Chapter 27
Agrobiodiversity and Advances in the Development of Millets in Changing Environment

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Abstract Selective utilization of crops and their forms of germplasm, of late, have threatened the world's agrobiodiversity. This trend along with forces of expansion of commercial agriculture, market links, unsustainable uses, modification of landscape, and largely changing climate led to the rapid erosion of food sources. These, in turn, affected the nutritional security of people particularly in poverty-driven human societies and those people suffering from "hidden hunger." One such neglected or underutilized group of grain crops is millets. Actually, these are ancient crops but orphaned or forgotten for some obvious reasons. However, they are regaining the fame as "nutritious" or "superfood grains" because of great flavor, taste, nutritional profile, high antioxidants, gluten-free, evidence-based health benefits, vital trace elements, etc. The present author attempts to review the entire realm of development of millets particularly when climate change is putting long strides the world over. Both biotic and abiotic impacts are thought over while evaluating millets in the present all-pervasive examination of problems. This communication helps divulge agrobiodiversity of major and minor millets worldwide in various forms of germplasm. To cope with agrarian crisis, the present researches especially in developing countries elsewhere have been carried out to redeem the situation. Agrobiodiversity of millets generally available and attempts to save and conserve them for human welfare are reviewed to unearth pros and cons of development of millets to date. More efforts in collecting germplasm; conserving, evaluating, and utilizing with value addition; and promoting cultivation, besides awareness about benefits from millet consumption under climate change scenario, are required for sustainable millet farming.

Keywords Agrobiodiversity · Millets · Germplasm · Climate change

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1 Introduction

Agriculture is the major land use across the globe. It is also a major economic, social, and cultural activity. Agrobiodiversity focuses mainly on that portion of the biodiversity that has undergone selection and modification over millennia by human civilization to serve human needs better (Subramanian and Thirumeni 2007). In general, agrobiodiversity refers to the variety and variability of plants or other organisms on Earth that are important to food and all other agricultural production systems along with the management systems and traditional practices used by farmers and farming communities (Rana 2002). Agrobiodiversity has a great role in sustaining and strengthening the food and nutritional security and health of humanity. One side of a coin represents a national emblem, while the other side gives its value. Biodiversity represents the former side of a coin, while the latter side expresses agrobiodiversity, which is most valued for humankind. So, it is very important to improve the crops under ongoing climatic changes (Hasanuzzaman et al. 2013, 2015; Roychowdhury 2014; Roychowdhury and Tah 2013; Roychowdhury et al. 2013a, b, c, 2014, 2018, 2019; Chakraborty et al. 2014; Anumalla et al. 2015).

We are living in an age that is witnessing an unprecedented agrarian crisis. In the modern period, just 150 plant species out of nearly 5000 plant species useful nutritionally are significant to meet our requirement of food. Of these, again just 20–30 plant species are mostly emphasized (Bermejo and Lean 1994). This trend culminated ultimately concentrating only these few crops. Their intensive agriculture resulted in diets containing inadequate nutrient-rich components and genetic erosion. Green evolution also aggravated this trend of neglecting local nutritionally useful resources. Many neglected or underutilized crop species are still surviving in some pockets. These are generally thought to be poor man's diet. One such group of crop species is "millets." They serve the dual purpose of meeting food (nutrition) for humankind and feed or fodder security for domestic animals and birds. Nevertheless, they are often classified as underutilized or orphan crops because of the paucity of scientific attention. They are available even in modern period as landraces, folk varieties, farmers' varieties, local varieties, or wild relatives of cultivated crops. There is a dire necessity to emphasize them from nutritional and conservation point of view. Millets stand sixth in most important grain crops of the world and sustain more than one-third of the world's population (Changmei and Dorothy 2014). A word about taxonomic limits especially about barnyard millets appears necessary. The identities of species complex have remained confused in the past and still need clarifications. I, therefore, have treated them here as they originally appeared in literature published.

2 Millets

Small-seeded edible grains yielded by grasses are collectively called “millets.” These do not constitute a taxonomic entity; however, they project as a functional or agronomic one. Mostly, they are consumed whole, rich in fat, and generally gluten-free. They are being cultivated since ancient times. However, none of the millet species have been able to compete with cereals in world commerce. Because of fast rate of acculturation worldwide and movements like the “Green Revolution,” they have been largely threatened.

2.1 Distribution

In the arid and semiarid tropical regions of Asia and Africa, millets constitute an important source of food for mankind, apart from feed and fodder for domestic animals. These regions generally represent developing nations. Millets are conveniently grouped as major millets, e.g., sorghum and pearl millet, and minor (small) millets, e.g., finger millet, foxtail millet, proso millet, kodo millet, little millet, teff millet, and barnyard millet. This grouping is obviously based on the size of grains and plants. Major millets are tall and drought resistant. Minor millets obviously belong to grasses and have short slender culms and small grains and can survive under severe drought. Their worldwide distribution is under Table 27.1.

2.2 Morphological Characteristics

They are typically annuals attaining maturity within 3–4 months. They range from 30 to 130 cm in height, except pearl millet and sorghum which grow 1.3–3.00 m tall. Florets are born in spikes, racemes, or panicles with dense clusters of small florets. Seeds (called grains) are enclosed usually by hulls, except pearl millet and sorghum seeds which are usually ovoid and white and sometimes otherwise. The agro-morphological characteristics, however, differ from species to species of millets’ w.r.t. plant height, number of tillers, days to flowering, and maturity and grain yield per plant. Morphological or qualitative characteristics include leaf (blade, color, sheath, pubescence), flag leaf (angle, ligules, and auricle shape), culm (culm angle, node color, internode color, and pubescence), panicles (inflorescence) type and their shattering, stigma (number and color), stamen (number and color), grain/seed (shape, grain awning, lemma and palea pubescence, seed coat color, and grain color), and root (type of root system).

Table 27.1 Worldwide distribution of commonly cultivated millets

Sl. No.	Common Name	Scientific Name	Countries/Areas of Cultivation
1	Sorghum	*Sorghum bicolor* (L.) Moench.	Africa, India, Pakistan, USA, Nepal.
2	Pearl millet	*Pennisetum americanum* L.	Africa, India, Pakistan, Arabian Peninsula
3	Finger millet	*Eleusine coracana* (L.) Gaertn.	India, Nepal, China, Myanmar, Sri Lanka, Uganda, Kenya, Eritrea, Sudan, Zambia, Zimbabwe, Malawi, Rwanda, Burundi, Madagascar.
4	Foxtail millet	*Setaria italica* (L.) P. Beauv.	Asia, Europe, North Africa, North America, Australia
5	Proso millet	*Panicum miliaceum* L.	Asia, Africa, Australia, Europe, North America
6	Little millet	*Panicum sumatrense* Roth ex Roem. and Schult.	India, Sri Lanka, Pakistan, Myanmar, China, Malaysia, Caucasus
7	Kodo millet	*Paspalum scrobiculatum* L.	India
8	Teff	*Eragrostis tef* (Zucc.) Trotter	Ethiopia
9	Barnyard millet (Indian+ Japanese)	*Echinochloa crus-galli* (L.) Beauv. and E. Colona (L.) Link.	India, China, Nepal, Japan, Korea

2.3 Agricultural vis-à-vis Agronomic Attributes

Millets are resilient to the extreme climatic and soil conditions prevalent in the semiarid and arid regions of Asia and Africa. They are grown under inadequate moisture and poor soil fertility, which are poorly suited to the major crops of the world (Bermejo and Lean 1994; Baker 2003). Millets also possess a C_4 photosynthesis system (Brutnell et al. 2010; Warner and Edwards 1988). They have prevalent photorespiration and so utilize the scarce moisture present in such regions. In spite agronomic, nutritional and health-related benefits, millets are low yielding in comparison to major cereals such as wheat, rice, etc. Their considerably low productivity is related to the challenging environment under which they are widely cultivated. Millets generally benefit agronomically as they are drought- and heat-tolerant to biotic stresses such as early maturity, antifungal, pest-tolerant, biotic stress-tolerant, and salt-tolerant, and even few millets are rain-fed and survive in marginal lands and environments. Agronomic or quantitative characters include (i) number of days of seedling emergence; (ii) at vegetative stage, days from emergence to panicle (inflorescence) initiation, number of leaves produced on the main culm from planting to panicle initiation, number of tillers produced from planting to panicle initiation, average panicle height, and final plant height; and (iii) at reproductive stage, ripening stage. Apart from these, shoots and roots are considered also for the following features: (a) shoots – number of days from blooming to ripening, fresh weight of aboveground biomass, fresh weight of panicle per plant, number of grains per panicle, dry weight 1000 grains per plant, and number of seeds per 1 gm per plant and (b) roots – root fresh weight, dry root weight, number of roots per plant, average length of roots per plant, and diameter of the biggest root per plant.

3 Status of Germplasm – Diversity of Millets

Diversity of organisms, where plant or animals, is not only expressed by its taxonomic categories like families, genera, or species but also now by its landraces, folk varieties, cultivars, farmers, or local varieties. Some of these are but natural and others released experimentally. All these are glimpsed in the following to know forms of germplasm especially of millets worldwide (Table 27.2).

4 Advances in Development of Millets in the Perspective of Climate Changes

4.1 Sorghum

Tongcheng et al. (2016) investigated potential impacts of climate change on grain sorghum productivity using the CERES-Sorghum model in the Decision Support System for Agrotechnology Transfer 44.S. The model was first calibrated in 1998 for a sorghum cultivar grown in a free-air CO_2 enrichment experiment at the University of Arizona (USA). This model was validated later in 1999. The simulated grain yield, growth, and soil water of sorghum for both years were found in statistical agreement with the corresponding measurement, respectively. The simulated and measured yields both did not respond to elevated CO_2; however, they both were found sensitive to water supply. This validated model was then implemented in western North America during 2080–2100 to simulate possible effects of climate change on sorghum grain yield and water use efficiency. The projected CO_2 fertilizer effect on grain yield was dominated by the adverse effect of projected temperature increases. Temperature, therefore, seems to be a dominant driver of the global climate change having an effect on future sorghum productivity. The CERES-Sorghum model provided a valuable preview of sorghum crop response to potential climate change forcing factors including CO_2, temperature and precipitation. It exhibited its capability to simulate the impact of global climate change on sorghum production.

Gupta et al. (2014) studied the impact of rainfall and temperature in India during the period of 1966–1999. They inferred that higher rainfall means higher yield. Similarly, the higher the average temperature, the lower the yield. These results also, in their opinion, corroborate with agronomic studies. They opined that

Table 27.2 Different types of millets and their number of germplasm, country of collections

Sl. No.	Form and No. of Germplasm	Country/Region	Reference
Sorghum [*Sorghum bicolor* (L.) Moench. (Great Millet)]			
1.	01 Accession	Arunachal Pradesh, India	Pal et al. (2011)
2.	25 Cultivars	Khandesh, Maharashtra, India	Khairnar et al. (2016a, b)
3.	18 Accessions of landraces	Andhra Pradesh, Odisha, India	Elangovan et al. (2017)
4.	36,771 Accessions	Different countries	Upadhyaya et al. (2006)
5.	7366 Germplasm collections	India	Sharma and Brahmi (2006)
6.	15 Accessions	Nepal	Ghimire et al. (2017)
7.	47 Landraces	Zimbabwe	Claid and Ereck (2008)
8.	02 Landraces	India and Nepal	Reghupathy et al. (2016)
9.	57 Varieties released	16 Countries	Dalton and Zereyeus (2013)
10.	25 Local varieties	Khandesh (M.S.) India	Khairnar et al. (2016a, b)
Pearl millet (*Pennisetum americanum* Schum.)			
1.	12 Accessions of landraces	Andhra Pradesh, Odisha, India	Elangovan et al. (2017)
2.	21,563 Accessions	Different countries	Upadhyaya et al. (2006)
3.	3100 Germplasm collections	India	Sharma and Brahmi (2006)
4.	169 Landraces	Rajasthan, India	Yadav (2008)
5.	180 Landraces	India	Khairwal (2007)
6.	225 Accessions (landraces or local varieties)	Sudan	Bashir et al. (2014)
7.	(i) 20,800 Accessions	28 Different countries	Upadhyaya et al. (2007a, b)
	(ii) 750 Wild relatives		
8.	81 Accessions from 78 landraces	28 West and Central African countries	Sattler et al. (2018)
9.	21,594 Accessions including 750 accessions of 24 species of genus *Pennisetum*	51 Countries	Manga (2015)
10.	(i) 22 Cultivars	Different states, India	Chowdari et al. (1998)
	(ii) 36 Landraces		
11.	27 Landraces	Lake Chad Basin	Naino Jika et al. (2017)
Finger millet [*Eleusine coracana* (L.) Gaertn.]			
1.	58 Accessions	Ethiopia	Tesfaye and Mengistu (2017)

(continued)

Table 27.2 (continued)

Sl. No.	Form and No. of Germplasm	Country/Region	Reference
2.	27 Accessions	Arunachal Pradesh, India	Pal et al. (2011)
3.	64 Landraces	Maharashtra, India	Kazi and Auti (2017)
4.	02 Cultivars	Khandesh (M.S.), India	Khairnar et al. (2016a, b)
5.	24 Accession of landraces	Andhra Pradesh, Odisha, India	Elangovan et al. (2017)
6.	5949 Accessions	Different countries	Upadhyaya et al. (2007a, b)
7.	(i) Local variety 01	Kenya	Amos (2016)
	(ii) Local landraces 16		
8.	(i) 850 Accessions	Nepal	Ghimire et al. (2017)
	(ii) 05 Improved varieties		
	(iii) 38 Landraces		
9.	07 Landraces	India and Nepal	Reghupathy et al. (2016)
10.	100 Accessions	Uganda	Owere et al. (2015)
11.	24 Improved varieties	Worldwide	Puranik et al. (2017)
12.	39 Varieties	South Asia	Anonymous (2014)
13.	10 Varieties released	Uganda	Wanyera (2007)
14.	03 Varieties released	Kenya	Oduori and Kanyenii (2007)
15.	282 Landraces	Tanzania	Kisandu et al. (2007)
16.	5949 Accessions	12 Asian and African Countries ICRSSAT, India	Upadhyaya et al. (2007a, b)
17.	37 Landraces	Bhutan	Anonymous (2008)
18.	9522 Accessions	India (NBPGR)	Dwivedi et al. (2012)
19	6804 Accessions	India (ICRISAT)	Dwivedi et al. (2012)
20.	6257 Accessions	India (AICMMP)	Dwivedi et al. (2012)
21.	32,875 Accessions	Kenya (KARI)	Dwivedi et al. (2012)
22.	2156 Accessions	Ethiopia (IBC)	Dwivedi et al. (2012)
23.	1231 Accessions	Uganda (SAARI)	Dwivedi et al. (2012)
24.	1037 Accessions	Lusaka, Zambia	Dwivedi et al. (2012)
25.	869 Accessions	Nepal (CPBBD)	Dwivedi et al. (2012)
26.	702 Accessions	USA (NCGRP)	Dwivedi et al. (2012)
27.	06 Local varieties	(Tamil Nadu) India	Padulosi et al. (2009)
Foxtail millet (Italian or German millet) [*Setaria italica* (L.) P.Beauv] (Syn. *Panicum italicum* L.)			
1.	02 Accessions	Arunachal Pradesh, India	Pal et al. (2011)
2.	01 Cultivars	Khandesh (M.S.), India	Khairnar et al. (2016a, b)

(continued)

Table 27.2 (continued)

Sl. No.	Form and No. of Germplasm	Country/Region	Reference
3.	741 Accessions	Tamil Nadu, India	Nirmalkumari and Vetriventham (2010)
4.	16 Accession of landraces	Andhra Pradesh, Odisha, India	Elangovan et al. (2017)
5.	1535 Accessions	Different countries	Upadhyaya et al. (2006)
6.	55 Accessions	Nepal	Ghimire et al. (2017)
7.	26,000 Accessions (90% of it landraces)	Beijing, China	Doust et al. (2009)
8.	250 Landraces	China	Wang et al. (2012)
9.	223 Accessions	India	Chander et al. (2017)
10.	04 Landraces	India and Nepal	Reghupathy et al. (2016)
11.	27 Landraces	Nepal	Yadav et al. (2018)
12.	324 Landraces	Taiwan	Lin et al. (2012)
13.	348 Improved varieties	Different provinces, China	Jia et al. (2015)
14.	36 Landraces	Bhutan	Anonymous (2008)
15.	26,670 Accessions	China	Wang et al. (2012)
16.	4330 Accessions	India (NBPGR)	Dwivedi et al. (12)
17.	3500 Accessions	France	Dwivedi et al. (12)
18.	2512 Accessions	(Bangalore) India	Dwivedi et al. (12)
19	1000 Accessions	USA	Dwivedi et al. (12)
20.	850 Accessions	France	Dwivedi et al. (12)
21.	712 Accessions	Kenya	Dwivedi et al. (12)
22.	350 Accessions	Mexico	Dwivedi et al. (12)
23.	07 Local varieties	(Tamil Nadu) India	Padulosi et al. (2009)
Proso millet (common millet or Vari) (*Panicum miliaceum* L.)			
1.	01 Cultivar	Khandesh (M.S.), India	Khairnar et al. (2016b)
2.	835 Accessions	Different countries	Upadhyaya et al. (2006)
3.	835 Accessions	Nepal	Ghimire et al. (2017)
4.	(i) 88 Accessions	China	Liu et al. (2016)
	(ii) 56 Cultivated varieties		
	(iii) 32 Landraces		
5.	849 Accessions	India (ICRISAY)	Singh and Upadhyaya (2016)
6.	8778 Accessions	Russian Federation	Habiyaremye et al. (2017)
7.	6517 Accessions	China	Habiyaremye et al. (2017)
8.	5022 Accessions	Ukraine	Habiyaremye et al. (2017)

(continued)

Table 27.2 (continued)

Sl. No.	Form and No. of Germplasm	Country/Region	Reference
9.	1432 Accessions	USA	Habiyaremye et al. (2017)
10.	842 Accessions	India	Habiyaremye et al. (2017)
11.	721 Accessions	Poland	Habiyaremye et al. (2017)
12.	400 Accessions	Mexico	Habiyaremye et al. (2017)
13.	302 Accessions	Japan	Habiyaremye et al. (2017)
14.	8778 Accessions	Russian Federation	Dwivedi et al. (2012)
15.	6517 Accessions	China	Dwivedi et al. (2012)
16.	3976 Accessions	Ukraine	Dwivedi et al. (2012)
17.	1046 Accessions	Ukraine	Dwivedi et al. (2012)
18.	721 Accessions	Poland	Dwivedi et al. (2012)
19	713 Accessions	USA	Dwivedi et al. (2012)
20.	400 Aaccessions	Mexico	Dwivedi et al. (2012)
Little millet (Sawa) (*Panicum sumatrense* Roth ex Roem. and Schult.)			
1.	20 Cultivars	Madhya Pradesh, India	Kumar et al. (2017a, b)
2.	03 Cultivars	Khandesh (M.S.), India	Khairnar et al. (2016a, b)
3.	08 Accessions of landraces	Andhra Pradesh, Odisha, India	Elangovan et al. (2017)
4.	462 Accessions	Different Countries	Upadhyaya et al. (2006)
5.	105 Accessions	Coimbatore, Tamil Nadu, India	Selvi et al. (2014)
6.	07 Landraces	India and Nepal	Reghupathy et al. (2016)
7.	(i) 20 Cultivars (ii) 100 Landraces	Madhya Pradesh, India	Kumar et al. (2017a, b)
8.	15 Varieties	South Asia	Anonymous (2014)
9.	10 Varieties released	India	Kumar (2005)
10.	473 Accessions	India (ICRISAT)	Singh and Upadhyaya (2016)
11.	544 Accessions	India	Dwivedi et al. (2012)
12.	08 Local varieties	(Tamil Nadu) India	Padulosi et al. (2009)
13.	460 Accessions	(ICRISAT) India	Upadhyaya et al. (2014)
14.	109 Accessions	(Tamil Nadu) India	Nirmalkumari et al. (2010)
Kodo millet (Kodra) (*Paspalum scrobiculatum* L.)			

(continued)

Table 27.2 (continued)

Sl. No.	Form and No. of Germplasm	Country/Region	Reference
1.	01 Cultivar	Khandesh (M.S), India	Khairnar et al. (2016a, b)
2.	02 Accessions of landraces	Andhra Pradesh, Odisha, India	Elangovan et al. (2017)
3.	656 Accessions	Different countries	Upadhyaya et al. (2006)
4.	05 Landraces	India and Nepal	Reghupathy et al. (2016)
5.	07 Varieties	South Asia	Anonymous (2014)
6.	665 Accessions	India (SCRIBT)	Singh and Upadhyaya (2016)
7.	2170 Accessions	India (Delhi)	Dwivedi et al. (2012)
8.	1111 Accessions	India (Banglore)	Dwivedi et al. (2012)
9.	656 Accessions	India (Patancheru)	Upadhyaya et al. (2014)
10.	01 Local variety	India (Tamil Nadu)	Padulosi et al. (2009)
Teff [*Eragrostis tef* (Zucc.) Trotter]			
1.	3842 Accessions	(PGRC/E) Ethiopia	Seyfu (1997)
2.	35 Cultivars	Ethiopia	Ebba (1975)
3.	60 Genotypes	Ethiopia	Abraha (2016)
4.	36 Genotypes	Ethiopia	Jefar (2015)
5.	15 Genotypes (10 accessions + 5 varieties)	Ethiopia	Asfaw and Danno (2011)
6.	10 Varieties	Ethiopia	Abate et al. (2013)
7.	42 Varieties	Ethiopia	Marga (2018)
8.	10 Genotypes	Ethiopia	Worku et al. (2018)
Indian barnyard millet (*Echinochloa frumentacea* Link.) [Syn. *Echinochloa colona* var. *frumentacea* (Link.) Ridl.]			
1.	01 Cultivar	Khandesh (M.S.), India	Khairnar et al. (2016a, b)
2.	743 Accessions	Different Countries	Upadhyaya et al. (2006)
3.	02 Accessions	Nepal	Ghimire et al. (2017)
4.	05 Landraces	India and Nepal	Reghupathy et al. (2016)
5.	11 Variety	South Asia	Anonymous (2014)
Japanese barnyard millet (*Echinochloa utilis* Ohwi *et* Yabuno) [Syn. *E. esculenta* (A. Braun) H.Scholz.]			
1.	120 Cultivars	Japan	Yabuno (1987)
2.	01 Accession	Florida, USA	Dvorakova et al. (2015)
3.	02 Varieties	Japan	Anonymous (2005)
Barnyard millet [*Echinochloa colona* (L.) Link.]			
1.	65 Accessions	ICRISAT, India	Wallace (2015)

(continued)

Table 27.2 (continued)

Sl. No.	Form and No. of Germplasm	Country/Region	Reference
Barnyard millet [*Echinochloa crus-galli* (L.) Beauv.]			
1.	30 Accessions	ICRISAT, India	Wallace (2015)

sorghum is better adapted to dry and cool conditions. Irrigation has a positive and significant effect on yield.

Olatoye et al. (2018) investigated signatures of clonal adaptation in sorghum to the precipitation gradient in West Africa using a panel (n = 607) of sorghum accessions from diverse agroclimatic zones of Nigeria. They observed significant correlations between common garden phenotypes of three putative climate-adaptive traits (flowering time, plant height, and panicle length) and climatic variables. They characterized the panel at >400,000 single-nucleotide polymorphisms (SNPs) using genotyping by sequencing (GBS). Redundancy analysis indicated that a small of SNP variation can be explained by climate (1%), space (1%), and climate collinear with space (3%). Discriminant analysis of principal component identified three genetic groups that are distributed differently along the precipitation gradient. Genome-wise association studies were conducted with phenotype and three climatic variables of overall enrichment of associations near a priori candidate genes implicated in flowering time, height, and inflorescence architecture in cereals, but several significant associations were found near a priori candidates including photoperiodic flowering regulators SbCN12 and Ma6. These findings together suggested that a small (3%) but significant proportion of nucleotide variation in Nigerian sorghum landraces reflects clinal adaptation along the West African precipitation gradient. Maccarthy and Vlek (2012) evaluated the potential impact of climate change on sorghum grain yield under different crop residue and nutrient management system in a small holder farming system. They used Agricultural Production System Simulator (APSIM) in this scenario analysis. They employed two crop residue management types (crop residue retention in soil and crop residue removal) and fertilizer management (no fertilization and application of 41.30 kg ha^{-1}). The impact of crop residue management on grain yield was lower under climate change weather conditions. This can be attributed, in their opinion, to higher soil moisture stress, which also contributed to lower rate of soil carbon decomposition in the topsoil. They noted instability (interannual standard deviation) in grain yield, which was higher under climate change (0.13–0.21) weather conditions than under historical (0.04–0.11) weather conditions. This was reflected in a higher change in yield and thereby rendering sorghum production under rain-fed agriculture riskier.

Dossou-Aminon et al. (2014) examined farmers' perceptions and adaptation strategies to mitigate impact of climate change on sorghum production and diversity in Northeastern Benin. They interviewed 300 sorghum farmers from 15 villages. They found that farmers in these villages were able to recognize that temperatures were increased and several fluctuations were observed in the rainfall pattern. Perceptions of farmers about climate scenarios involved low productivity, soil poverty, increase in damage by insects, and sorghum varietal diversity loss. Sorghum farmers developed strategies to face these impacts due to climate change such as (i) sowing of drought-resistant varieties, (ii) utilization of fertilizers, (iii) resowing, and (iv) rotation and/association of sorghum production with leguminous crops. These authors, therefore, also made suggestions like organization of information campaigns and institutional strengthening including farmers, agricultural extension agencies, NGOs, decision-makers, and public investment programs. They further called attention of breeders and policy-makers to create an enabling environment to lend support to farmers' adaptation to climate change.

4.2 Pearl Millet

A fair realization of the impacts of climate on crop productivity is a fundamental requirement to enhance climate resilience in crop varieties through breeding or for adapting current varieties more resilient to climate-induced stress through management options employing different strategies to respond the contrary impacts of climate change on crop economic part.

Pearl millet is stiff, climate-smart grain crop, idyllic for environments prone to stresses (drought and heat). It is a water-saving, drought-tolerant, and climate change-compliant crop. It germinates well under optimum temperature (25–30 °C) but can be also planted under cool soil conditions, before the soil temperature reaches 23 °C. Tillering from primary tillers at all stages of apical development is every 40–45 °C days. The optimal rainfall prerequisite of pearl millet differs between 300 and 350 mm and can be also cultivated in low annual rainfall receiving (<300 mm) areas. Due to deep root penetration, pearl millet performs reasonably in unpredicted weather conditions. It quickly reacts to good production options such as planting time, planting density, inter-/intra-row spacing, nitrogen application, and irrigation, besides high growth rate, large leaf area index, and high radiation use efficiency (Ullah et al. 2016). Ullah et al. (2016) adapted and dilated various strategies in respect of climate change such as (i) improving resource use efficiency (e.g., water use efficiency, nitrogen use efficiency, radiation use efficiency), (ii) production options under changing climate (e.g., adjusting planting time intra-row species), (iii) crop modeling to avoid wasting time as a strategy for further implementation in the fields, and (iv) briefing farmers/cultivars regarding fundamentals of climate information inclusive of all possible mitigation and adaptation strategies.

Singh et al. (2017) used the modified CSM-CERES-Pearl Millet model to evaluate the genetic traits of pearl millet for adaptation to climate change at selected sites in India and West Africa. In higher rainfall environments of Aurangabad and Bijapur, the potential yield gains with the 10% longer maturity cultivar are observed to the extent of 47% as compared to the baseline cultivar (Sharda) under current climate and climate change by midcentury. Although the yields increased with 10% longer maturity at other sites, viz., Hisar, Jaipur, Jodhpur, and Bikaner, they were nonsignificant statistically in both present and future climates. In their opinion, the baseline cultivar life cycle duration (ICMK-356) remained the highest yielding at the four locations under both climate regimes, possibly due to better fit to the rainfall patterns of those sites, which minimized the benefit of the longer maturity types. Likewise, at Sadore and Cinzana (West Africa) under base climate, the yields were higher for the baseline cultivar (CIVT) as compared to type yields with the 10% shorter or longer maturity cultivar. The baseline cultivar went the highest yield at Sadore under climate change. However, at Cinzana, a 4% increase in yield was simulated with a 10% longer maturity cultivar, which was, in their opinion, statistically nonsignificant. They reached to a conclusion that the cultivars that are of longer maturity in current climate will generally be more suitable as the warmer climate typically shortens the life cycle and longer maturity cultivars will compensate for these conditions and produce higher yields than the default baseline cultivars. They further stated that identification of a proper cultivar according to the length of growing period is the best way to tackle climate change impacts because sufficient genetic diversity exists in pearl millet maturity groups. This would minimize drought and heat stress during the crop life cycle, and the available seasonal resources would be fully utilized. This investigation will help the breeders to assess new promising traits of pearl millet for adapting to climate change.

Renolds et al. (2016) discussed a need for an integrated and coordinate approach worldwide to maintain productivity under climate change. They focused sorghum and pearl millet in both millets, besides other cereals. In their opinion, the global condition of agricultural research will greatly improve ability to develop crops and cropping systems which will be more resilient in the face of climate change. They proposed a better-coordinating and fairly standardized way to crop research in domains such as (i) characterization of target agroecosystems, (ii) standardized experimental environments, (iii) phenotyping platform, and (iv) comparative biology. This approach will boost, according to them, the cost-effectiveness and facilitate genetic gains of these crops.

Haussmann (2012) experimented for breeding strategies for adaption of pearl millet to climatic variability and changes in West Africa. They proposed a wide range of crop improvement options for enhancing adaptation to climate variability. These include the choice of type of cultivar (degree of heterozygosity and heterogeneity); direct selection in multiple environments, including farmer participatory testing; indirect selection for individual adaptation traits using conventional or genomic selection methods; a dynamic gene pool management approach; and selection for responsiveness or compatibility to improved crop and soil management techniques. Seed systems, in their opinion, need to be strengthened so that they effectively provide access to new varieties and a diverse range of varieties that respond to farmer's current and evolving needs, including adaptation to variable and changing climatic conditions. They made observations on traits such as photoperiod sensitivity, plastic tillering, very early maturity, and flooding tolerance.

Gupta et al. (2014) studied the impact of climate change, especially the effects of rainfall and temperature, on pearl millet in India during 1966–1999. They concluded that the greater the rainfall, the higher the yield. Irrigation has a positive and considerable effect on the yield. They noted, however, that the average temperature is highly insignificant. The sign, in their opinion, is positive, suggesting the possible hardiness of pearl millet to increasing temperatures. They further stated that these results corroborate with agronomic researches which indicate that the pearl millet is resistant to drought and it is also thought more efficient in the utilization of soil moisture. It shows a higher degree of heat tolerance than sorghum.

Johannes (2015) observed trends of pearl millet yields under climate variability conditions in the Oshana region of Namibia. Climate change impacts have been felt in Namibia over the past years. It was noted that in 2009–2011, pearl millet yields were significantly reduced due to severe floods. The rainfall data showed a change in rainfall intensity with shorter rainfall seasons and late arrival on the rainfall. Pearl millet is a rain-fed, dry crop type and does not grow well in waterlogged soils, contributing the low yields under flood conditions. The author suggested farmers to start sowing on the every 25 December every season. He also advised farmers to make use, at least, of both pearl millet available cultivars through intercropping, one with long duration to reach maturity and the other one with short duration to reach maturity depending on the climate situation. He further suggested having alternative crop varieties like cassava and rice as a possible solution to climate change adaptation. This alternative, in his opinion, will enhance diversification of pearl millet cultivars within a crop field to adapt to climate scenarios. A method of variety types of pearl millet cultivars with high degrees of heterozygosity and genetic heterogeneity for adaptation traits will help to achieve better individual and population buffering capacity in pearl millet. He opined that crop improvement exclusively cannot produce miracles. Therefore, the development of new improved and climate-proof cultivars must go simultaneously with sustainable soil fertility management and water conservation and drainage techniques.

4.3 Finger Millet

Onyango (2016) highlighted the positive attributes of finger millet based on agricultural research and development reports in Kenya, especially when the frequency and increased intensity of extreme climatic events have become additional challenges for global agriculture. The author pointed out a need for focusing on sound nutritional and medicinal values of finger millet to the residents since consumption patterns of finger millet are very specific and continue to remain region-specific. Their population in the broader range is essential. He further emphasized to prepare ready-to-use or ready-to-cook products, which would help in increasing its consumption among non-millet consumers and address the problem of food insecurity. He clearly earmarked four broad areas of adaptation of crop production systems as climate change: (i) new crop introduction and phasing out of previous ones, (ii) development of new varieties of existing crops, (iii) evolution of crop management practices, and (iv) dealing with climate uncertainty through the provision of information. These adaptions, in his opinion, will involve many trade-offs and possibly some synergies at different scales, requiring decisions to be made. He specifically emphasized a need for characterization of finger millet varieties to support farmers' decision-making.

Shibario et al. (2016) carried out an investigation on finger millet production in lower eastern Kenya in view of constraints and climate change. Eastern Kenya is characterized by aridity and semiaridity region. Because of drought-resistant nature, high nutritional content, and the ability to produce with few inputs, availability of finger millet is one of the crops to combat food insecurity. These authors used Logit model to determine the effect of education, land size, age, and gender on finger millet production. The imports revealed constraints like lack of seeds, pests and diseases, overdependence on maize, and climate change. The author saw potential for production in aspects of climate change, extension services, nutritional content, and marketability. In their opinion, education and land size had a positive effect on finger millet production, while gender had a negative effect. Based on the Logit model results, extension service providers should lay emphasis on farmer's age, education, land size, and gender when deciphering a target group for finger millet dissemination. Respondents thought finger millet to have a lot of potential in dealing with effects of climate change due to its drought-resistant nature and ability to provide good yield with low rainfall.

Masood and Azam Ali (2007) grew two landraces of finger millet, viz., TZA-01 and T2M-01, in glasshouses under two moisture regimes (fully irrigated and after a drought) to investigate the effects of environmental stress on the growth, SPAD measurement, radiation use efficiency, and yield. They imposed the drought treatment at 28 DAS beyond what was applied to the drought treatment. Growth and development were monitored between 21 DAS and 105 DAS. They showed a clear subjection of the two finger millet landraces to a progressively severe treatment of soil moisture stress. They recorded reduction in the growth and development of both the landraces in this study between 35 DAS and 105 DAS. The similarity in the moisture content at the time of imposing drought treatment (i.e., at 28 DAS) indicated the uniformity of the condition in the glasshouses with respect to the soil moisture content. These authors reached to a conclusion that drought has a significant influence on the vegetative and reproductive growth of finger millet. Besides the water use, other parameters were dependent on soil moisture content. This knowledge will be, in their opinion, useful to strengthen the research activities.

4.4 Foxtail Millet

Ning Na et al. (2017) studied correlation between grain quality of foxtail millet and environmental factors. Variations in climate and ecological resource lead to variations in grain quality. Quantification of effects of environmental conditions is critical for the large-scale promotion of high quality. These authors analyzed the said correlations during the growing season (May to September) using multivariate statistical analysis under different ecological/climate conditions at five locations in China. They inferred that the difference in grain quality across different locations was mainly affected by altitude, followed by precipitation, diurnal temperature range, latitude, sunshine hours, and ≥20 °C accumulated temperature. The precipitation of July and diurnal temperature range of July to September had the greatest effect on grain quality. Precipitation and ≥20 °C accumulated temperature showed a significant negative effect. Thus, the effect of environmental factors on grain quality of foxtail millet is the result of a combination of factors. According to these authors, the regression equation proposed in this study can be used to predict and forecast grain quality of foxtail millet.

Yang et al. (2016) investigated water use efficiency (WUE) of foxtail millet in relation to climate charge in China, particularly in arid and semiarid northwest regions. They examined the impact of climate change on WUE and considered yield, soil water content, rainfall, and temperature data at three experimental sites between 1978 and 2007 at Pingliang, Yulin, and Huhebot. The accumulated temperature increased by 502, 541, and 857 °C, respectively, at these sites. These temperatures have a significant climate-warming trend during the period of study. Temperature warming and decreasing precipitation, according to these authors, caused severe droughts in the said region. These resulted in high WUE to adapt arid environment during the said period. Strategies such as improving crop distribution, increasing plant areas of foxtail millet with high WUE, and the adoption of drought-resistant farming techniques are advised by the authors to mitigate the influences of global warming on crop production, especially in arid and semiarid regions.

4.5 Proso Millet

Zhang et al. (2012) studied leaf senescence and antioxidant enzymes in three cultivars of proso millet (*Panicum miliaceum* L.) after anthesis. They investigated the changes in chlorophyll content, antioxidant enzymes (SOD, CAT, POD), MAD, and superoxide anion during seed filling to maturity with the primary goal of using these indices in the selection of drought-resistant varieties. The cultivar ‘Ningmi 13’ was noted for slower degradation ratio of chlorophyll content, higher activity of SOD and CAT, lesser POD, and smaller accumulation of MDA and superoxide anion, resulting to delayed leaf senescence and prolonged leaf functional period. The longer functional leaf period and higher SOD activities can be, therefore, used as indices for selection of drought-tolerant genotypes (cf. Dai et al. 2011).

Lin et al. (2006b) used a forward subtracted cDNA library constructed from normally watered leaves and leaves dehydrated after drought to investigate the genes induced by drought in *Panicum miliaceum* (proso millet). They employed a suppressive subtraction hybridization technique to construct the cDNA library and 60 positive clones identified and sequenced. Out of a total of 60 sequences, only 32 EST were observed highly homologous to known plant sequences manifested in a response to abiotic or biotic stress. Furthermore, 28 ESTs are homologous to known proteins involved in signal transduction, transcription, and protein processing. AFLP markers were generated from this cDNA library (Lin et al. 2006a) to analyze genes differentially expressed in seedlings watered normally, those subjected to drought, and seedlings rehydrated after drought. Twelve fragments were amplified from the leaf samples under drought and rehydration regimes. Using the same cDNA library, Lin et al. (2008) carried their study further. Their results showed that its expression declined under drought, increased after rehydration, and then settled to normal levels 6 h after rehydration. Thus proso millet utilizes moisture efficiently.

Nielsen and Vigil (2017) collected proso millet water use data and yield data from 1995 to 2016 as a part of ongoing long-term alternative crop rotation experiment conducted at the USDA-ARS Central Great Plains Research Station under dry land conditions. The objectives of this experiment were to determine the water-limited yield relationship for proso millet and to identify environmental factors that cause yields to be lower than predicted by the water-limited yield relationship. They used stepwise linear regression analysis to determine important environmental factors influencing yield. The water-limited yield relationship had a slope on growing season water use, plant-available soil water at planting, precipitation received from 12 to 18 August, number of days in July and August with maximum temperature greater than 36 °C, daily average wind run, and maximum wind gust during the week before swathing explained 88% of yield variability. The regression parameters suggested that plant breeding efforts should be directed toward improving shattering resistance and heat tolerance and that cropping systems management should be directed toward crop sequencing and no-till production methods. This improves precipitation storage efficiency during the non-crop period prior to millet planting and increases available soil water at millet planting.

4.6 Little Millet

Matsuura et al. (2012) using PBC tubes filled with sandy soil investigated the effect of moisture before and after flowering in little millet. A significant yield reduction was recorded, as compared to the well-watered plants, when the drought treatment was implemented at early developmental stage, i.e., before flowering. Terminal drought condition occurring from the flowering stage to the harvesting phase of little millet contributed to a significant yield loss.

4.7 Kodo Millet

Kumar et al. (2017c) carried out experimental analysis, looking for climate-resilient potential, among 43 advanced breeding lines of kodo millet (*Paspalum scrobiculatum*) to interpret the stress tolerance mechanism and homogenize crop improvement parameters of widespread economic domestication of the hilltop. They observed maximum canopy length in genotype BK31 (74 cm) followed by BK6 (73 cm), BK48 (68 cm), BK2, and BK23 (64 cm each). They noted 50% flowering by 64–75

DAS. In contrast, very early blooming genotype (PCGK18, 50 DAS; PGCK 8 and 19, 50 DAS; PGCK 13, 59 DAS) exhibited comparative lower yield owing to exceedingly short vegetative phase. Among early maturing accessions, viz., PGCK 18 (81 DAS); PGCK 8, PCK 16, and BK60 (94 DAS); and others in similar category suffered from yield penalty. Hence, genotypes should be bread for 100–105 DAS to optimize yield potential. They concluded that optimal vegetative growth is essential for grain yield physiology and yield increases in accordance with total biomass following normal distributional curve. Genotype BK 48 with 70.50 cm plant height turned to reproductive phase by 76 DAS, accomplished crop cycle by 111 DAS, and produced significantly higher biomass and maximum yield. The plant vegetative organs, during primary development phase, are well protected by vegetative tissues, and unless the stress is semilethal or lethal, the reproductive cells and or structures respond to unfavorable conditions indirectly, as mediated by the vegetative plant organs. The author concluded that the success of reproduction as well as the realization of yield potential of a given genotype, however, are dependent not only on the stress sensitivity of the reproductive and grain-filling stages but on overall plant growth and development. They further opined that resourceful photosynthesis system and stem reserve accumulation throughout the vegetative development segment have a definite function in the formation of reproductive organs and thus may directly affect final yield.

4.8 Teff

The production areas of teff range from the cool highlands to the dry lowlands that are generally associated with moisture deficit during critical stages of plant development. Studies are conducted to investigate the effect of moisture deficit on the performance of teff plants (Degu et al. 2008; Mengistu 2009; Ginhot and Farrant 2011). These studies showed that there is genetic variability among the genotypes investigated suggesting that the teff gene pool harbors moisture stress-tolerant genotypes that could be examined through efficient tools such as molecular markers.

Teff is also investigated for the anticipated changes in the climate and expansion of farmlands in the rift valley areas. Asfaw and Dano (2011) showed presence of broad intraspecific variability among the ten teff accessions studied for salinity tolerance. One accession also showed presence of genetic variability for tolerance to soil acidity and aluminum toxicity in selected genotypes (Abate et al. 2013).

Lodging is the major constraint to yield increases in teff. It is so weak in nature and cannot endure several internal and external factors like wind and rains. Recently, several semidwarf and lodging-tolerant candidate lines have been developed (Marga 2018; Worku et al. 2018). Zhu et al. (2012) also experimented on a similar line and succeeded to improve yield by semidwarfing mutants. Jost et al. (2015) also stated that productivity in teff is extremely low mainly due to susceptibility to lodging. This feature, viz., lodging in his opinion, is aggravated by wind, rain, or application of nitrogen fertilizer. These anthers, therefore, developed semidwarf lodging-tolerant teff line, called “Kegne.”

Salinization of soil is a major factor to limit crop production particularly in arid and semiarid regions of the world. Teff is cultivated in such areas. Salt stress is known to perturb a multitude of physiological processes. It exerts its undesirable effects through inhabitation and ionic toxicity (Norean and Ashraf 2008; Munns et al. 2006). Increased salinity causes a significant reduction in germination percentage, germination rate, and root and shoot length vis-à-vis weight (Jamil et al. 2006). To deal with this problem, in case of teff, Asfaw and Dann screened 15 lowland teff genotypes. They divulged the presence of broad intraspecific genetic variation in teff accessions and varieties for salt tolerance.

Araya (2015) assessed impacts of climate change on teff (*Eragrostis tef*) productivity in Debre Zeit area of Ethiopia in three different periods using different models and pathway. They recorded median yields which increased and decreased by up to 10% and 38% for early and late sowing, respectively. Increase in yield was observed mainly due to early sowing and efficient use of rainwater over the growing period, relatively conductive early seedling establishment and better synchronization of the crop growing cycle with the rainy period. On the contrary, they noted late sowing resulting in significant yield reduction because of poor synchronization of the rainy period with the growing cycle of the crop, especially exposure to the long dry period after the reproductive phase. They concluded that rainfall distribution and amount have the greatest impact on teff yield under future time, and, therefore, early sowing can be on adaptive strategy for teff under future climate.

Felix (2018) investigated the impact of climate change on teff production in southeast Tigray (Ethiopia). He employed farm characteristics and socioeconomical settings in a low-income developing country. He used the Ricardian model to evaluate data gained. Out of 14 predictor variables fitted in the model, 6 variables, viz., climate factors, adaptation strategies, production factors, weather and climate information, socioeconomic factors, and agroecology, were found to have significant influence on net revenues. Increase or decrease in temperatures affects teff revenues. Thus, climate factors and adaptation to climate change seem, according to the author, to be strong determinants in influencing teff revenues.

Scientist evaluated climate change impacts on crop productivity of teff using the Geographic Information Systems (GIS). They estimated the effects of altered environments on teff’s productivity. They recorded a nonlinear relationship between suitability indices, the output of spatial analysis, and teff yield data collected from varied ecological zones. They also conducted a socioeconomic survey to understand the agricultural activities in the study area. Their results indicated that crop yield varied significantly as a function of climatic variation, and the model is applicable at different levels into consideration of spatial variability of climate.

4.9 Barnyard Millet

Trivedi et al. (2017) assessed barnyard millet (*Echinochloa frumentacea*) diversity in the central Himalayan region for environmental stress tolerance. They noted significant variability in days to 50% flowering, days to 80% maturity, and 1000 seed weight and yield potential of the germplasm. These traits are considered crucial for tailoring new varieties for different agroclimatic conditions. Variations in biochemical traits such as lipid peroxidation, nmol malondialdehyde formed, total glutathione, and total ascorbate content indicated the potential of collected germplasm for abiotic stress tolerance. They identified trait-specific populations that could be useful in crop improvement programs and climate-resilient agriculture.

5 Efforts Dealt with Climate Change and Millets: General Considerations

In semiarid and arid environments where millets are the dominant crops, drought or inadequate moisture is the major abiotic stress affecting productivity. Ajitkumar and Pannerselvam (2014), in the case of pearl millet, showed that drought impacts include growth, yield, membrane integrity, pigment, osmatic adjustment, water relations, and photosynthetic activity. Drought is also usually manifestation of a shortage or absence of rainfall causing drought a loss in rain-fed agriculture. For example, the decline in the level of rainfall during severe drought years in Ethiopia was accompanied by serious reductions in rain-fed agricultural outputs.

Matssura et al. (2012) earmarked the effects of moisture deficit before and after flowering on four millets, viz., proso millet, little millet, foxtail millet, and wild millet [*Setaria glauca* (L.) Beauv.]. Compared to the well-watered plants, a considerable yield decrease was obtained in all of them when the drought treatment was implemented at the early developmental stage before flowering. Nevertheless, terminal drought, which occurs from the flowering stage to the harvesting of the crop, culminated into a considerable yield loss only in proso and little millets, while the effect on foxtail and wild millets was negligible.

The annual rainfall in Niger is about 200 mm. Winkel et al. (1997) investigated the impact of water deficit at three stages of pearl millet development. These three stages were (i) prior to flowering, (ii) at flowering, and (iii) at the end of flowering. The authors concluded that the grain yield of pearl millet was severely reduced when moisture was limited prior to and at the flowering stage but not at the end of flowering. Terminal drought in which irrigation was terminated from the flowering until crop maturity was severe. It resulted in 60% yield loss (Bidinger et al. 1987).

Drought is defined as a temporary reduction in moisture availability in which the amount of available water is significantly below normal for a specified period. Drought can be meteorological, hydrological, or agricultural. Agricultural drought occurs when there is not enough soil moisture to meet the needs of a particular crop at a particular time. The plants or crops have to cope with drought using strategies, viz., drought escape, drought avoidance and drought tolerance, or even drought recovery. Traits associated with drought escape are rapid growth, early flowering, high leaf nitrogen level, and high photosynthetic capacity (Kooyers 2015). Pearl millet matches its phenology to the mean distribution of the rainfall where precipitation in limited and erratic (Sivakumar 1992). The development of main panicle, in case of pearl millet, coincides with an increasing period of rain and thus reduces the risks associated with drought occurring prior to or at the beginning of flowering. Drought avoidance mechanisms generally reduce water loss through transpiration or maintain water uptake during drought period (Fang and Xiong 2015; Kooyers 2015). Traits associated with drought tolerance are increased osmoprotectants and osmotic adjustment (Blum 2005; Kooyers 2015). Desiccation-tolerant or resurrection plants, e.g., wild *Eragrostis nindensis*, stabilize their cells or membranes at desiccated stage (Vander Wilingen et al. 2004).

Initiating to promote millet production is one way to conserve germplasm and to utilize their full potential. For example, the Government of India launched some programs to promote millet farming: (i) Initiative for Nutritional Security through Intensive Millet Promotion (INSIMP) as a part of Rashtriya Krishi Vikas Yojana (RKVY) and (ii) Rainfed Area Development Programme (RADP) as a part of RKVY. Some Indian state governments also aid in improving both production and consumption of millets, for example, (i) state of Kerala, its Agriculture Department implemented mega millet cultivation drive in the backward region with active involvement of the local community; (ii) state of Odisha, took measures to improveme a millet mission in 2016 to fillip farming of millets and also provided market linkage to millet farmers; (iii) state of Maharashtra, announced subsidies for millet; and (iv) state of Karnataka, selling of finger millet in the south India and sorghum in north India through networks (Behera 2017).

Millets exhibit several morphological, molecular, biochemical, and physiological attributes. These confer better tolerance to environmental stresses than other crops such as cereals. First, the short life cycle of millets helps in escaping from stress since they need only 12–14 weeks to complete their seed-to-seed life cycle. Nevertheless, the prevalence of stress conditions and their impacts are overcome by some traits, e.g., small leaf areas, short stature, thicker cell walls, and the capability to form dense root system (Li and Brutnell 2011). Millets have enhanced photosynthetic rates at worm conditions and confer immediate water use efficiency and nitrogen use efficiency (Li and Brutnell 2011). Also, increase in biochemical activities, e.g., enhanced levels of antioxidants, reactive oxygen species and their scavenging enzymes, activities by catalase and superoxide, and synthesis of osmolytes and other stress-related proteins, is known in response to the abiotic stresses in case of foxtail millet (Lata et al. 2011), little millet (Ajithkumar and Pannerselvam 2014), and teff (Smirnoff and Colombe 1988).

The use of molecular biomarkers, sequence information, creation of mapping populations, and mutants has led to the development and release of high-yielding varieties of millets (Joel et al. 2005; Brink 2006). Newly developed hybrids are resistant to diseases and have increased per hectare production as compared to their parent varieties (Joel et al. 2005; ICAR 2017). Millets have vast natural diversity (Tables 27.1 and 27.2), and the release of new hybrids increases this variation by multifold.

The production of edible millets was limited in the past due to lack of suitable machinery and traditional methods like pounding, winnowing, etc. used for the decortication of millet grains. These methods were labor-intensive. Recently, millet-specific threshers, decorticators, and polishers have been fabricated or designed. These have eased the postharvest operations of millets. These paved the way of utilization of millets in the developments of food and products and to check loss of millet production because of climate change and thereby benefit the millet farmers.

6 Miscellaneous Constraints

Various socioeconomics have restricted uses of millet consumption and hence contributed to a loss of a cultivated diversity: (i) millets typically labor-intensive, manual postharvest processing, grain threshing and milling (Rengalakshmi 2005), (ii) low yield as a result of the lack of scientific attention (Plaza-Wuthrick and Tadele 2012), (iii) family farm-level diversity heavily affected by community access to seed which again limited by current rural seed system (Nagarajan et al. 2007), (iv) agricultural policies in different nations having negative impact on cultivation of and research of small millets, and (v) displacement of production partially or completely in many areas by mainstream cereals.

7 Remedial Measures

A target of 70% more food production by 2050 has been set by the World Summit on Food Security (Tester and Langridge 2010). Additional difficulties will be caused by climate change as many regions are becoming drier. The small millets have the potential to meet these challenges because of (i) their drought tolerance and ability to grow under low-input conditions and (ii) health-promoting traits valued by mankind. Our priority, therefore, should be

(I) Exploitation of diversity within seed banks: The small millets possess considerable morphological and genetic sequence variation, which can be used by the breeders to generate improved varieties. The seed bank infrastructure and associated reporting in the scientific literature and in online databases should be more accessible for breeders. Improved funding, coordination, communication, and sharing of genetic resources are necessary to face various problems.

(II) Genes from wild relatives: The wild relations of small millets can serve as donors of useful genes for crop improvement. The wild germplasm generally does not find place in gene/seed/germplasm banks. Only traditional ones are favored. They are also treated as weeds or avoided being invasively mature in some cases.

(III) Weightage for traditional knowledge: Small millets are usually cultivated in remote regions of the world. Diversity is rich in these inaccessible pockets in the hands of some ethnic or aboriginal communities. These human societies have also their own system of classification of landraces or cultivars. Their wisdom can be profitably used using modern technology and made accessible for the world community at large.
(IV) Molecular and genetic knowledge: Several small millets are still lacking molecular and genetic markers, and linkage maps are available for breeders for the crop improvement programs. Sequencing of genome is again a rarity for this group of crop species.
(V) Molecular mechanism: Millet diversity has largely remained untapped at the level of molecular mechanism. Study on this line is very limited. An understanding of the molecular mechanisms underlying various traits can lead to agronomic improvement. A special drive is a need of hour on this line.
(VI) Dominance of few crops: Modern agriculture is dominated by few crop species which has obviously marginalized some indigenous crop species. To redeem this situation, traditional landraces or cultivars or species of small millets should be continued for cultivation. Awareness about millet production because of nutritional content, health benefits, and low inputs should be familiarized to modern communities.
(VII) Support for water-intensive crops should be phased out.
(VIII) Efforts should be pursued to improve agronomic practices of farmers to understand the strategic choice of crop associations and rotations within the production systems.

8 Promises from Minor Millets

Climate change scenario calls for urgent and strategic interventions toward adaptive agricultural measures. A great ally to that end is represented by the genetic resources of minor millets:

(i) Minor millets are fairly adapted to enhance resilience of local production systems and strengthen food and nutrition security, particularly among the poor.
(ii) They have a wide genetic adaptation and are able to grow successfully in diverse soils, varying rainfall regimes, diverse photoperiods, and in marginal, arid, and mountainous terrains wherein major cereals have less possibility of success.
(iii) They have the potential to thrive with low inputs and can withstand severe edaphoclimatic stresses.

(iv) These qualities are also combined with excellent nutritional values and opportunities for strengthening income generation through value addition.
(v) Millets are generally thermophilic and xerophilic. They are hardy crops with short growth periods.
(vi) Millets have an excellent nutritional profile and are usually a non-glutinous food. This renders them easily digestible and nonallergic foods. They are safer for consumption especially for diabetic patients having a low glycemic index.
(vii) Millets have powerful root systems and are able to penetrate down easily to a great depth of soil to extract water and minerals.
(viii) They resist against drought. Also, they are a good element to diversity crop rotations.
(ix) Millets possess a C_4 photosynthesis system; hence they prevent photorespiration and, as a consequence, efficiently utilize the scarce moisture present in the semiarid regions. Being C_4 plants, they are able to close stomatal openings for longer periods and thereby reduce moisture loss significantly through the foliar surfaces.
(x) They have been proved to release fewer greenhouse gases and hence are beneficial in reducing the contributions of the agro-fed sector to global warming.
(xi) The nutrient requirement for millets is minimal, and a few millet varieties can be grown in soils with low fertility, e.g., sandy loam and slightly acid soils.
(xii) Also, millets are mostly pest-free due to their strong disease resistance traits. They thus benefit from reducing the use of pesticides and consequent soil pollution caused by pesticide use.
(xiii) Millets have the potential to reduce the carbon footprint as it has the least global warming potential.

9 Epilogue

This review summarizes influences of climate change on the millets and their diversity and benefits for well-being of humans, apart from human attempts to modify them. Millets have an excellent nutritional profile and are also important for health benefits. Being C_4 plants, they efficiently use water in semiarid or arid regions of the world. Moreover, they have sufficient potential to thrive with low inputs and are genetically diverse with fair number of forms of germplasm. Still, they are called orphan crops, underutilized or minor or small crops, etc. This is so because they often sustain the poverty-driven populations and hence remained neglected scientifically. Live forms of germplasm of millets are available in rather inaccessible pockets in arid or semiarid areas. They are also preserved in gene banks or seed banks. But both sources have not received desired attention for welfare of mankind. The modern and conventional crop improvement techniques have not been employed sufficiently. Moreover, environmental changes and disasters are putting long strides and severely affecting economy especially in arid and semiarid regions of the world.

Millets certainly provide alternative climate smart crops since they adapted better to changing climates. At this backdrop, concrete efforts of donors, policy-makers, agronomists, breeders, and NGOs are dire necessities to enhance the productivity of millets.

Millets as climate change-compliant crops score highly over other grain crops. Furthermore, millet production is helpful to mitigate climate change since it emits fewer greenhouse gases than other grain crops and has less environmental impacts. They have climate-resilient features. Millets also hold great promise for food security and nutrition when agricultural costs are ever-increasing. All these features accentuate millets as crops of choice for the world population. Even though they are ancient crops of primitive human societies, they have been proved to be nutritionally excellent, and hence, of late, they are being accepted as sources of "superfood." Millets also provide the best option to the farmers for achieving the triple objectives of farming, viz., sustainability, profitability, and adaptability. Of course, there is still a need for increasing awareness among the populace by the scientific community and urban elites worldwide for increased consumption of millets. The challenge to feed the ever-growing population with healthy balanced diets and the threats faced by agricultural crops due to changing climate highlight the immediate requirement to exploit the beneficial attributes of millets. Of late, postharvest operation of millets has been eased due to newly designed machinery. A ray of hope to combat food and nutrition security is indiscernible but needs further substantial coordination on all grounds.

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