Natural Resources Conservation and Research 2024, 7(1), 5479.
https://doi.org/10.24294/nrcr.v7i1.5479

Review

Contribution of Millets in food and nutritional security to human being: Current status and future perspectives

Priyanka Baduni[1,*], R.K. Maikhuri[1], Girish Chandra Bhatt[2], Harendra Rawat[1],Ravindra Singh[1], C.P. Semwal[1], Ashok Kumar Meena[1]

[1] Department of Environmental Science, HNBGU, Srinagar Garhwal 246174, India
[2] ICSSR, New Delhi 110067, India
*** Corresponding author:** Priyanka Baduni, priyankabaduni24@gmail.com

CITATION

Baduni P, Maikhuri RK, Bhatt GC, et al. Contribution of Millets in food and nutritional security to human being: Current status and future perspectives. Natural Resources Conservation and Research. 2024; 7(1): 5479. https://doi.org/10.24294/nrcr.v7i1.5479

ARTICLE INFO

Received: 27 March 2024
Accepted: 9 April 2024
Available online: 17 May 2024

Abstract: Globally food and nutrition insecurity remain a serious challenge however the situation is more sever to the groups of people living under marginal and disadvantaged society. The causes of food and nutrition insecurity are multifaceted and complex, and influenced by a range of factors including high poverty, natural resource degradation, climate change, low level of market development, uncertain food support, and inadequate policy and institutional support. Considering the acute shortage of food and nutrition facing by global population, strengthening food and nutritional security is crucial in order to feed the ever-growing world population. One of the promising approaches of promoting millets, which requires low external inputs, a novel candidate for nutrients and adapted to thrive in harsh and dry environment. These crops play an important role in global food and nutrition security, and may have potential to contribute to sustainable food systems under changing climatic conditions. Keeping in view the importance of the millets in diversifying diet as well as a source of rich nutrition, we conducted an analysis by reviewing the research articles/reports/books as well as online databases to identify the prospects of millets crops crucial for continuous supply of food and nutrition, traditionally managed genetic resources for future crop improvement and making agricultural system resilient under changing climatic conditions. Evidences suggested from the meta-analysis that as a product of generations of agricultural landrace, there are range of millet crops are rich in nutrients, resilient, and adapted to location specific agricultural environments. Such millet crops in the existing cropping systems could support diverse food systems and nutrient suppliers and represent a broad gene pool to improving crops with suitable genetic interventions in the future. The study advocates for advancement in genomics coupled with molecular breeding for improving the genetic potential of millet crops and open avenues for developing sustainable food systems. The study also emphasis on developing strategies and roadmap for future research engagement and a policy interface to facilitate conservation and management of traditional landraces and associated indigenous knowledge of cultivation and consumption while adopting sustainable production of millet crops under marginal environmental conditions.

Keywords: millets, nutrition insecurity, climate change, traditional knowledge

1. Background

It is well established that around 924 million people worldwide (11.7%) are facing acute food and nutritional insecurity due to increasing population and shrinking natural resource base. In order to mitigate the adverse impact of climate change and continued land degradation as well as to increase global food and nutritional security, there is need to promote climate resilient and nutritional rich crops [1]. The lesser-known crop as often referred millets are such a crop grown by the marginal, traditional

and ethnic communities have unprecedented role to fulfil food and nutritional security and help to attain the sustainable developmental goals (SDGs) of the United Nations (UN) including no poverty, zero hunger (2) and good health and wellbeing (3). Millets are a group of minor-seeded annual grasses that are predominantly grown as grain crops on marginal land in the areas where the climatic conditions are harsh and dry. The ancient food grain known as millet was initially domesticated for human consumption and is now produced in 131 nations. In Asia and Africa, millets are consumed as staple food and about 590 million people directly dependent on millets for their food and nutritional security. A majority of millet grains have higher protein, fibre, calcium and micro-nutrients than the common food crops consumed widely such as wheat, rice and maize and hence now often being regarded as health foods. Besides, millets are drought resistant and hardy crops which play an important role in marginal agriculture, particularly in rain-fed agriculture [2–4]. Millets are C_4 plants and hence have a very efficient photosynthetic system than C_3 plants like wheat and rice and are considered as a climate resilient/climate proof food crop [5]. Considering the resistance potential and nutritional value of millets, these crops could become a frontline crop in addressing issues like food, fodder, fuel, starvation and illness under the changing scenario of the climate. Millets can thrive well even in infertile soil and are suited to a wide range of ecological amplitudes requiring minimum water, nutrients and other external inputs. In India, nine different varieties of millets are grown and Sorghum, Pearl Millet, and Finger Millet cover maximum area accounting for 95% of the country's total millet growing area. The other millets varieties cover 5% of the area under cultivation includes (such as Little Millet, Foxtail Millet, Barnyard Millet, Proso Millet, Kodo Millet, and Brown Top Millet). Millets are a rich source of nutrients and also possess medicinal properties and are now recognised as nutri-cereals [3,6]. The traditional millets crops grown in rainfed agriculture of Uttarakhand includes finger millets (*Eleusine coracana*), foxtail millets or Italian millet (*Setaria italica*), barnyard millet (*Echinochloa frumentacea*) and proso millets (*Panicum miliaceum*). Regarding health benefits and nutritional advantages, millets are remarkable (Ref.). Millets are thus miraculous. Among the millets, pearl millet is a rich source of iron and could be useful to treat anaemia as it contains 4 to 8 milligrams per 100 g of grain. It is advised for pregnant mothers to consume more food items made from pearl millets as it is also rich in zinc and folic acid. In comparison to milk, pearl millet has twice as much protein. Recent meta-analyses and systematic reviews of millets highlighted their potential to manage and reduce diabetes. Millets' low glycemic index aids in the control of diabetes. The highest calcium level is found in finger millet, also known as ragi, with 364 mg per 100 g of grains. It has three times as much calcium as milk. Strong bones and teeth are maintained by this calcium-rich grain. The high dietary fibre content of millets aids in digestion and helps to prevent constipation. Evidences also suggest that kodo millet is three times higher in dietary fibre than wheat and maize, and ten times higher than rice. Millets have a high fibre content, which means they can function as prebiotics and contribute to the preservation of a healthy microbiome in the gut. Millets are excellent for celiac patients because they are completely gluten-free. Millets include a high concentration of antioxidants, which help to defend our cells against damage caused by free radicals and also helps in weight reduction. Weight loss is aided by the particular components of millets, such

as tryptophan, dietary fibre, and policosanols [7]. Millets can lower the chance of acquiring cardiovascular problems, according to a recent study [8]. Millets aid in weight reduction. Weight loss is aided by the specific elements of millets, such as tryptophan, dietary fibre, and policosanols [9].

In addition to their positive health effects, millets are hardy crops and can thrive well in a variety of temperatures and moisture levels with minimal external inputs. They are climate resilient crops, require little water, can withstand droughts and can even survive on 350–400 mm of rain. In view of the above positive attributes, the United Nations General Assembly enacted a resolution declaring 2023 the International Year of Millets, as suggested by India to the Food and Agriculture Organization. The primary objective of this initiative is to develop an understanding of millets' health advantages among the people and their adaptability for growing under harsh climatic conditions. It is anticipated that rising temperatures will result in lower rice yields. Therefore, in order to deal with changing in agricultural patterns, adaptive strategies must be taken into consideration. Climate change causes a decrease in yield, which resulted food insecurity, an increase in pest and disease outbreaks, soil degradation, a shift in crop timing, and desertification. In wake of climate change and its negative impact on the production of rice, wheat and maize, millets are more suitable alternative crop, and may be considered potential crops for future. India is the world's top producer of millets and the fifth-largest exporter of millets worldwide. As the demand for millets rises quickly, the exports of millets are expanding dramatically. Millet's by-products (straw) meet the fodder needs of livestock and also used as fuel. More business opportunities are being created for entrepreneurs as millet's demand rises nationally and globally. The millet market was worth over US$ 9 billion in 2018 and is expected to grow at a rate of over 4.5% CAGR from 2018 to 2025, reaching a value of over US$ 12 billion.

It is obvious that non-sustainable economic benefits, low economic value, declining knowledge about traditional foods, farming, and processing, reduced area under cultivation, and the non- availability of stable markets contributed to the decline in cultivation of millets and other traditional landraces [3,4,6,10]. Growing demand for millet is being met with competition from the return to more conventional farming methods, which produce more reliable crops like maize, rice, and beans. Farmers now have a better understanding of the cultivation techniques required to cultivate these crops as a direct result of research and development activities that have been dedicated to these crops. This is having a rapid and permanent effect on traditional crop farming zones as well as millet growing areas [6,11]. A further contributor to this risk was the artificial promotion of maize. In addition, the wildlife, such as monkeys and birds, who nibble on the young grains of these millets in open fields, the abnormal rainfall, the availability of varieties with improved characteristics, and the cultivation technique are all contributing factors in the reduction. Alterations in lifestyle have further necessitated a reduction in agricultural production, which has simultaneously led to a reduction in food consumption [12].

2. Objective of the review

The objective of this review is to comprehensively examine and evaluate the

contribution of millets in ensuring food and nutritional security for human beings. The review aims to achieve the following specific objectives:

Provide an overview of the nutritional composition of millets: This includes analysing the macronutrient and micronutrient content of different millet varieties, their dietary fibre content, and antioxidant properties. Understanding the nutritional composition of millets is crucial in assessing their potential to address malnutrition and improve dietary diversity.

Explore the health benefits of millets: Investigate the specific health benefits associated with the consumption of millets. This includes examining their role in preventing malnutrition and micronutrient deficiencies, managing non-communicable diseases such as diabetes and cardiovascular diseases, promoting gut health, and providing gluten-free alternatives for individuals with celiac disease or gluten sensitivity.

Evaluate the role of millets in addressing food and nutritional security: Analyse the contribution of millets to food security by assessing their climate resilience, suitability for sustainable agriculture, and potential for cultivation in marginalized or arid regions. Additionally, examine their role in diversifying staple diets and improving dietary diversity, particularly in populations vulnerable to malnutrition.

Provide recommendations for future actions: Based on the review findings, present recommendations for future actions to harness the full potential of millets in ensuring food and nutritional security. This includes strategies for scaling up millet cultivation, strengthening market linkages, enhancing research and innovation, promoting consumer awareness and education, and fostering supportive policies and partnerships.

3. Methodology

I had conducted a thorough literature search to gather 40 (fourth) relevant research articles, scholarly publications, reports, and other credible sources related to millets. Utilize academic databases, such as PubMed, Scopus, and Google Scholar, and include keywords such as “millets,” “nutritional composition,” “health benefits,” “cultivation practices,” “traditional crops,” “climate change,” “sustainable developmental,”. I had established a specific criterion for selecting relevant studies such as publication date, study design, sample size, geographical location. I had organized the extracted data in a structured manner, such as using tables or matrices, to facilitate analysis and synthesis. Synthesize the findings from the selected studies to provide a comprehensive overview of the contribution of millets to food and nutritional security.

4. Role of millets in traditional food system

Consumption of traditional millets (crops) contributes to meeting the region’s high energy demands for work, as compared to consumption of modified millets, which supply less energy per unit than traditional millets. As the gradient of elevations increases, the millets become a more significant source of protein and calories [3]. As the imported enhanced variety was relocated to lower altitudes, its condition gradually improved. This could be due to the fact that the common food crops like rice and wheat

are more readily available at lower elevations or accessible areas. Pseudo cereals and millets and pulses were preferred at high elevations, but millets and other tiny grains (traditional crops) were consumed at all altitudes. Higher elevations also showed higher protein consumption than middle elevations and lower elevations, likely due to the fact that market considerations are less prominent at higher elevations and there is a desire to be self-sufficient in such circumstances.

Proteins, dietary fats, carbs, and fibre are all abundant in millets. Millets like *Setaria italica* and pseudeo cereals such as *Fagopyrum spp*. are rich in dietary fats, which provide the highest calories per unit. To meet their high energy needs, people who live in high-elevation areas consume a lot of these products. In contrast to the typical carbohydrate- and protein-based meals of people who live in the lowlands, the rich variety of the traditional grain-based diet found in the mountain region which satisfies nutritional and energetic needs. Reduced consumption of these traditional crops has led to nutritional imbalances and energy shortages among the people. Some traditional crop varieties have therapeutic benefits as well (**Table 1**).

Table 1. Millet crops and their common and scientific name and other special characteristics.

Millet	Common name	Botanical name	Special characteristics	Reference
Sorghum	Great millet, Jowar, Kafir corn, Guinea corn, Kaolin in China, and Milo in Spain	Sorghum bicolor	Tolerate moisture stress and high temperature better than another crops	-
Pearl millet	Bajra, Cattail millet, Black millet, German millet	Pennisetum glaucum	Grow in arid and semi-arid region, richest source of folic acid	-
Finger millet	Ragi, Wimbi, Mandua, Nachni, Kapai, Nagli, Marua	Eleusine coracana	Wider adaptability, rich source of calcium	Seetharam [13]
Prosomillet	Cheena, Common millet, Broom millet	Panicum miliaceum	Short duration, tolerant to heat and drought	Seetharam [14]
Foxtail millet	Indian paspalum, Kangni, Water couch, Italian millet	Setaria italica	Short duration, tolerant to low soil fertility and drought	Jijau [15]
Kodomillet	Kodo, Ditch millet, Creeping paspalum	Paspalum scrobiculatum	Long duration, grown well in shallow and deep soil, rich in folic acid	Hegde and Gowda [16]
Barnyard millet	Sawan, Jhingora, Kudraivali, Oodalu	Echinochloa frumentacea	Fastest growing, voluminous fodder	Gupta et al. [17]
Littlemillet	Kutki, Samai, Samalu, Hogmillet	Panicum sumatrense	Short duration withstands both drought and waterlogging	Doggett [18]
Brown top millet	Koralein Kannada	Brachiaria ramosa	Rapidly maturing, best suited for catch crop	Sheahan [19]
Teff	Teff, love grass, annual bunch grass, Williams lovegrass	Eragros tistef	Massive fibrous rooting system, drought tolerant, ephemeral nature	-
Fonio	Fonio, Acha, Hungry rice	Digitaria exilis (White fonio) Digitaria iburua(White fonio)	Smallest seeds among millets, fast growing and highly nutritious	NRC [20]
Job's tears	Adlag, Adlay millet	Coixlaeryma	Grown in higher areas, used in folk medicine	Duke [21]
Guinea millet	False signal grass, Babala, Bajra/Bajira	Urochloa deflexa	Potential as grain crop	-

These findings and the issues raised lead to the conclusion that diversity contributes significantly to preserving the long-term stability of traditional agro-ecosystems in a variety of ways. As some crops perform better than others in a mixed-

cropping system, it helps to reduce crop loss caused by pests, improve soil fertility while including legumes in the crop mixture, reduce crop loss caused by plant diseases and nematodes, inhibit, or suppress weed growth, increase productivity per unit area, produce a varied diet, prevent soil erosion on steep slopes, and provide insurance against total crop failure [6].

5. Millets a source of rich nutrients and dietary diversification

The majority of us believe that a lack of essential nutrients puts our health at risk. As a result, everyone is aware of what they eat on a regular basis, and food product development teams around the world are working hard to fill in any gaps in the health equation. Therefore, nutrition forms the basis of people's diets. In terms of protein, calories, vitamins, and minerals, millet grains are comparable to and even better than the fine grains [22]. Compared to rice, wheat or maize, millets are a richer source of minerals, nutraceuticals, and dietary fibre. They also include 9%–14% protein and 70%–80% carbohydrates [23]. These millets are abundant sources of micronutrients and phytochemicals [24] (**Table 2**).

Table 2. Nutrient composition of sorghum, millets and other cereals (per 100 g edible portion; 12 percent moisture) [25–28].

Food	Protein[a](g)	Fat (g)	Ash (g)	Crude fibre (g)	Carbohydrate (g)	Energy (kcal)	Ca (mg)	Fe (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)
Rice (brown)	7.9	2.7	1.3	1.0	76.0	362	33	1.8	0.41	0.04	4.3
Wheat	11.6	2.0	1.6	2.0	71.0	348	30	3.5	0.41	0.10	5.1
Maize	9.2	4.6	1.2	2.8	73.0	358	26	2.7	0.38	0.20	3.6
Sorghum	10.4	3.1	1.6	2.0	70.7	329	25	5.4	0.38	0.15	4.3
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	42	11.0	0.38	0.21	2.8
Finger millet	7.7	1.5	2.6	3.6	72.6	336	350	3.9	0.42	0.19	1.1
Foxtail millet	11.2	4.0	3.3	6.7	63.2	351	31	2.8	0.59	0.11	3.2
Common millet	12.5	3.5	3.1	5.2	63.8	364	8	2.9	0.41	0.28	4.5
Little millet	9.7	5.2	5.4	7.6	60.9	329	17	9.3	0.30	0.09	3.2
Barnyard millet	11.0	3.9	4.5	13.6	55.0	300	22	18.6	0.33	0.10	4.2
Kodo millet	9.8	3.6	3.3	5.2	66.6	353	35	1.7	0.15	0.09	2.0

All values except protein are expressed on dry weight basis; protein = N × 6.25.

As a result, it is now understood that the nutrition level of a community is a key determinant of national development [29]. Millets can be a potential alternative to address the issue of food insecurity and malnutrition in the face of a rising population, stagnated wheat and rice production and climate change. The necessary amino acids in protein play a major role in determining its quality. Finger millet contains 44.7% of the total amino acids as necessary amino acids [30], which is greater than the 33.9% of essential amino acids in FAO's reference protein [31]. The analysis of millet grain proteins reveals that the prolamin fraction makes up the majority of the grain's storage protein and that lysine is the most limited amino acid, followed by cystine. However, millets have a very high methionine content [32,33]. These millets have a true digestibility range of 95.0 to 99.3 and a biological value of 48.3 to 56.5, respectively

[34]. Among the millets, pearl millet (Bajra) contains the highest concentration of macronutrients such as iron, zinc, magnesium, phosphorus, folic acid, and riboflavin. It is also very rich in resistant starch and soluble and insoluble dietary fibres [35,36]. The edible finger millet seed coat has a considerable amount of nutritional fibre, minerals, and phytochemicals. As a by-product of the millet milling, malting, and decortication industries, the seed coat matter (SCM) can be used to make composite flour for biscuit making [37]. Ragi, also known as finger millet, is an exceptional source of calcium. While low in fat content, Kodo millet and small millet are believed to contain the greatest levels of PUFA (polyunsaturated fatty acids) among grains, with 37% to 38% of dietary fibre [23,38]. Additionally, it contains a lot of critical amino acids, including lysine, threonine, valine, and sulfur-containing amino acids, with a leucine to isoleucine ratio of roughly 2 [38,39]. The antioxidant activity in sorghum and millets is far higher than in any other cereal. The large amounts of vitamin B, folic acid, phosphorus, iron, and potassium found in millets make them a valuable food. In comparison to maize, finger millet has 16 times more calcium. Pearl millet has the highest niacin level of any cereal. Additionally, millets are devoid of gluten, simple to digest, a fantastic source of antioxidants, and they may even be anti-carcinogenic [40]. Consequently, millet has a higher energy content than sorghum and is almost as high as brown rice. The iron level of finger and teff millet is substantial, and they are rich sources of dietary calcium and magnesium.

6. Status of millet cultivation: A global scenario

For poor farmers in hot, arid regions of the developing world, particularly in Africa and Asia, millets constitute an essential source of food [41]. Millets (pearl millet and other minor millets) are grown in more than 93 nations worldwide. The most extensively grown millet crop is sorghum and grown under 42.1 million ha of land in 105 nations. Production estimates for pearl millet and other minor millets are known from 93 countries [42]. Developing nations, particularly those in Africa and Asia, produce and eat about 97% of the world's millets (**Figure 1**).

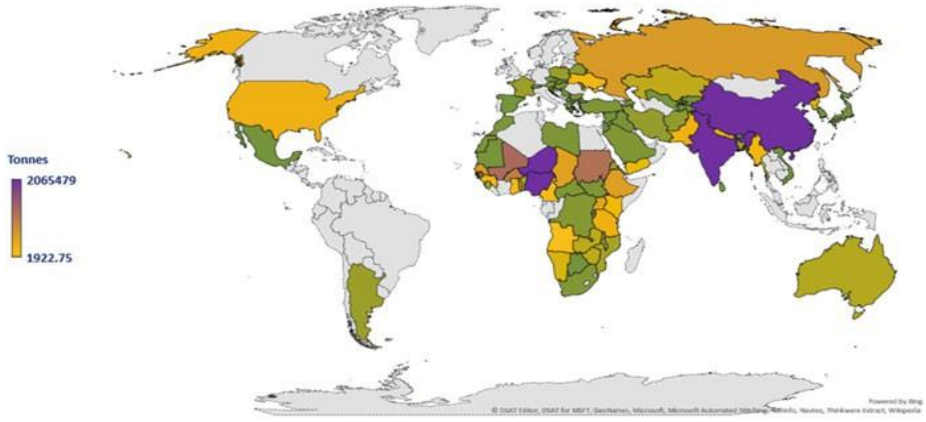

Figure 1. Country-wise production of millets [43].

India is the world's largest millet producer, accounting for 26.6% of the world's millet farming area and 83.0% of Asia's. In the Indian states of Odisha, Madhya Pradesh, Jharkhand, Rajasthan, Karnataka, and Uttarakhand, millets have long been a

staple cuisine of traditional and marginal communities [3,4,6,11,44]. However, due to their incredible nutraceutical potential, they have recently started to gain popularity in urban areas as well. The area cultivated under millets worldwide has decreased by an estimated 25.7% between 1961 and 2018 [43]. Asia experienced the greatest decline in area under cultivation among the continents (148%), while Africa experienced the least. This decrease may be linked to factors such as a lack of concerted agricultural improvement initiatives, a shift towards high-value cash crops, a lack of government regulations and appropriate policy implementation, and low farm profitability. Millets are now considered to be minor or underutilised grains as a result of a steady decrease in the amount of cultivated land around the world over the past several decades. Millets are more productive than other commercial crops due to their capacity to adapt to rainfed areas as well as low external input farming conditions. Future agricultural systems would benefit from their ability to tolerate environmental stress and the C_4 photosynthetic pathway, in addition to many other positive attributes. They are extremely valuable crops due to their nutritional advantages over main cereals such as Wheat, Rice and maize in terms of a balanced micronutrient profile and bioactive flavonoids with a variety of medicinal uses [44]. Millets have seen a rise in worldwide export and import over the past one decade due to their enormous health benefits; the highest values (155.26 and 127.60 million US dollars, respectively) were recorded over the years 2011–2017 [43]. Despite their enormous market value, millet cultivation and production have decreased or stayed stagnant globally over the past 50 years compared to other common cereals. This is mostly because millets have not yet experienced considerable genetic gain from modern plant breeding. Also, the key to making them the valuable crops of the future is to use methods of crop management that are both sustainable and cost effective.

7. National status of millets cultivation

Global millet production is expected to rise from an average of 28.2 MMT in 2019 to 30.5 MMT in 2020, as per the report of Food and Agriculture Organization of the United Nations. In 2020, India could hold a 33.3% market share, making it the largest producer in the world (**Figure 2**). Millet's status as a staple meal has decreased during the past 40 years, especially in India, as a result of a number of factors, including introduction of high yielding varieties of rice and wheat and other cash crops, an increase in urbanisation, and ignorance of these minor millets in govt. agricultural policies. Currently, more than 50.0% of millet output is going to alternate uses rather than being consumed as a staple food. India's request to mark an International Year of Millets in 2023 was approved by the Food and Agriculture Organization (FAO) Council in 2018. During recent past millets has been given the status of superfoods because it is rich source of minerals and vitamins like copper, magnesium, phosphorus, and manganese. Food prepared from millets are good and highly useful to patients suffering with chronic illnesses like diabetes, obesity, and heart disease. Fibre found in millets aids in digestion and prevents intestinal problems. Millets help prevent stomach problems and a number of kidney and liver diseases when they are eaten regularly. The millets are gaining popularity in breakfast food market is due to customers' rising demand for foods high in fibre and free of gluten.

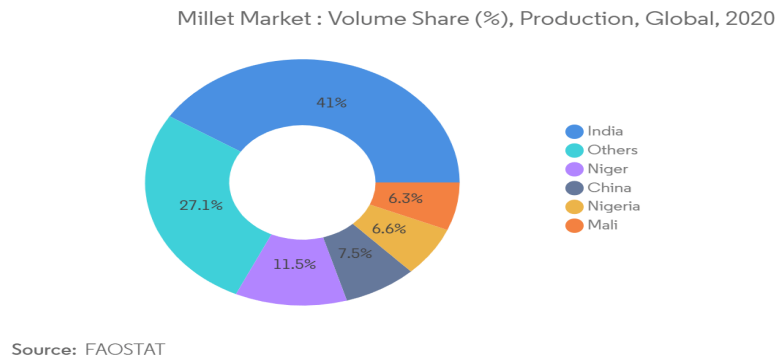

Figure 2. Millet market: Volume Share (%), production, global, 2020.

8. Global status of millets consumption

In Africa, millet has traditionally been one of the essential nutrients for people. Niger, Mali, Nigeria, Burkina Faso, and Sudan account for the majority of the African nations with over 40% of the world's millet consumption (**Figure 3**). Millets are widely consumed in nations like India and Africa, where securing food and nutrition is a major concern. The millets crops are hardy and have great ability to perform better under adverse environmental conditions. India is the top millet grower in the world. Governments in Africa started implementing policies in May 2021 to encourage the production and consumption of millets through local seed banks, seed fairs, and farmer networks. The development and production of millet seed is the only focus of public and private investment. Millets' international prices are incredibly unpredictable, heavily influenced by supply levels, and frequently unrelated to those of other significant coarse grains like maize, sorghum, or barley. Millets are important to the food and nutritional security and economies of many African countries, so people are likely to consume a large quantity of the millet's varieties.

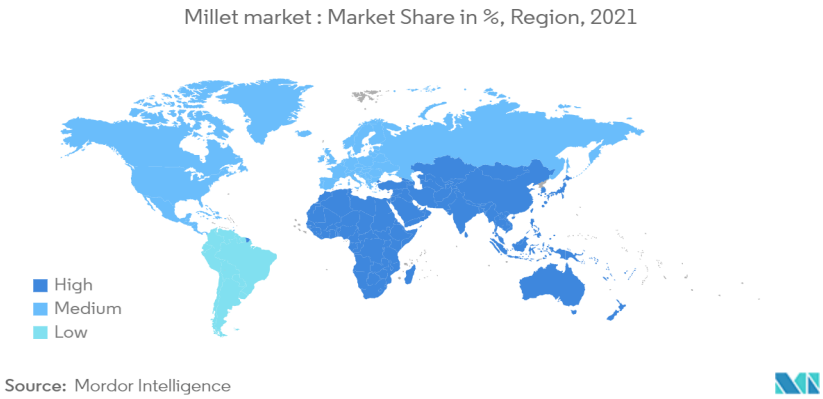

Figure 3. Millet market: Market share in %, Region, 2021.

9. Contribution of millet in sustaining traditional agrobiodiversity

More than 60% of the population in the Uttarakhand region relies mostly on subsistence farming for their food. Rainfed and irrigated farming are the two primary methods of crop production practice by farmers in this region. Rainfed farming is the more traditional method. In irrigated agriculture, two crops are harvested each year with a focus on cereals (wheat and paddy). On the other hand, millets, pulses, and

tubers are cultivated alongside cereals and oil seeds on the rainfed system. Monoculture is a typical aspect of irrigation-based agriculture. Contrarily, mixed cropping is frequent in rainfed agriculture, which has two major cropping seasons, namely Kharif (April–October) and Rabi (October–April), with elevations typically up to 1800 masl and occasionally up to 2500 masl (in remote high-altitude areas). Only summer crops (April to October) are planted at higher elevations (between 2500–3000 masl). The whole agricultural land under a rainfed system is split into two halves, locally referred to as "Mallasari" and "Mulla/Talla sari." This region's agriculture is extremely complicated since it is intertwined with crop- husbandry, animal- husbandry, and forestry to form a production system. Inaccessibility, environmental heterogeneity, and ecological fragility favoured the evolution of subsistence production systems based on organic matter and nutrients derived from forests [3,4,6,45]. Inaccessible high-altitude regions rely more on traditional crops than accessible low-altitude ones. In comparison to residents of middle- and lower-altitude villages, people in higher-altitude villages consume more food per person per year. In high-altitude regions where HYVs of wheat and paddy have rarely reached, traditional finger millet, barnyard millet, and amaranth cultivars still provide about 40% of the dietary energy. Additionally, traditional cultivars offer parent genetic material for creating HYVs that were artificially developed [46]. Local food security may rely on resilient traditional staples like millets in the traditional diversified agricultural system during unpredictably bad weather years. If necessary, several traditional crops, like *Panicum miliaceum*, *Setaria italica*, and *Fagopyrum spp*., can be harvested over a 50- to 90-day period. Though HYVs of wheat and paddy allow for higher yields when compared to traditional cultivars, the maximum outputs are usually not realised due to inadequate irrigation systems and limited access to pesticides and fertilizers because of hillside restrictions. The bulk of traditional crops have powerful healing properties. When someone has jaundice, pneumonia, or any other abdominal problems, the grains of *Setaria italica*, *Panicum miliaceum*, and *Echinochloa frumentacea* are used. Traditional crops can grow even under adverse environmental conditions and have considerable ecological and economic potential. The change (%) in area, production, and yield of small millets in different districts of Uttarakhand from 2011–2012 to 2019–20 is shown in **Table 3**.

However, due to population pressure, socio-cultural shifts, inappropriate technology interventions, market forces, land tenure/ownership rules, etc., a number of modifications to this region's conventional farming system have recently emerged. Negative agricultural trends like less crop diversity, soil degradation, unstable water supplies, human-wildlife conflict, and the breakup of communities have made it hard for agriculture in this region to be both economically and ecologically sustainable. This, in turn, has put agriculture in this region in danger [3,48]. The area under to millet cultivation has drastically decreased. Millets and other crops such as (*Panicum miliaceum*) has declined by 98%[6]. In order to promote its people's movement and ensure that Indian millets, recipes, and value-added products are recognised nationally and internationally, the Indian government has suggested to the United Nations that 2023 be designated as the International Year of Millets (IYOM). Over 60% of the population of Uttarakhand depends on agriculture for their livelihood, with the sector contributing around 23.4% of the state's gross domestic product however, in the state,

underweight and child malnutrition are serious issues [49]. According to the National Family Health Survey (2018), one third (34%) of children under the age of five are stunted, or too small for their age, which suggests that they have been malnourished for some time. Twenty percent of people are wasting away or excessively short for their height, which may be the result of recent malnutrition (FAO, India Brief). By creating nutria-cereal model towns in tribal or hilly settings, these two issues can be resolved [50].

Table 3. Area(ha), Production (tones) and Yield (tonnes per hectare) of small millets in districts of Uttarakhand [47].

Area (ha) of small millets				**Production (tones) of small millets**			**Yield (tones per hectare) of small millets**		
District	**2011–2012**	**2019–2020**	**Change (%)**	**2011–2012**	**2019–2020**	**Change (%)**	**2011–2012**	**2019–2020**	**Change (%)**
Almora	14,870	12,387	−16.70	18,366	13,919	−24.21	1.235	1.124	−9.02
Bageshwar	881	614	−30.31	543	776	42.91	0.616	1.264	105.05
Chamoli	5074	4914	−3.15	5061	6285	24.18	0.997	1.279	28.23
Champawat	1369	718	−47.55	1773	1059	−40.27	1.295	1.475	13.88
Dehradun	1497	733	−51.04	1330	823	−38.12	0.888	1.123	26.38
Nainital	538	157	−70.82	696	178	−74.43	1.294	1.134	−12.36
PauriGarhwal	15,536	9003	−42.05	19,438	12,074	−37.88	1.251	1.341	7.19
Pithoragarh	1250	1029	−17.68	1891	1516	−19.83	1.513	1.473	−2.61
Rudraprayag	2833	3135	10.66	4382	4805	9.65	1.547	1.533	−0.91
TehriGarhwal	16354	14,165	−13.39	21,691	22,040	1.61	1.326	1.556	17.31
Uttarkashi	3741	3450	−7.78	4693	4492	−4.28	1.254	1.302	3.79

10. Status of millets in Uttarakhand

Both finger millet (1.08 lakh ha) and small millet (0.6 lakh ha) are cultivated on a larger area in the state of Uttarakhand than in any other state, and the state's yield levels per unit area are higher than the national average in both cases [51]. The state's increased productivity can be attributed to its moderate climate, relatively more fertile soils, and protective moisture supplies. The majority of the produce is consumed by households, leaving less surplus that may be sold. Among other crops, finger millet, foxtail millet, and barnyard millet are some of the main crops grown during the kharif season. In some regions, mixed cropping (baranaja) of millets, legumes, amaranths, sesame, etc. during the kharif season is a typical practise. One significant problem that inhibits the continued survival of traditional landraces, in particular those cultivated by subsistence farmers, is the absence of a systematic seed exchange system for traditional landraces. The proportion of dry fodder from different millet crops are contributing to livestock feeding in Uttarakhand is shown in **Figure 4**.

Figure 4. Proportion of different sources of dry fodder contributing to livestock feeding in Uttarakhand [52].

Some of the crops that were previously grown in numerous villages have gone extinct locally in the last 2–3 decades. In the state of Uttarakhand, where it was once widely grown, foxtail millet is now all but extinct [53]. It was one of the key crops in the Baranaja system because it ripened 15–20 days earlier than barnyard millet. The foods made from foxtail millet were nutritionally rich. Additionally, the people had previously grown sorghum for roughly three decades, but they no longer do [53]. Finger millet and barnyard millet production has doubled in the past three years ago. The Department of Agriculture has maintained the revised aim in order to further increase the production. Thus, the productivity of remaining millet crops may rise in the upcoming years. According to statistics, traditional crops like finger millet and barnyard millet are doing well in Uttarakhand. In the years 2014–2015, the yield of finger millet grain was 6–7 quintals per hectare, but in 2017–2018, it was 12 quintals per hectare. These harvests are now selling for a fair price on the market. In Uttarakhand, barnyard porridge is a well-known meal (locally called madira ki kheer). The local varieties of millet crop in Uttarakhand are shown in **Table 4**.

Table 4. Millets in Uttarakhand.

Millet crop	Local name	Local varieties
Finger millet	Ragi/ Mandal	Nangchuniya, Tokaria, Putkya, Garhwalo, Jhankaria, Bhuwakhetia (round head inflorescence variety), Lumariyaw, Dhuniyaw, Lal madu (red grains), Safed Madu (whitish grain), Garau, Putki, Dwit, Ganoli, Gol Madu (fingers closed), Timasi (matured in three months), Chhaimari (matured in six months), Chaumasi (fingers smaller as matured during rainy season), Chhitalu (fingers open and drooping), Nangchuni (The ears can be removed with the help of nail after maturation), KaturiyaMandua (big or long fingers and closed).
Barnyard millet	Madira, Jhangora, Sanwa	ThulMadira (The ears long, thick and red), Nan Madira (The ears small, ash coloured, and taste), JharuMadira (Wild relatives of Madira), BhatkkahntiMadira (Grains easily removed from the ears after maturation)

11. Recipes made by millets in Uttarakhand

The Himalayan natives created ethnic dishes to cope with the tough terrain and surroundings. People have adapted these foods to protect and sustain them because they have been consumed for generations. Ethnic foods have antioxidant, antibacterial, probiotic, and bio nutrient capabilities, as well as some significant health-benefiting chemicals. Different recipes from millets are shown below in **Table 5**.

Table 5. Recipes made by millets in Uttarakhand.

S.No.	Millets	Recipes
1	Finger Millets (Mandua)	Mandua ki Roti
		Mandua ki Baadi
		ManduakeMomos
		Mandua ka cake
		Mandua ka Dosa
		Mandua ka Biscuits
		Mandua ka Chocolate Pudding
		Mandua ka Upma
2.	Barnyard (Jhangora)	Jhangore ki Kheer
		Paleu or Chencha
		Chhachhindu
		Jhangore ka shake, Icecream
		Jhangora ka Kalajamun
		Jhangora ka milk cake (Kalakhand)
3.	Proso Millet (Cheena)	Cheena ka Cheela
		Cheena ka Dosa, Idli
		Cheena in place of rice serve with Sambar
		Cheena ka Upma
4.	Foxtail Millet	Foxtail millet kheer
		Foxtail millet Mango Rice
		Foxtail Millet cutlet
		Foxtail millet Coconut Rice
		Foxtail millet Vegetable Biryani
		Foxtail Bread

12. Impact of green revolution reduced the cultivation of traditional crops and millets varieties

Due to the green revolution and a good road network, the traditional communities' exposure to lowlands populations, therefore food preferences have moved from coarse local grains to introduced fine grains. As a result of this shift in consumer food tastes, the emphasis on farming fine grains has increased. Unfortunately, the area's erratic monsoon conditions are not ideal for these newly imported types, which regularly break at even the minor weather fluctuation. Traditional types, in comparison, are better adaptable to climate fluctuations and provide enough yields to sustain a family. Soil fertility and erosion significantly limit the region's food output. As human density has increased, agriculture has moved to unsuitable marginal terrain. Maikhuri et al. [4] identified some surprising information regarding the rapid decline of traditional crop diversity within the time period of two decades (1974–1994). Traditional crops used to cover 72%–95% of the land have been replaced by cash crops. The region previously occupied by *Setaria italica* (foxtail millet) and *Panicum miliaceum* (hog millet) has been replaced with high-yielding rice cultivars, covering around 65% of

the area. The area cultivated with rice and wheat hasn't changed significantly, but the farmer-selected traditional cultivars grown until the 1970s have been entirely replaced with HYVs of rice and wheat that were artificially bred. Crop diversity has decreased in part due to the introduction of HYVs and in part due to the cultivation of conventional income crops receiving more attention. Traditional agroecosystems, which conserve and safeguard biological diversity, are giving way to modern agroecosystems, which are based on intense cropping (e.g., monocropping, plantations, etc.) and have evolved primarily to boost yield and economic returns at the expense of a significant loss of traditional agro-biological diversity [3,54–56]. There is a discernible weakening of links among the components of conventional agroecosystems, which has, as a direct result, led to the destruction of agrobiodiversity. Sen et al. [57] observed that soil erosion was higher for the introduced cash-oriented cropping systems than for the traditional subsistence crop-based systems on all categories of slopes when comparing the soil losses for traditional and introduced crop varieties. Additionally, with traditional types, the needs for managing soil fertility are compatible with the resources at hand.

13. Implications for promoting millets cultivation and conservation

Millets should be made more well-known to the public or young generation in order to benefit from their health-improving properties as well as the growth of a lucrative market. It is necessary to develop a relationship between agriculture, nutrition, and farmers in order to transform hilly villages and farming communities into economically and nutritionally self-sufficient units through the use of existing resources and awareness of nutrition education. The creation of Nutria cereal model villages in hilly rural landscape through institute-farmer partnerships (participatory breeding programmes) is urgently needed for in-situ millets germplasm conservation, the development of acceptable crop varieties, and the improvement of the economic and health status of underprivileged local communities. At the same time, a new strategy called "nutria cereal seed villages" can help farming communities grow tiny millet in a sustainable way [50]. During the forecast period (2022–2027), it is anticipated that the worldwide millet market will grow at a CAGR of 4.8%. In 2020, COVID-19 had both a beneficial and a negative effect on the millet market. The market experienced supply chain disruption, a labour shortage, the closure of small processing facilities, etc. as a result of the recurrent application of lockdowns. In spite of the aforementioned drawbacks, retail sales have increased dramatically. People have switched from consuming junk food to nutrient-rich delicacies like millets and their derivatives in an effort to strengthen their immune systems. Around the world, millet is produced in a variety of forms, including sorghum, finger millet, pearl millet, barnyard millet, proso millet, and tiny millet. The consumption of millet declined by 0.9% globally but is predicted to increase during the projection period. The three countries that account for more than 55.0% of the world's millet output are India, Niger, and China [58]. For a long time, India was the world's top millet grower but recently Africa has seen a sharp rise in millet production. These grains are good for vegetarians because of their high protein content, which is primarily found in the Americas, Europe, and Asia-Pacific. As a result, millet-based products are in high

demand in these areas.

14. Challenges and opportunities

Limited awareness and market linkages:

One of the significant challenges faced in the cultivation and promotion of millets in Uttarakhand is the limited awareness among farmers and consumers about the nutritional benefits and potential of millets. Many farmers are not adequately informed about the agronomic practices and techniques for millet cultivation. Similarly, consumers may lack knowledge about the diverse culinary uses and health advantages of millets.

To address this challenge, there is a need for awareness campaigns, training programs, and knowledge-sharing initiatives targeting both farmers and consumers. Providing information about the nutritional value, climate resilience, and market potential of millets can help create demand and promote their cultivation.

Establishing robust market linkages is crucial for the successful cultivation and commercialization of millets. Farmers need access to reliable markets and fair prices for their produce. Developing partnerships with local food processors, retailers, and institutional buyers can create a sustainable market ecosystem for millets in Uttarakhand.

Climate change and adaptation strategies:

Climate change poses a significant challenge to agriculture, including millet cultivation, in Uttarakhand. Erratic rainfall patterns, increased temperature, and extreme weather events can impact crop growth and yield. Millets, being inherently resilient to water scarcity, are suitable for climate-smart agriculture practices. Promoting climate-resilient millet varieties that can withstand drought, heat, and other climatic stresses is essential. Research and breeding programs focused on developing climate-smart millet varieties can help farmers adapt to changing environmental conditions. Additionally, adopting climate-smart agricultural practices such as conservation agriculture, integrated soil fertility management, water harvesting, and efficient irrigation techniques can enhance the resilience of millet cultivation systems.

Infrastructure and processing facilities:

The lack of adequate infrastructure and processing facilities is a challenge for millet farmers in Uttarakhand. Insufficient storage facilities can result in post-harvest losses, while limited processing units hinder value addition and product diversification. Investment in infrastructure development, including construction of storage facilities, processing units, and milling equipment, can help overcome these challenges. These facilities would enable farmers to store their produce safely, add value to millet grains through processing, and meet the requirements of diverse markets.

Government initiatives and support:

Government initiatives and policy support play a crucial role in promoting millet cultivation in Uttarakhand. Encouraging policies that incentivize millet production, provide subsidies for inputs and machinery, and facilitate market access can boost the confidence of farmers and encourage their participation in millet cultivation.

Furthermore, financial support, capacity-building programs, and research and development initiatives can empower farmers with the necessary knowledge, skills,

and resources to adopt sustainable millet cultivation practices.

By addressing these challenges and leveraging the opportunities, the cultivation of millets in Uttarakhand can be revitalized, leading to improved food security, enhanced farmer livelihoods, and sustainable agricultural systems.

15. Research initiatives and innovations

Research on millet cultivation techniques:

Research institutions and agricultural universities in Uttarakhand have been actively involved in studying and promoting millet cultivation techniques. These research initiatives focus on various aspects, including improved agronomic practices, climate resilience, pest and disease management, and soil fertility enhancement.

Efforts are being made to develop high-yielding millet varieties that are adapted to local agroclimatic conditions. Research institutions collaborate with farmers to conduct on-farm trials, evaluate different millet varieties, and identify the best performing ones in terms of yield, nutritional content, and adaptability.

Furthermore, research is being conducted to explore water-efficient irrigation techniques, nutrient management strategies, and integrated pest and disease management approaches specific to millets. These research initiatives aim to provide evidence-based recommendations to farmers and enhance the productivity and sustainability of millet cultivation.

Value addition and product diversification:

Innovation in value addition and product diversification has the potential to enhance the market value of millets and create new business opportunities. Research initiatives are focused on developing millet-based processed products such as millet flour, flakes, ready-to-cook mixes, snacks, and beverages. These initiatives involve collaboration between research institutions, food processing industries, and entrepreneurs. They aim to develop innovative millet-based products that cater to changing consumer preferences and meet the demand for nutritious and convenient food options. Value addition not only increases the marketability of millets but also opens avenues for income generation and employment opportunities along the value chain.

Climate-Smart agriculture:

Climate change adaptation and mitigation strategies are being integrated into millet cultivation research. Research initiatives explore climate-smart agricultural practices such as conservation agriculture, agroforestry, precision farming, and water management techniques to enhance the resilience of millet cultivation systems. Efforts are being made to identify climate-resilient millet varieties that can withstand extreme weather conditions and maintain stable yields. Participatory research involving farmers is conducted to assess the performance of these varieties under different climatic scenarios and provide feedback for further improvements.

Farmer-Researcher collaborations:

Recognizing the importance of farmer knowledge and experiences, research initiatives are promoting farmer-researcher collaborations and participatory approaches. Farmers are actively involved in on-farm trials, demonstration plots, and knowledge-sharing platforms. These collaborations facilitate the exchange of

traditional and scientific knowledge, enabling researchers to understand local contexts and challenges better. Farmers contribute to research by sharing their practical insights and providing feedback on the effectiveness of various interventions. Such collaborative approaches strengthen the research outcomes and ensure their relevance and applicability in the field.

Conservation and genetic diversity:

Conserving and utilizing the genetic diversity of millets is crucial for their long-term sustainability and resilience. Research initiatives focus on the conservation of landraces and traditional millet varieties, documenting their genetic traits and cultural significance. Efforts are also being made to explore the genetic diversity of millets for traits such as drought tolerance, disease resistance, and nutritional content. These initiatives involve the collection, characterization, and conservation of millet germplasm to preserve valuable genetic resources. By promoting research initiatives and innovations, Uttarakhand can enhance the productivity, profitability, and sustainability of millet cultivation. These initiatives should be complemented by supportive policies, capacity-building programs, and market linkages to create an enabling environment for the successful adoption and promotion of millets in the region.

16. Conclusion and recommendation

In conclusion, millets are a type of crop that contributes to a healthy diet, may offer nutritional security, and helps to keep the environment safe because it requires little to no external inputs and is largely adapted to growing on rainfed and marginal land. Millets are excellent choices for functional foods because they also include fibre and health-promoting phytochemicals that act as immune boosters, antioxidants, etc. but its cultivation has declined due to various reasons. Millet's cultivation needs immediate support from both policy and the market, as well as value addition and promotional effort, in order to stop its future decline. Special attention needs to be given to the creation of healthy meals and their commercialization in order to encourage millets consumption among the urban elite and so reduce the prevalence of lifestyle-related diseases as diabetes, cardiovascular disease, cancer, etc. To provide greater returns as well as better nutrition from rainfed/dryland agriculture, research programmes need to address the key crop production constraints that prevent the achievement of potential yield of enhanced cultivars within farmers' fields. Increasing the availability of millet through the public distribution system and including millet-based items into feeding programmes like the Midday meal and Integrated Child Development Services are two ways to boost consumption of millet. Numerous traditional mountain crops have favourable market characteristics. Amaranths (Ramdana) and buckwheat have potential economic rewards that are more than twice as high as those from HYVs of wheat and paddy. Farmers limited and scattered holdings prevent them from revealing the true profits. The eventual conservation of traditional crops along with economic development may result from the lack of policy protection for small and marginal hill farmers and the exploitation by middlemen in marketing.

17. Strategic action for policy-planning for the sustainable agricultural development in local/regional/national/global levels

Researchers and policymakers have come up with a number of different suggestions on how to preserve crop diversity, in particular with regard to crop types that are either extremely rare and on the verge of extinction, or else are threatened or otherwise endangered in some other way.

Ex-situ and in-situ measures are both being considered as potential solutions. Thus, in-situ conservation (conservation in small pockets) in the area ensures the survival of these variations and crop types. The shift in emphasis towards a smaller number of HYVs and indigenous crop varieties appears to have been driven in large part by the absence of financial incentives for the cultivation of traditional crop varieties.

Millets could be marketed as organic produce and health foods using already existing expertise in order to tap into expanding niche markets. A crucial and effective approach to rekindle interest in and expand the market potential for indigenous crops is value addition. The cultivation of these commodities would resume right away if consumption is brought back to reasonable levels.

Develop decentralized approaches for the mobilization and strengthening of formal and informal decision-making institutional mechanisms.

Redefine research and development (R&D) priorities in agricultural universities/colleges and institutions at all levels (local/Regional/National/Global) with mountain perspectives.

Develop strong linkages between R&D institutions, agricultural universities/NGOs and the private sector.

Improve integration of cross-sectoral linkages and inter-dependences between different policies.

Replicate success stories and identify lessons from failures.

Transfer appropriate agro-technology for the promotion of millets promotion and conservation to user groups.

Awareness creation-Nutrition and health benefits, Branding, labelling and promotion of millets food products and recipes.

Address human resource development issues in agriculture policies.

Properly implement extension and support services systems.

Ensure conservation of traditional agro-biodiversity and associated traditional knowledge.

Improve effectiveness of existing agricultural institutions, their arrangements and capabilities.

Promote organic cultivation, emphasizing millets and traditional mountain crops and value addition, value supply chain.

Data availability statement: Data will be provided by author publicly to readers as many for of the data are collected from the secondary sources.

Conflict of interest: The authors declare no conflict of interest.

References

1. Tilman D, Balzer C, Hill J, et al. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences. 2011; 108(50): 20260-20264. doi: 10.1073/pnas.1116437108
2. Maikhuri RK, Nautiyal MC, Khali MP. Lesser-known crops of food value in Garhwal Himalaya and a strategy to conserve them. 1991.
3. Maikhuri RK, Rao KS, Saxena KG. Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. International Journal of Sustainable Development & World Ecology. 1996; 3(3): 8-31. doi: 10.1080/13504509609469926
4. Maikhuri RK, Senwal RL, Rao KS, et al. Rehabilitation of degraded community lands for sustainable development in Himalaya: a case study in Garhwal Himalaya, India. International Journal of Sustainable Development & World Ecology. 1997; 4(3): 192-203. doi: 10.1080/13504509709469954
5. Hariprasanna K, Gomashe S, Ganapathy KN, Patil JV. Millets for ensuring nutritional security. 2014.
6. Maikhuri RK, Rao KS, Semwal RL. Changing scenario of Himalayan agroecosystems: Loss of agrobiodiversity, an indicator of environmental change in Central Himalaya, India. Environmentalist. 2001; 21(1): 23-39. doi: 10.1023/A:1010638104135
7. Carr TP, Weller CL, Schlegel VL, et al. Grain Sorghum Lipid Extract Reduces Cholesterol Absorption and Plasma Non-HDL Cholesterol Concentration in Hamsters. The Journal of Nutrition. 2005; 135(9): 2236-2240. doi: 10.1093/jn/135.9.2236
8. McKeown NM, Meigs JB, Liu S, et al. Whole-grain intake is favorably associated with metabolic risk factors for type 2 diabetes and cardiovascular disease in the Framingham Offspring Study. The American Journal of Clinical Nutrition. 2002; 76(2): 390-398. doi: 10.1093/ajcn/76.2.390
9. Dayakar Rao B, Bhaskarachary K, Arlene Christina GD, et al. Nutritional and health benefits of millets. ICAR_Indian Institute of Millets Research (IIMR) Rajendranagar, Hyderabad, 2. 2017.
10. Kanade AM, Bhosale RS. Decline in traditional millet farming in tribal trace areas of Ambegaon taluka. Int. Res. J. of Science & Engineering, 2013, 1(2): 69-70.
11. Sundriyal RC, Negi GCS, Maikhuri RK, et al. Family and smallholder farming in Himalayan communities. Deep Roots. 2014; 105-108.
12. Sood S, Gallagher IJ, Lunnon K, et al. A novel multi-tissue RNA diagnostic of healthy ageing relates to cognitive health status. Genome Biology. 2015; 16(1). doi: 10.1186/s13059-015-0750-x
13. Seetharam A. Small millets research: Achievements during 1947-97. The Indian Journal of Agricultural Sciences. 1998; 68(8).
14. MILLET F. Finger millet is believed to have originated in African highlands of Uganda and Ethiopia (Seetharam, 1997) around 3,000 years c and spread to India.
15. Jijau C. Importance and genetic resources of small millets with emphasis on foxtail millet (Setaria italica) in China. In: Seetharam A, Riley KW, Harinarayana G (editors). Small millets in global agriculture, 1st ed. (Delhi, India: Oxford and IBH Publishing Company), 1989; 93-100.
16. Hegde BR, Gowda L. Cropping systems and production technology for small millets in India. In: Proceedings of the first international small millets workshop. Bangalore, India; 1989. pp. 209-236.
17. Gupta A, Mahajan V, Kumar M, et al. Biodiversity in the barnyard millet (Echinochloa frumentacea Link, Poaceae) germplasm in India. Genetic Resources and Crop Evolution. 2009; 56(6): 883-889. doi: 10.1007/s10722-009-9462-y
18. Doggett H. Small millets-a selective overview. New Delhi: Small Millets in Global Agriculture Oxford and Ibh Publishing; 1989. p. 3-17.
19. Sheahan C. Millet Adaptation Trial in Coastal Plain Sandy Loam Following Fall-Seeded Cover Crops in Southern NJ.
20. National Research Council. Lost crops of Africa: volume I: grains. National Academies Press; 1996.
21. Duke RC, Chervenak R, Cohen JJ. Endogenous endonuclease-induced DNA fragmentation: an early event in cell-mediated cytolysis. Proceedings of the National Academy of Sciences. 1983; 80(20): 6361-6365. doi: 10.1073/pnas.80.20.6361
22. Sehgal S, Kawatra A, Singh G. Recent technologies in pearl millet and sorghum processing and food product development. Alternative Uses of Sorghum and Pearl Millet in Asia, 60. 2003.
23. Hadimani NA, Malleshi NG. Studies on milling, physico-chemical properties, nutrient composition and dietary fibre content of millets. Journal of Food Science and Technology (India), 1993; 30(1), 17-20. doi: 10.1016/0144-8617(93)90028-3
24. Singh A, Panda SN. Development and application of an optimization model for the maximization of net agricultural return.

Agricultural Water Management. 2012; 115: 267-275. doi: 10.1016/j.agwat.2012.09.014
25. Millet-Market Share Analysis, Industry Trends & Statistics, Growth Forecasts 2019-2029. Available online: https://www.researchandmarkets.com/reports/4520082/millet-market-growth-trends-covid-19-impact. (accessed on 20 January 2024).
26. Hulse JH, Laing EM, Pearson OE. Sorghum and millets: their composition and nutritive value. Academic Press; 1980.
27. Committee on Diet N, National Research Council. 12 Naturally Occurring Carcinogens. In Diet, Nutrition, and Cancer. National Academies Press (US). 1982.
28. Rand WM, Young VR. Report of a planning conference concerning an international network of food data systems (INFOODS). The American Journal of Clinical Nutrition. 1984; 39(1): 144-151. doi: 10.1093/ajcn/39.1.144
29. Pragya Singh. Finger millet for food and nutritional security. African Journal of Food Science. 2012; 6(4). doi: 10.5897/ajfsx10.010
30. Mbithi-Mwikya S, Van Camp J, Yiru Y, et al. Nutrient and Antinutrient Changes in Finger Millet (Eleusine coracan) During Sprouting. LWT - Food Science and Technology. 2000; 33(1): 9-14. doi: 10.1006/fstl.1999.0605
31. World Health Organization. Protein Quality Evaluation: Report of the Joint FAO/WHO Expert Consultation, Bethesda, Md., USA 4-8 December 1989 (Vol. 51). Food & Agriculture Org; 1991.
32. Monteiro WO, Noshirvani HF, Marks IM, et al. Anorgasmia from Clomipramine in Obsessive-Compulsive Disorder. British Journal of Psychiatry. 1987; 151(1): 107-112. doi: 10.1192/bjp.151.1.107
33. Sudharshana L, Monteiro PV, Ramachandra G. Studies on the proteins of kodo millet (Paspalum scrobiculatum). Journal of the Science of Food and Agriculture. 1988; 42(4): 315-323. doi: 10.1002/jsfa.2740420405
34. Geervani P, Eggum BO. Nutrient composition and protein quality of minor millets. Plant Foods for Human Nutrition. 1989; 39(2): 201-208. doi: 10.1007/bf01091900
35. Usha Antony, Sripriya G, Chandra TS. Effect of Fermentation on the Primary Nutrients in Finger Millet (Eleusine coracana). Journal of Agricultural and Food Chemistry. 1996; 44(9): 2616-2618. doi: 10.1021/jf950787q
36. RAGAEE S, ABDELAAL E, NOAMAN M. Antioxidant activity and nutrient composition of selected cereals for food use. Food Chemistry. 2006; 98(1): 32-38. doi: 10.1016/j.foodchem.2005.04.039
37. Krishnan Y, Simmel FC. Nucleic Acid Based Molecular Devices. Angewandte Chemie International Edition. 2011; 50(14): 3124-3156. doi: 10.1002/anie.200907223
38. Usha Antony, Sripriya G, Chandra TS. Effect of Fermentation on the Primary Nutrients in Finger Millet (Eleusine coracana). Journal of Agricultural and Food Chemistry. 1996; 44(9): 2616-2618. doi: 10.1021/jf950787q
39. Ravindran G. Seed protein of millets: amino acid composition, proteinase inhibitors and in-vitro protein digestibility. Food chemistry. 1992; 44(1): 13-17. doi: 10.1016/0308-8146(92)90251-V
40. Dykes L, Rooney LW. Sorghum and millet phenols and antioxidants. Journal of Cereal Science. 2006; 44(3): 236-251. doi: 10.1016/j.jcs.2006.06.007
41. McDonough CM, Rooney LW, Serna-Saldivar SO. The millets. In Handbook of cereal science and technology, revised and expanded. CRC Press; 2000. pp. 177-201.
42. Obilana AB. Overview: importance of millets in Africa. World (all cultivated millet species). 2003; 38(2): 28.
43. Ricciardi V, Ramankutty N, Mehrabi Z, et al. An open-access dataset of crop production by farm size from agricultural censuses and surveys. Data in Brief. 2018; 19: 1970-1988. doi: 10.1016/j.dib.2018.06.057
44. Sood P, Singh RK, Prasad M. Millets genetic engineering: the progress made and prospects for the future. Plant Cell, Tissue and Organ Culture (PCTOC). 2019; 137(3): 421-439. doi: 10.1007/s11240-019-01587-6
45. Rao KS, Saxena KG. Sustainable Development and Rehabilitation of Degraded Village Lands in Himalaya. Bishen Singh and Mahendrapal Singh, Dehra Dun; 1994.
46. Altieri MA. Traditional farming in Latin America. 1991.
47. Srivastava S, Srivastava SK. Food security and climate change: Role of small millets with special reference to Uttarakhand. The Pharma Innovation Journal. 2022; SP-11(7): 1506-1509.
48. Rao KEP, de Wet JMJ. Small Millets. Biodiversity in Trust. Published online August 28, 1997: 259-272. doi: 10.1017/cbo9780511470851.019
49. Bora JK, Saikia N. Neonatal and under-five mortality rate in Indian districts with reference to Sustainable Development Goal 3: An analysis of the National Family Health Survey of India (NFHS), 2015–2016. Moise IK, ed. PLOS ONE. 2018; 13(7): e0201125. doi: 10.1371/journal.pone.0201125

50. Rawat L, Karnatak AK, Nautiyal BP, et al. Management of shoot fly damage in barnyard millet by seed treatment for higher monetary return in hills of Uttarakhand. J Entomol Zool Stud. 2020; 8(3): 1762-1767.
51. Bhatt BV, Arunachalam A, Kumar D, et al. Millets in the Indian Himalaya. Indian Council of Agricultural Research; 2019.
52. Gaur VS, Kumar L, Gupta S, et al. Identification and characterization of finger millet OPAQUE2 transcription factor gene under different nitrogen inputs for understanding their role during accumulation of prolamin seed storage protein. 3 Biotech. 2018; 8(3). doi: 10.1007/s13205-018-1150-1
53. Kala CP. Status of an indigenous agro-forestry system in changing climate: A case study of the middle Himalayan region of Tehri Garhwal, India. Journal of Forest Science. 2010; 56(8): 373-380. doi: 10.17221/113/2009-jfs
54. Maikhuri R, Nautiyal S, Rao KS, Saxena KG. Role of medicinal plants in the traditional health care system: a case study from Nanda Devi Biosphere Reserve. Current Science. 1998; 152-157.
55. Mal B, Paroda RS, Kochhar S. Underutilized crops and their implications in farming systems in India. Domestication, Production and Utilization of New Crops. International Centre for Underutilized Crops, Southampton, UK, 1997. pp. 30-45.
56. Pandey A, Sharma E, Palni LMS. Influence of bacterial inoculation on maize in upland farming systems of the Sikkim Himalaya. Soil Biology and Biochemistry. 1998; 30(3): 379-384.
57. Sen A. On economic inequality. Oxford University Press; 1997.
58. Chiew FHS, Kamaladasa NN, Malano HM, McMahon TA. Penman-Monteith, FAO-24 reference crop evapotranspiration and class-A pan data in Australia. Agricultural Water Management. 1995; 28(1): 9-21.