areas of this country. In Bangladesh, millet was grown on 9333 ha of land in the fiscal year 2020–2021 (Fig. 4), which produced a total of 9616 metric tons [26]. Throughout the last few decades, millet output in Bangladesh has been progressively declining. In 2021 the area and production of millets were reduced by 73% and 19%, respectively compared to the area and production of millets in 2010 [26].

Sorghum, pearl millet, proso millet, and foxtail millets are the major grains grown in Bangladesh, where proso millet and foxtail millet predominate (Table 2).

Proso millet is gluten-free and hence perfect for those who cannot consume gluten and also it is high in protein, mineral, vitamin, and different micronutrients. Proso millet has nutritional characteristics that are on par with or better than those of ordinary grains [33]. It also produces more than any other crop in drought and poor soil conditions, while other grain crops have a chance of failing

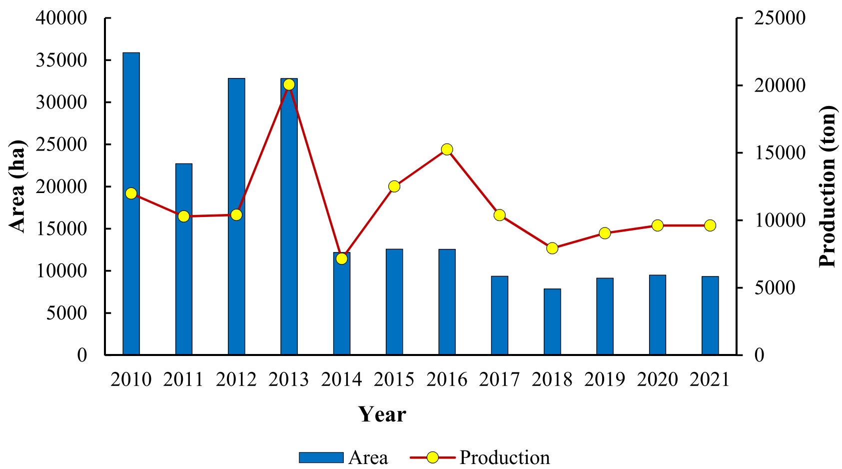

Fig. 4. Area and production of millets in Bangladesh [26].

Table 2
Area and production of important millets in Bangladesh from 2010 to 2021 [32].

Year	Sorghum		Pearl millet		Proso millet and Foxtail millet	
	Area (ha)	Production (MT)	Area (ha)	Production (MT)	Area (ha)	Production (MT)
2010–2011	195	251	66	251	1180	1040
2011–2012	93	125	92	125	1138	1029
2012–2013	133	152	133	152	1161	1128
2013–2014	241	197	41	58	1176	1670
2014–2015	197	124	38	50	1178	1738
2015–2016	93	102	36	48	1182	1229
2016–2017	83	92	30	40	1063	1054
2017–1018	73	87	28	38	908	940
2018–2019	79	87	–	–	623	617
2019–2020	66	77	–	–	526	464
2020–2021	54	64	–	–	804	942

completely [18]. Though the cultivation of foxtail millets is now neglected but it can withstand drought which might play a significant role in the future food supply as temperatures rise and the world becomes possibly drier [34].

4.2. Millets growing region in Bangladesh

The millets growing areas of Bangladesh are shown in Fig. 5. Kurigram, Gaibandha, Sirajgonj, Thakurgaon, and other areas of the nation produced the majority of the proso millet and foxtail millet [32]. In the north, north-west, and central regions close to the rivers Padma/Ganges, Brahmaputra, Jamuna, and Meghna, the cultivation of proso and foxtail millets is increasing gradually. On the other hand, the cultivation of sorghum is confined in Chittagong district. Of the overall net cropped area, two millet-based cropping patterns [Millet (Cheena) – Fallow – Fallow and Millet (Cheena) – Jute – Fallow] occupies about 0.018% of the net cropped area of Bangladesh [35].

However, this represents a small fraction of the total cereal production in Bangladesh, which is dominated by rice and wheat [36]. The decrease in millet farming has detrimental effects on the farmers' ability to feed their families and maintain their way of life, especially in the northeastern area where millets are a significant subsistence crop [37].

5. Recent advancement in millets production

Despite the fact that millet farming has declined in many areas, there has been a resurgence of interest in these cereals in recent years due to their advantages in terms of nutrition and health, as well as their resistance to drought and other environmental stressors. Efforts are underway to promote the cultivation of millets in various parts of the world through the development of improved varieties, better agronomic practices, and raising knowledge about the advantages of these crops [25]. To completely realize millets' potential as a sustainable and nourishing food supply for millions of people worldwide, however, much work still needs to be done. In recent years, there has been a renewed interest in millets as a climate-resilient and nutrition-rich crop, and as a means of enhancing food security and livelihoods in regions affected by climate change [38]. Therefore, there is growing support for the promotion of millets cultivation worldwide, including through research and development, extension services, and market linkages. Several studies were carried out by the researchers at home and abroad which showed why millets are model plants (Tables 3 and 4).

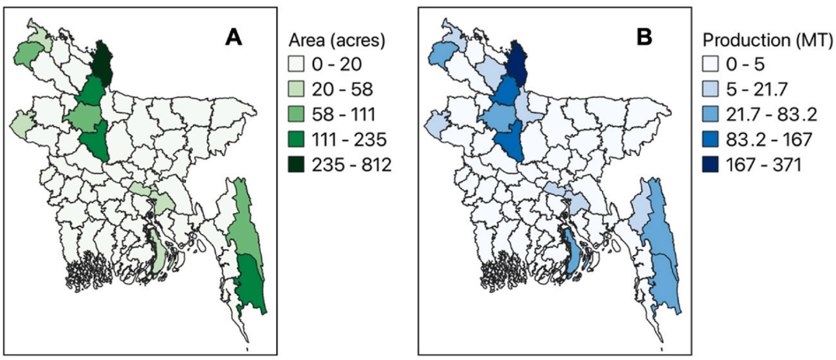

Fig. 5. Area (A) and production (B) of sorghum, proso millet and foxtail millet in different regions of Bangladesh [32].

Table 3
Millets variety developed by BARI (Source: [59]).

Crop name	Germplasm (no.)	Variety			
		Name	Year of release	Duration (Days)	Yield (t ha^{-1})
Sorghum (Jowar)	100	BARI Jowar-1	2020	143–157	3.56
Foxtail millet (Kaon)	12	BARI Kaon-1 (Titas)	1989	90–95	2.5–3
		BARI Kaon-2	2001	120–125	2.75–3.0
		BARI Kaon-3 (Dwarf)	2001	120–125	2.5–3
		BARI Kaon-4	2019	108	3.5–4.0
Proso millet (Cheena)	100	BARI Cheena -1 (Tushar)	1990	90–95	2.5–3
Pearl millet (Bajra)	12	–	–	–	–
Finger millet (Raghi)	4	BARI Raghi-1	2021	126–139	2–3

Table 4
Climate resilient traits of millets (adapted from Ref. [14]).

Crop name	Traits
Sorghum	Greater ability to withstand heat and moisture stress
Proso millet	Crops with a short growing season that are suited to high altitude and dry conditions
Foxtail millet	Adaptable to conditions of high altitude and little rainfall.
Pearl millet	Extremely tolerant to extreme heat and drought, they may be grown in very poor soils, and they respond to intensive input management.
Finger millet	Adaptable to all altitudes, with a modest tolerance for drought, temperature stress, and humidity.
Little millet	Suited to poor soils and little rainfall, and somewhat tolerant of waterlogging
Kodo millet	Long-lasting and extremely resilient, they can thrive on poor soils and with little rain, and they respond well to better agronomic techniques.
Barnyard millet	Crop with a short growing season that is well suited to high elevations and dry climates.

6. Challenges of millets cultivation in Bangladesh

Millets are a rich source of food, fodder, and revenue that are mostly farmed by smallholder farmers in marginal areas in Bangladesh. Unfortunately, there are a number of obstacles to millet production in Bangladesh that limit its potential to improve food security and reduce poverty there. The primary obstacles to millet farming in Bangladesh are a lack of availability to better varieties and production techniques. Most of the millet varieties grown in Bangladesh are local landraces that have not been improved for yield, disease resistance, or other desirable traits. Furthermore, as farmers are unable to access more advanced production technology, such as higher-quality seeds, fertilizers, pesticides, and irrigation systems, they face restriction in boosting yields and enhancing the quality of their crops. Millets are typically grown in marginal lands that are unsuitable for other crops like rice, wheat and maize. However, the increased availability of modern varieties of these crops has made them more attractive to farmers, leading to a decline in millet cultivation in recent years. Hossain et al. [58] reported that millet cultivation in Bangladesh is also constrained by poor market access and low prices. Millets are often sold at lower prices than other crops, making it less profitable for farmers to grow them. In addition, the lack of formal market channels and market information increased the problem of low prices, as farmers are forced to sell their crops to middlemen who offer low prices. Additionally, climate change poses a significant threat to millet production in Bangladesh, as rising temperatures and changing rainfall patterns are likely to increase the frequency and intensity of droughts and other weather-related hazards in the country [32]. Some major challenges in millet cultivation in Bangladesh are discussed below.

Table 5
Recent research work done in Bangladesh.

Crop name	Recent advancement	References
Sorghum	Sorghum lines were screened under waterlogging stress condition	[39]
	Base population in sorghum was developed	
	Under drought conditions, sorghum (C_4) and barley (C_3) cereals' tolerance to oxidative stress was examined.	
Finger Millet	Drought induced oxidative stress in finger millet by trehalose and methyl jasmonate was modulated	
Pearl millet	Attempt was made to maintain pearl millet germplasm	
	Population development of pearl millet	
Foxtail millet	In Bangladesh's saline-affected (6 dS/m) coastal regions, foxtail millets genotypes BD-897 and BD-881 may be grown.	[40]
	Mutagenesis was induced in foxtail millet to develop variable population	[40]
	Maintenance and seed increase of foxtail millet germplasm	
Proso millet	Due to the low cost, accessibility of their seeds, low danger, low water demand, and ease of cultivation without the use of contemporary technology, all proso millet kinds and cultivars may be produced in char land.	[41]
	Maintenance of proso millet germplasm	[39]
	Potential proso millet lines were verified in a rainfed environment	

6.1. Lack of high yielding variety

One of the main challenges of millet cultivation in Bangladesh is the lack of access to improved varieties and production technologies. Most of the millet varieties grown in Bangladesh are local landraces. BARI has already developed different millets varieties (Table 5) but the farmers mostly grow local cultivars. BARI Jowar-1 is the sole sorghum cultivar that is approved for use in Bangladesh. There are 268 sorghum accessions that the Plant Genetic Resource Center (PGRC) of BARI has collected and preserved [59]. The single cultivar of Cheena is Tushar, while BARI has issued four cultivars of Kaon: Titas, BARI Kaon-2, BARI Kaon-3, and BARI Kaon-4. In BARI, 515 foxtail millet accessions and 197 proso millet accessions are also preserved. The PGRC, BARI only has two accessions of pearl millet germplasm [59]. However, pearl millet went totally out of cultivation in the successive year [31]. Though BARI developed some varieties of millets but still there are shortage of suitable varieties which are accessible to farmers.

6.2. Decreasing cultivable land

There are significant natural and human-made issues that the millet farming in Bangladesh must address. Due to urbanization, serious deterioration of environmental assets like soil, water, climate, etc., the reoccurring onset of disastrous flood and drought, and the impending threat of salinity increase in the coastline, the amount of arable land is declining at an alarming rate (0.1% yr^{-1}) [60]. A significant number of agricultural lands are being degraded, including by soil degradation (1.70 m ha), river erosion (1.70 m ha), declining soil fertility (8.00 m ha), loss of soil organic matter (7.50 m ha), waterlogging (0.70 m ha), soil salinity (0.84 m ha), pan creation (2.82 m ha), acidification (0.06 m ha), and forest destruction (0.30 m ha) [61]. Millets in Bangladesh are mostly seen in those areas where soil erosion and siltation are prominent and, in most cases, soils are light-textured and less fertile. Bangladesh is a land of rivers of which four mighty rivers significantly transform land areas in their vicinity. Around the Ganges, Jamuna, Meghna, and Padma rivers, erosion and land reclamation are common occurrences [31]. Nevertheless, flood, erosion, land degradation, and loss of soil fertility are the primary obstacles to using such areas. On the other hand, hilly soils are mainly excessively to moderately well-drained, sandy loams to sandy clay loams, strongly to extremely acidic having low moisture holding capacity and low organic matter contents [33]. Otherwise, rice is the staple food of Bangladesh and majority of cultivable area is occupied by rice and other major cereals and also farmer prefer to grow these crops because of more profit. Due to the cultivation of major food grain, millet cultivation is under human negligence and area under millet cultivation is declining day by day.

6.3. Low productivity

Yadav et al. [62] stated that millets are typically regarded as low-yielding crops with lesser productivity as comparing to other crops like rice and wheat. Low productivity is caused by a number of factors, including the absence of better varieties, insufficient inputs, and poor agronomic techniques. Inadequate crop, soil, and water management combined with ongoing land degradation result in a significant yield gap between farmers' practices and crops' potential yields. Bangladesh is a land of rivers and floods are common occurrence. The waterlogging situation during flood also resulted in poor yield of millets. Low productivity is also caused by insufficient programs and facilities for the production and delivery of high-quality seeds and other agricultural inputs to farmers.

6.4. Limited access to inputs and credit

Another barrier to the production of cereal crops in Bangladesh is the lack of quality and timely delivery of agricultural inputs. According to a report ICRISAT [7] smallholder farmers who cultivate millets often face challenges in accessing inputs like seeds, fertilizers, and pesticides, as well as credit to invest in their farms. The report notes that this limits their ability to increase productivity and yield. Only 18% of the nation's total seed needs may be satisfied by seeds that have been certified and properly labeled from Government and commercial sources, with the other 82% coming from farmers' own seed storage [63]. It should be highlighted that farmers' poor seed quality is viewed as one of the key factors limiting agricultural yield. Due to the absence of facilities for seed processing and preservation, the commercial sector's and NGOs' contribution to the production of high-quality seeds is still minimal [63]. The majority of farmers in Bangladesh (about 90%) are small and marginal [32], and they frequently face financial constraints that prevent them from affording substantial management costs. Due to the requirement for collateral, their access to institutional finance is extremely limited. These farmers are compelled by the circumstances to use inputs, particularly pricey P and K fertilizers, much less frequently than is suggested, which ultimately results in low output.

6.5. Pest and disease

According to Motagi et al. [64], millet crops are vulnerable to pests and diseases that can significantly reduce yields. The study notes that the lack of effective pest and disease management strategies is a major challenge for farmers. It is significant to highlight that, as a result of the negative consequences of climate change, notably the rise in temperature, the occurrence of diseases and pests has recently increased severely [65].

6.6. Climate change

According to FAO [66], millets are often cultivated in dry and semi-arid areas that are susceptible to the effects of climate change, such as droughts and unpredictable rainfall. Storm surges and cyclones will occur more frequently and intensely as a result of climate change and global warming. Storm surges will cause flood plains and char lands to erode mildly to severely.

Around 1.00 m ha of the 2.85 m ha of the coast are impacted by various levels of salt, which will keep on rising as a result of climate change. Roughly 2.32 million ha and 1.2 million hectares of net cultivated land are severely and moderately drought affected areas, and the issue will worsen due to climate change. Furthermore, around 1.32 million ha and 5.05 million ha of the net cropped area are severely and moderately flood affected, which adversely impair crop productivity [67].

Crop yield will be lowered by around 30% as a result of the temperature increase. Climate change is now threatened by the frequent cutting down of green trees especially in coastal zones for constructing shipyards. The window of optimum temperature for growing sorghum and finger millet in Bangladesh will be reduced greatly by 2050 compared to 2010 because of temperature rise. If no control measure to reduce GHG emissions is undertaken, it is predicted that global mean surface temperatures would rise by 3.7–4.8 °C by the end of the 21st century relative to 1850–1900 [68]. Amadou and Gounga [69] noted that minor cereals are excellent in fixing carbon even in high-temperature and low-nitrogen environments [70], therefore future food security will depend on enhanced management and variety development of these crops.

6.7. Limited market opportunities

Other challenge includes limited access to market opportunities for millets. Joshi et al. [20] stated that millets are often considered a traditional and niche crop, with limited market opportunities and low prices. The study notes that this limits the potential for farmers to earn a good income from millet cultivation, which can discourage them from investing in these crops. Bangladesh's most productive farmers are primarily in the small and marginal groups. These farmers lack a farmer's cooperative or farmer's association to negotiate for reasonable rates for their goods. Thus, they must sell their products to middlemen for cheap prices. The government sets a price for the sale of agricultural products, but farmers frequently are unable to satisfy the standards (14% moisture content, no foreign elements in seeds, etc.). As a result, they are unable to sell their output at the set price.

6.8. Lack of investment in millets research and development

Although agriculture provides 13% of GDP and employs 50.28% of the working force in Bangladesh [32], investment in agricultural research now accounts for only 0.20 of GDP [71]. There is also limited research and development of improved millet varieties, and a lack of availability of quality seeds. The National Agricultural Research System (NARS) has been underperforming as a result of low funding. Due to funding limitations, there are also less opportunities to promote and develop future scientists in many sectors.

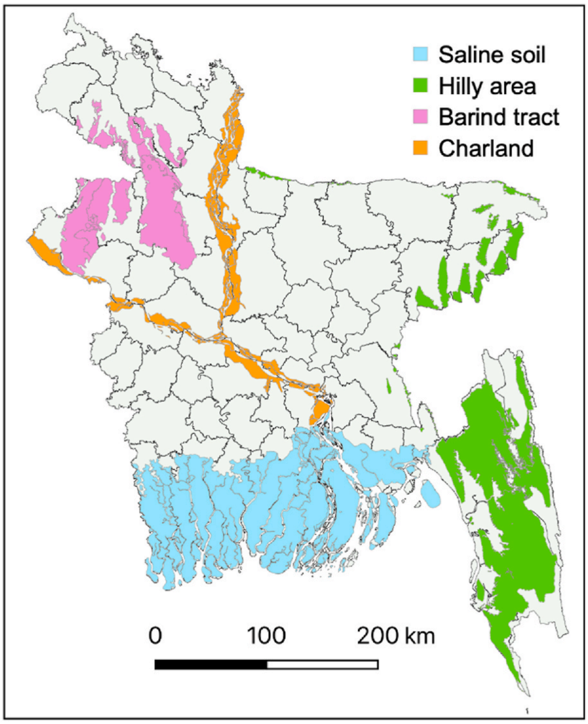

Fig. 6. Four agro-ecologies of Bangladesh that are suitable for millets cultivation.

6.9. Other challenges

There are few more challenges for millets cultivation in Bangladesh. For example, lack of awareness about the health benefits of millets, lack of market to sell, difficult post-harvest operation, lack of available processing units and high labor demands etc. Despite these difficulties, there is rising interest in expanding millet production in Bangladesh as a way to improve small-scale farmers' incomes and food security. Addressing these challenges is necessary for the successful promotion and expansion of millet cultivation in Bangladesh [72].

7. Prospects of millet cultivation in Bangladesh

Millets are considered a climate-resilient crop, as they require less water and are better adapted to drought and other environmental stresses [31]. Millets are also very nutritious and can help to improve the health and well-being of rural communities [73]. As compared to other grains, millets are superior because of their physiological, morphological, biochemical, and molecular characteristics, which give them the ability to withstand and resist environmental stress. In addition, millets' life cycle is completed in 84–98 days as opposed to the 140–168 days needed by rice, wheat, and maize. Abiotic stressors can be mitigated by a number of other characteristics of millets, including shorter plant, big leaf area index despite small leaf area, upright leaf type with high radiation use efficiency, thicker cell walls, and dense root system [74]. The C_4 photosynthetic pathway of millets helps plants by increasing their water and nutrient use efficiency as well as by allowing for more flexible biomass allocation, lower hydraulic conductivity per unit leaf area, better growth, and increased tolerance to high temperatures [75].

Millet crops are planted on marginal soils and in low-input agricultural settings, where main cereal crops frequently provide low yields [70]. Millets have the ability to dramatically improve Bangladesh's food security and standard of living, especially in the char, saline, hilly areas and Barind regions where other crops face difficulties in growing. The prospects of millets cultivation in the char, saline, Barind tracts and hilly areas of Bangladesh are significant, according to various studies (Fig. 6).

7.1. Char areas

A char is a section of land that is encircled by an ocean, sea, lake, or stream; it often refers to any accretion in a river channel or estuary. There are approximately 0.83 mha of char land in Bangladesh [76]. The Bengali word "Charland" (which translates to "Riverine Island" in English) refers to a mid-channel island that occasionally protrudes from a riverbed as a result of accretion [77]. The Jamuna, Ganges, Padma, upper Meghna, and lower Meghna Rivers are only a few of the five sub-areas in Bangladesh's char lands that have a great potential for producing groundnuts. Other sub-areas include the Tista and the old Brahmaputra [78]. According to Uddin et al. [79], millets might be a significant crop for Bangladesh's Char regions. Although BARI has previously developed millets varieties, farmers in the Charland region mostly cultivate local types. Farmers in Bangladesh are currently particularly interested in cultivating high-yielding varieties with early maturity and resistance characteristics. Rahman et al. [41] compared the yield performance of BARI Cheena-1 with two local cultivars of proso millet in the Charland area of Jamalpur and revealed that BARI Cheena-1 performed better than other local cultivars. They also suggested that all proso millet cultivars may be produced in char land due to its low cost, ease of cultivation without the use of modern equipment, availability of its seeds, and minimal risk. So, this study notes that millets can provide food and income security for Char farmers, and also have potential for export markets.

7.2. Saline areas

The coastal region of Bangladesh has salty water on roughly 1 million acres is salt affected. Yet the options for battling salinity are quite limited. By 2050, Bangladesh's coastline region might be submerged beneath salt water, according to Uddin et al. [80]. Sea level rise brought on by climate change would result in the flooding of 16% of all farmed land, the displacement of 10% of the inhabitants, salt accumulation in the coastal zone, and decreased crop yields, which will ultimately result in a loss of 2 MT of agricultural production [68]. Millets are an important crop for the saline tracts of Bangladesh, as they can grow in soils with high salinity levels [81]. The study suggests that improved varieties and better agronomic practices can help to increase yields and enhance the resilience of farmers in these regions. According to reports, foxtail millet possesses a level of saline tolerance. Due to its high level of saline tolerance and the possibility for salt "escape" as a result of its quick growth cycle, foxtail millet can be a crop for soils with a salt problem [82].

7.3. Barind tracts

Hossain et al. [83] reported that millets can be a profitable cereal crop for farmers in the Barind tracts of Bangladesh, as they are well-suited to the semi-arid conditions found in these regions. Proso millet outperforms all other crops in terms of yield under drought and in areas with poor soil. These crops are regarded as climate-smart since they can grow in hot and dry climates with little impact on the environment [84]. Millets produce green cover in sloppy, dry areas that are prone to erosion and also reduces soil and nutrient depletion. In drylands, soil organic carbon loss is a significant issue, and millet farming with little water guarantees carbon sequestration.

7.4. Hilly areas

Bangladesh's hilly regions, which make up around 12% of the country's total geographical area and are primarily found in its eastern and southeastern regions [85]. The hills of Bangladesh are mainly distributed in the Bandarban, Rangamati and Khagrachari districts (Chittagong Hill Tracts), parts of Chittagong, northern and southern parts of Sylhet division, northern parts of Mymensingh division, eastern border of Comilla and north eastern strip of Feni district. The Chittagong Hill Tracts (CHTs) covers the major hilly areas of Bangladesh *i.e.* 70% of the hilly areas that belongs to 10% of total country area [86]. Agriculture is the main source of income for the most of people of hilly areas. Plowing of fields, shifting cultivation, fruit gardening, paid wage labor, timber production, raising of animals and poultry, and unpaid fishing are all examples of agricultural activity. Ahammad and Stacey [87] highlighted that in hilly areas, more than 35 distinct crop varieties are planted annually. Jhum (Shifting cultivation) has been used by the local indigenous populations of CHTs for generations and is the predominant land-use system in the steep terrain [88].

As stated earlier low-fertile soils are ideal for millets' cultivation. As millets have C_4 carbon-sequestering characteristics that help to reduce atmospheric CO_2 levels and they are the ideal crops for the climate issue. They are also water-efficient, so they can survive in low soil moisture conditions in rainfed areas. On the other hand, the hilly region's agriculture depends heavily on rainfall. Hills are challenging to irrigate and are prone to erosion. In these backdrops of hilly areas and the special features of millets, this can be a suitable option to introduce in the hilly locations of Bangladesh as mono culture or intercropping with other crops. Millets are cultivated widely in the hilly areas of India [89,90] and Nepal [91].

7.5. Climate smart crop

The primary impacts of climate change are elevated temperature, unpredictable rainfall patterns, and increased greenhouse gas emissions, particularly carbon dioxide. According to many research, a 1 °C increase in temperature would cause 18% of Bangladesh to become submerged. In addition, as a result of climate change, the nation will experience regular floods, droughts, cyclones, and salinities.

During this present era, climate change is an important concern and this impact of climate change negatively influenced yield of major cereals. Under these situation millets can be chosen as ecofriendly crops those can withstand adverse impacts of global warming as well as climate change (Table 6). Millets, which are C_4 plants, can consume more ambient CO_2 and transform it into biomass [92]. Millets release less green house gas (GHG) in the range of 3218–3358 kg CO_2 eq. ha^{-1} [93]. Millets are called climate-smart crops since they are environmentally sound, have a minimal carbon impact in agriculture, and can survive in hot and dry weather. Millets are renowned for their climate-resilient characteristics, which include adaptability to a variety of ecological conditions, reduced irrigation needs, improved growth and productivity under conditions of low nutrient input and minimal risk to environmental stressors [94]. Millets may grow well at temperatures that are substantially higher and can survive with less water. Millets have a substantially smaller carbon footprint than other crops, which can reduce the global carbon impact [95]. Millets have a quick life cycle compared to

Table 6
Recent research work done in different corners of the world.

Crop name	Recent advancement	References
Sorghum	Sorghum genotypes were examined under a range of drought stress situations. Future breeding strategies will utilize genotype's drought tolerance features to produce genotypes that are resistant to drought.	[42]
	It is required to investigate the molecular mechanisms of drought tolerance using genetic, genomic, proteomics, and metabolomics studies in order to enhance the drought tolerance of desirable sorghum germplasm.	[43]
	Using environment interaction, correlation, AMMI, GGE biplot, and cluster analysis, grain yield and other agronomic characteristics of the sorghum genotype were discovered. In sorghum breeding efforts, the selected genotypes having high yielding features could be utilized as important genetic resources.	[44]
Finger Millet	In order to increase production and improve grain nutritional characteristics, appropriate finger millet cultivars were discovered.	[45]
	The genotypes of finger millet respond to blast disease differently depending on the circumstances, and possible landraces with field resistance to leaf, finger, and neck blast will eventually play a significant role in the development of blast resistance in finger millet breeding.	[46]
	Natural diversity within genotypes is crucial for the selection and creation of varieties that are appropriate for Nepal's various agro-climatic regions.	[47]
Pearl millet	Transcriptomic investigation of methyl jasmonate treatment showed gene networks responsible for drought resistance in pearl millet.	[48]
	Conventional and genomics-assisted approaches were utilized in breeding approaches of drought-tolerant pearl millet genotypes.	[49]
	The functionally confirmed genes for pearl millet and other millet crops may be used as potential candidates in genomic. Selection, backcross breeding and gene-editing strategies to increase yield in semi-arid and drought-prone ecosystems.	[50]
Littlle millet	Genic microsatellite marker characterization and development in small millet were carried out using transcriptome sequencing.	[51]
	Agronomic management of little millet can increase production and sustainability of the crop.	[3]
	For the climate-resistant, nutrient-dense little millet, a thorough transcriptome database was discovered.	[52]
Foxtail millets	Genome sequencing was used to assess the resistance to biotic stress in foxtail millet.	[53]
	RIL population and widely targeted metabolome were used to conduct QTL analysis of significant agronomic characteristics and metabolites in foxtail millet.	[54]
	In foxtail millet, male sterility-controlling genes were discovered.	[55]
Proso millet	For crop diversification, the APSIM millet model for proso millet was calibrated and validated.	[56]
	Genome-wise identification of agronomic and seed properties in a global collection of proso millet	[57]

rice and wheat, which helps to avoid stress. Even so, characteristics including low stature, tiny leaf area, thicker cell walls, and the capacity to establish deep root systems mitigate the occurrence of stress situations and their effects [76]. Furthermore, millets greatly benefit from the C_4 photosynthetic characteristic which inhibits photorespiration and oxygenation [96]. As a result of these qualities, millets are considered to be next-generation crops with the potential for their capacity to adapt to changing climates.

Pearl millet can grow on poor sandy soils and is easily more adaptable to dry climates. Finger millet can withstand salinity, high temperature, variable soil pH (5.0–8.2) and medium rainfall [97]. Almost similar environments prevail in south-west and northwest regions of Bangladesh indicating the suitability of finger millet cultivation. We hypothesize that millets would be playing a vital role in future agriculture under a changing climate.

As stated earlier millets are low water consuming crops. The rainfall needed for Sorghum, Pearl millets and Finger millet is 25% less than Sugarcane and Banana, and 30% less than rice [98]. To produce 1 kg of rice 4000L of water is needed, while no additional water is needed for millets. Comparative water requirements of some major crops and millets are shown in Fig. 7. It has been reported that 17 Mha of irrigated rice land of Asia may experience 'physical water scarcity' and 22 Mha may have 'economic water scarcity' by 2025 [99]. Therefore, millets could emerge as the food of security in a future where a water and food catastrophe confront us.

Such scenario may indicate that cultivation of millets is climate smart for reducing GHG emission and water demands. In future consumption of major cereals as staple food does not guarantee nutrient security of the people, especially in developing and under developed countries. So, growing millets having high nutritive values and their uses with staple food could be an avenue of food security.

So, it can be said that millets are well-suited to the climate and soil conditions of the char, saline, hilly areas and Barind tracts. These areas are often affected by droughts, floods, and salinity, making it difficult for farmers to grow other crops. Millets are drought-tolerant, require low inputs, and can provide food, fodder, and income for smallholder farmers in these areas. The study suggests that improved varieties, better seed production systems, and better access to markets can help to increase the adoption of millets among farmers in these regions.

The prospects of millet cultivation in Bangladesh are promising because of their nutritional benefits, resilience to adverse weather conditions, and potential for increasing farmers' income. The demand for millets is increasing in Bangladesh, particularly for their nutritional benefits. Therefore, there is a growing demand for millets in urban markets and among health-conscious consumers, which presents an opportunity for farmers to earn higher prices for their crops.

The government of Bangladesh has recognized the potential of millets and has initiated several programs to promote their cultivation. For example, the Department of Agricultural Extension (DAE) has distributed improved varieties of millets to farmers and provided training on their cultivation. The Bangladesh Agricultural Research Institute has also released a number of improved millets with higher yields and better local adaptation. There is potential for millet-based value-added products in Bangladesh. Millets may be transformed into a number of goods, including flour, flakes, and porridge, which can be consumed by humans or used as animal feed. Therefore, there is an opportunity for entrepreneurs to invest in millet processing and marketing, which can create employment opportunities and increase the income of smallholder farmers.

The government and relevant stakeholders need to support and promote millet cultivation to ensure its successful adoption and integration into the food system. However, to realize its potential, there is a need for further research on millet cultivation, dissemination of improved varieties and production technologies, and development of market linkages and value chains. The study recommends promoting millet cultivation among farmers, providing them with adequate training and resources, and creating market linkages for millet-based products.

8. Future scope of research

For food and economic security of Bangladesh, millets can be a potential crop, particularly in areas with challenging environmental conditions such as the Char, Saline, Barind tracts and hilly areas. To enhance millets' adoption and production in the nation, a number of issues need to be resolved. The major problems faced by millet farmers in Bangladesh include lack of access to quality seeds, poor storage facilities, limited market opportunities, and inadequate research and development activities. In order to encourage millet cultivation and maintain sustainable production systems, it will be necessary for the government, corporate sector, and civil society groups to work together. There is a need to promote millets as a viable alternative to other cereal crops, and to develop innovative value chains that connect farmers with consumers and markets. Promotion of millets cultivation may help attain the sustainable development goals (SDGs) especially SDG number 1 (no poverty), 2 (zero hunger), 3 (good health and well-being) and 13 (climate action). Fig. 8 summarizes the existing problems, probable solutions and future prospects of millets cultivation in Bangladesh.

However, it is abundantly obvious from the study findings and literary sources that millet has not received nearly enough attention. In light of the crop's value and current demand, the following research directions should be pursued.

- Improvement of promising millet cultivars and assessments of their suitability for various agroclimatic areas.
    - ✓Early, dwarf and lodging tolerant variety development.
    - ✓Stress tolerant, nutrition rich and high yielding variety development.
    - ✓Dissemination in drought, saline, hilly and char areas.
- Maintenance breeding and seed production.
- Strengthened germplasm collection.
- It's important to start processing, adding value, and developing products from the produce.

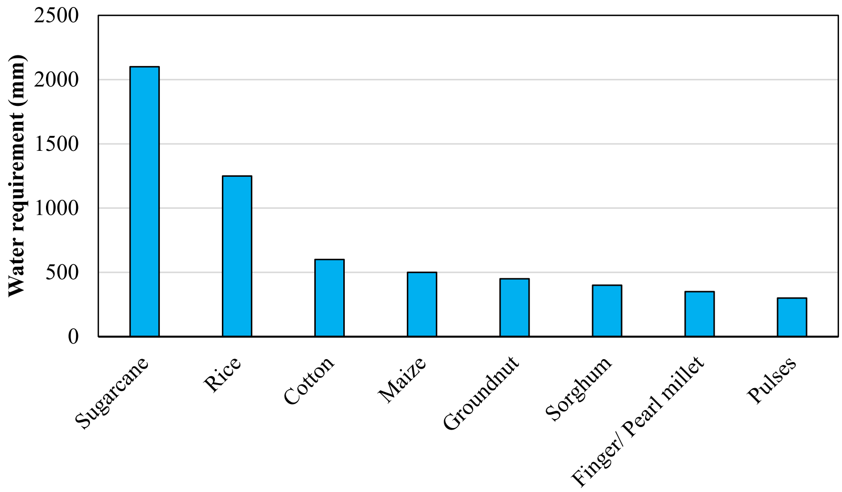

Fig. 7. Comparative water requirements of some major crops and millets [98].

Fig. 8. List of existing problems, probable solutions and future prospects of millets cultivation in Bangladesh.

- Maintaining millets as well as conducting research and development for them requires regional and international collaboration in the form of technical and financial support.

Moreover, millets have the ability to significantly contribute to Bangladeshi rural communities' resilience, reduction of poverty, and assurance of food security.

9. Conclusion

Millets have the potential to satisfy the global food and nutritional security, particularly in areas with challenging environmental conditions. However, there are several challenges that need to be addressed to increase the adoption and production of millets. The major problems faced by millet farmers in Bangladesh include lack of access to quality seeds, poor storage facilities, limited market opportunities, and inadequate research and development activities. Addressing these challenges will require coordinated efforts from the government, private sector, and civil society organizations to promote millet cultivation and ensure sustainable production systems. The prospects for millet cultivation in Bangladesh are encouraging, given the increasing demand for nutrient-dense and climate-resilient crops, as well as the growing interest in local and organic foods. There is a need to promote millets as a viable alternative to other cereal crops, and to develop innovative value chains that connect farmers with consumers and markets. Future research should focus on improving the productivity and profitability of millets through the development of better varieties, improved agronomic practices, and the use of modern technologies. Overall, millets could help attain the SDGs goal for many tropical countries especially India and Bangladesh.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Sinthia Afsana Kheya: Writing - original draft. **Shishir Kanti Talukder:** Writing - original draft. **Prantika Datta:** Writing – original draft. **Sabina Yeasmin:** Writing – review & editing, Visualization, Supervision, Data curation. **Md. Harun Rashid:** Validation, Formal analysis, Data curation. **Ahmed Khairul Hasan:** Validation, Formal analysis, Writing - review & editing. **Md. Parvez Anwar:** Writing – review & editing, Validation, Supervision, Formal analysis. **A.K.M. Aminul Islam:** Validation, Supervision, Formal analysis. **A.K.M. Mominul Islam:** Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization, Writing - original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] S. Ramashia, M. Mashau, O. Onipe, Millets Cereal Grains: Nutritional Composition and Utilisation in Sub-saharan Africa, 2021.
[2] V. Verma, S. Patel, Value added products from nutria-cereals, Finger millet (*Eleusine coracana*), Emir. J. Food Agric. 25 (3) (2013) 169–176.
[3] S. Maitra, T. Shankar, Agronomic management in little millet (*Panicum sumatrense* L.) for enhancement of productivity and sustainability, Int. J. of Bioresour. Sci. 6 (2) (2019) 91–96.
[4] A. Kumar, P. Singh, Millets: nutritional composition, some health benefits and processing – a review, J. Food Sci. Technol. 52 (5) (2015) 2481–2495.
[5] J.M. Awika, Major cereal grains production and use around the world, in: Advances in Cereal Science: Implications to Food Processing and Health Promotion, ACS Publications, Washington, DC, USA, 2011, pp. 1–13.
[6] R. Saxena, S.K. Vanga, J. Wang, V. Orsat, V. Raghavan, Millets for food security in the context of climate change: a review, Sustainability 10 (2018) 2228, https://doi.org/10.3390/su10072228.
[7] Millets ICRISAT, The Missing Crop in the Food Bowl of Bangladesh, International Crops Research Institute for the Semi-Arid Tropics, India, 2019.
[8] S.K. Bai, K.H. Nagaraj, G.K. Reddy, S.C. Ranganatha, Participatory varietal selection through front line demonstration and impact assessment on value addition in foxtail millet in Ramanagara district Karnataka, Pharm. Innov. 10 (2021) 86–89.
[9] M.S. Thilakarathna, M.N. Raizada, A review of nutrient man- agement studies involving finger millet in the semi-arid tropics of Asia and Africa, Agronomy 5 (2015) 262–290.
[10] R. Devkota, K. Khadka, H. Gartaula, A. Shrestha, S. Karki, K. Patel, P. Chaudhary, Gender and labour efficiency in finger millet pro-duction in Nepal, in: Transforming Gender and Food Security in the Globalsouth, Routledge, 2016.
[11] P.B. Devi, R. Vijayabharathi, S. Sathyabama, N.G. Malleshi, V.B. Priyadarisini, Health benefits of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: a review, J. Food Sci. Technol. 2014 51 (6) (2014) 1021–1040, https://doi.org/10.1007/s13197-011-0584-9.
[12] S. Anitha, D.I. Givens, K. Subramaniam, S. Upadhyay, J. Kane-Potaka, Y.D. Vogtschmidt, R. Botha, T.W. Tsusaka, S. Nedumaran, H. Rajkumar, A. Rajendra, D. J. Parasannanavar, S. Vetrventhan, R.K. Bhandari, Can feeding a millet-based diet improve the growth of children?-A systematic review and meta-analysis, Nutrients 14 (1) (2022) 225.
[13] FAO (Food and Agriculture Organization), Millets, Retrieved from, http://www.fao.org/millet/en/, 2019. (Accessed 20 December 2022).

[14] A.U. Paschapur, D. Joshi, K.K. Mishra, L. Kant, V. Kumar, A. Kumar, Millets for life: a brief introduction, Millets Millet Technol. (2021) 1–32.
[15] A. Seetharam, Small millets research: achievement during 1947–97, Indian J. Agric. Sci. 68 (1998) 431–438.
[16] J.T. Habiyaremye, D. Ntwari, D. Murekezi, Finger millet (*Eleusine coracana* L.): a review of its potential for sustainable food and nutrition security in Africa, Sustainability 10 (6) (2018) 1941.
[17] S. Bhattacharya, S. Kumar, S. Mishra, V. Verma, Pearl millet: a review of its potential for sustainable food and industrial applications, Front. Sustain. Food Syst. 5 (2021), 717867.
[18] C. Jiaju, Importance and genetic resources of small millets with emphasis on foxtail millet (*Setaria italica*) in China, in: A. Seetharam, K.W. Riley, G. Harinarayana (Eds.), Small Millets in Global Agriculture, Oxford & IBH Pub Co Pvt Ltd., New Delhi, 1986, pp. 93–100.
[19] H. Zhang, Y. Zhao, L. Wang, Q. Wang, R.H. Liu, A review of the chemical composition and nutritional value of foxtail millet, J. Agric. Food Chem. 69 (10) (2021) 2999–3007.
[20] P.K. Joshi, G. Srinivasan, A. Kumar, 2015. Millets: a solution to agrarian and nutritional challenges, SAT eJournal 12 (2015) 1–9.
[21] A. Gupta, V. Mahajan, M. Kumar, H.S. Gupta, Biodiversity in the barnyard millet (Echinochloa frumentacea Link, Poaceae) germplasm in India, Genet. Resour. Crop Evol. 56 (6) (2009) 882–889.
[22] B.R. Hegde, B.K.L. Gowda, Cropping systems and production technology for small millets in India, in: A. Seetharam, et al. (Eds.), Small Millets in Global Agriculture, Oxford & IBH PublishingCo, Delhi, India, 1989, pp. 209–235.
[23] K.N. Gujar, N.B. Patel, C.R. Patel, Kodo millet: a review of its potential for sustainable food and nutrition security in India, J. Pharmacogn. Phytochem. 5 (6) (2016) 53–56.
[24] H. Doggett, Small millets –a selective overview, in: A. Seetharam, et al. (Eds.), Small Millets in Global Agriculture, Oxford & IBH Publishing Co., Delhi, India, 1989, pp. 59–70.
[25] J.R. Taylor, K.G. Duodu, Effects of processing methods on the physicochemical and nutritional properties of millet grain, Compr. Rev. Food Sci. Food Saf. 14 (1) (2015) 1–18.
[26] FAO (Food and Agriculture Organization) FAOSTAT, Retrieved from, http://www.fao.org/faostat/en/#home, 2021. (Accessed 21 February 2023).
[27] M.F. Dreccer, K.B. Wockner, J.A. Palta, C.L. McIntyre, R.M. Trethowan, Millet breeding in Australia—progress, opportunities and future prospects, Crop Pasture Sci. 65 (7) (2014) 667–680.
[28] B.V. Bhat, K. Hariprasanna, Sooganna, C.V. Ratnavathi, Indian Farming 16 Global and Indian scenario of millets, Indian Farming 73 (1) (2023) 16–18.
[29] NRC (National Research Council), Lost Crops of Africa: Volume I: Grains, National Academies Press, 1996.
[30] Z. Zhao, H. Liu, C. Wang, J. Xu, Millet grains: nutritional quality, processing, and potential health benefits, Compr. Rev. Food Sci. Food Saf. 18 (4) (2019) 824–835.
[31] M.S.H. Bhuiyan, M.S. Hoque, S. Akhter, M.S. Islam, M.S. Millets, A potential crop for climate change adaptation and food security in Bangladesh, Int. J. Agric. Biol. 26 (1) (2020) 1–9.
[32] BBS (Bangladesh Bureau of Statistics), Statistical Yearbook of Bangladesh, Bangladesh Bureau of Statistics. Ministry of Planning, Govt. People's Republic. Bangladesh, 2021, pp. 32–41.
[33] J. Kalinova, J. Moudry, Content and quality of protein in proso millet (*Panicum miliaceum* L.) varieties, Plant Foods Hum. Nutr. 61 (2006) 43–47.
[34] C. Wang, G. Jia, H. Zhi, Z. Niu, Y. Chai, W. Li, Y. Wang, H. Li, P. Lu, B. Zhao, X. Diao, Genetic diversity and population structure of Chinese foxtail millet (*Setaria italica* (L.) Beauv.) landraces, G3 (Bethesda) 2 (7) (2012) 769–777.
[35] M. Nasim, S.M. Shahidullah, A. Saha, M.A. Muttaleb, T.L. Aditya, M.A. Ali, M.S. Kabir, Distribution of crops and cropping patterns in Bangladesh, Bangladesh Rice J 21 (2) (2017) 1–55.
[36] M.A. Islam, M.A.R. Sarker, M.G. Kibria, Rice production in Bangladesh: current scenario, environmental issues and possible solutions, Environ. Sci. Pollut. Res. 24 (4) (2017) 3158–3175.
[37] S.K. Paul, R. Nandi, Status and future prospects of millets in Bangladesh, J. Cereal. Sci. 74 (2017) 180–186.
[38] V.V. Bhaskar, B. Venkateswarlu, M.D. Devi, G.B. Reddy, Millets: potential for climate-resilient agriculture and food security, J. Agric. Meteorol. 23 (1) (2021) 1–9.
[39] BARI (Bangladesh Agricultural Research Institute), Annual report (2021-2022), BARI, Gazipur. https://bari.portal.gov.bd/sites/default/files/files/bari.portal.gov.bd/annual_reports, 2022. Accessed on January 25, 2023.
[40] A. Nahar, M.A. Mannan, M.A.A. Mamun, T.K. Ghosh, Growth and yield performance of foxtail millets under salinity, Bangladesh Agron. J. 21 (1) (2018) 51–59.
[41] J. Rahman, M.I. Riad, A.A. Begum, M.R. Ali, R.R. Saha, Performance of proso millet in charland area, Acta Scientifica Malaysia (ASM) 4 (1) (2020) 9–10.
[42] M. Qadir, A. Bibi, M.H.N. Tahir, M. Saleem, H. Sadaqat, Screening of sorghum (*Sorghum bicolor* L) genotypes under various levels of drought stress, Maydica 60 (4) (2015) 35.
[43] K.B. Abreha, M. Enyew, A.S. Carlsson, R.R. Vetukuri, T. Feyissa, T. Motlhaodi, D. Ng'uni, M. Geleta, Sorghum in dryland: morphological, physiological, and molecular responses of sorghum under drought stress, Planta 255 (2022) 20.
[44] M. Enyew, T. Feyissa, M. Geleta, K. Tesfaye, C. Hammenhag, A. Carlsson, Genotype by environment interaction, correlation, AMMI, GGE biplot and cluster analysis for grain yield and other agronomic traits in sorghum (*Sorghum bicolor* L. Moench), PLoS One 16 (10) (2021), e0258211.
[45] A. Nirmalakumari, V. Ulaganathan, Evaluation and identification of suitable finger millet genotypes for higher productivity in combating climate change, in: 3rd International Conference on Neglected Crop, 2016, p. 108.
[46] K. Ghimire, H. Manandhar, M. Pandey, B. Rastogi, S. Ghimire, A. Karkee, S. Gurung, G. Bahadur, G. Netra, Devendra, multi-environment screening of Nepalese finger millet landraces against blast disease [*Pyricularia grisea* (cooke) sacc.)], J. Nepal Agric. Res. Counc. 8 (2022) 35–52.
[47] M. Kandel, N. Dhami, J. Shrestha, Phenotypic diversity of fingermillet (*Eleusine coracana* (L.) Gaertn.) genotypes, Malays. J. Sustain. Agric. 3 (2019) 20–26.
[48] A. Ndiaye, A.O. Diallo, N.C. Fall, R.D. Diouf, D. Douf, N.A. Kane, Transcriptomic analysis of methyl jasmonate treatment reveals gene networks involved in drought tolerance in pearl millet, Sci. Rep. 12 (1) (2022) 5158.
[49] R.K. Srivastava, O.P. Yadav, S. Kaliamoorthy, S.K. Gupta, D.D. Serba, S. Choudhary, M. Govindaraj, J. Kholová, T. Murugesan, C.T. Satyavathi, M.K. Gumma, Breeding drought-tolerant pearl millet using conventional and genomic approaches: achievements and prospects, Front. Plant Sci. 13 (2022) 530.
[50] A. Chakraborty, A. Viswanath, R. Malipatil, J. Semalaiyappan, P. Shah, S. Ronanki, N. Thirunavukkarasu, Identification of candidate genes regulating drought tolerance in Pearl Millet, Int. J. Mol. Sci. 23 (13) (2022) 6907.
[51] H. Desai, R. Hamid, Z. Ghorbanzadeh, N. Bhut, S.M. Padhiyar, J. Kheni, R.S. Tomar, Genic microsatellite marker characterization and development in little millet (*Panicum sumatrense*) using transcriptome sequencing, Sci. Rep. 11 (2021) 1–14.
[52] S. Shekhar, A.S. Prasad, K. Banjare, A. Kaushik, A.K. Mannade, M. Dubey, V. Premi, A.K. Viswakarma, A. Sao, R.R. Saxena, A. Dubey, LMTdb: a comprehensive transcriptome database for climate-resilient, nutritionally rich little millet (*Panicum sumatrense*), Front. Plant Sci. 14 (2023), 141106104.
[53] S. Rana, L. Pramitha, P. Aggarwal, M. Muthamilarasan, Genomic Designing for Biotic Stress Tolerance in Foxtail Millet (*Setaria italica* L.), Genome Designing for Cereal crops, 2021, pp. 255–289.
[54] W. Wei, S. Li, P. Li, K. Yu, G. Fan, Y. Wang, F. Zhao, X. Zhang, X. Feng, G. Shi, W. Zhang, QTL analysis of important agronomic traits and metabolites in foxtail millet (*Setaria italica*) by RIL population and widely targeted metabolome. Front. Plant Sci. 13 (2–22) 5511.
[55] W. Wei, P. Wang, S. Li, G. Fan, F. Zhao, X. Zhang, G. Shi, X. Feng, G. Song, X. Wang, F. Wang, Rapid identification of candidate genes controlling male-sterility in foxtail millet (*Setaria italica*), Mol. Breed. 41 (12) (2021) 73.
[56] E.M. Wimalasiri, M.J. Ashfold, S. Walker, S.P. Nissanka, A.S. Karunaratne, Calibration and validation of APSIM millet model for proso millet (*Panicum miliaceum* L.) accessions as a basis for crop diversification, J. Agric. Sci.–Sri Lanka. 18 (1) (2023) 55–57.
[57] S. Boukail, M. Macharia, M. Miculan, A. Masoni, A. Calamai, A. Palchetti, M. Dell'Acqua, Genome wide association study of agronomic and seed traits in a world collection of proso millet (*Panicum miliaceum* L.), BMC Plant Biol. 21 (1) (2021) 330.
[58] A.K.M.G. Sarwar, J.K. Biswas, Cereal grains of Bangladesh – present status, constraints and prospects, Intech (2021), https://doi.org/10.5772/intechopen.97072.

[59] BARI (Bangladesh agricultural research Institute), about BARI, Available at: http://www.bari.gov.bd/about.php, 2021. (Accessed 20 December 2022).
[60] AIS (Agriculture Information Service), Krishi Dairy. Khamarbari, Farmgate, Dhaka, 2021, p. 5.
[61] MoA (Ministry of Agriculture), FAO (Food and Agriculture Organization), towards a Food Secure Bangladesh: Country Programming Framework 2010-2015 (Former National Medium Term Priority Framework), Dhaka, 2011, p. 53.
[62] S.S. Yadav, B. Reddy, V.S. Kumar, R.V. Kumar, Millets: Crop Production Science in Horticulture, Academic Press, 2019.
[63] M.H. Mondal, Crop agriculture of Bangladesh: challenges and opportunities, Bangladesh J. Agric. Res. 35 (2) (2010) 235–245.
[64] B.N. Motagi, M. Krishnappa, B.D. Biradar, Pests and Diseases of Finger Millet: Biology and Management, Springer, 2014.
[65] IPCC (Intergovernmental Panel on Climate Change), Climate Change 2007. Synthesis Report: Summary for Policymakers. Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, UK, 2007.
[66] FAO (Food and Agriculture Organization), Millets: Nutritious Grains for Food Security and Nutrition, 2018. http://www.fao.org. (Accessed 18 January 2022).
[67] BARC (Bangladesh Agricultural Research Council), Agricultural Research Vision 2030, Project Coordination Unit, National Agricultural Technology Project, Dhaka, 2012.
[68] IPCC (Intergovernmental Panel on Climate Change), Climate Change 2014. Synthesis Report: Summary for Policymakers, Retrieved from, 2014, https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf. (Accessed 10 March 2022).
[69] I. Amadou, M.E. Gounga, G.W. Le, Millets: nutritional composition, some health benefits and processing-A review, Emir. J. Food Agric. 25 (2013) 501–508.
[70] C. Habiyaremye, J.B. Matanguihan, J.D. Guedes, G.M. Ganjyal, M.R. Whiteman, K.K. Kidwell, K.M. Murphy, Proso millet (*Panicum miliaceum* L.) and its potential for cultivation in the Pacific Northwest, US: a review, Front. Plant Sci. 7 (2017) 1961.
[71] Z. Karim, Accelerated Agricultural Growth in Bangladesh. Seminar on Agricultural Research on Development in Bangladesh, BARC, 1997.
[72] M.A. Haque, M.S. Hossain, M.A. Ali, M.S. Khan, M.S. Islam, Challenges and prospects of millet cultivation in Bangladesh, Asian J. of Med. Biol. Res. 5 (2) (2019) 248–255.
[73] B. Das, A. Bhowmik, M.A. Khan, Millet cultivation in Bangladesh: status, challenges, and opportunities, J. Agric. Rural Dev. 18 (1) (2020) 1–13.
[74] P. Li, T.P. Brutnell, *Setaria viridis* and *Setaria italica*, model genetic systems for the panicoid grasses, J. Exp. Bot. 62 (2011) 3031–3037.
[75] R.F. Sage, X.G. Zhu, Exploiting the engine of C4 photosynthesis, J. Exp. Bot. 62 (2011) 2989–3000.
[76] M.M. Ahmed, N. Alam, N.K. Kar, A.F.M. Maniruzzaman, Z. Abedin, G. Jasimuddin, Crop production in saline and charlands-existing situation and potentials, Adv. Agron. Res. Bangladesh 2 (1987) 1–27.
[77] K.M. Elahi, Impacts of Riverbank Erosion and Flood in Bangladesh: an Introduction. Riverbank Erosion Impact Study, Jahangirnagar University, Dhaka, 1991, pp. 11–67.
[78] M.S. Islam, T. Hasan, M.S.I.R. Chowdhury, M.H. Rahaman, T.R. Tusher, Coping techniques of local people to flood and river erosion in char areas of Bangladesh, J. Environ. Sci. Nat. Resour. 5 (2) (2012) 251–261.
[79] M.M. Uddin, M.R. Islam, M.N. Islam, M.A. Haque, M.R. Islam, Potentiality of millet cultivation for food and livelihood security in the chars of Bangladesh, J. Agric. Environ. Sci. 6 (1) (2017) 25–31.
[80] IPCC (Intergovernmental Panel on Climate Change), Climate Change 2001. Synthesis Report: Summary for Policymakers. Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, UK, 2001.
[81] M. Begum, M.R. Islam, M.M. Hossain, M.M. Rahman, M.F. Alam, Millet, A climate-smart crop for saline-prone areas of Bangladesh, J. Clim. Change 3 (1–2) (2017) 33–38.
[82] E.V. Maas, Crop tolerance to saline sprinkling water, Plant Soil 89 (1985) 273–284.
[83] M.M. Hossain, M.R. Islam, M.M. Rahman, M. Begum, M.F. Alam, Millet as a climate-resilient crop in the Barind tracts of Bangladesh, J. Agric. Environ. 19 (2018) 102–110.
[84] S. Maitra, S. Pine, T. Shankar, A. Pal, B. Pramanick, Agronomic management of foxtail millet (*Setaria italica* L.) in India for production sustainability: a review, Int. J. of Bioresour. Sci. 7 (1) (2020) 11–16.
[85] A.F.M. Zakaria, N.M. Majumder, Are khasis of Bangladesh eco-friendly agro manager? Reflections on hill farming practices and forest conservation, J. Sci., Technol. Environ. Inform. 8 (1) (2019) 574–582.
[86] M.A. Hossain, M. Jashimuddin, T.K. Nath, P. O'Reilly, Spiny coriander (Eryngium foetidum L.) cultivation in the Chittagong Hill Tracts of Bangladesh: sustainable agricultural innovation by indigenous communities, Indian J. Tradit. Knowl 16 (1) (2017) 59–67.
[87] R. Ahammad, N.E. Stacey, Forest and Agrarian Change in the Chittagong Hill Tracts Region of Bangladesh. Agrarian Change in Tropical Landscapes, 2016, pp. 190–233.
[88] S.K. Khisa, M. Mohiuddin, Shrinking Jhum and Changing Livelihoods in the Chittagong Hill Tracts of Bangladesh. Shifting Cultivation, Livelihood and Food Security, 2015, p. 41.
[89] B. Shalini, V.K. Didal, Sustaining minor millet production in hilly areas of uttarakhand through intercropping of minor millets and pulses- a review, Int. J. Curr. Microbiol. App. Sci. 8 (11) (2019) 397–406.
[90] B.V. Bhat, A. Arunachalam, D. Kumar, V.A. Tonapi, T. Mohapatra, Millets in the Indian Himalaya, Indian Council of Agricultural Research, New Delhi, 2019, p. 84.
[91] D. Parajulee, S. Panta, A review on maize-finger millet relay cropping in hills of Nepal: prospects and constraints, Arch. Agri. Environ. Sci. 6 (4) (2021) 570–574.
[92] K. Brahmachari, S. Sarkar, D.K. Santra, S. Maitra, Millet for food and nutritional security in drought prone and red laterite region of eastern India, Int. J. Plant Sci. 26 (6) (2018) 1–7.
[93] N. Jain, P. Arora, R. Tomer, S.V. Mishra, A. Bhatia, H. Pathak, D. Chakraborty, V. Kumar, D. Dubey, R.C. Harit, J.P. Singh, Greenhouse gases emission from soils under major crops in northwest India, Sci. Total Environ. 542 (2016) 551–561.
[94] C. Kole, M. Muthamilarasan, R. Henry, D. Edwards, R. Sharma, M. Abberton, M. Prasad, Application of genomics-assisted breeding for generation of climate resilient crops: progress and prospects, Front. Plant Sci. 6 (2015) 563, https://doi.org/10.3389/fpls.2015.00563.
[95] P.V. Prasad, S.A. Staggenborg, Growth and production of sorghum and millets, in: Soils, Plant Growth and Crop Production, vol. 2, EOLSS Publishers Co., Ltd., Oxford, UK, 2009.
[96] S. Aubry, N.J. Brown, J.M. Hibberd, The role of proteins in C_3 plants prior to their recruitment into the C4 pathway, J. Exp. Bot. 62 (2011) 3049–3059, https://doi.org/10.1093/jxb/err012.
[97] H. Upadhyaya, V.G. Reddy, D. Sastry, Regeneration Guidelines Finger Millet, CGIAR System-Wide Genetic Resource Programme, Rome, Italy, 2008.
[98] MINI (Millet Network of India), Millets- future of food and farming. Millet network of India, deccan development society, FIAN, India, Available at: https://www.milletindia.org/pdf/Publications/English.pdf. (Accessed 25 September 2023).
[99] T.P. Tuong, B.A.M. Bouman, Rice production in water scarce environments, in: J.W. Kijne, R. Barker, D. Molden (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement, CABI Publishing, Wallingford, UK, 2003, pp. 53–67, https://doi.org/10.1079/9780851996691.0053.