Underutilized Climate-Smart Nutrient Rich Small Millets for Food and Nutritional Security

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ABSTRACT: Small millets such as finger millet, foxtail millet, proso millet, kodo millet, little millet and barnyard millet are considered as climate-smart and nutrient rich crops. They have diverse adaptation and play an important role in food and nutritional security in rural households in areas where these crops are grown globally. However, their presence in the food basket has been declining over the years, mainly because of the increased availability of rice and wheat, lack of crop improvement efforts in developing high yielding cultivars, and lack of modern technologies for processing and utilization. Over the last few years, there is an increasing recognition of their nutrient composition and benefits as healthy food. Considering their diverse adaption and agronomic and health benefits, small millets could be an alternate/supplement crop to widen food basket to ensure food, feed and nutritional security. More research effort in germplasm collecting, conserving, evaluating and utilizing, and developing high yielding cultivars, processing and utilization technologies, and policy innervations are required to promote small millets cultivation, and for food and nutritional security of vulnerable population under climate change scenario for sustainable agriculture.

Key words: Climate change, climate-smart crop, germplasm resources, small millets

Introduction

Small millets, also called as minor millets, include the group of small seeded millets such as finger millet, foxtail millet, proso millet, kodo millet, little millet and barnyard millet (Table 1, Fig. 1). These crops were grown globally in a limited acreage, and are used as food, feed and fodder purposes. Small millets have several agronomic advantages, including diverse adaptation, less affected by biotic and abiotic stresses, short-duration, high water use efficiency, drought tolerance, etc. and play an important role in supporting marginal agriculture. Small millets are the source of important food grain in their areas of cultivation, while their straw is highly valued as fodder. Many kinds of traditional foods and beverages are made from these crops and play an important role in the local food culture. Nutritionally, small millets are characterized by high micronutrient content, particularly rich in calcium and iron, and high dietary fibre. The nutraceutical value of small millets' grains, because of their high dietary fibre and low glycemic index, is receiving increasing attention.

Small millets are under-utilized and under-researched crops and continued to be neglected in terms of support for production, promotion, research and development. Their presence in the food basket has been declining over the years. One of the main reasons for this decline is the increased availability of other staple and commercial crops such as rice, wheat, maize, etc. The lack of crop

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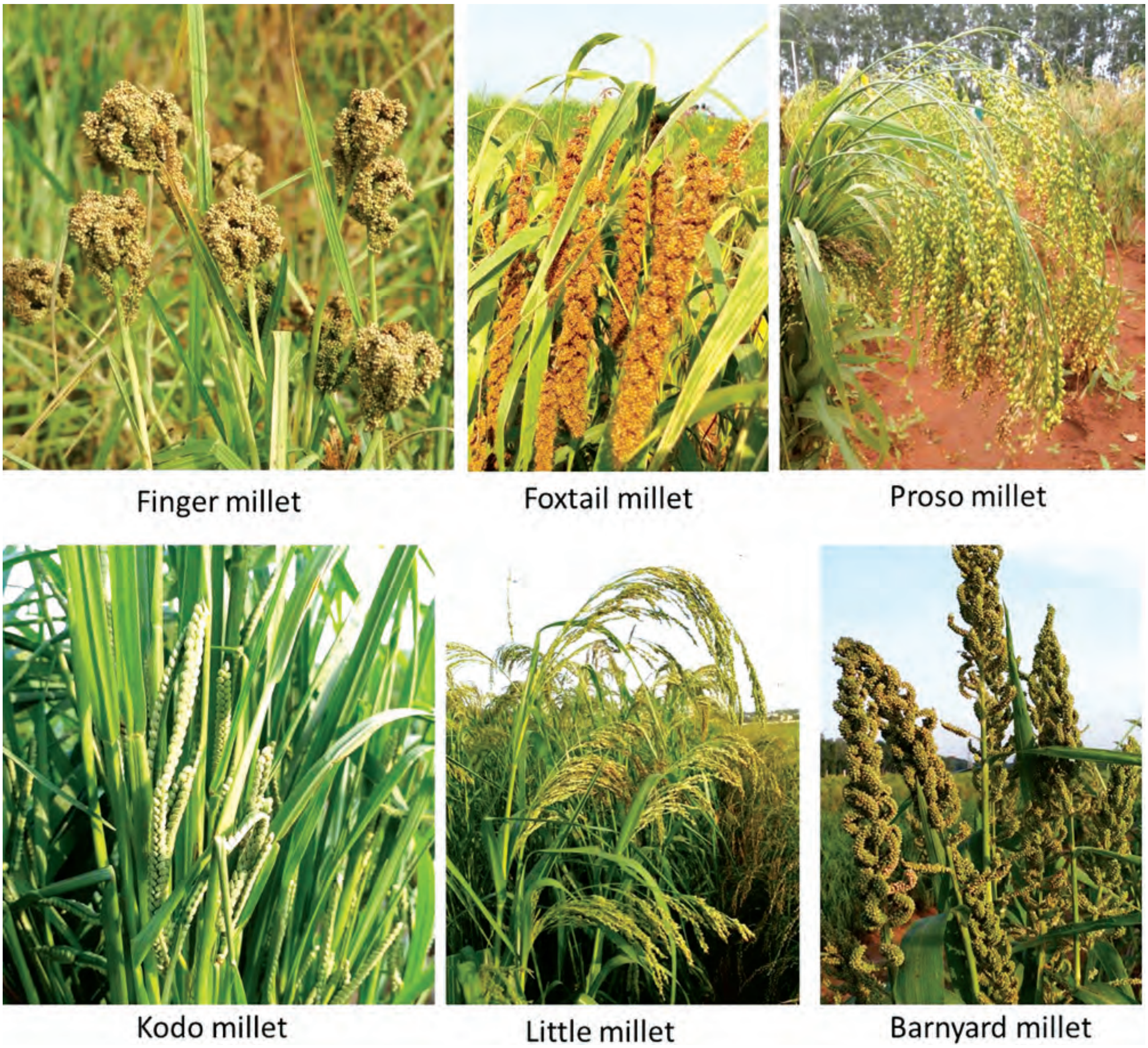

Fig. 1. *Small millets: (top row; L to R) Finger millet, foxtail millet, proso millet; (bottom row; L to R) prodo millet, little millet and barnyard millet.*

improvement efforts in developing high yielding cultivars and lack of modern technologies for seed processing and utilization are also the main reasons for their declining importance. Over the last few years, there is an increasing recognition of their nutrient composition and benefits as healthy food. Thus, apart from their continued strategic role as staple for the poor in marginal agricultural regions, they are also assuming a new role as a health food for the urban high-income people. More research efforts in developing high yielding cultivars, processing and utilization technologies, and policy innervations are required to promote cultivation and consumption of these underutilized grains for sustainable agriculture and healthy lives.

Origin and Domestication

Finger millet [*Eleusine coracana* (L.) Gaertn.] is an allotetraploid evolved from its wild progenitor, *E. africana*. Domestication of cultivated finger millet started around 5,000 years ago in Western Uganda and Ethiopian highlands and the crop has extended to Western Ghats of India around 3,000 BC (Hilu *et al.,* 1979; Hilu and de Wet, 1976). Foxtail millet [*Setaria italica* (L.) P. Beauv.] is a member of the subfamily Panicoideae and the tribe Paniceae. The green foxtail (*S. viridis*) is a wild ancestor of cultivated foxtail millet. Foxtail millet is grown since >10,500 years ago in China (Yang *et al.,* 2012). Several hypotheses regarding the origin and domestication have been proposed and a multiple domestication hypothesis (China, Europe and Afghanistan-Lebanon) has been widely accepted (Li *et al*., 1995). Proso millet (*Panicum miliaceum* L.) is an annual herbaceous plant in the genus *Panicum.* Vavilov (1926) suggested China as the centre of diversity for proso millet, while Harlan (1975) suggested that proso millet probably was domesticated in China and Europe. The earliest records come from the Yellow River valley site of Cishan, China dated between 10300 and 8700 cal BP (Lu *et al.,* 2009). Evidence of proso millet also occurs at the number of pre-7000 cal BP sites in Eastern Europe, in the form of charred grains and grain impressions in pottery (Hunt *et al.,* 2008). These two centres of earlier records suggest independent domestication of proso millet in eastern Europe or Central Asia or may have also originated from a domestication within China and then spread westward across the Eurasian steppe (Hunt *et al.,* 2011; Jones, 2004). Hunt *et al.* (2014) suggested the allotetraploid origin of proso millet with the maternal ancestor being *P. capillare* (or a close relative) and the other genome being shared with *P. repens*, however, further studies of *Panicum* species, particularly from the Old World are required. Little millet (*Panicum sumatrense* Roth. ex. Roem. & Schult.) was domesticated in India particularly important in the Eastern Ghats of India, where it forms an important part of tribal agriculture (de Wet *et al.,* 1983a). In barnyard millet, two species namely *Echinochloa crus-galli* and *E. colona* are cultivated as cereals. *E. crus-galli* is native to temperate Eurasia and was domesticated in Japan some 4000 years ago, while *E. colona* is widely distributed in the tropics and subtropics of the Old world, and was domesticated in India (de Wet *et al.,* 1983b). Kodo millet belongs to the genus *Paspalum,* a diverse genus comprising about 400 species, most of which are native to the tropical and subtropical regions of the Americas, and the main center of origin and diversity of the genus is considered to be South American tropics and subtropics (Chase, 1929). Kodo millet was domesticated in India some 3000 years ago and cultivated by tribal people in small areas throughout India, from Kerala and Tamil Nadu in the south, to Rajasthan, Uttar Pradesh and West Bengal in the North. It occurs in moist or shady places across the tropics and subtropics of the Old World (de Wet *et al.,* 1983c).

Racial Diversity

Small millets have considerable within specific diversity and are further subdivided into races and subraces based on comparative morphology of accessions. The species *E. coracana* consists of two subspecies, *africana* (wild) and *coracana* (cultivated). The subsp. *africana* has two wild races, *africana* and *spontanea*, while subsp. *coracana* has four cultivated races; *elongata*, *plana*, *compacta*, and *vulgaris*. These cultivated races are further divided into subraces; *laxa*, *reclusa*, and *sparsa* in race *elongata*; *seriata*, *confundere*, and *grandigluma* in race *plana*; and *liliacea*, *stellata*, *incurvata*, and *digitata* in race *vulgaris*. The race *compacta* has no subraces (de Wet *et al.,* 1984; Prasada Rao and de Wet, 1997). Prasada Rao *et al.* (1987) suggested three races of foxtail millet based on the comparative morphology of the foxtail millet accessions: (i) *moharia* (ii) *maxima* and (iii) *indica*. These races can be further divided into ten subraces (*aristata*, *fusiformis*, and *glabra* in *moharia*; *compacta*, *spongiosa*, and *assamense* in *maxima*; and *erecta*, *glabra*, *nana* and *profusa* in *indica*). Proso millet can be divided into five races; *miliaceum, patentissimum, contractum, compactum* and *ovatum* (de Wet, 1986*).* Little millet has two races; *nana* and *robusta*, and two subraces each; *laxa* and *erecta* in *nana,* and *laxa* and *compacta* in *robusta* (de Wet *et al.,* 1983a). The species *E. crus-galli* is classified into two subspecies; *crus-galli* and *utilis,* four races; *crus-galli* and *macrocarpa* in subsp. *crus-galli*, and *utilis* and *intermedia* in subsp. *utilis*. Similarity, *E. colona* has two subspecies, *colona* and *frumentacea*. The subsp. *colona* has no races and subsp. *frumentacea* is divided into four races: *stolonifera, intermedia, robusta* and *laxa* (de Wet *et al.,* 1983b). Kodo millet has three races namely *regularis*, *irregularis* and *variabilis* (de Wet *et al.,* 1983c).

Small Millets Cultivation and Production Status

Small millets contribute considerably to the total global millets production; however, area and production of small millets are usually merged with pearl millet and called together as 'millets'. Foxtail and finger millets rank second and third after pearl millet, respectively in total world production of millets (http://www.cgiar.org/our-research/crop-factsheets/millets/). Finger millet is grown in more than 25 countries in eastern and southern Africa, and across Asia from the Near East to the Far East. The major finger millet producing countries are Uganda, India, Nepal and China. In India, finger millet was grown in about 1.13 m ha with a production of 1.88 million tons during 2014. In Nepal, finger millet is the fourth major cereal crop, cultivated in 0.27 million ha with an annual production of 0.31 million tons. Foxtail millet is widely cultivated in Asia, Europe, North America, Australia and North Africa for grains or forage, and an essential food for human consumption in China, India, Korea and Japan (Austin, 2006). China ranks top in foxtail millet production with 1.81 million tons from 0.72 m ha during 2014. Though considerable yield improvement has been made in China, area under foxtail millet cultivation has been reduced from 9.2 m ha in 1949 to 0.72 m ha in 2014, with corresponding decrease in grain yield from 7.79 m tons to 1.81 million tons, respectively because of low grain yielding potential and other marketing factors (Diao, 2017). In India, foxtail millet is cultivated mostly in Telangana, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh, Tamil Nadu and Chhattisgarh. Proso millet is grown in Asia, Australia, North America, Europe and Africa, and used for feeding birds and as livestock feed in the developed countries and for food in some parts of Asia (Rajput *et al.,* 2014). The total cultivated area of proso millet in the United States is approximately 0.20 million ha, and most of the proso millet crop is utilized for birdfeed and in cattle-fattening rations. The United States is among the top producers and exports 15–20 per cent of its annual millet production to over 70 countries, primarily as feed (Habiyaremye *et al.,* 2017). Barnyard millet is mainly grown in India, China, Japan and Korea for human consumption as well as fodder (Upadhyaya *et al.,* 2014). Kodo and little millets are largely cultivated throughout India by tribal people in small areas.

Table 1. Small millets and the region of cultivation

Crop	Botanical name	Chromosome number	Region of cultivation
Finger millet	*Eleusine coracana* (L.) Gaertn.	2n=4x=36	India, Uganda, Nepal, China, Myanmar, Sri Lanka, Kenya, Eritrea, Sudan, Zimbabwe Zambia, Malawi, Madagascar, Rwanda, Burundi
Foxtail millet	*Setaria italica* (L.) P. Beauv.	2n=2x=18	Asia, Europe, North America, Australia and North Africa
Proso millet	*Panicum miliaceum L.*	2n=4x=36	Asia, Australia, North America, Europe, Africa
Little millet	*Panicum sumatrense* Roth. ex. Roem. & Schult.	2n=4x=36	India, Sri Lanka, Pakistan, Myanmar
Kodo millet	*Paspalum scrobiculatum* L.	2n=4x=40	India
Barnyard millet	*Echinochloa crus-galli* and *E. colona*	2n=6x=54	India, Japan, Korea, China, Nepal

Potential Uses

Small millets are good sources for micro- and macro-nutrients with high nutraceutical and antioxidant properties. These crops are rich in protein, fat, crude fiber, iron and other minerals and vitamins. Finger millet contains over >10 fold higher calcium (350 mg per 100g); proso, foxtail and barnyard millets are rich in protein (11 to 12.5%); foxtail and little millets are rich in fat (4.0 to 5.2%); barnyard, little and foxtail millet are rich in crude fiber (6.7 to 13.6%), little and barnyard millets are rich in iron (9.3 to 18.6 mg per 100g) compared to other major cereals such as rice, wheat and sorghum (Saleh *et al.,* 2013). Small millets are used as an ingredient in multigrain and gluten-free cereal products and serves as a major food component for various traditional foods and beverages, such as bread, porridges, and snack foods, and while grains are feed to animals, including pigs, fowls, and cage birds. All these crops have superior nutritional properties including high micronutrients, dietary fibre content and low glycemic index (GI) with potential health prospective (Chandel *et al.,* 2014; Dwivedi *et al.,* 2012; Saleh *et al.,* 2013).

Germplasm Resources: Global Status

Large numbers of small millets germplasm accessions are available to scientific community. Over 46,000 foxtail millet, >37,000 finger millet, >29000 accessions of proso millet, >8000 accessions each of barnyard and kodo millet, >3000 accessions of little millet germplasm accessions have been conserved *ex situ* in genebanks globally (Upadhyaya *et al.,* 2015; Vetriventhan *et al.,* 2015). The major collections of foxtail millet germplasm accessions are housed in genebanks at China, India, France, and Japan, while India and African countries (mainly Kenya, Ethiopia, Uganda and Zambia) conserve major finger millets collections. The major collection of proso millet germplasm accessions are assembled in Russian Federation, China, Ukraine and India; barnyard millet in Japan and India; kodo millet in India and USA; and little millet in India (Upadhyaya *et al.,* 2015; Vetriventhan *et al.,* 2015).

Germplasm Diversity Representative Subsets

Germplasm resources provide pool of genes for breeding high-yielding, biotic and abiotic resistant cultivars. Systematic breeding efforts and utilization of genetic resources are limited in small millets. Use of germplasm accessions in breeding programme can be enhanced if small subsets of a few hundred germplasm lines, which represent the entire diversity of is available. Such germplasm representative subsets are available in small millets collection from ICRISAT (Table 2). These diversity sets such as core and mini-core collections could be effectively evaluated to identify germplasm trait-specific sources for their enhanced utilization in breeding high yielding cultivars with diverse adaptation.

Table 2. Germplasm diversity representative sets of small millets developed at ICRISAT, India

Crop	Germplasm subsets	Accessions used (no.)	Traits/ SSRs (no.)	Accessions in subset (no.)	Reference
Finger millet	Core collection	5940	14	622	Upadhyaya *et al.* (2006a)
	Mini-core collection	622	20	80	Upadhyaya *et al.* (2010)
	Composite collection	-	-	1000	Upadhyaya *et al.* (2005)
	Reference set	1000	19 SSRs	300	Upadhyaya (2008a)
Foxtail millet	Core collection	1474	23	155	Upadhyaya *et al.* (2008)
	Mini-core collection	155	21	35	Upadhyaya *et al.* (2011b)
	Composite collection	-	-	500	Upadhyaya *et al.* (2006b)
	Reference set	500	20 SSRs	200	Upadhyaya (2008b)
Proso millet	Core collection	833	20	106	Upadhyaya *et al.* (2011c)
Barnyard millet	Core collection	736	21	89	Upadhyaya *et al.* (2014)
Little millet	Core collection	460	20	56	Upadhyaya *et al.* (2014)
Kodo millet	Core collection	656	20	75	Upadhyaya *et al.* (2014)

Core and Mini-core Collection as Source of Trait-specific Germplasm Sources

Small millets germplasm collection conserved globally has large variation for morpho-agronomic traits. Researchers at ICRISAT and elsewhere have assessed germplasm collections and identified sources for various biotic and abiotic stresses tolerance and for grain quality traits (see Upadhyaya *et al.,* 2015; Vetriventhan *et al.,* 2015). Core and mini core collections of small millets developed at ICRISAT (Table 2) have been extensively evaluated and identified sources for important traits. At ICRISAT, Upadhyaya *et al.* (2011b) have identified 21 diverse accessions having agronomically (earliness and high grain yield) and nutritionally (protein, 15.6 to 18.5%; Ca, 171.2 to 288.7 mg kg^{-1}; Fe, 58.2 to 68.0 mg kg^{-1}; and Zn, 54.5 to 74.2 mg kg^{-1}) superior traits from core collection of foxtail millet. Similarly, in finger millet core collection, 15 accessions each for grain, Fe (37.66 to 65.23 mg kg^{-1}), Zn (22.46 to 25.33 mg kg^{-1}), Ca (3.86 to 4.89 g kg^{-1}) and protein (8.66 to 11.09%) contents were identified, and 24 of them were identified based on their superiority over control cultivars for two or more grain nutrients (Upadhyaya *et al.,* 2011a). In little millet, Vetriventhan and Upadhyaya (2016) have identified high grain and biomass yielding accessions. Proso millet, kodo millet and little millets germplasm (200 accessions each, including core collections) were assessed for grain yield and grain nutrient contents and sources for high grain yielding and nutrients dense accessions were identified (ICRISAT, Unpublished).

Small millets are less affected by biotic and abiotic stresses however, a large variation exist among germplasm for stress tolerance. Identification and utilization of such trait specific sources in breeding programme will enhances yield and adaption. Blast in both finger and foxtail millets, grain smut and sheath blight in little millet, head smut and blight in kodo millet, smut and leaf spot in barnyard millet, and head smut, sheath blight and bacterial spot in proso millet are important diseases. In finger millet mini-core collection, 66 accessions with combined resistance to leaf, neck and finger blast have been identified, of which nine accessions also had desirable agronomic traits such as early flowering, medium plant height, semi-compact to compact inflorescence (Babu *et al.,* 2013). Similarity in foxtail millet, Sharma *et al.,* (2014) have evaluated the core collection accessions for blast resistance and identified 21 accessions resistant to neck and head blast under field evaluation and 11 accessions had seedling leaf blast resistance in the greenhouse. Further evaluation against four isolates of blast pathogen resulted in identification of 16 accessions which were resistance to leaf, sheath, neck and head blast to at least one isolate, and two accessions (ISe 1181 and ISe 1547) were free from head blast infection and were resistance to leaf, neck and sheath blast against four isolates (Sharma *et al.,* 2014). Foxtail and finger millets are the potential crops for salt-affected soils (Krishnamurthy *et al.,* 2014a, b).

At ICRISAT, Krishnamurthy *et al.* (2014b) assessed the finger millet mini-core collection for response to salinity in terms of total shoot or grain biomass at maturity and grouped the accessions into tolerant (22accessions), moderately tolerant (20), sensitive (21) and the sensitive and late ones (5) based on yield under saline condition. Similarly, Krishnamurthy *et al.,* (2014a) screened the foxtail millet core collection under saline condition in pot culture which revealed a large variation for salinity tolerance and identified salinity tolerant accessions. For drought tolerance, Krishnamurthy *et al.* (2016a, b) evaluated finger millet mini-core collection and foxtail millet core collection and identified 16 foxtail millet and 11 finger millet drought tolerant accessions. Ramakrishnan *et al.,* (2017) have identified finger millet mini-core accessions tolerant to low Phosphorus stress, and five (IE5201, IE2871, IE7320, IE2034, IE3391) of which had high root and shoot length, root hair density and root hair length. Limited number of resistant sources for major diseases and to some extent for pests in proso millet, barnyard millet, little and kodo millet have been reported (Upadhyaya *et al.,* 2015; Vetriventhan *et al.,* 2015). Barnyard millet reported to be tolerant to both drought and waterlogging (Zegada-Lizarazu and Iijima, 2005), while proso millet is susceptible to drought (Seghatoleslami *et al.,* 2008). Lodging is a constraint in many crops including finger millet, foxtail millet, proso millet, little millet, barnyard millet and kodo millet causing substantial losses in grain yield and quality. Use of lodging resistant cultivars along with good crop husbandry is the most effective way to minimize losses due to lodging.

Genomics Resources

Genomic resources such as DNA markers, linkage maps, and genome sequence are essential for gene tagging, QTL (quantitative trait loci) mapping, marker-assistant selection for rapid crop improvement. In foxtail millet large numbers of molecular markers have been developed like SSR (simple sequence repeat), EST-SSR (expressed sequence tag- simple sequence repeat), ILP (Intron length polymorphic) TE (Transposable element), and microRNA (miRNA) based markers during pregenome sequence era. The major breakthrough in the area of Setaria genomics is the release of two reference genome sequences (Brutnell *et al.,* 2012; Wang *et al.,* 2012). Recently, Hittalmani *et al.* (2017) have reported genome and transcriptome sequence of finger millet. In proso millet, Rajput *et al.,* (2016) constructed a genetic linkage map and mapped 18 QTLs for eight morpho-agronomic traits. Foremost challenge for the molecular characterization of barnyard, little and kodo millets is the availability of very limited genomic resources like DNA markers, lack of genetic/ linkage maps and genome sequences. However, genomic resources of closely related species like foxtail millet where two reference genome sequences can be utilized towards enriching genomic resources in these underutilized crops. DNA markers such as SSR, EST-SSR, ILP and microRNA based molecular markers developed using foxtail millet genome sequence information showed >85 per cent of cross-genera transferability among other millets including proso, barnyard, little and kodo millets, as well as non-millet species (Kumari *et al.,* 2013; Muthamilarasan *et al.,* 2014; Pandey *et al.,* 2013; Yadav *et al.,* 2014).

Developments in sequencing technologies have made it possible to analyze large amounts of germplasm against low production cost. It enables to screen genebank collections more efficiently for DNA sequence variation which will be useful for mining sequence variation associated with economically important traits through genome wide association studies (GWAS). In barnyard millet, Wallace *et al*. (2015) genotyped the barnyard millet core collection (Upadhyaya *et al.,* 2014) using genotyping-by-sequencing (GBS) approach and identified several thousand SNPs, and investigated the patterns of population structure and phylogenetic relationships among the accessions. The procedure used to identify SNPs following GBS approach in barnyard millet can also be applied easily and rapidly to characterize germplasm collections of other crops as well (Wallace *et al.,* 2015). The GBS approach can play a major role in the crop species like proso millet, barnyard millet, little and kodo millet for which genome sequence is not available. Research is in progress at ICRISAT to characterize proso millet, kodo millet and little millets using GBS approach.

Small Millets Improvement

Globally, small millets have received very limited research attention in terms of crop improvement for enhanced yields and adaptation to biotic and abiotic stresses. Majority of cultivars released globally were through pure line selection from landraces.

In India, the All India Coordinated Research Project on Small Millets (AICRP-Small Millet) was launched in 1986. The research project under AICRP-Small Millet is carried out through network of 13 centres located in State Agricultural Universities, ICAR institutes and 21 cooperating centres. The AICRP-Small Millet has the responsibility to plan, coordinate and execute the research programmes to augment the production and productivity of six small millets. The research in the project focuses state/regional needs from the point of developing appropriate agro production technology for maximizing production/ productivity. The crop improvement through AICRP-Small Millet led to the development of high yielding varieties with resistance to blast disease, quality fodder, early and medium maturity and white seed in finger millet, resistance to head smut in kodo millet and resistance to shoot fly in both proso and little millets. So far, a total of 245 varieties in 6 small millets have been released in India (http://www.aicrpsm.res.in/). Majority of released cultivars were following pure line selection. Two ICRISAT germplasm accessions, one each in barnyard millet (IEc 542 originated from Japan was released as PRJ 1 in India during 2003) and proso millet (IPm 2769 originated from Ukraine was released as DHPM 2769 in India during 2015) were directly released in India. Currently recombination breeding has been the approach especially in finger millet resulting in developing diverse and high grain yielding cultivars. Recombination breeding also been used in foxtail millet, proso millet and barnyard millet. The modern finger millet varieties yield up to 5 to 6 tons/ha, and cultivars other small millets yields up to 2.5 to 3 tons/ha under optimum management conditions.

In Africa, finger millet is an important food crop in small scale cereal-based farming systems, particularly the upland areas of Eastern Africa (Uganda, Ethiopia, Tanzania and Kenya). Systematic breeding efforts are very limited in Africa; majority of cultivars grown were either landraces or direct introduction. The ICRISAT-HOPE project in collaboration with Department of Research and Development (DRD), Tanzania, released cultivars such as P224 and U 15 in Tanzania, and the same cultivars were also released in Kenya and Uganda because of their high yielding, blast resistance and drought tolerance than the existing cultivars (http://hope.icrisat.org/new-varieties-promise-an-increase-in-tanzanias-finger-millet-production/). Three finger millet germplasm accessions of were directly released in Zambia (IE2929 as Lima and IE2947 as FMV287 during 1987) and Kenya (IE4115 as ICRISAT' KAK-WIMBI 2 during 2016).

In China, foxtail millet is one of the important crops. Breeding of foxtail millet began with simple grain yield comparisons among landraces in the 1950s and 1960s, while hybridization-based pedigree selection become popular in the 1970s and remains the main breeding method in China. About 870 cultivars were released since 1950. Research using heterosis began in the 1960s with the development of male sterile lines by various approaches. Various male-sterile lines have been identified having dominant, recessive genes and photo/thermosensitive nuclear system, gene interaction male-sterile lines, cytoplasmic male sterility, and cytoplasmic- nuclear male-sterile type. These lines are potential sources for heterosis breeding and have been used in developing hybrid cultivars in China. For example, Zhangzagu 5, a high yielding hybrid cultivar, was released from Zhangjiakou Academy of Agricultural Sciences, Hebei Province, China, and yielded 12159 kg/ha versus conventional cultivars ranging from 4500 to 6000 kg/ha in 2007 (Liu *et al.,* 2014). The development of herbicide resistant foxtail millet cultivars has made the use of foxtail millet heterosis a reality by us of herbicide resistant varieties as the restorer line (Diao, 2017).

Among the millet species produced worldwide, proso millet is the most important species traded in the world market. In the United States of America (USA) the focused breeding programme for proso millet productivity improvement was started in the year 1972 under the alternative crops breeding programme at Panhandle Research and Extension Centre (PHREC), and released several cultivars such as Sunup, Dawn, Cerise, Rise, Early bird, Hutsman, Sunrise and Horizon. In the United States of America (USA) there are 15 cultivars of proso millet available to growers, and nine of these were selections from adapted landraces, and six were developed through hybridization (Habiyaremye *et al.,* 2017).

Opportunities of Networking for Research and Development

Research and development activities on small millets are meager as compared to major cereals such as maize, wheat and rice. Limited efforts have been made in India (all six small millets), Africa (finger millet), China (foxtail millet) and USA (proso millet) on cultivar development and towards enhancing millets cultivation and marketing. Recently, there is a considerable interest in millets consumption due to their better nutritional quality and health benefits besides their ability to withstand changing climatic conditions. Integrated approaches and networking among key players on research and promotion of small millets are crucial for wider impact. Research on processing and utilization technologies and developing value added products such as easy-to-cook and ready-to-eat will add value in commercialization of small millets as healthy foods.

Conclusions

Small millets have the potential to improve food security, health, income, livestock production, diversifying agriculture, supporting traditional farming systems and overall development of smallholders living in marginal lands. Small millets are environmentally friendly crops and are much more tolerant to biotic and abiotic stresses compared to major crops such as maize, wheat, and rice. Despite of many advantages, these crops have received very little attention in terms of research and development to enhance their cultivation and utilization. Currently small millets are recognized as healthy foods and there is a rapidly growing global market for diverse and healthy foods. Globally there are significant numbers of germplasm accessions have been conserved in genebanks and reported to have substantial variation for economic important traits. The germplasm diversity representative subsets such as core and mini-core collections are available in small millets and trait specific sources for important traits such as resistance/tolerance to biotic and abiotic stresses and high yield and grain nutrients content were identified. Except finger millet and foxtail millet, other small millets have received very poor research attention in terms of genetic and genomic resources development and breeding for yield enhancement. Considerable breeding efforts were made in finger and foxtail millets, in India and China, respectively. Both finger millet and foxtail millet genomes have been decoded, while other small millets yet to come. Research is in progress at ICRISAT to characterize proso millet, kodo millet and little millets using genotyping-by-sequencing approach. Considering diverse adaption and agronomic and health benefits small millet crops offer, these crops could be an alternate/supplement crop to widen food basket to ensure food, feed and nutritional security. More research effort in developing high yielding varieties and processing and utilization technologies and policy innervations are required to promote small millets cultivation, and to diversify food habits for healthy lives and to face the global threats of malnutrition and climate change.

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