GLOBAL STRATEGY FOR THE CONSERVATION AND USE OF GENETIC RESOURCES OF SELECTED MILLETS

With support from

CROP TRUST

The International Treaty ON PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Federal Ministry of Food and Agriculture

Global strategy for the conservation and use of genetic resources of selected millets: Covering pearl millet (*Cenchrus americanus* (L.) Morrone), finger millet (*Eleusine coracana* (L.) Gaertn.), foxtail millet (*Setaria italica* (L.) P. Beauv.), proso millet (*Panicum miliaceum* L.), barnyard millet (*Echinochloa crus-galli* (L.) P. Beauv. and *Echinochloa colona* (L.) Link), teff (*Eragrostis tef* (Zucc.) Trotter), fonio (*Digitaria exilis* Stapf. and *Digitaria iburua* Stapf.), little millet (*Panicum sumatrense* Roth. ex. Roem & Schult.) and kodo millet (*Paspalum scrobiculatum* (L.)).

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COVER

Panicles of Maridadi, a finger millet variety growing in Kakamega County of Western Kenya. Photo: Michael Major for Crop Trust

DISCLAIMER

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Pennisetum glaucum in field in India.
Photo: Shanmugamp7 on Wikimedia

Millets are a group of small-seeded cereals that are important crops in areas where it is difficult to produce reliable yields with other crops, such as rainfed areas in semi-arid regions. Because they can grow in marginal areas, millets can foster climate resilience and food security.

Globally, pearl millet is the most important millet crop, followed by foxtail millet, finger millet and proso millet. Barnyard millet is mainly grown in Asia, especially in India, China, Korea and Japan. Little millet and kodo millet have local significance, mainly in India. Teff is the most important food grain in Ethiopia, and fonio is predominantly grown in West Africa.

Although there is evidence of increased productivity in some millet crops, others have seen historical declines in their production areas, mainly because of shifts to other crops that require less intensive labor for household production and processing or that have a higher market value. Therefore, while millet crops continue to be important to local farmers and consumers, they are considered as minor crops in many countries and they are being replaced by other crops.This trend is threatening the genetic resources of these crops, as losses are occurring in areas where most of the diversity is maintained by local farmers.

Research on millet genetic resources is inadequate compared with other cereal crops, such as rice, wheat and maize. However, genomic tools are available and are being used to assess the diversity in *ex situ* collections and to improve millet crops.

Importantly, the future of such crop improvement depends on the availability of adequate diversity conserved in, and available from, *ex situ* collections. The status of *ex situ* conservation for millet crops in the global system was determined based on survey results received from nearly 50% of the 60 institutions worldwide; together, the respondents conserve about two-thirds of all accessions in *ex situ* millet collections. The collections conserved by survey respondents were found to have a high proportion of unique local landrace accessions. For teff, fonio and barnyard millet, it was found that the majority of the diversity is held in a few key collections; for the other millet crops, the diversity is more widely dispersed among collection holders globally. A major concern that must be addressed is that collections lack of a significant number of accessions of wild relatives.

The current global system for conserving millet diversity is neither secure nor efficient, with some collections experiencing constraints and vulnerabilities. Generally, few of the survey respondents meet all the international standards for the conservation of orthodox seed. Globally, there are problems related to the regeneration of accessions that are losing viability and to the multiplication of seed for distribution. These difficulties have already resulted in insufficient seed to meet distribution requests. Survey respondents also reported constraints with the key facilities and equipment for storage and for routine operations. Furthermore, routine operations do not fully comply with the most efficient and secure procedures and protocols. Finally, ***the absence of safety duplication for more than three-quarters of the accessions conserved globally is a critical vulnerability that needs to be addressed.***

Currently, ***there is limited availability of and access to accession-level information for users through searchable online platforms. Much of the genebank information and accession-level information has not been digitized, or is available only within internal databases.*** Wider adoption of genebank information systems, such as GRIN-Global or others, will lead not only to increased monitoring and management efficiency for conservation, but also to greater online sharing of accession-level information. It will also allow for better backup of documentation and better linking of collections within the global system, which will enhance use and security of conservation efforts.

Millet crop diversity is generally distributed only within institutions or nationally. ***International distribution is hampered by policy, costs of distribution and administrative complexity.*** The main users of millet crop collections tend to be nationally based researchers; international users are mainly genebank curators from other countries. The lack of public or private sector breeding programs for most of these crops means there are few researchers seeking to use these collections.

The current global system of conservation and use is not meeting international agreed standards in most collections and is generally insecure. The system is characterized by inefficient and poorly resourced operations, limited availability of seed for users, little sharing of accession-level information with users and limited engagement between conservers and users globally, nationally and locally. This is not the sustainable, rational, secure and cost-effective system that is needed for the long-term conservation and use of these very important cereal crops. One reason for the weaknesses in the system is that these crops are considered a low priority by international donors, national governments, local authorities, local farmers, local and urban markets and consumers. This decline in priority poses risks not only to *ex situ* conservation, but also to the continued conservation of diversity in farmers' fields.

This global strategy identifies three key strategic areas for priority actions, based on the survey findings:

- To secure the long-term conservation of millet crop genetic resources, with the main focus on addressing vulnerabilities in *ex situ* conservation caused by suboptimal routine operations, facilities and safety duplication; to address the risk of loss of unique diversity conserved only in farmers' fields and in natural areas; to address constraints to global engagement between conservers and between conservers and users; and to increase communication on the importance of millet crops and their conservation.
- To increase the availability and exchange of germplasm, with the key focus on addressing constraints to distribution caused by insufficient seed quantity, quality and viability, and by technical and policy bottlenecks.
- To increase the use of genetic diversity in collections by: facilitating access to accession-level information, preferably by making it available online for all users; increasing evaluation and genotyping; making core collections or other subsets available to facilitate use; and increasing research and farmer engagement.

Actions in these three key strategic areas will enable a sustained, longer-term focus on developing a more rational system for the global conservation and use of millet genetic resources. The necessary actions are identified both in the 2012 global strategies for pearl millet and finger millets and in this strategy. The main obstacle to these priority actions for individual participants across the global system is the requirement for commitment and resources.

To address the key strategic areas, three priority actions have been identified, based on results of the survey and a background review:

- To establish a global platform to engage conservers and users.
- To establish a global fund to increase resources for upgrades and overall secure conservation of key national collections in the center of diversity.
- To establish a global initiative to secure the unique diversity of millet crops that exists only in farmers' field or in natural areas.

Men and women harvest the Ethiopian staple grain teff in a roadside field in Northern Ethiopia. Photo: Alan Davey/Flickr

1 INTRODUCTION

The Crop Trust is an international organization that works to safeguard crop diversity for the very long term by focusing on *ex situ* conservation in genebanks. Since 2006, it has worked with crop conservation and facilitated the development of global *ex situ* conservation strategies for key global food crops and commodities. The aim of the global conservation strategies is to facilitate a transition from the current complex, fragmented and independent crop conservation system to a more integrated, collaborative and cooperative global conservation system. The aim of the global strategy for millets is to provide evidence to guide priority strategic actions.

In 2009, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Crop Trust initiated the development of global strategies for the conservation of pearl millet and finger millet genetic resources. In 2012, a global *ex situ* conservation strategy for finger millet (*Eleusine coracana* (L.) Gaertn.) and a global *ex situ* conservation strategy for pearl millet (*Cenchrus americanus* (L.) Morrone) were completed (Mathur and Upadhyaya 2012a; Mathur and Upadhyaya 2012b). Each of these strategies involved a survey of the key *ex situ* collection holders on the status of conservation and use to assess the state of global conservation. Workshops were then held to discuss the survey findings and to identify key recommendations. Conclusions were similar for the two crops, with the following key issues identified:

- Some countries identified gaps in their collections, along with a need for a systematic effort to document gaps globally and gain support for collecting to fill gaps.
- A number of key constraints hampered secure and effective conservation, including limited safety duplication, an urgent need for regeneration, irregular monitoring of seed viability and poor storage infrastructure.
- In general, there was limited sharing of accession-level information with users.
- There was limited availability of accessions to users, except for a few collections such as ICRISAT and USDA-ARS (US Department of Agriculture – Agricultural Research Services).
- Only a fraction of the accessions of these two millet crops conserved in genebanks were used in crop improvement programs.

- The main reason for the limited use was the poor quality of the evaluation data and the very limited sharing of accession-level information.
- There was a need for a common platform for information sharing and collaboration for conservers.
- There was a lack of effective links between conservation and use due to poor information flow between genebanks and users, poor level of engagement between genebanks and crop-based research institutes and poor links between genebanks and *in situ*/on-farm conservation efforts.

The draft global strategies for these two millet crops were then discussed at a consultation workshop that brought together key experts in conservation and use. The workshops identified key recommended actions and set out the key steps that were needed to secure conservation and use for the long term in a global system. The workshop concluded that the strategy should be published and efforts made to implement it. It was recognized that the global strategy was not static and would need regular review and revision.

The present global strategy for the conservation and use of pearl millet (*Cenchrus americanus* (L.) Morrone), finger millet (*Eleusine coracana* (L.) Gaertn.), foxtail millet (*Setaria italica* (L.) P. Beauv.), proso millet (*Panicum miliaceum* L.), barnyard millet (*Echinochloa crus-galli* (L.) P. Beauv. and *Echinochloa colona* (L.) Link), teff (*Eragrostis tef* (Zucc.) Trotter), fonio (*Digitaria exilis* Stapf and *Digitaria iburua* Stapf.), little millet (*Panicum sumatrense* Roth. ex. Roem & Schult.) and kodo millet (*Paspalum scrobiculatum* (L.)) genetic resources is the result of a background study of the importance of millet crops, their genetic diversity and the use of their germplasm; an assessment of various databases containing accession-level information on collections; and a survey of major millet collection holders. The 2020 survey focused on the composition of the accessions conserved in *ex situ* collections and on the status of *ex situ* collections in terms of the security, effectiveness and sustainability of conservation. It considered the interrelationship between individual collections and other collections in the global system, based upon collection history, collection composition and specific activities linking conservers. Finally, the survey assessed the state of engagement between collection holders and users.

For pearl millet and finger millet, the response to the 2020 survey of key collection holders was used to review and update the global conservation strategies published in 2012. For the other millet crops, the survey was used to assess the current status of conservation and use of *ex situ* collections. Hopefully, the survey will be followed by consultation workshops with genebank curators and users, as done for the earlier strategies for pearl millet and finger millet. This follow-up consultation process will strengthen commitment to a global system in which efforts to conserve and use millet crop genetic resources could become more secure, coordinated, systematic and efficient. A key aspect of this draft strategy are the priority actions identified to address shortfalls in the current global conservation system. These actions will be used by the Crop Trust and others to identify the key investments needed to secure conservation and use for the long term.

Echinochloa crus-galli. Photo: Rudolphous/Wikimedia

2 ECONOMIC IMPORTANCE

The term millets refers to a group of small-seeded cereal crops in the Poaceae family.

Millets are important crops in areas where it is difficult to obtain reliable yields from other crops, such as rainfed areas in semi-arid regions (Vetriventhan et al. 2020).

This global conservation strategy focuses on pearl millet, finger millet, foxtail millet, proso millet, teff, fonio, barnyard millet, little millet and kodo millet. These crops, with the exception of pearl millet, are also referred to as small millets.

Globally, pearl millet is the most important millet crop, followed by foxtail millet, finger millet and proso millet (Vetriventhan et al. 2016; Vetriventhan et al. 2020; Habiyarenemye et al 2017). Barnyard millet is mostly grown across Asia, especially in India, China, Korea and Japan (Renganathan et al. 2020; Vetriventhan et al. 2020). Little millet and kodo millet have local significance, mainly in India (Vetriventhan et al. 2020). Teff is the most important food grain in Ethiopia (Lee 2018), and fonio is predominately grown in West Africa (FAOSTAT (Apr. 13, 2021).

According to reviews focusing on the trends in millet production and productivity (Dwivedi et al. 2012; Vetriventhan et al. 2020) and data from FAOSTAT (Figure 2.1), there is evidence of increased productivity for some millet crops. However, many millet crops have seen historical declines in their production areas, mainly because of shifts to other crops that require less intensive labor for household production and processing or that have a higher market value, such as rice and maize (Magha 2004; Dida et al. 2008; Bhag Mal et al. 2010; Bonham et al. 2012; King and Bala Ravi 2012a).

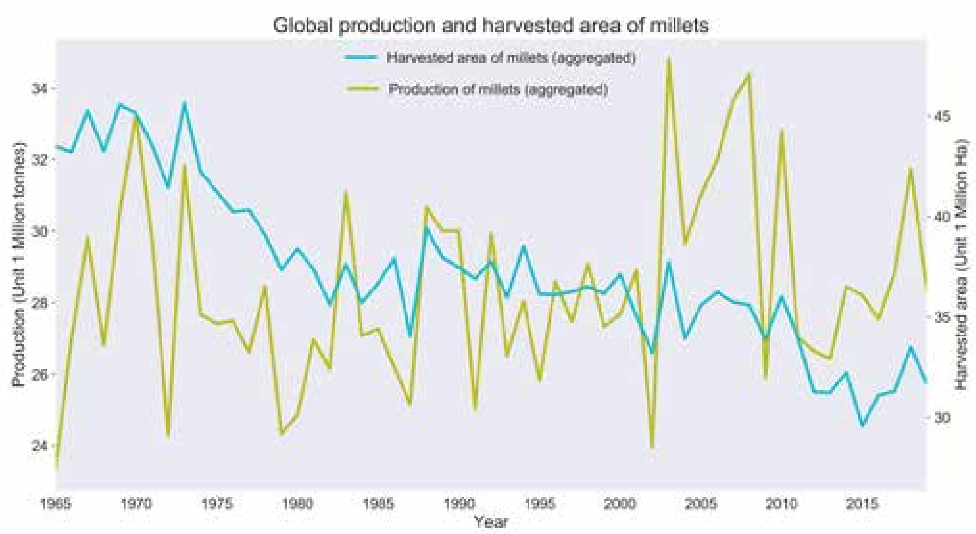


Figure 2.1 Trends in millet production and harvested area. Data Source: FAOSTAT (Apr. 13, 2021)

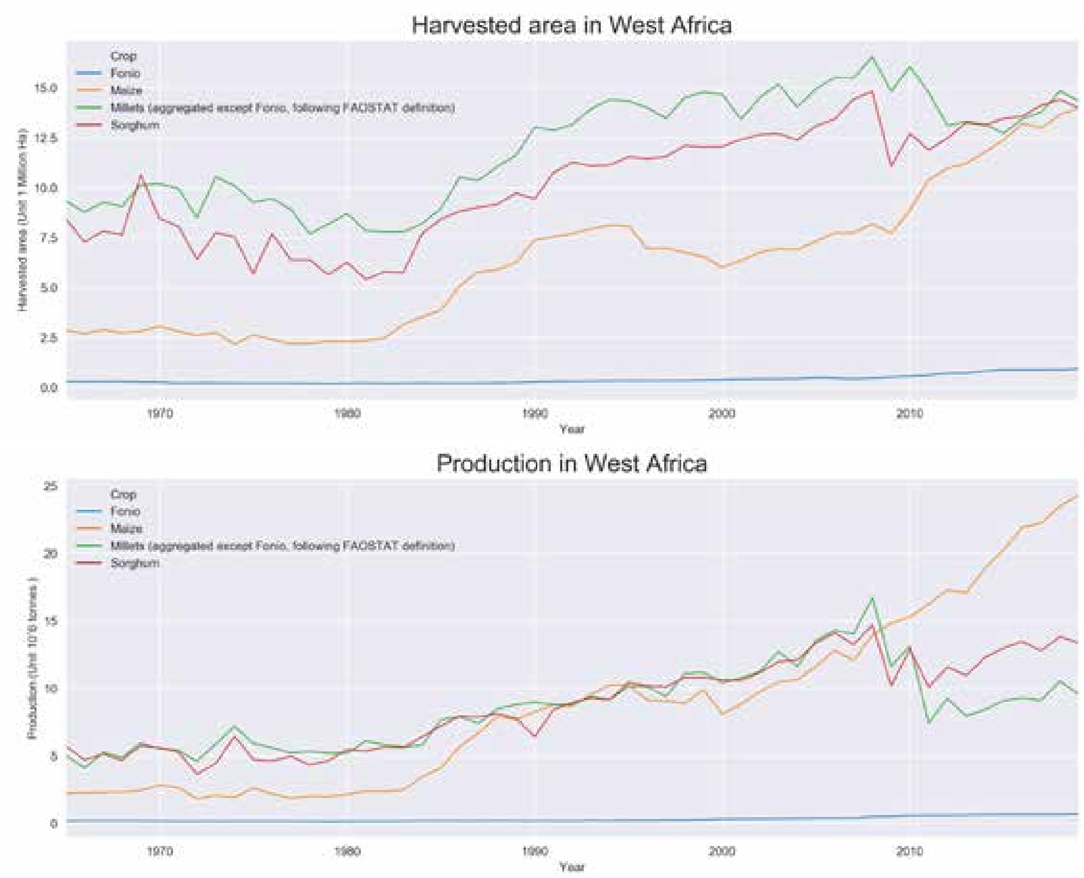


Figure 2.2 Harvested area (above), and production of millets in West Africa. Millets (except fonio) are aggregated following FAOSTAT definition. Data Source: FAOSTAT (Apr. 13, 2021)

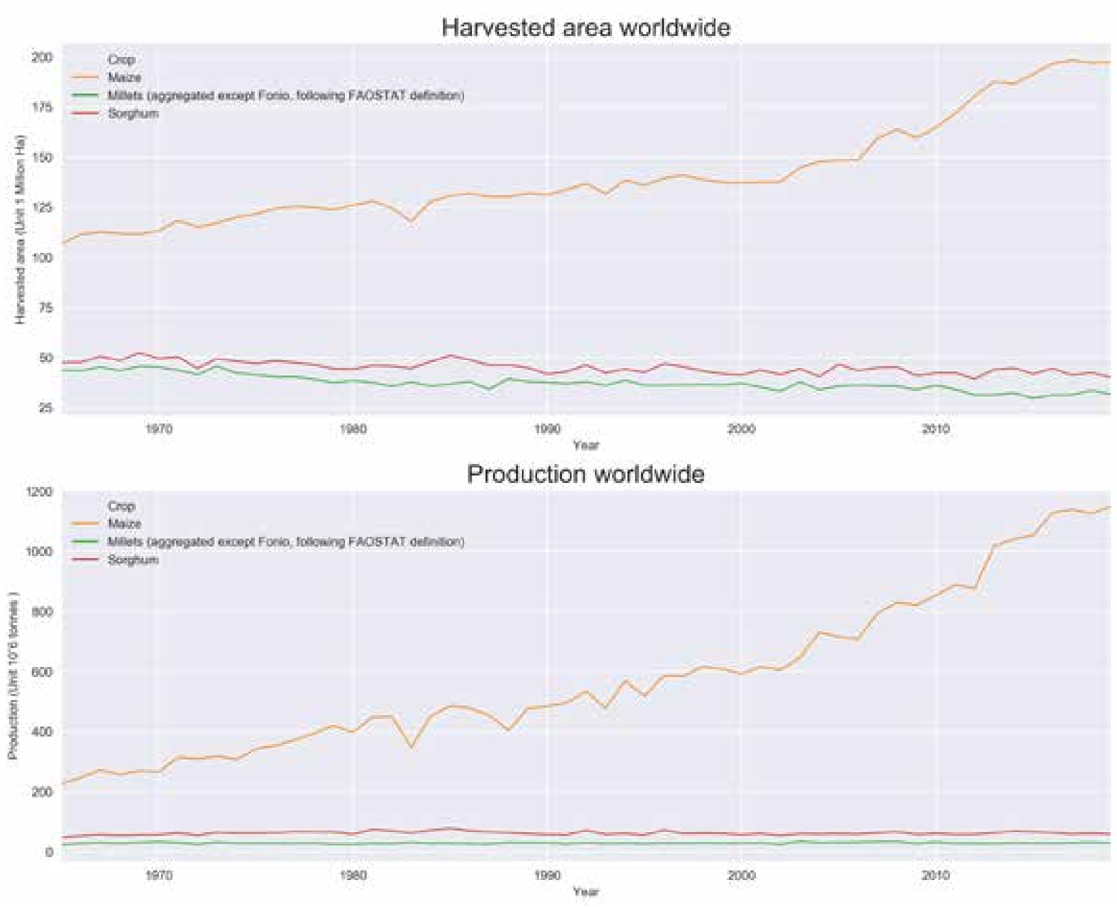


Figure 2.3 Worldwide harvested area (upper panel) and production (lower panel) of millets. Data represent aggregated millets (all except fonio) following FAOSTAT definition. Data source: FAOSTAT (Apr. 13, 2021).

Table 2.1 Proportion of global production and area of production for millets in 2018 for the top producing countries by region (FAOSTAT (Apr. 13, 2021).

Region	Main millet crops grown	Number of countries	% of 2018 global production	% of 2018 global area
West Africa	Pearl millet	16	34.7%	47.5%
South Asia	Pearl millet, proso millet, finger millet, foxtail millet, barnyard millet, little millet, kodo millet	5	38.7%	29.7%
East and Southern Africa	Finger millet, pearl millet, teff (in Ethiopia)	14	14.3%	17.5%
Eurasia	Foxtail millet, proso millet, barnyard millet	6	10.9%	4.7%
Europe	Foxtail millet, proso millet	3	0.2%	0.1%
North America	Foxtail millet, proso millet	1	1.0%	0.5%
Australia	Pearl millet, proso millet	1	0.1%	0.1%
Total		**46**	**99.6%**	**99.5%**

On a global scale, the harvested area of millet declined between 2000 and 2019 (Figure 2.1). Therefore, while millet crops continue to be important to local farmers and consumers, they are considered as minor crops in many countries.

Crop-based statistics on production area, total production, productivity and economic importance are not readily available for individual millet crops at national and global levels, because countries report on millets to FAO as an aggregate crop; the only exception is fonio, which is reported as a separate crop. A few countries also report millet as canary seed, as some or all of their millet production is for birdseed. Some countries report national statistics for individual millet crops, but these statistics are not easily accessed.

Composite statistics from FAO in 2018 were used to determine the top millet-producing countries. Table 2.1 shows the percentage of global production in each region, covering the top 46 millet-producing countries. Table 2.1 lists the main millet crops produced in each region, and highlights the variation in crop composition across regions. For example, in West Africa, only pearl millet is grown, while it is likely that pearl millet and finger millet are grown in East and Southern Africa, and teff is grown only in East Africa. By contrast, the main millet crops grown in Eurasia are foxtail millet, proso millet and barnyard millet. Overall, according to FAOSTAT (Apr. 13, 2021), 26 of these top 46 millet-producing countries account for 97% of the global value of millet, and 10 of the top millet-producing countries are in West Africa, where pearl millet is the main millet crop.

To put the economic importance of millets into perspective Figure 2.2 shows the harvested area, and production for millets in West Africa, the largest region for millet production compared to other crops.

Similarly Figure 2.3 shows the global harvested area (above), and global production for millets compared to other crops.

Fonio is the only millet species that is reported as an individual crop to FAO (FAOSTAT Apr. 13, 2021). Fonio production was reported by nine countries: Benin, Burkina Faso, Côte d'Ivoire, Guinea, Guinea-Bissau, Mali, Niger, Nigeria and Senegal. The total production of fonio in 2018 was about 630,000 mt, produced on about 88,000 ha, which is only 6% of the production of other millets grown in West Africa. The top fonio-producing countries are Guinea and Nigeria, with the former accounting for 76% of global production.

Because millets can produce reliable yields in marginal lands with poor soils and in semi-arid regions, they considered as important crops for climate resilience and food security (Dwivedi et al. 2012). Reviews of millet production and productivity (Dwivedi et al. 2012; Baye 2014; Upadhyaya et al. 2016; Vetriventhan et al. 2016; Hariprasanna 2017; Kanlindogbe et al. 2020; Renganathan et al. 2020; Vetriventhan et al. 2020) have attributed the decline in production of various millet crops to the overall low productivity of local landraces; the lack of research on the development and promotion of new, higher-yielding varieties; and replacement by other crops. Millet crops tend to be replaced by other crops because millets are very laborious to produce and process, and very little machinery is available to reduce the burden. Furthermore, markets outside the local area are limited, as there is little demand for millets as ingredients of processed foods and other products. The trend to replace millets with other crops is threatening the genetic resources of millets, as losses are occurring in areas where most of the diversity is maintained by local farmers.

Farmer in Busia County, Kenya produces finger millet smart foods like these "crackies." Photo: Michael Major for Crop Trust

3 CROP USES

A number of reviews have focused on the production of millets and their uses as food, livestock feed or fodder, birdseed, and as an ingredient in beverages (Dwivedi et al. 2012; Baye 2014; Cruz and Beavogui 2016; Upadhyaya et al. 2016; Vetriventhan et al. 2016); and on their nutritional attributes and health benefits (Dwivedi et al. 2012; Baye 2014; Shadang and Jaganathan 2014; Goron and Raizada 2015; Chandra et al. 2016; Upadhyaya et al. 2016; Vetriventhan et al. 2016; Hariprasanna 2017; Vinoth and Ravindhran 2017; Bhat et al. 2019; Kanlindogbe et al. 2020; Renganathan et al. 2020; Vetriventhan et al. 2020).

Dwivedi et al. (2012) concluded that despite the cultural, nutritional and medicinal value of millet crops, their production and consumption have been declining in traditional production areas, alongside a shift to other crops. This shift needs to be addressed through efforts to increase production and consumption, with a focus on raising public awareness of the nutritional value of millet crops. This should be accompanied by research to boost production and reduce the labor burden of production and post-harvest processing. There is also a need to invest in creating and marketing value-added products. Vetriventhan et al. (2020) concluded that the main steps to promote millet crops are to support production and improve productivity; link farmers to value chains; build consumer awareness; ensure the supply of food products; support other sectors to incorporate millets into products; and ensure policy support.

The FAO has designated 2023 as the International Year of Millets. The Smart Food Initiative (2020) has been established to promote millet crops internationally through a broad international collaboration. The Indian Institute for Millet Research of the Indian Council of Agricultural Research (ICAR) has established a ready-to-eat line of millet products for consumers, "Eatrite" (IIMR 2020). These are just some of the efforts being made to reduce the decline in millet production in many key localities, by growing markets and household consumption of millet-based foods. The decline in traditional household production and consumption is also a threat to millet genetic diversity, which is maintained and used by smallholder farmers. Much of this diversity has not been secured through either *ex situ* or *in situ*/on-farm approaches.

4 CROP EVOLUTION AND DIVERSITY

Several reviews have summarized the taxonomy, domestication and spread, genetic resources and breeding of millet crops. Table 4.1 summarizes the taxonomy, crop evolution and distribution of millets.

Millet crops of African origin

Pearl millet

Pearl millet is an important grain and fodder crop for environments with limited water, high temperatures and low fertility. This crop is grown over about 30 million hectares worldwide, mostly in Africa and Asia (Yadav and Rai 2013).

Oumar et al. (2008) concluded that pearl millet was domesticated from *Pennisetum glaucum* subsp. *monodii* (*Pennisetum violaceum*) in the area from eastern Mali through northwestern Niger to the Aïr Mountains. Tostain (1998) proposed that pearl millet was domesticated around 8000 years before present (YBP) in West Africa, and it spread from there around 4500–5000 YBP. Pearl millet diffused into eastern Africa, southern Africa and South Asia. South Asia is a secondary center of diversity for the crop.

During the domestication of pearl millet, various morphological changes occurred, including suppression of shattering, a reduction in the size of the bristles and bracts, increases in seed size, spikelet pedicel length, and spike length, and a reduction in basal tillering (Poncet et al. 1998).

Clotault et al. (2012) investigated various models for the domestication of pearl millet and considered the role of flowering genes in its adaptation during domestication. They found that cultivated pearl millet maintained 68% of the nucleotide diversity of its wild progenitor, *P. glaucum* subsp. *monodii*. The domestication model with the best fit assumed geneflow between wild and cultivated pearl millet, exponential growth after domestication, and a protracted domestication period. They estimated that domestication started 4,821 YBP, with a 28-fold decrease in the effective population size for the cultivated crop. Thus, the contribution of the wild population to the cultivated peal millet gene pool is only 3.6%, which equates to a moderately severe genetic bottleneck. They reported that a few flowering genes have played a role in changes during domestication.

Hu et al. (2015) reported low nucleotide diversity in pearl millet accessions from individual countries when compared with those from Senegal in West Africa, a finding that is congruent with genetic bottlenecks during the diffusion of the crop outside West Africa. They also reported a relationship between the geographic distance of an accession from West Africa and the level of divergence, indicative of a major effect of the isolation that occurred with diffusion. Novel variation was found in materials from outside West Africa, likely due to adaptation to new environments. In fact, they found a slightly higher level of genetic diversity among global accessions as a whole compared with the Senegalese accessions.

Pearl millet also shows diversity in South Asia. Bonham et al. (2012) reported that farmers in Rajasthan, India, grow approximately 200 distinct landraces of pearl millet (Bonham et al. 2012, page 85), but also that many millet crops have been replaced by other crops.

Pearl millet wild relatives are a source of genetic diversity that can be used in pearl millet breeding and improvement (Sharma et al. 2020). The primary gene pool of pearl millet includes the wild progenitor *P. glaucum* subsp. *monodii* and the secondary gene pool (shown in Table 4.2) includes *Pennisetum purpureum* and *Pennisetum squamulatum*, both of which can be crossed relatively easily with pearl millet (Vincent et al. 2013; Sharma et al. 2020). Assoumane et al. (2018) found that hybridization between wild (*P. glaucum* subsp. *monodii*) and cultivated pearl millet occurs throughout the Sahel where pearl millet is cultivated. They also found that the diversity of wild populations decreases from west to east, and that wild populations group into three clusters corresponding to the western part of West Africa, central West Africa and the eastern part of the Sahel. They concluded that some of the wild diversity could be lost by introgressions with cultivated pearl millet, and it is therefore important to collect these and/or to have reserves of wild diversity that are isolated from cultivated pearl millet.

In conclusion, the process of domestication has resulted in a large pool of genetic diversity within the wild progenitor and cultivated pearl millets in West Africa, as well as in the germplasm of millets from all of the regions they have spread to.

Finger millet

The *Eleusine* genus includes nine annual and perennial grasses, six of which are diploid species and three of which are polyploid species (Agrawal and Maheshwari 2016). *Eleusine* species are mainly distributed in the

Table 4.1 Taxonomy, ploidy levels, progenitors, centers of domestication and current distribution for selected millet crops.

Crop	Tribe	Genus/ species	Subspecies/ race	Ploidy level	Progenitor	Center of domestication	Current distribution
Pearl millet	Paniceae	*Cenchrus americanus* (L.) Morrone (syn. *Pennisetum glaucum* (L.) R.Br.)	subsp. *violaceum;* subsp. *stenostachyum*; subsp. *glaucum*, races: *typhoides, nigritarium, globosum, leonis*	2n=2x=14	subsp. *violaceum*	Eastern Mali to western Niger	Arid and semi-arid regions of Africa and South Asia
Finger millet	Eragrosteae	*Eleusine coracana* (L.) Gaertn.	subsp. *africana*, races: *africana, spontanea*; subsp. *coracana*, races: *elongata, plana, compacta, vulgaris*	2n=4x=36	subsp. *africana*	Western Uganda, Ethiopian Highlands	Uganda, Kenya, Sudan, Ethiopia, Eritrea, Zambia, Zimbabwe, India, Malawi, Madagascar, Rwanda, Burundi, Nepal, Myanmar, China, Sri Lanka
Foxtail millet	Paniceae	*Setaria italica* (L.) P. Beauv.	Races: *moharia, maxima, indica, nana*	2n=2x=18	*Setaria viridis*	China, Europe, Afghanistan to Lebanon	China, India, Nepal, Afghanistan, Korea, Japan, Russia, USA, France
Proso millet (broomcorn millet or common millet)	Paniceae	*Panicum miliaceum* L.	Races: *miliaceum, patentissimum, contractum, compactum, ovatum*	2n=4x=36	*Panicum capillare, Panicum repens*	China, Europe	India, China, Japan, Russia, Afghanistan, Iran, Iraq, Syria, Turkey, Mongolia, Romania, USA
Japanese barnyard millet	Paniceae	*Echinochloa crus-galli* (L.) P. Beauv.	subsp. *crus-galli*, races: *crus-galli, macrocarpa*; subsp. *utilis*, races: *utilis, intermedia*	2n=6x=54	subsp. *crus-galli*	Japan	Temperate Eurasia, mainly China, Japan, Korea
Indian barnyard millet	Paniceae	*Echinochloa colona* (L.) Link	subsp. *colona*, no races; subsp. *frumentacea*, races: *stolonifera, intermedia, robusta, laxa*	2n=6x=54	subsp. *colona*	India	Tropics and subtropics of Asia and Africa
Little millet	Paniceae	*Panicum sumatrense* Roth ex. Roem & Schult.	subsp. *psilopodium*; subsp. *sumatrense*, races: *nana, robusta*	2n=4x=36	subsp. *psilopodium*	Eastern Ghats of India	India, Nepal, Myanmar, Sri Lanka
Kodo millet	Paniceae	*Paspalum scrobiculatum* (L.)	Race: *regularis, irregularis, variabilis*	2n=4x=40		India	Upland rice regions in India, Indonesia, Philippines, Thailand, Vietnam, Bangladesh, Myanmar; as a wild annual cereal in West Africa and India
Teff	Eragrosteae	*Eragrostis tef* (Zucc.) Trotter		2n=4x=40	diploid ancestor unknown	Northern highlands of Ethiopia	Ethiopia, Eritrea, South Africa, Kenya, USA, Canada, Netherlands
Fonio	Paniceae	*Digitaria exilis* Stapf		2n=36		Mountainous regions of Fouta-Djalon in Guinea	West African Savannah from Senegal to Lake Chad in West Africa; Dominican Republic
Black fonio	Paniceae	*Digitaria iburua* Stapf.		2n=36		Nigeria	Nigeria, Benin, Togo
Job's tears	Andro-pogoneae	*Coix lacryma-jobi* L.		2n=10, 20, 30		Southern and East Asia	Myanmar, China, India, Malaysia, Philippines, Thailand, Taiwan, Brazil
Guinea millet	Paniceae	*Urochloa deflexa* (Schumach.) H. Scholz.		2n=18, 36		Semi-domesticated weed of West Africa	Guinea, Sierra Leone
Browntop millet	Paniceae	*Urochloa ramosa* (L.) T.Q. Nguyen		2n=2x=18, 2n=2x=36, 72		Southeast Asia	India

Crop	Tribe	Genus/ species	Subspecies/ race	Ploidy level	Progenitor	Center of domestication	Current distribution
Haze or wild fonio	Paniceae	*Panicum laetum* Kunth.				Wild stands in Mauritania, Senegal, Gambia	Eastward from Mauritania along southern Sahara and Sahel to Eritrea
Early barnyard millet	Paniceae	*Echinochloa oryzoides* (Ard.) Fritsch.				Weed in rice field in China and Southeast Asia	Native range from Caucasus to Japan and the Philippines but introduced in many areas globally

Sources: This table compiles information from various reviews: all millet crops: Dwivedi et al. (2012); small millets: Vetriventhan et al. (2020), Goron and Raizada (2015); pearl millet: Yadav et al. (2017); barnyard millets: Renganathan et al. (2020), Sood et al. (2015); kodo millet: Hariprasanna (2017); proso millet: Habiyaremye et al. (2017); fonio: Kanlindogbe et al. (2020), Abrouk et al. (2020), Cruz and Beavogui (2016); teff: Assefa et al. (2017).

Table 4.2 Confirmed and potential uses of priority wild relatives of pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). Confirmed uses are in bold. Gene pool category for *Eleusine* species are from Sood et al. (2019)

Species	Gene pool	Confirmed or potential use
P. glaucum subsp. *monodii*, synonym: *P. violaceum* (Lam.) Rich.	Primary	**Dry matter yield; yield improvement; leaf spot resistance; rust resistance**; Striga resistance; **cytoplasmic male sterility; days to maturity**
P. purpureum Schumacher	Secondary	**Cytoplasmic male sterility; fertility restoration genes; panicle length; days to maturity**; dry matter yield
P. squamulatum Fresen.	Secondary	**Fertility restoration genes**; apomixis
Eleusine africana K. O'Byrne, synonym: *E. coracana* subsp. *africana*	Primary	**Gene transfer**; blast resistance; micronutrients content; protein content
Eleusine indica (L.) Gaertn.	Secondary	–
Eleusine kigeziensis S.M. Phillips	Tertiary	**Gene transfer**
Eleusine floccifolia (Forssk.) Spreng.	Secondary	–
Eleusine intermedia (Chiov.) S. M. Phillips	Tertiary	–
Eleusine tristachya (Lam.) Lam.	Secondary	–
Eleusine jaegeri Pilger	Tertiary	–
Eleusine multiflora Hochst. ex A. Rich.	Tertiary	–
Ochthochloa compressa (Forssk.) Hilu	Tertiary	–

subtropical parts of Africa, Asia and South America. They are all wild except for *Eleusine coracana* (finger millet), which is mostly cultivated in East Africa, but also in India, Nepal, China and Myanmar. The center of diversity for *Eleusine* is East Africa, where eight of the nine species in this genus are found; i.e., *Eleusine africana*, *Eleusine coracana*, *Eleusine indica*, *Eleusine intermedia*, *Eleusine jaegeri, Eleusine kigeziensis, Eleusine floccifolia* and *Eleusine multiflora* (Agrawal and Maheshwari 2016).

The cultivated species *E. coracana*, referred to by many authors as *E. coracana* subsp. *coracana,* was domesticated in the region corresponding to the highlands in Ethiopia and Uganda from the wild species *E. africana* (also referred to as *E. coracana* subsp. *africana*) (Neves et al. 2005; Dida et al. 2008; Agrawal and Maheshwari 2016). Finger millet then spread to the lowlands of eastern and southern Africa and was taken to India through sea trade routes about 1000 BC. India is now considered a secondary center of diversity (Hilu et al. 1979).

Zhang et al. (2019) demonstrated that *E. indica* is the maternal genome donor of *E. coracana* and they also identified a maternal relationship between *E. indica* and *Eleusine tristachya*. They hypothesized that *E. africana* could be an autotetraploid resulting from the doubling of *E. indica* or the product of hybridization between *E. indica* and *E. tristachya*, but this has not been confirmed.

Dida et al. (2008) assessed the level of divergence and clustering for a set of accessions from Africa and Asia. They concluded that the level of diversity was highest within the wild subspecies and lowest among accessions from Asia. The accessions were clustered into three subpopulations: subsp. *africana*, African subsp. *coracana* and Asian subsp. *coracana*. There was evidence of a domestication bottleneck in Africa and of a second bottleneck between African and Asian germplasm of cultivated finger millet. They also found that about 10% of the accessions were admixtures that could be predicted as genotypes from crosses among the three subpopulations. They also concluded that the wild subspecies are a very important source of diversity for the breeding of finger millet in the future (Dida et al. 2008). A similar geographical pattern among finger millet accessions was also reported by Panwar et al. (2010). Kumar et al. (2016) analyzed 113 finger millet accessions and detected three subpopulations, as well as genotypes with admixtures of alleles (from different populations) ranging from 10% to 55%.

Overall, studies on diversity patterns and population structure have found that accessions cluster together based on their country of origin and on the ecology of the collection site (lowlands versus highlands) (Fakrudin et al. 2004; Dida et al. 2008; Panwar et al. 2010; Arya et al. 2013; Kumar et al. 2016).

Teff

Eragrostis tef (teff) is the only cultivated species in the *Eragrostis* genus. Teff was domesticated in Ethiopia and has been widely cultivated in the Horn of Africa (Ethiopia and Eritrea). In a review of the morphological and molecular diversity of teff, Assefa et al. (2015) concluded that teff is an allotetraploid with a close relationship to *Eragrostis pilosa*, a wild allotetraploid. An assessment of phenotypic diversity among diverse accessions (Assefa et al. 2015) revealed high overall phenotypic diversity for many traits, with greater variation in phenotypes within regions than among regions. Some studies detected an impact of the altitude of the collection site on the diversity of some traits, but others did not detect this relationship (Assefa et al. 2015). Using simple sequence repeat (SSR) markers, Abraha et al. (2016) assessed the diversity of 60 accessions of teff that included 33 improved varieties from six regional centers, 18 landraces from five diverse teff-growing regions, and nine new accessions collected from northern Ethiopia. The highest level of diversity was within the landraces and the lowest was within the new accessions from northern Ethiopia. There was a high degree of diversity among the improved varieties, which indicated the breeders' use of diverse parental material. In a clustering analysis, the accessions from the three groups did not cluster on the basis of the three types of accessions.

Fonio

The term fonio refers to a number of species belonging to the *Digitaria* genus that are grown for their edible grain: *D. exilis* (white fonio), *D. iburua* (black fonio), *Digitaria sanguinalis* (known as hairy crabgrass in Europe) and *Digitaria cruciata* (raishan in Northeast India). *D. exilis* is the most widely cultivated among these species and is mainly grown in West Africa. *D. exilis* was likely domesticated in the central delta of the Niger River, and its putative wild progenitor is *Digitaria longiflora* (Abrouk et al. 2020; Hilu et al. 1997). West Africa has remained the region where fonio is mostly widely grown (FAOSTAT; Adoukonou-Sagbadja et al. 2006; Adoukonou-Sagbadja et al. 2007).

Abrouk et al. (2020) assessed a diversity panel of 166 *D. exilis* accessions and 17 *D. longiflora* accessions that were selected from a collection of 641 georeferenced accessions collected by IRD during 1977–1988. They found that *D. exilis* is genetically closer to *D. longiflora* accessions from Southern Togo and West Guinea. They also found evidence for a genetic bottleneck from domestication and the expansion of fonio cultivation into other areas of West Africa. They concluded that climate, geography, ethnicity and language have shaped the genetic population structure of fonio.

In an analysis of genetic diversity and population differentiation among 122 accessions that included both white and black fonio, Adoukonou-Sagbadja et al. (2007) found a clear separation between the two species and identified three groups related to ecotype or geographic origin.

In a study conducted in 55 villages in Togo, Adoukonou-Sagbadja et al. (2006) documented 42 fonio landraces but pointed out that fonio production in Togo is declining. Dansi et al. (2010) conducted a similar study covering 15 villages in Benin, and recorded 15 "farmer-named landraces" that could be grouped in five morphotypes. Kanlindogbe et al. (2020) conducted a systematic review and analysis of the literature on fonio genetic resources and varietal breeding and presented evidence of genetic erosion of fonio in its center of diversity caused by its substitution with other crops.

Millet crops of Eurasian origin

Foxtail millet

The genus *Setaria* includes 104 accepted species and 118 taxa (The Plant List 2013) that can be found in temperate, subtropical and tropical areas (Rominger 1959).

It is estimated that foxtail millet (*S. italica*) was domesticated in China around 8700 YBP (Lu et al. 2009; Wang et al. 2010) and green millet (*Setaria viridis*) is its wild progenitor (Wang et al. 2010; Fukunaga et al. 2003). Both *S. viridis* and *S. italica* are diploid species. From eastern Asia, foxtail millet spread into central Asia and then into western Asia and Europe (Dong et al. 2017; Stevens et al. 2016). The spread of foxtail millet into Yemen and Sudan followed a route that was travelled in reverse by pearl millet and finger millet as they moved from Africa to Asia (Stevens et al. 2016).

In a study on accessions of foxtail and green millet, Wang et al. (2010) reported that foxtail millet contained only 55% of the diversity of its progenitor, indicative of a domestication bottleneck. They also found that foxtail millet shared a high proportion (75%) of polymorphisms with its progenitor.

Wang et al. (2012) evaluated the diversity among 250 accessions of foxtail millet landraces collected from all the production areas in China. The average number of alleles per locus was high, as expected given that the crop was domesticated in China. Their findings were consistent with the hypothesis that foxtail millet was domesticated in the Yellow River region, which is also supported by archaeological evidence (Barton et al. 2009). They also found a subpopulation genetic structure among the accessions that was consistent with recognized ecotypes and ecoregions. They recognized two foxtail millet centers of diversity; one in the spring sowing region, and the other in the summer-spring sowing region.

Jia et al. (2013) assessed the diversity among 288 wild or green foxtail millets using the same set of SSR markers that Wang et al. (2012) used to analyze a set of cultivated foxtail millets; their accessions of wild foxtail millet corresponded to those of the cultivated landraces. They found that 69 of the 77 SSR markers were amplified from the wild foxtail millets, and that the number of alleles per locus was almost 60% higher in the wild foxtail millets. Compared with the cultivated foxtail millet accessions, the wild accessions had a lower allele frequency and higher number of private alleles. These findings were indicative of a significant loss of genetic diversity through domestication. The wild foxtail millets formed two clusters that were not consistently associated with ecoregions. The results of Jia et al. (2013) also supported the theory that domestication occurred in northern China, where there is high diversity among local wild accessions. Chander et al. (2017) found much less diversity among a set of landraces from India, and less differentiation among subpopulations based on their geographic origin.

Proso millet

Proso millet is a tetraploid species in the genus *Panicum*, which comprises 439 accepted species (The Plant List 2013). Researchers have proposed several sites for the origin and domestication of proso millet. Currently, the evidence suggests that it was domesticated in China and possibly also in Europe (Hunt et al. 2011; Johnson et al. 2019). Researchers detected some relationships between population structure and the geographic origins of proso millet accessions (Hunt et al. 2011; Rajput and Santra 2016). Vetriventhan and Upadhyaya (2018) analyzed variations in morpho-agronomic traits and grain nutrient contents in the proso millet germplasm and found that the geographical regions, country of origin and race were related to the pattern of diversity.

Millet crops of Asian origin

Barnyard millet

The term barnyard millet refers to two cultivated species, *Echinochloa frumentacea* and *Echinochloa esculenta*, which are also known as Indian and Japanese barnyard millet, respectively (Goron and Raizada 2015). *E. frumentacea* (synonym: *E. colona* subsp. *frumentacea*) was domesticated from *E. colona* (synonym: *E. colona* subsp. *colona*) and is cultivated in tropical and subtropical areas of Africa and Asia, especially in India, Tanzania, Central Africa Republic and Malawi (Gupta et al. 2009; Sood et al. 2015; Wallace et al. 2015).

De Wet et al. (1983b) distinguished four races of *E. frumentacea* based on morphological differences. *E. esculenta* was domesticated in eastern Asia from *E. crus-galli* (Goron and Raizada 2015). Traditionally, it was grown in areas unsuitable for the cultivation of rice, especially in Japan (Goron and Raizada 2015). Wallace et al. (2015) genotyped a core collection of 89 accessions of Indian and Japanese barnyard millet. Analyses of the population structure revealed a clear separation of the two species, with four different subgroups in Indian barnyard millet and three subgroups in Japanese barnyard millet. However, these subgroups were not related to the morphological races of Indian and Japanese barnyard millets.

Little millet

Little millet (*P. sumatrense)* was domesticated in India (de Wet et al. 1983a) from *P. sumatrense* subsp. *psilopodium*, and is mainly cultivated in South and Southeast Asia, especially India, Nepal, Pakistan and Myanmar (Dendy 1995; Johnson et al. 2019). There are two morphologically distinct races of little millet: nana and robusta (de Wet et al. 1983a). Each of these races is classified in two further subraces (Johnson et al. 2019). Johnson et al. (2019) assessed the genetic diversity within 165 accessions of little millet and found eight putative subpopulations that were unrelated to their race classification.

Kodo millet

Wild *P. scrobiculatum* grows in tropical and subtropical areas of Africa and Asia. Its cultivated form (kodo millet) was domesticated in India, were it is predominately grown (Goron and Raizada 2015; de Wet et al. 1983b). A small-seeded and a large-seeded variety of cultivated kodo millet are recognized in India (de Wet et al. 1983b), and three different races can be distinguished based on inflorescence morphology (Johnson et al. 2019). Assessment of the population structure in 165 accessions using single nucleotide polymorphic markers detected seven subpopulations, five of which clustered together, while the other two were separated. There was no correspondence between the morphological races based on inflorescence structure and the clusters detected using molecular markers. M'Ribu and Hilu (1996) used molecular markers to show that kodo millet accessions from Africa were distinct from kodo millet accessions from India.

Farmer in Kakamega County, Kenya examining the panicle of a wild finger millet. Photo: Michael Major for Crop Trust

5 *IN SITU* CONSERVATION OF CROP WILD RELATIVES

The degree of threats to 35 *Pennisetum/Cenchrus* CWR was examined using the IUCN Red List database (accessed 21 April 2020). Of these 35 species, 29 are classified as Least Concern (82.9%), three as Endangered (8.6%), two as Data Deficient (5.7%) and one as Extinct (2.9%). Only three of the priority CWR of *Pennisetum* have been assessed; *P. orientale* and *P. purpureum* are classified as Least Concern and *P. squamulatum* as Data Deficient. Only six *Eleusine* CWR are recorded in the IUCN Red List database (as at 21 April 2020), of which four are classified as Least Concern (66.7%) and two as Data Deficient (33.3%) (Annex 6).

For the six minor millets (see Table 5.1), a total of 102 taxa are on the IUCN Red List (as at 21 April 2020; Annex 6), with 70.6% of them the Least Concern category. Of the 13 *Digitaria* spp. (fonio) assessed, seven are classified as Least Concern and four as Data Deficient, with one each in the categories Vulnerable and Endangered. Of the 30 *Eragrostis* spp. (teff) assessed, 19 species fall under Least Concern and two under Data Deficient, with three taxa in each of the categories Vulnerable, Endangered and Critically Endangered. For *Echinochloa* spp. (barnyard millet) and *Setaria* spp. (foxtail millet), all the six and four assessed taxa, respectively, were of Least Concern. Of the 28 *Panicum* spp. (proso millet) assessed, 17 were of Least Concern, with one classified as Near Threatened, two as Endangered and three each in the Vulnerable and Critically Endangered categories (the remaining two were in the Data Deficient category). For *Paspalum* spp. (kodo millet), 17 of the 21 assessed taxa were categorized as Least Concern, and one as Near Threatened, one as Vulnerable and two as Endangered.

The occurrence data of millet CWR in the Global Biodiversity Information Facility (GBIF) (www.gbif.org, accessed 26 October 2020) were analyzed to map the distribution of the CWR of various millets (pearl millet, finger millet and six minor millets) and to study their coverage within protected areas. The data are summarized in Table 5.1.

In total, 59 records of *Pennisetum* and *Cenchrus* CWR were found, including the cultivated species, *Pennisetum glaucum* (synonym: *Cenchrus americanus*). A total of 11,382 entries were retrieved for all *Pennisetum* species (as accepted name), including 8,598 records of the cultivated species. After excluding entries for the cultivated *Pennisetum* along with invalid coordinates, duplicates or entries with no coordinates, only 2,784 valid entries remained. These valid entries represented 41 wild relatives that were spread mainly across Africa and Australia, with some in India and a few countries in South America (Figure 5.1).

Vincent et al. (2013) estimated CWR relatedness for 173 priority crops including millets, in order to define priority CWR species for the priority crops. In their assessment, only five CWR of pearl millet were prioritized for conservation: *Pennisetum orientale*, *P. purpureum*, *P. squamulatum*, *P. polystachion* and *P. violaceum.* After invalid and duplicated coordinates for these five priority *Pennisetum* CWR were removed, only 490 valid and unique occurrences were

Table 5.1 Summary of data extracted from GBIF for major and minor millet species.

Millet type	No. of records	Total no. of entries	No. of valid entries	No. of CWR
Pearl millet	59	11,382	2,784	41
Finger millet	23	4,203	644	8
Minor millets (6 species): fonio (*Digitaria* sp.), barnyard millet (*Echinochloa* sp.), proso millet (*Panicum*), foxtail millet (*Setaria*), teff (*Eragrostis* sp.), kodo millet (*Paspalum* sp.)		14,293	8,629	4

Source: Global Biodiversity Information Facility (GBIF) (www.gbif.org, accessed 26 October 2020) retrieved. According to these data, 49 countries have *Pennisetum* priority CWR, with Mali (69), Niger (55) and Côte d'Ivoire (51) having the highest number of valid, nonduplicated occurrences recorded on GBIF (as at 26 October 2020). Among the five priority species, *P. polystachion* has the most records (243 occurrences), followed by *P. violaceum* (151) and *P. purpureum* (83). According to Vincent et al. (2013), five of the *Pennisetum* wild species are of global priority for *in situ* conservation. Cameroon, Democratic Republic of the Congo (DRC), Ethiopia and India, each have three of the five priority CWR species, which is the greatest diversity recorded (as at 26 October 2020).

Very few occurrences of the five priority CWR of *Pennisetum* recorded from GBIF occur in protected areas. For example, in Cameroon, which has three of the priority species (*P. polystachion*, *P. purpureum*, *P. violaceum*), none of the records are related to protected areas (Figure 5.2). DRC, also one of the countries with the highest number of different priority CWR species, also has only single record for each priority species (*P. polystachion*, *P. purpureum*, *P. squamulatum*), none of which is found in a protected area. Mali, which has the highest number of data occurrences recorded in GBIF, but only two different priority species (*P. polystachion*, *P. violaceum*), shows a similar trend, with only two occurrences within protected areas (Figure 5.3).

For *Eleusine* CWR species, 23 records were retrieved from GBIF, including the cultivated species, *Eleusine coracana* (as at 28 October 2020). A total of

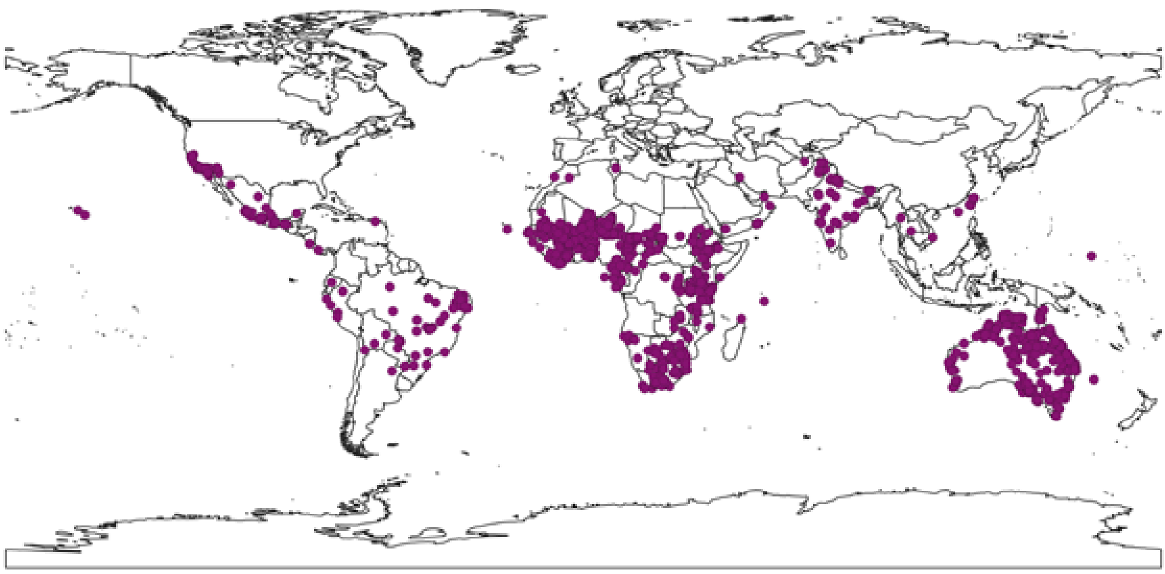


Figure 5.1 Global distribution of valid GBIF occurrences recorded for 41 *Pennisetum* crop wild relative species. (Data source: www.gbif.org, accessed 26 October 2020)

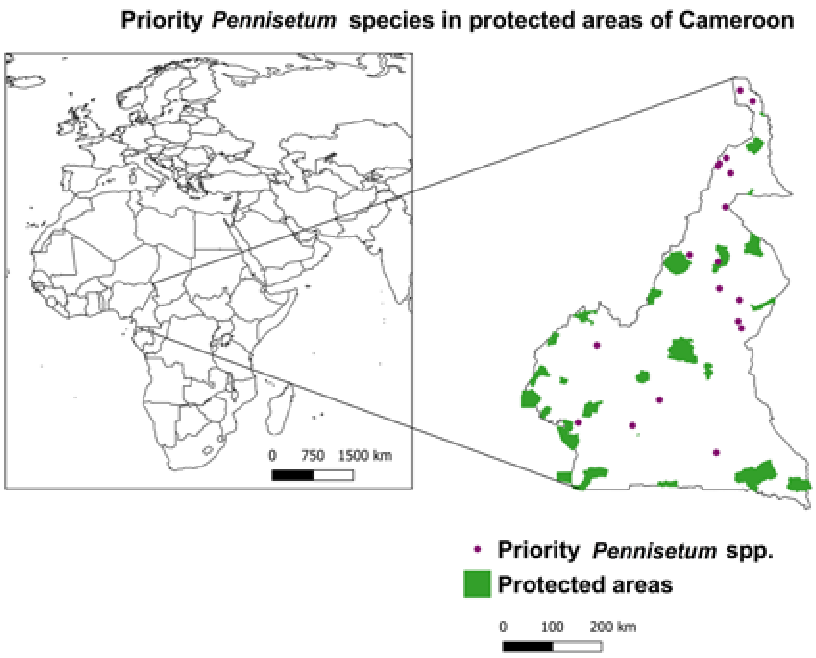


Figure 5.2 Occurrence data of three priority crop wild relatives of *Pennisetum* spp. within and outside protected areas of Cameroon. (Data sources: www.gbif.org and World Database on Protected Areas -WDPA -, accessed October 2020)

4,203 entries were retrieved for all *Eleusine* species, including 2,992 records of the cultivated species. After excluding the occurrences of the cultivated *Eleusine* as well as invalid coordinates, duplicates or entries with no coordinates, only 644 valid entries remained. These represented eight wild relatives that were spread mainly across Africa and Australia, followed by South America and Asia (Figure 5.4).

For finger millet, only six CWR were prioritized for *in situ* conservation (Vincent et al. 2013): *Eleusine africana*, *E. floccifolia*, *E. indica*, *E. intermedia*, *E. kigeziensis* and *E. tristachya*. For these six species, a total of 476 valid and unique occurrences were retrieved (invalid and duplicate coordinates were removed). The data show 62 countries with *Eleusine* priority CWR, with Australia (163), USA (60) and Taiwan (58) having the highest number of valid, nonduplicated occurrences (accessed 28 October 2020). Among the six priority species, *E. indica* has the most occurrences (373 data points), followed by *E. tristachya* (49) and *E. africana* (41). Very few data points are recorded for *E. floccifolia* (8), *E. intermedia* (3) and *E. kigeziensis* (2). Most of the 62 countries (95.2%) with records of the six priority CWR species of finger millet had either one or two species only. Ethiopia had the highest number of different species, with four (*E. africana, E. floccifolia*, *E. indica*, *E. intermedia*). Kenya (*E. africana*, *E. indica*, *E. intermedia*) and USA (*E. africana*, *E. indica*, *E. tristachya*) each had three of the priority species (accessed 26 October 2020).

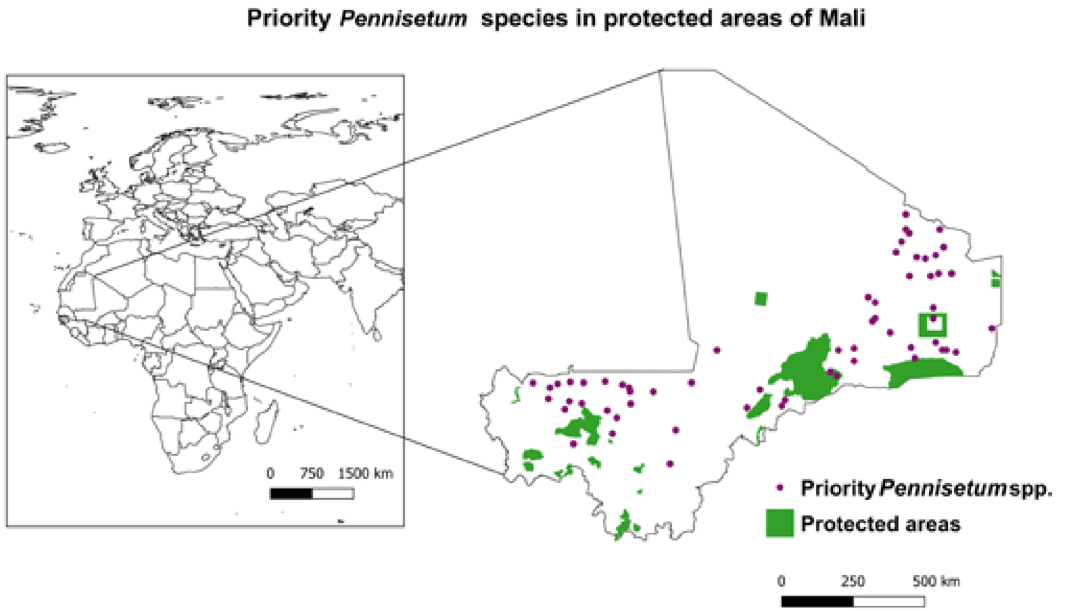


Figure 5.3 Occurrence data of two priority crop wild relatives of *Pennisetum* spp. within and outside protected areas of Mali. (Data sources: GBIF and WDPA, accessed October 2020)

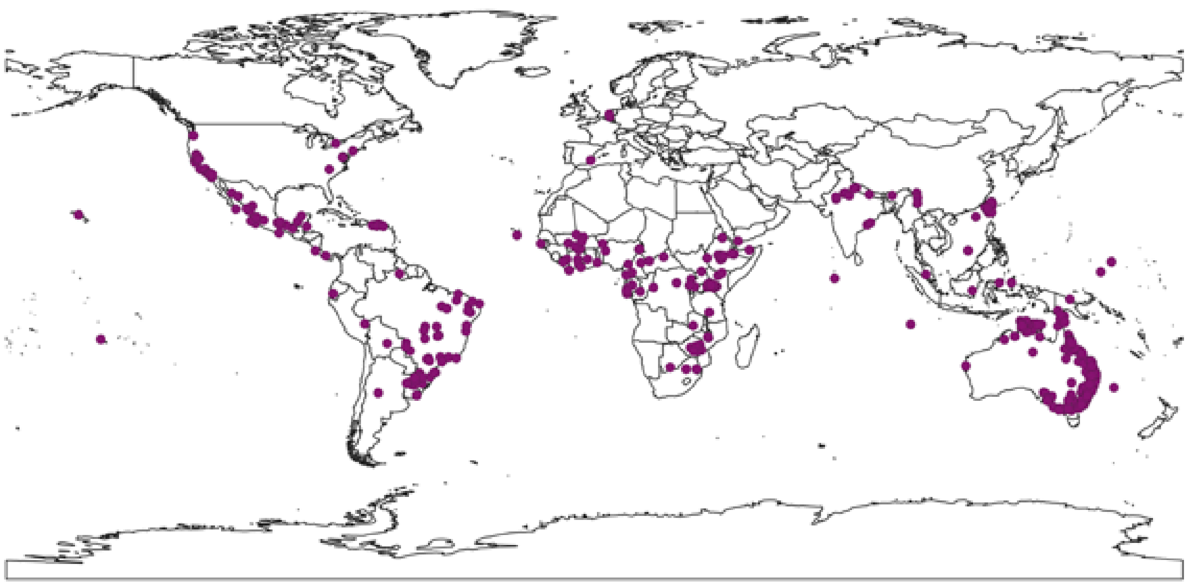


Figure 5.4 Global distribution of valid GBIF occurrences for eight *Eleusine* crop wild relative species. (Data source: GBIF, accessed 28 October 2020)

Few occurrences of the six priority CWR of *Eleusine* are in protected areas. For example, Ethiopia and Kenya, which have four and three of the global priority *Eleusine* species, respectively, each has only two data points within protected areas; another two appear to be at the edge of protected areas of Ethiopia, and in Kenya, four of the data points (44.4% of the total occurrences retrieved) were within or in close proximity of protected areas (Figure 5.5). In contrast, in Australia, which has the highest number of records (163) in GBIF, but only two of the priority species (*E. indica* and *E. tristachya*), most of the occurrences appear to be within or around protected areas (Figure 5.6).

For the six minor millets, a total of 14,293 entries were retrieved from GBIF (accessed 28 October 2020). After data cleaning, 8,629 valid records remained for only four minor millets: *Digitaria*, *Echinochloa*, *Panicum* and *Setaria* (Figure 5.7). No occurrences were found for *Eragrostis* and *Paspalum*. In terms of CWR for each of the four cultivated minor millets, the GBIF records included 115 spp. for fonio (*Digitaria*), 32 spp. for barnyard millet (*Echinochloa*), 203 spp. for proso millet (*Panicum*) and 60 spp. for foxtail millet (*Setaria*). *Panicum* spp. were the most recorded with 3,178 entries, followed by *Digitaria* spp., *Setaria* spp. and *Echinochloa* spp. with 2,585, 1,618 and 1,248 entries, respectively.

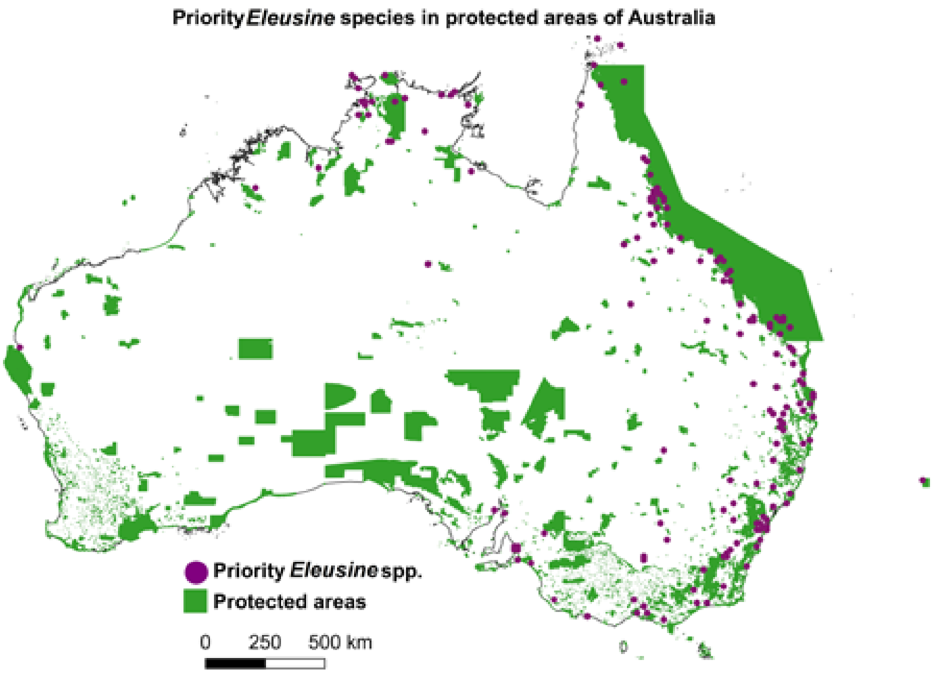


Figure 5.6 Occurrence data of two priority crop wild relatives of *Eleusine* spp. within and outside protected areas of Australia. (Data sources: GBIF and WDPA, accessed October 2020)

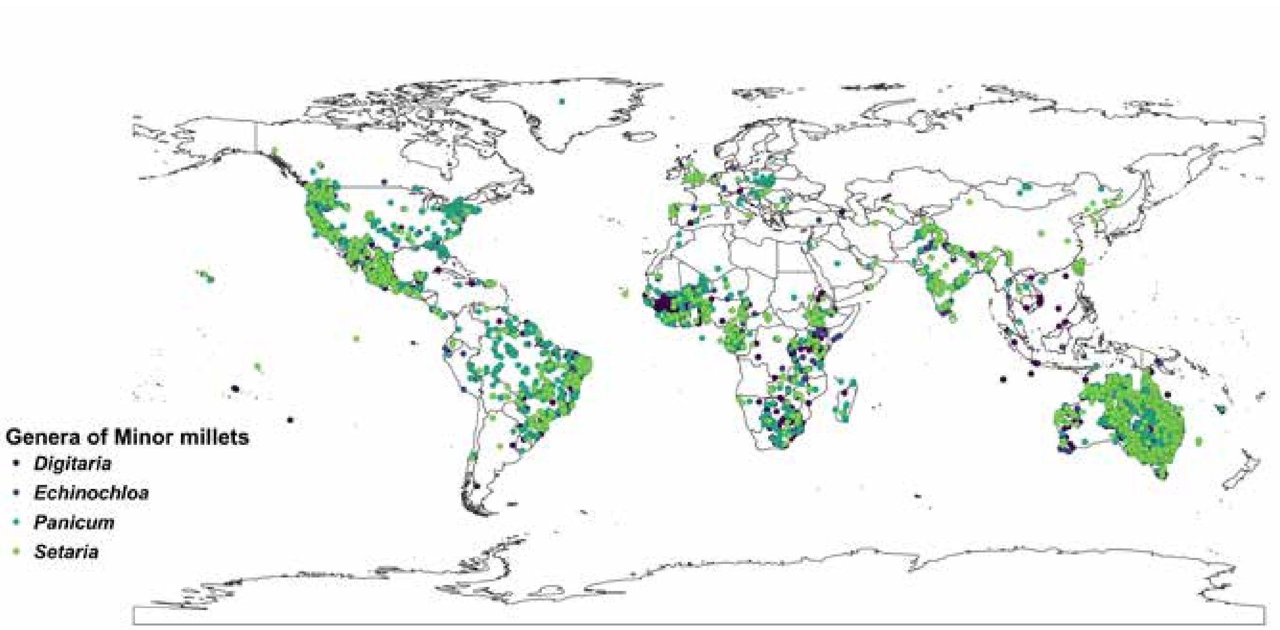


Figure 5.7 Distribution of all valid GBIF occurrences recorded for the crop wild relatives of four genera of minor millets (Data source: www.gbif.org, accessed 28 October 2020)

Farmers displaying a wild finger millet in their finger millet field in Kakamega County, Western Kenya. Photo: Michael Major for Crop Trust

6 ON-FARM CONSERVATION OF LANDRACES

In this section, we review the status of *in situ* conservation and on-farm management of the main cultivated millets, namely pearl millet (*Pennisetum glaucum* (L.) R. Br. / *Cenchrus americanus* (L.) Morrone) and finger millet (*Eleusine coracana* (L.) Gaertn.) and their wild relatives. We also consider other small millets, namely foxtail millet (*Setaria italica* (L.) P. Beauv.), kodo millet (*Paspalum scrobiculatum* L.), proso millet (*Panicum miliaceum* L.), barnyard millet (*Echinochloa* spp.), little millet (*Panicum sumatrense* Roth), fonio (*Digitaria exilis* (Kippist) Stapf and *Digitaria iburua* Stapf) and teff (*Eragrostis tef* (Zucc.) Trotter).

The management of these millet genetic resources *in situ* and on farm is of great importance for ensuring the food security and livelihoods of local communities living in the semi-arid regions of Africa and Asia. Nevertheless, there is very little active on-farm management of millet landraces and practically no *in situ* conservation of millet wild relatives. Local landraces of millets are being displaced by more profitable crops and improved millet varieties. However, some notable initiatives have been implemented to promote the conservation of local millet. At the turn of the 21st century, there were two major global on-farm conservation projects, coordinated by Bioversity International (now Alliance of Bioversity International and CIAT) that greatly promoted and enhanced on-farm diversity of small millets in India and Nepal (Bhag Mal et al. 2010; Jarvis et al. 2011; Padulosi et al, 2015).

The global on-farm project “Strengthening the scientific basis of *in situ* conservation of agrobiodiversity,” funded by the International Development Research Centre and the governments of Switzerland (Swiss Agency for Development and Cooperation) and the Netherlands (Directorate-General for International Cooperation), was implemented in nine countries, including Nepal and Burkina Faso. In Nepal, the project led to better understanding of the *in situ* conservation of small millets, among other crops (Jarvis et al. 2011). The project was implemented by the Nepal Agricultural Research Council and Local Initiatives for Biodiversity, Research and Development (LI-BIRD). The partners worked with local communities, and a multi-stakeholder platform was established in which participatory methodologies were used to study *in situ* conservation of agrobiodiversity on farm (Subedi et al. 2013). In Burkina Faso, the project also examined women’s roles in *in situ* conservation of local crops, including millets (Dossou et al. 2004). They showed that women are involved in the on-farm management of local landraces, including in selecting varieties and contributing to field work, processing techniques, marketing and distribution. In effect, women play an important role in maintaining local traditions, and they help to combine culture, economy and environment to derive direct and indirect benefits from *in situ* conservation (Dossou et al. 2004).

As part of the IFAD-NUS project “Enhancing the contributions of nutritious but neglected crops to food security and to incomes of the rural poor: Asia component-nutritious millets,” supported by the International Fund for Agricultural Development, the M.S. Swaminathan Research Foundation (MSSRF), a nongovernmental organization (NGO) based in Chennai, India, became very active in supporting community on-farm management of small millet landraces in the Kolli Hills in Tamil Nadu, India. They identified key constraints and obstacles that local farmers faced in cultivation of local landraces, including poor seed quality, poor yield, processing and marketing of the small millets. Their key strategies for millet conservation involved seed collection, multiplication, seed distribution and farmer-to-farmer exchange through traditional seed storage. They supported the establishment of 13 community seed banks fostering the conservation and use of several millet species, to the benefit of more than 300 farm households (King and Bala Ravi 2012a). According to Joshi et al. (2020), 144 community seed banks have now been established in Nepal. Poor yield of local landraces was another major problem, so MSSRF carried out participatory yield enhancement activities to improve the yield of local landraces. This resulted in a doubling of *Panicum sumatrense*, while yields of finger millet increased by about 40% in the Kolli Hills and 65% in Koraput (King and Bala Ravi 2012a). Processing small millets for food demands considerable manual labor, so the provision of low-cost milling units to villages to remove the hard seed coat revived farmers' interest in cultivating small millets. MSSRF also established Self-Help Groups for storage, exchange and distribution among local farmers, as well as for marketing of value-added products from various millet landraces (King and Bala Ravi 2012a). Traditional knowledge is also important for on-farm conservation of agrobiodiversity. King and Bala Ravi (2012b) shared experiences and lessons learned regarding documentation and monitoring of traditional knowledge, which is intricately associated with the conservation of traditional landraces of these millets. The MSSRF initiative resulted in the revitalization of traditional millet on-farm conservation traditions and livelihood systems, reduced the rate of erosion of millet diversity and reinforced on-farm conservation of local landraces.

In Nepal, the IFAD-NUS project addressed issues along the entire chain for finger millet, from cultivation to the marketing of the final products (Bhandari et al. 2010). The Nepalese Country Report to FAO (2008) lists several measures taken to support on-farm conservation. A National Agrobiodiversity Conservation Committee was created as the policy body responsible to promote conservation and sustainable use of agrobiodiversity. In three sites in Nepal, Participatory Rural Appraisal, baseline surveys and diversity fairs, were conducted to assess farmers' knowledge and their perspective on the diversity maintained on farm. Although there are no subsidies to promote on-farm management, *in situ* conservation is linked to genetic socioeconomic and ecological benefits to farming communities. The government also encourages participatory plant-breeding programs to strengthen the process of on-farm conservation. The government has also placed significant emphasis on the development of local or small-scale seed production. Community-based seed production groups and district-level seed self-sufficiency programs were launched to grant the farming community with increased access to quality seed. Special attention was given to address the rises in food prices by ensuring the security of seeds in seed banks.

In 2014, a major earthquake hit Nepal, resulting in large numbers of casualties and deaths. The earthquake greatly affected the agriculture sector, and traditional seed stocks on which rural farmers depended for their livelihoods were destroyed (Dongol et al. 2017). The National Agriculture Genetic Resources Center, LI-BIRD and Bioversity International formulated a project "Rebuilding local seed system: rescue collection, conservation and repatriation in earthquake affected areas of Nepal," which was funded by the Global Crop Diversity Trust and the Netherlands through GRPI-2 Project from August 2015 to December 2017. During the rescue collection mission, farmers showed a keen interest in growing landraces of rice, legumes and foxtail millet, among other crops. Sites were selected where farmers had already lost landraces due to the unavailability of seeds. Among the landraces of crops that were repatriated from the genebank, 20 kg of landraces of foxtail millet were repatriated to 20 farmers in Ghanapokhara, Lamjung (Dongol et al. 2017). This project, played an important role in rescuing endangered germplasm for safe conservation in the national genebank and on farm through communities and community seed banks. This is an excellent example of how *ex situ* and *in situ* approaches can, and must, complement each other (Joshi et al. 2017).

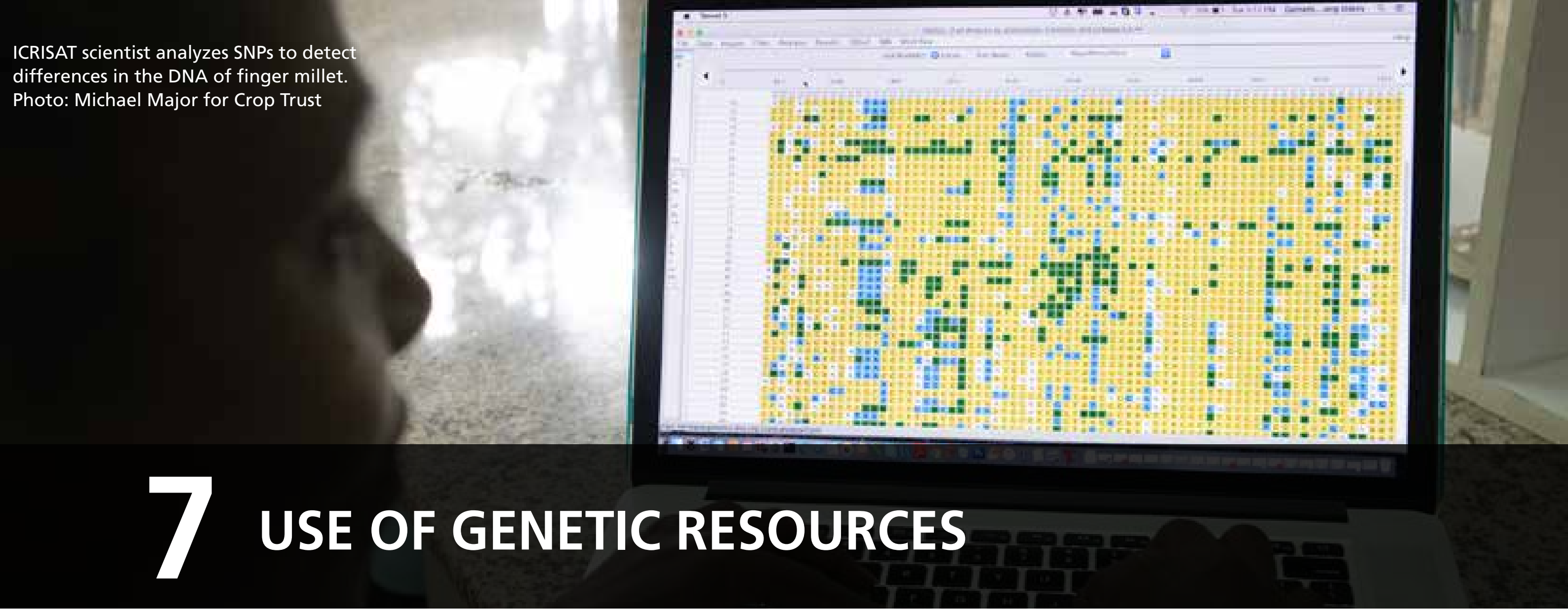
In India, apart from MSSRF's work described above, efforts to promote on-farm conservation of millets have been limited, considering the size of the country, the number of crops cultivated and the amount of genetic diversity available in the various crops. NBPGR has undertaken participatory conservation and management of minor millets (finger millet, proso millet, foxtail millet, barnyard millet) in many areas of Himachal Pradesh, with a focus on building capacity and awareness among local farmers (NBPGR 2007). These activities resulted in an increase in demand for seeds of traditional crops. In the Changer area of Hamirpur and Kangra, finger millet has been brought back into cultivation (NBPGR 2007). Other programs sought to promote the conservation of CWR and wild plants relevant to food production, and efforts were initiated to update and revise the status of wild relatives of crop plants in India (Pandey et al. 2005). In addition, Bonham et al. (2012) studied the determinants of on-farm diversity among pearl millet farmers in Rajasthan, in terms of the patterns of use of intraspecific diversity, the characteristics of both the agricultural systems and the farmers who conserve agrobiodiversity, as well as the factors that motivate farmers to grow a diverse crop.

In Africa, the native cereal teff (*Eragrostis tef*) is the most important staple food in Ethiopia. It accounts for 20% of the land allocated to cereals in the country and is used for making injera, a sour fermented flatbread (Ethiopia Country Report to FAO 2007). As in other countries, the diversity of landraces of *Eragrostis* was generally unaffected until the 1970s, when high crop diversification strategies started to displace landraces and greatly reduced the genetic diversity of local landraces (Ethiopia Country Report to FAO 2007). Ethiopia recognizes the role that local farmers have played in maintaining the diversity of landraces of local crops. The Institute of Biodiversity and Conservation (IBC) has developed *in situ* landrace conservation and enhancement programs that involve breeders, farmers and other stakeholders in several stages of maintenance, restoration and improvement processes of traditional crop varieties. Based on a number of previous empirical data surveys conducted under the project "A dynamic farmers-based approach to the conservation of Ethiopia's plant genetic resources," which ran from 1997 to 2002 and was funded by Global Environment Facility (GEF), IBC identified 12 major areas of crop genetic diversity that have been used as community genebanks. The community genebanks collected 22 crop species consisting of 400 farmer varieties in six agroecological zones of the country. IBC proposed a similar initiative for conservation of CWR and wild plants relevant to food production (Ethiopia Country Report to FAO 2007).

In 2016, another GEF/UN Development Programme project "Mainstreaming of agrobiodiversity into agricultural production systems" (UNDP/GEF 2016) was implemented with the aim of improving *in situ* conservation of the agrobiodiversity of forest coffee, ensete, durum wheat and teff. The key objectives of the project were to enable development of a policy and institutional framework for *in situ* conservation, creation of market incentives through market development and the conservation of CWR and farmers' varieties in *in situ* genetic reserves and on-farm conservation sites. As a result of this project, operational *in situ* genebanks, including two community genebanks (teff and wheat), two field genebanks (ensete and coffee), and market sheds (teff and wheat) were put in place.

In their report to FAO, most of the countries that cite millet as an important crop have identified a number of key constraints hampering *in situ* conservation and on-farm management of various crops. Although no specific reference is made to millets, the constraints mentioned are highly applicable to them. Some of the key constraints listed are as follows:

- Lack of financial resources, lack of skilled manpower and poor institutional capacity (India, Nepal, Ethiopia).
- Low yields of small millets due to lack of scientific attention.
- Poorly organized information and documentation systems for registering the PGRFA of the country.
- Replacement by uniform improved varieties.
- Market availability (India, Nepal).
- Socioeconomic constraints. For example, diversity in barnyard millet is being fast eroded due to considerable reduction in acreage and changing sociocultural and economic dimensions of the farming community in India (Maikhuri et al. 2001; Sood et al. 2015).
- Post-harvest processing (e.g. fonio and small millets are labor intensive).
- Limited participatory plant breeding activities to promote use of PGRFA.
- Availability of seed of traditional varieties (i.e. access to seed may be limited by current rural seed systems).
- Agricultural policies in various countries have negatively impacted cultivation and research of small millets (e.g., in Kenya, the focus has been shifted to cultivation of maize rather than finger millet (Dida et al. 2008); in northern Japan, cold-tolerant rice has almost completely replaced barnyard millet (Yabuno 1987)).
- Cultivated barnyard millets threatened by pest and diseases, including shoot fly, stem borer, grain smut, and loose smut at different growth stages of the crop.
- Inadequate awareness of the significance of *in situ* conservation.
- No priority in research and development for native genetic resources including millets (Joshi et al. 2020).



ICRISAT scientist analyzes SNPs to detect differences in the DNA of finger millet. Photo: Michael Major for Crop Trust

7 USE OF GENETIC RESOURCES

There have been a number of extensive reviews on the evaluation and use of millet genetic resources for crop improvement: Dwivedi et al. (2012) for all millet crops; Vetriventhan et al. (2020), Goron and Raizada (2015) and Vinoth and Ravindhran (2017) for small millets; Vetriventhan et al. (2015) for finger millet and foxtail millet; Upadhyaya et al. (2016) for proso millet, barnyard millet, little millet and kodo millet; Yadav et al. (2017) for pearl millet; Wambi et al. (2020) for finger millet; Renganathan et al. (2020) and Sood et al. (2015) for barnyard millet; Hariprasanna (2017) for kodo millet; Habiyaremye et al. (2017) and Bhat et al. (2019) for proso millet; Kanlindogbe et al. (2020), Ayenan et al. (2017), Abrouk et al. (2020) and Cruz and Beavogui (2016) for fonio; and Assefa et al. (2017) and Assefa et al. (2011) for teff. These reviews include lists of accessions that are sources of resistance to prevalent biotic and abiotic stresses, as well as nutritional traits. For example, Dwivedi et al. (2012) concluded that collections of pearl millet, finger millet, foxtail millet and proso millet had been extensively evaluated for resistance to major diseases. Sources of resistance were found and transferred to improved genetic backgrounds, except for rust in teff and smut in barnyard millet. Other reviews have similarly described evaluations of the germplasm for resistance or tolerance to abiotic stresses.

These reviews indicate that, although some research has focused on the evaluation and use of millet genetic resources, it is limited compared with other cereal crops, such as rice, wheat and maize. For most of these crops, sources of resistance, tolerance or improvement have been identified for important traits and, in some cases, they are already being used in breeding programs. The availability of core and mini-core collections has made such evaluations possible for millets to some extent (Dwivedi et al. 2012; Upadhyaya et al. 2016; Goron and Raizada 2015; Vinoth and Ravindhran 2017; Yadav et al. 2017; Vetriventhan et al. 2020). Consequently, sources of genetic improvement for millet crops are available, and evaluations of various traits have been conducted for all the millets except for teff and fonio.

For all crops, genomic tools are available and are being used for crop improvement and to assess the diversity in *ex situ* collections. Wambi et al. (2020) reviewed the availability and use of genomic tools for finger millet. Their review included lists of specific molecular markers associated with traits, as well as candidate genes, transcription factors and cloned functional genes that could be used to improve the crop for climate-smart traits. These resources are available for other millet crops as well (Assefa et al. 2011; Upadhyaya et al. 2016; Goron and Raizada 2015; Assefa et al. 2017; Ayenan et al. 2017; Hariprasanna 2017; Vinoth and Ravindhran 2017; Yadav et al. 2017; Bhat et al. 2019; Abrouk et al. 2020; Kanlindogbe et al. 2020; Renganathan et al. 2020; Vetriventhan et al. 2020). The genomes of pearl millet, foxtail millet, finger millet, proso millet, teff, Japanese barnyard millet and fonio have been sequenced.

Several reviews have focused on the use of germplasm in released cultivars and breeding efforts to improve millet crops (Assefa et al. 2011; Upadhyaya et al. 2016; Vetriventhan et al. 2016; Assefa et al. 2017; Hariprasanna 2017; Vinoth and Ravindhran 2017; Yadav et al. 2017; Bhat et al. 2019; Renganathan et al. 2020; Vetriventhan et al. 2020). They all reported the prevalence of the direct selection from landraces in the pedigree of released varieties. Vetriventhan et al. (2020) concluded that in India, about 65% of the released varieties were selections within landraces for six millet crops. The only exception was fonio, with Kanlindogbe et al. (2020) concluding that there had been no releases of improved fonio varieties from true fonio breeding programs. The cultivars available were ecotypes resulting from natural selection that were tested and adopted by farmers. For millet crops, key resources are available for the further use of germplasm, such as core subsets of accessions and genomic tools, and these will continue to be used in breeding programs for crop improvement in the future. The key for future improvement will be the availability of adequate diversity that is conserved and accessible in *ex situ* collections.

Paspalum commersonii at Peradeniya Royal Botanical Garden, Sri Lanka.
Photo: Gihan Jayaweera/Wikimedia

8 STATUS OF *EX SITU* CONSERVATION: COMPOSITION

For the purpose of this global conservation strategy, a survey was conducted of *ex situ* collection holders for the nine millet crops. A similar survey was conducted for the previous global conservation strategies for pearl millet (Mather and Upadhyaya 2012b) and finger millet (Mather and Upadhyaya 2012a). A questionnaire was sent to 52 key collection holders who were identified from the 2012 strategies and other references (Dwivedi et al. 2012; Vetriventhan et al. 2020). The questionnaire was completed by 26 of these collection holders; another three collection holders sent general information on their collections only. Four of the respondents were from Asia, 15 were from Africa, five were from Europe, two were from North America, two were from Australia and one was from the Middle East. Thus, the global sampling was adequate, but there were notable gaps for a few crops.

An estimate of the total number of collections globally and the number of accessions they conserve for each crop is given in Table 8.1. The estimate was based upon information obtained from FAO-WIEWS (2020), Genesys, the previous survey done in 2009, Dwivedi et al. (2012) and the responses to the current survey. The compilation of information from all these sources filled gaps from institutions that have not reported to FAO. Globally, more than 220,000 accessions of these millet crops are conserved in about 60 institutions. To determine the representativeness of the respondents, the number of key collection holders was compared with the proportion of accessions conserved both globally and by survey respondents. Among the survey respondents were all the key collection holders for pearl millet, finger millet, kodo millet, little millet and teff. For pearl millet, the 24 survey respondents conserved 93% of global accessions, and included 15 of the top 20 collection holders. For finger millet, the 13 respondents conserved 85% of global accessions and included nine of the top 10 collection holders. For kodo millet, five of the 13 collection holders globally responded to the survey, accounting for 89% of global accessions. For little millet, six of the 12 collection holders responded to the survey, accounting for 90% of global accessions. For teff, only four of the 10

Table 8.1 Numbers of *ex situ* collections of millet crops and accessions held, both globally and among survey respondents.

Crop	No. of collections globally	Total no. of accessions globally	No. of collections in survey	Total no. of accessions in survey	% of global accession captured by the survey
Pearl millet	57	73,578	24	68,426	93%
Finger millet	49	43,862	13	37,487	85%
Foxtail millet	46	46,368	12	12,070	26%
Proso millet	52	29,865	11	11,368	38%
Barnyard millet	34	8,920	10	3,006	34%
Kodo millet	13	4,398	5	3,915	89%
Little millet	12	3,734	6	3,370	90%
Teff	21	8,305	7	8,242	99%
Fonio	13	1,170	8	529	45%

collection holders responded to the survey, but they conserved 99% of global accessions. For fonio, eight of the 13 collection holders responded, accounting for 45% of global accessions.

The main collections not represented by survey respondents were for foxtail millet, proso millet, barnyard millet and fonio, due to a lack of responses from collection holders from China, Japan, Russia and France. Some of these collection holders did respond to the 2012 survey. Despite these gaps, the respondents included those who hold significant collections for these crops. For foxtail millet, four of the top 10 collection holders responded to the survey, but institutes in China alone account for more than 50% of global accessions. For proso millet, seven of the top 10 collection holders responded, but VIR in Russia, which holds nearly one-third of global accessions, did not participate in the survey. For barnyard millet, seven of the top 10 collection holders participated in the survey, but the national genebank in Japan, which conserves nearly 40% of global accessions, did not participate. For fonio, IRD in France conserves about 50% of global accessions, but did not send details on the status of the accessions of fonio conserved. The fonio accessions conserved by IRD were collected alongside institutes from West Africa who did participate in the survey. Despite these gaps, there was sufficient representation to conclude that survey responses represent the status of conservation for the key collection holders for these crops.

Nearly all the respondents were government institutions or departments in a government institution (23 of 26 respondents). The remaining three respondents were international organizations. Fourteen of the institutions had genebanks that were established 20–50 years ago, and the others were established in the 2000s. About half of these institutions operate under a national strategy for conservation of biodiversity. Only five of the 26 respondents have a governing body or stakeholder committee involved in their management or governance. In most cases, the curator or the institution's management was solely responsible for managing the collection. Collectively, all of the respondents conserve a total of 148,413 accessions of millet crops (Table 8.1). Collections range from 529 accessions of fonio held by eight respondents, to 68,426 accessions of pearl millet conserved by 24 of the 26 respondents.

Survey respondents were asked to indicate the number of accessions that were categorized as one of the following:

- landraces collected within the country or acquired from outside the country;
- old cultivars and released varieties;
- research or breeding advanced lines, populations or genetic stock;
- wild relatives; or
- biological status unknown.

An assessment of the general composition of the accessions held by all respondents was made based on the proportion of the total number of accessions with known biological status that were classified as local landrace accessions (collected in the country), landraces that had been acquired from outside the country and accessions of wild relatives (Figure 8.1). Of the accessions of pearl millet and proso millet, 40–50% are landraces acquired from outside the country; this suggests a high likelihood that there is duplication in the global *ex situ* conservation system for these crops. For fonio, teff, foxtail millet and barnyard millet, the

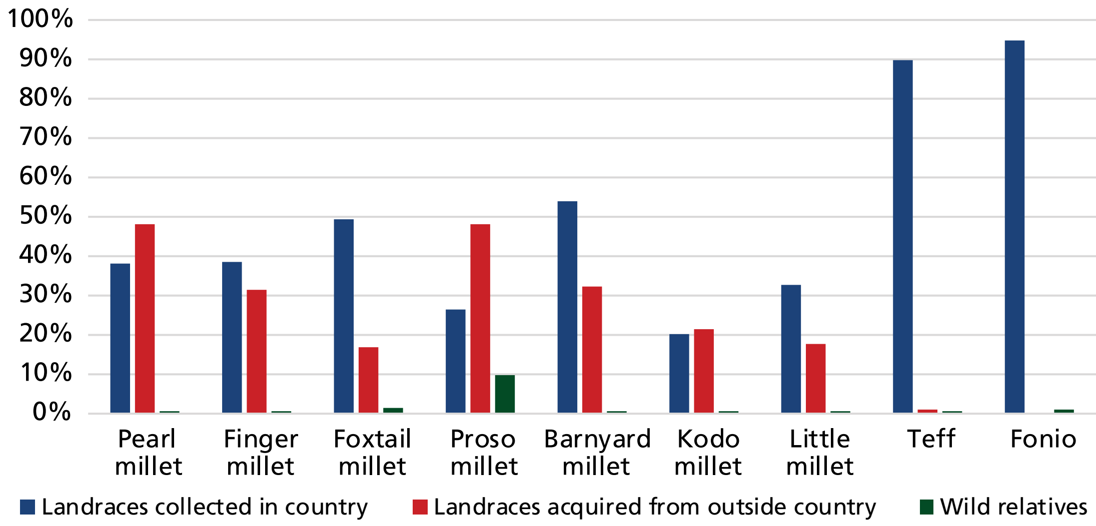


Figure 8.1 Percentage of total accessions of each crop that were landraces collected in the country, landraces acquired outside the country, and closely related wild relatives.

global system is characterized by a higher proportion of unique local landraces and a high likelihood that there are few duplications across collections. Across all crops, less than 1% of the accessions conserved are wild relatives, except for proso millet, of which 10% of accessions are wild relatives. The low numbers of wild accessions is a concern, given the importance of these relatives for future crop improvement and the fact that many are at risk in natural areas.

Each institution was asked: "To what extent do you consider the millet crop accessions in your collection to be unique and not duplicated extensively elsewhere (excluding safety-duplication)?" The responses were compiled into four categories that were 0% unique, <50% unique, >50% unique, and 100% unique. The number of respondents in each category for each crop is given in Table 8.2. In general, across all crops, most respondents indicated that their collections were 0–50% unique except for pearl millet, proso millet and fonio. For teff, only one respondent had 100% unique accessions.

When the proportion of all accessions for each crop was assessed for each category of uniqueness (Figure 8.2), it was found that the few respondents with mainly unique accessions held a high proportion of the accessions for teff, fonio and barnyard millet. Thus, the global system for these crops is characterized by a few key collection holders who conserve the majority of the unique local diversity. For the other crops, there is more duplication: more of the respondents are conserving diversity acquired from others, so the unique diversity is more dispersed among the collection holders. This difference in the distribution of diversity has implications both for the security of conservation within the global system and for the focus of global actions.

In general, respondents indicated that they had only lost about 1,074 accessions overall, mainly from eight institutions. Four institutions indicated that they had repatriated or recollected 21,567 accessions. A total of 22 of the 26 respondents reported that they had collected a total of 41,051 accessions over the past 10 years. Therefore, for these millet crops, there has been significant focus on collections to fill gaps, but many gaps remain. For example, the respondents from pearl millet production countries in West and Central Africa, indicated that insecurity and difficulty in access are major constraints to collecting wild relatives in many areas.

Gaps in pearl millet *ex situ* collections

A diversity tree has been developed for pearl millet. The original concept of a diversity tree is described in van Treuren et al. (2009). A diversity tree is a stratification of the crop diversity within a gene pool obtained by dividing the gene pool in a hierarchical manner. This stratification is based on published information

Table 8.2 Proportions of respondents' collections that are considered as unique accessions (0% unique, less than 50% unique, more than 50% unique, 100% unique), for each crop.

Crop	0% unique	<50% unique	>50% unique	100% unique
	Number of respondents			
Pearl millet	5	5	5	9
Finger millet	5	3	3	2
Foxtail millet	4	4	2	2
Proso millet	4	0	4	3
Barnyard millet	5	3	0	2
Fonio	2	1	0	5
Teff	6	0	0	1
Kodo millet	1	1	1	2
Little millet	2	1	1	2

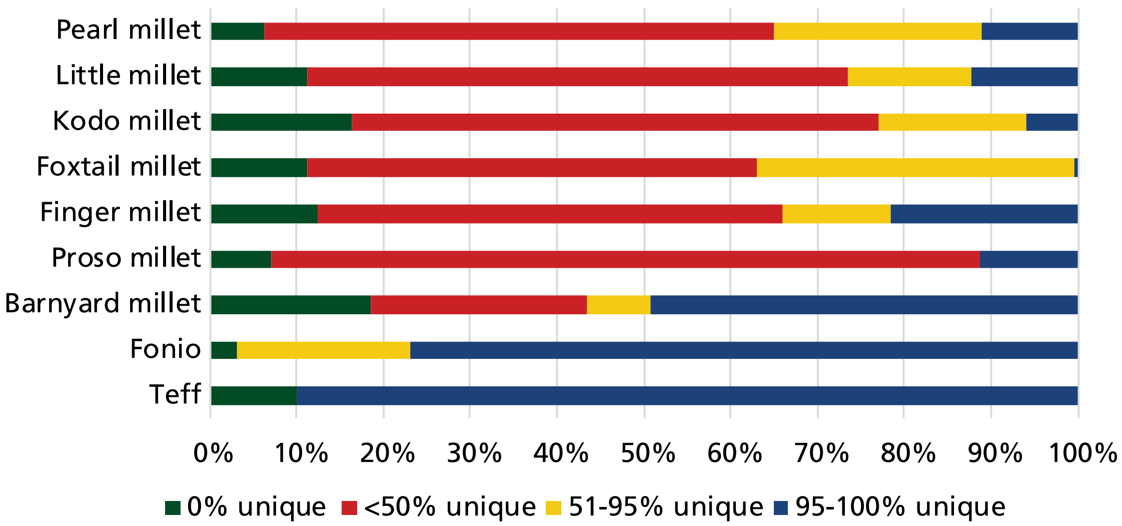


Figure 8.2 Percentage of total accessions for each crop conserved by the respondents that are considered unique (0% unique, less than 50% unique, more than 50% unique, 100% unique).

and consultation with experts. For the pearl millet diversity tree, an assessment was done on the distribution of diversity among the accessions listed in FAO-WIEWS, Genesys and the USDA's GRIN-Global after taking care to avoid double-counting of accessions listed in more than one databases[1] and removing from the dataset any accessions recorded as duplicates in the passport data[2]. The resulting dataset of 61,019 accessions was used to estimate the number of accessions globally conserved *ex situ* for the genus *Cenchrus* or *Pennisetum*, grouped by taxon (Annex I). There are 58 species held in *ex situ* collections and four undefined species groups. There are nine species for which more than 100 accessions are conserved *ex situ*. These species include cultivated species, wild progenitor subspecies, the single member of the secondary gene pool, *C. purpereus*, and four forage grasses (*C. ciliaris, C. orientalis, C. pedicellatus*, *C. setigerus*). Given the importance of these forage crops, the number conserved may be inadequate to capture the global diversity *ex situ*. There are 23 species with fewer than 10 accessions conserved *ex situ* globally, which could be considered gaps, but all are within the tertiary gene pool for cultivated pearl millet.

The same dataset (compiled using data from FAO-WIEWS, Genesys and GRIN-Global) was also used to assess the current state of conservation of the landraces of pearl millet in terms of the representation in countries where landraces were/are cultivated (based on the countries listed in the pearl millet diversity tree). The table in Annex II gives the number of accessions for pearl millet landraces by country of origin and for each genebank to determine the level of sampling from these countries. Some countries appear in the diversity tree but are not represented in *ex situ* collections globally: Angola, Guinea, Guinea-Bissau, Côte d'Ivoire, South Sudan, Madagascar, Bangladesh, Nepal and Brazil. Some countries have very few accessions conserved globally, including Benin (50 accessions), Gambia (15 acc.), Mauritania (9 acc.), Somalia (4 acc.), Ethiopia (28 acc.), Republic of the Congo (11 acc.), DRC (14 acc.), Mozambique (14 acc.), Swaziland (4 acc), all countries in North Africa (166 acc.), and Myanmar (10 acc.). However, landraces from Guinea and Côte d'Ivoire are conserved at IRD (based on data shared by IRD with the Crop Trust), but these do not seem to be duplicated with those held by ICRISAT, which also conserves some of the other accessions in the IRD collection. All of these could be seen as important gaps in the conservation of the global diversity of pearl millet. In addition, some countries have relatively low numbers of accessions given their location in areas of high diversity.

ICRISAT (IND002 in Annex II) has the largest collection of pearl millet globally, which includes diversity from most of the important regions of the world. More in-depth gap analyses of the ICRISAT pearl millet collection are available in Yadav et al. (2017), Upadhyaya et al. (2012), Upadhyaya et al. (2010a), and Upadhyaya et al. (2010b).

The suitability map for pearl millet based on agroecological variables (IIASA/FAO 2010) was overlaid with the map of the collection sites of landraces globally for all collection holders (Figure 8.3). The gaps identified in Figure 8.3 are consistent with those identified with the diversity tree and are highly consistent with the ICRISAT assessment of their own gaps; these gaps should be considered global priorities. In the survey, respondents also indicated past collecting activities and their priority gaps for pearl millet. Some countries, such as Nepal and South Sudan, were identified

[1]The same accession was identified by using the institute code and the accession number.

[2]DONORNUMB and DONORCODE information from passport data was used to identify duplicates. In most cases, it is not possible to identify duplicates from passport data as the DONORNUMB and DONORCODE are often not recorded.

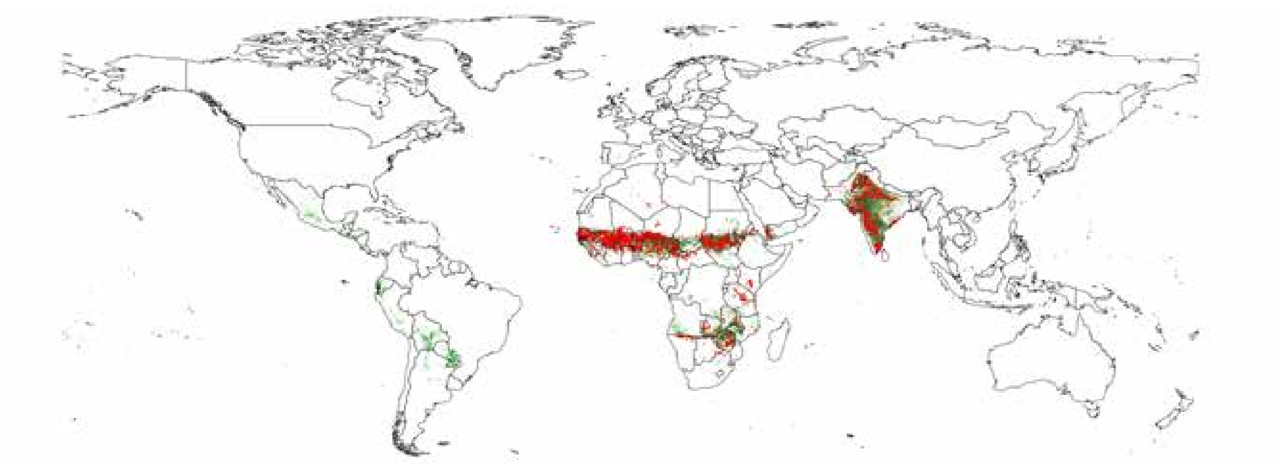


Figure 8.3 Landrace accessions (red dots) on a suitability map for low-input, rainfed pearl millet (green areas). (Sources: Data for suitability are from IIASA/FAO (2010). Data for accessions are from Genesys (2020), FAO-WIEWS (2020), NPGS-GRIN-Global (2020) and IRD (2019))

as gaps, since no collections had been conducted. Some gaps were identified for specific agroecological regions.

As part of the work conducted by the CGIAR Genebank Platform (2020), Ramirez-Villegas et al. (2020) developed a new methodology to assess gaps in geographic coverage for landraces conserved *ex situ*. The methodology is based on modeling the potential geographic distribution of crop landraces and comparing this with the geographic coverage of the accessions conserved *ex situ*. More details about the methodology can be found in Ramirez-Villegas et al. (2020). This methodology was applied to pearl millet, and it was found that landraces in collections with accessible and georeferenced data covered about 66% of the geographic area where landraces are expected to be found based on their distribution model (Figure 8.4). Gaps were categorized as low-probability gaps (gap found with one approach), medium-probability gaps (gap found with two approaches) and high-probability gaps (gaps found with three approaches) (Figure 8.5). More details on the three different approaches (cost distance, networking, environmental distance) are described in Ramirez-Villegas et al. (2020). The gap area for each country estimated by this analysis is listed in Annex IV.

Gaps in finger millet *ex situ* collections

A similar assessment for gaps was done based upon the finger millet diversity tree. The initial assessment covered species in the genus *Eleusine* (Table 7). Data for the biological type (landraces, breeding line, wild, etc.) are not available for many of the accessions, which made it difficult to determine if accessions for *E. coracana* were subsp. *coracana* or subsp. *africana.* Genebanks that conserve finger millet accessions should include this information in their accession-level passport data, if available. It is therefore possible that this assessment of the number of accessions of the two subspecies is biased toward subsp. *coracana*.

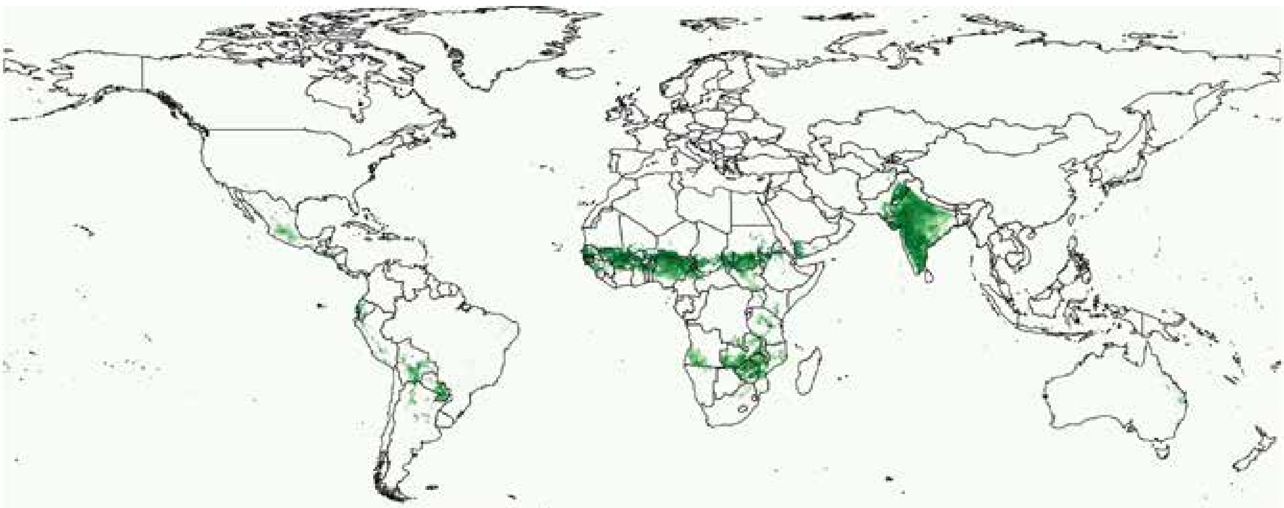


Figure 8.4 Distribution model of pearl millet landraces. The intensity of green shows the probability (0 to 1) of landraces occurring in a location, according to the model. (Source: CGIAR Genebank Platform 2020).

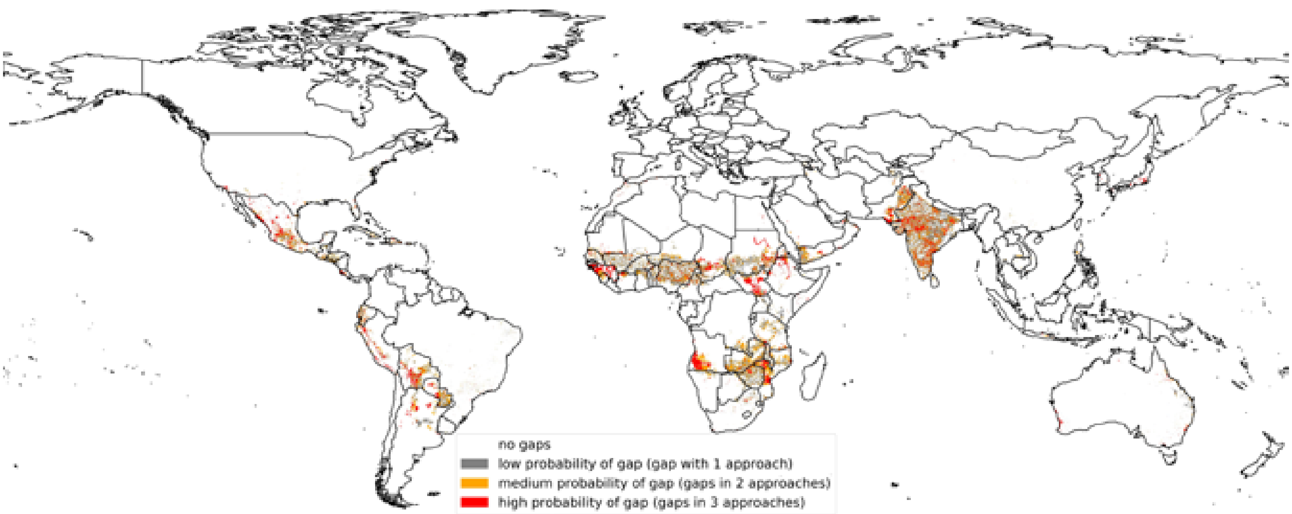


Figure 8.5 Gaps in the distribution of accessions of pearl millet landraces mapped according to three categories: low-probability gaps (gap found with one approach), medium-probability gaps (gap found with two approaches), high-probability gaps (gaps found with three approaches). (Source: CGIAR Genebank Platform 2020).

In the secondary gene pool, *E. floccifolia* has eight accessions conserved *ex situ* (of these only three have unique coordinates), of which three were collected in Ethiopia and five in Kenya. There is no record of accessions collected in Eritrea, Somalia and Yemen, which are also within the native area for this species. *E. indica* is widespread and common, but its distribution is not well represented *ex situ*. Considering that it is a widespread weed it is understandable that it is not a priority for *ex situ* conservation. For *E. tristachya* (Lam.), there are 42 accessions conserved *ex situ*. Currently no accessions from Paraguay are conserved *ex situ*.

In the tertiary gene pool, *E. kigeziensis* has only seven accessions of this species conserved *ex situ*, four of which were collected in DRC, three in Burundi and one in Uganda. There are no records of accessions from

Table 8.3 Number of accessions within genus *Eleusine* conserved globally.

Taxa	Accessions*
Eleusine coracana subsp. *coracana* (L.) Gaertn.	29,253
Eleusine coracana subsp. *africana* (Kenn.- O'Byrne) Hilu & de Wet	702
Eleusine sp.	553
Eleusine indica (L.) Gaertn.	277
Eleusine coracana (L.) Gaertn.	61
Eleusine tristachya (Lam.) Lam.	42
Eleusine jaegeri Pilg.	24
Eleusine multiflora Hochst. ex A. Rich.	19
Eleusine floccifolia (Forssk.) Spreng.	8
Eleusine kigeziensis S. M. Phillips	7
Eleusine intermedia (Chiov.) S. M. Phillips	3
Ochthochloa compressa (Forssk.) Hilu	1

Data sources: Genesys, FAO-WIEWS, USDA-GRIN.

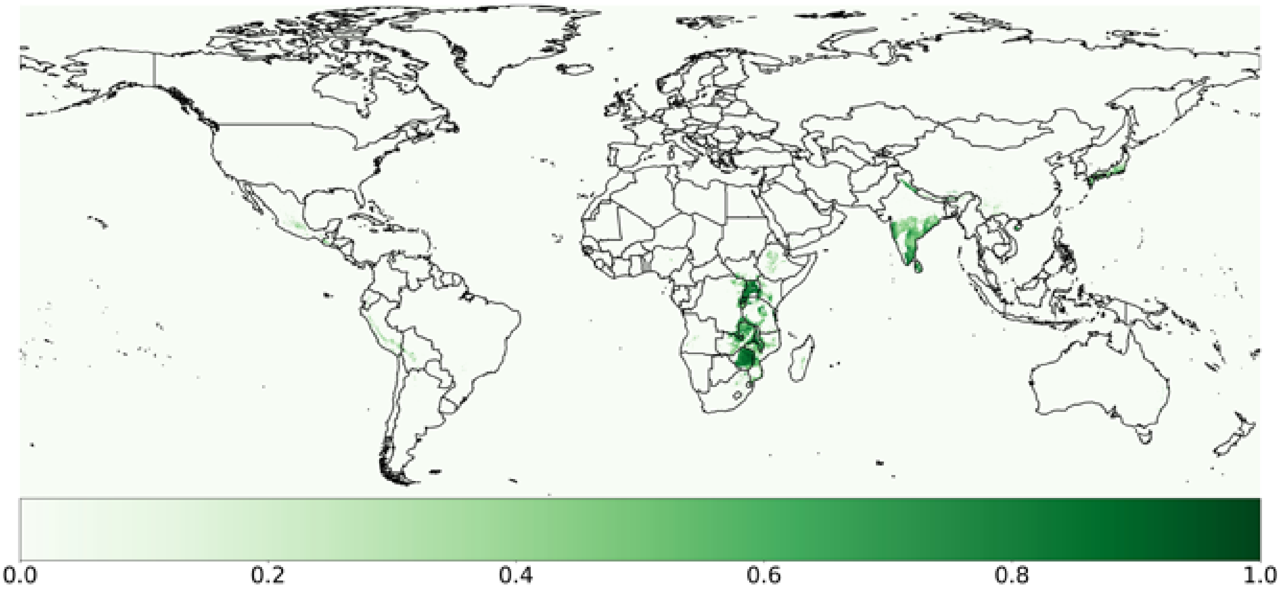


Figure 8.6 Distribution model for finger millet landraces. The intensity of green shows the probability (0 to 1) of landraces occurring in a location. (Source: CGIAR Genebank Platform 2020)

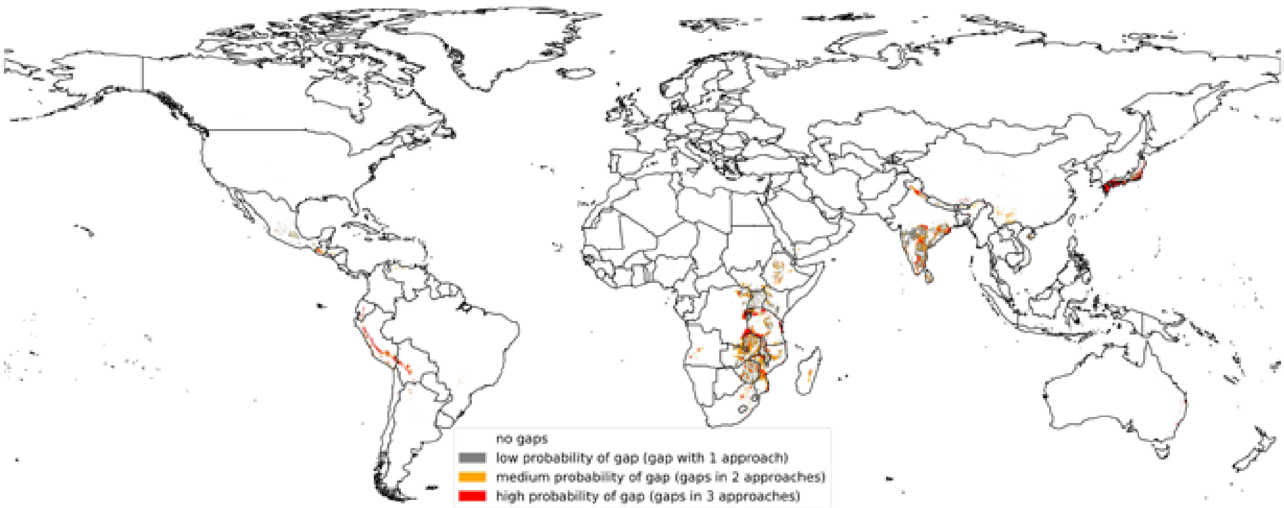


Figure 8.7 Gaps in the distribution of accessions of finger millet landraces, mapped according to three categories: low-probability gaps (gap found with one approach), medium-probability gaps (gap found with two approaches), high-probability gaps (gaps found with three approaches). (Source: CGIAR Genebank Platform 2020)

Rwanda, although there are occurrences of this species in this country. *Eleusine intermedia* is distributed in Kenya and Ethiopia, *E. jaegeri* is distributed in the east African highlands and *E. multiflora* is distributed in Ethiopia, Eritrea, Kenya and Tanzania. Very few accessions of any of these are conserved globally.

In our dataset (combined data from Genesys, FAO-WIEWS and USDA-GRIN), we found 702 accessions conserved globally of the wild diploid progenitor, subsp. *africana* (Annex III). Of these, only 65 have unique coordinates and are explicitly recorded as wild in the passport data (some of the others are recorded as landraces, which makes the recorded taxa doubtful). The potential gaps were identified based on a model of the distribution of this species. Thus, the priority gaps for the wild progenitor cover all its potential localities. Namibia, Mozambique, Eswatini, DRC and Rwanda are not among the countries holding this in *ex situ* collections, but there are records of occurrences for this species in these countries. To fill these priority gaps, there have been joint collection missions that involved International Plant Genetic Resources Institute (IPGRI), IRD, ICRISAT, International Institute for Tropical Agriculture (IITA), Kew Gardens, Crop Trust and other national institutes. Many of these samples were shared and conserved in all the participating institutions. There are also ongoing efforts to use these wild relatives in pre-breeding projects (Crop Wild Relatives Project n.d.). However, a comparison of the unique accessions with coordinates available in our dataset with the results of a study conducted before the collecting phase of the CWR project (Castañeda-Álvarez et al. 2016) does not show a significant increase in the numbers of unique accessions of *E. floccifolia*, *E. intermedia*, *E. tristachya* or *E. kigeziensis* conserved *ex situ*.

When the numbers of accessions conserved globally are assessed based on the groups in the finger millet diversity tree for the cultivated subsp. *coracana*[3], the gaps in the collections of cultivated species appear for Central African Republic, DRC, Rwanda, Mozambique, Botswana and South Sudan (Annex III).

As part of the conservation module of the CGIAR Genebank Platform (2020), spatial gap analysis was also conducted for finger millet landraces. This analysis found that landraces in collections with accessible and georeferenced data covered about 66% of the geographic area where landraces are expected to be found based on their distribution model (Figure 8.6). A map of gaps in finger millet and their geographic location is given in Figure 8.7; Annex V lists the estimated gap area for each country.

In conclusion, for all the millet crops, the compositions of the collections conserved by the survey respondents were characterized by a high proportion of unique local landrace accessions. Redundancies among collection holders seem to be lower for foxtail millet, little millet, teff, fonio and barnyard millet. There may be more duplication for pearl millet, proso millet and finger millet. The conservation system for teff, fonio and barnyard millet was characterized by a few key collections holding the majority of the diversity, but the diversity of the other millet crops is more widely dispersed among collection holders globally. The lack of a significant number of accessions of wild relatives in these collections is a concern that may need to be addressed in the future, especially for those plants that are threatened in natural areas.

[3]A map of production sites for finger millet in Africa National Research Council (1996) was also used to further refine groups in the finger millet diversity tree.

Barcoding pearl millet accession, ICRISAT.
Photo: Michael Major for Crop Trust

9 STATUS OF *EX SITU* COLLECTIONS: CONSERVATION

A key aspect of the development of the global strategy is an assessment of the efficiency, effectiveness and security of the conservation of current *ex situ* collections. For this assessment, the survey included questions on the routine operations being conducted; the type and state of the facilities; type of conservation research; and the security of conservation. Seven survey respondents conserve accessions in long-term storage only, while five respondents have medium-term storage only and one respondent has only short-term storage conditions. Twelve of the respondents have both long-term and short-term storage conditions. The vast majority of accessions for all these millet crops are securely conserved both long and medium term, except for seven cases of specific crops at an institution (three cases of pearl millet, one case of finger millet, two cases of barnyard millet, one case of proso millet). In no case did it seem the crop was at risk of loss, except for the respondent conserving pearl millet and fonio in short-term conditions only.

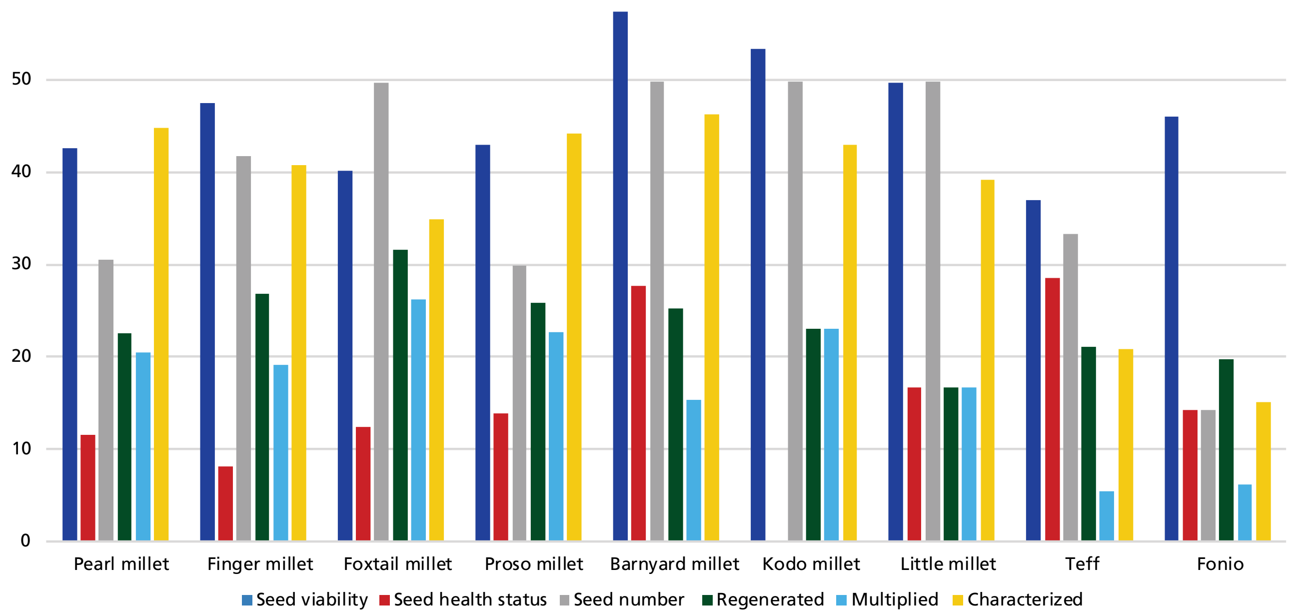


Figure 9.1 The proportion (%) of accessions across all respondents that have been subject to routine operations: seed viability testing, seed health testing, determination of number of seeds conserved, regeneration, multiplication, and characterization.

The assessment of routine operations covered seed viability testing, seed health testing, determination of the number of seeds conserved (calculated from 100/1000 seed weight and seed quantity in storage), regeneration, seed multiplication and characterization. Overall, baseline seed viability testing has been done for 46% of accessions, baseline seed health testing for 14%, seed number determinations for 37% of accessions, regeneration for 24% of accessions, multiplication to increase seeds for 18% of accessions, and characterization for minimal traits for 38% of accessions.

Seed viability testing, the determination of seed number and characterization are the most frequently completed routine operations across all the crops except for fonio for seed number (Figure 9.1). Seed health testing seems to be rarely conducted on these millet crops, given the very low percentage of accessions tested. The proportion of accessions that have been regenerated ranged from 17% for little millet to 32% for foxtail millet. In Mathur and Upadhyaya (2012a; 2012b), survey respondents indicated that their key limitations for managing collections were related to staff, land and funding for regeneration and multiplication. A number of respondents to the 2012 survey indicated that they were unable to meet distribution requests due to insufficient seed. This is clearly the case for many respondents to the present survey, although not for all.

The respondents were classified into four groups based on the proportion of their accessions of each crop that were subject to the six routine operations discussed above. The results are given in Figure 9.2, as a proportion of the total 93 possible respondent × crop combinations. The majority of respondents have carried out seed viability testing and characterization for 50–100% of their accessions; however, almost 40% of respondents had done no testing or characterization. As seen, 60–80% of crop collections have no routine activities for seed health testing, seed number determination, regeneration, or multiplication. The respondents to this survey were not asked specifically to list their constraints for routine operations, but more details were requested on the state of these possible constraints.

The efficiency and security of routine conservation operations depend upon the presence of trained staff with adequate facilities, equipment, key consumables such as packaging, and procedures or processes. In the previous surveys (Mathur and Upadhyaya 2012a; Mathur and Upadhyaya 2012b), participants identified a number of constraints they encountered in securing the conservation of pearl millet and finger millet. To better understand the exact nature of these constraints and their prevalence among the target genebanks, a set of questions addressed these issues. Respondents were asked to classify the types of storage facilities they used for long-, medium- and short-term conservation (Table 9.1). Cold storage units are mainly used for long-term, medium-term conservation or both, but eight of the respondents do not have cold storage units. Individual freezers are mainly used for long-term conservation or both long- and medium-term conservation, but 13 of the respondents do not use freezers for conservation. Short-term seed storage mainly refers to the use of an air-conditioned room, with or without control of the relative

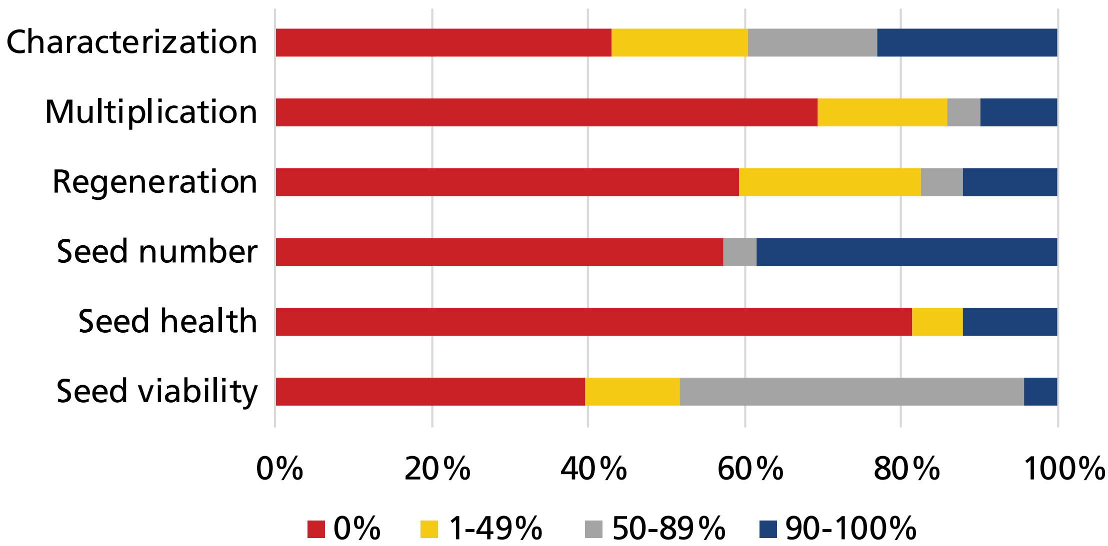


Figure 9.2 Proportion of respondents that had subjected 0%, 1–49%, 50–89% or 90–100% of their accessions to various routine operations: seed viability testing, seed health testing, determination of the seed number, regeneration, multiplication or characterization for minimal traits.

humidity. At least five respondents reported using an air-conditioned room with humidity control for medium-term storage.

According to FAO's international standards for genebanks (FAO 2014), airtight packaging is necessary for long-term conservation to minimize losses to seed viability. FAO recommends non-airtight packaging only for medium-term conservation where the seeds are accessed for distribution fairly frequently. The majority of respondents in our survey reported using sealed aluminum packs with or without vacuum packing for long-term conservation. The use of aluminum packs would indicate that the seeds were being appropriately stored if the packs are of sufficient thickness and sturdy (material with multiple layers). The lack of vacuum packing to remove the air may indicate that only seven of the 26 respondents are using airtight packaging to meet international standards. Seven of the respondents reported using mainly aluminum cans, plastic containers, glass containers, paper envelopes/bags or cloth bags for long-term storage; 17 of the respondents reported using these for medium-term storage. For short-term seed storage, respondents mainly reported the use of paper envelopes/bags.

The FAO (2014) genebank standards suggest that monitoring devices for temperature and relative humidity be used in storage units. This is best done with monitoring devices placed inside the storage unit and an external readout, to allow for monitoring without opening the unit. The readouts from the monitoring devices then need to be reviewed on a regular basis to identify issues with fluctuation. While the majority of respondents have internal monitors for freezers or cold storage units, few have external monitoring of the temperature, especially in long-term storage units. Fewer respondents monitor relative humidity than temperature.

According to FAO (2014), fluctuations in temperature and relative humidity in cold storage are more detrimental to seed viability for the long term than no cold storage at all. FAO therefore recommends the use of a backup power supply to ensure a constant temperature and relative humidity. Respondents mainly use backup generators for long-term storage, long- and

Table 9.1 Types of storage facilities, packaging and security/monitoring used by respondents for long-, medium- and/or short-term millet crop conservation.

	Long term	Medium term	Short term	Long and medium term	Medium and short term	Long, medium and short term
			Number of respondents			
Storage facilities						
Cold storage unit	4	4	1	7	1	1
Individual freezers	6	1	1	2	–	3
Air-conditioned room	2	1	3	–	–	3
Air-conditioned room with dehumidifier	2	5	5	3	1	1
Ambient temperature room	–	–	2	–	–	–
Packaging						
Sealed aluminum packs	6	2	–	7	–	1
Sealed and vacuum-packed aluminum packs	4	–	–	3	1	1
Aluminum cans	3	–	–	–	–	–
Plastic containers	2	6	2	–	1	–
Glass containers	1	4	–	–	–	–
Paper envelopes/bags	1	1	11	–	2	–
Cloth bags	–	6	–	–	1	–
Security and monitoring						
Backup generator	4	–	–	4	–	6
Internal temperature monitors	5	3	2	5	1	3
External temperature monitors	2	1	8	1	1	1
Internal relative humidity monitors	2	6	–	2	1	1
External relative humidity monitors	2	2	–	3	2	–
External sounding alarms	3	–	–	3	–	3
Automated monitoring system with link to security or curator	2	–	–	4	–	1
Daily visit by genebank staff or security staff	6	1	1	7	1	6

medium-term storage, and long-, medium- and short-term storage, but only about 50% of respondents who use refrigerant storage have a backup generator. Many of these respondents reported that their backup generator was at least adequate, but noted several constraints, such as lack of funding for maintenance, repair and replacement, and the lack of an automatic on/off system for the generator.

The international standards also indicate the need for adequate security to monitor and protect the collection. Respondents' main approach to security is a daily visit by genebank staff or security staff. These visits are adequate if they are frequent and if status logs are kept. Also required is an adequate protocol for ensuring that swift action is taken to rectify issues; the survey did not explore this issue. Only about 25% of the respondents reported using an automated system for monitoring, but that number is expected to increase, as the technology is readily available. This approach is likely to be more secure, as monitoring devices run continuously and record fluctuations in temperature and relative humidity.

Other sources of risk for genebanks are the impact of aging infrastructure and equipment and the lack of appropriate facilities for routine operations. Overall, 16 of the 26 respondents indicated the age of their facilities and equipment. Four of the respondents have had new genebank building and facilities built in the past 10 years, while one respondent operates in a facility that is more than 100 years old. Seventy-two percent of the 21 respondents considered their genebank building and facilities to be adequate. For others, the main issues are related to inadequate funding, electricity supply and inadequate space in the genebank.

For six of the respondents, storage facilities are less than 10 years old; for the others, facilities are 11–50 years old. The majority of the 21 respondents to this question (72%) reported that their storage facilities were adequate or excellent. The constraints identified included a lack of funding for repair, maintenance, or replacement; irregular energy supply; and lack of key equipment such as shelving, monitoring devices and appropriate packaging.

Four of the respondents have newly established laboratory facilities with new equipment, but many of the others have older facilities and equipment that are mainly adequate or excellent. For those with inadequate facilities or equipment, the main constraints were lack of funding for purchase, maintenance, repair or replacement of obsolete basic equipment for laboratories, and the lack of dedicated space for laboratories.

Seven of the respondents reported that their field equipment was less than 10 years old, and four reporting having equipment that was 11–50 years old. 11 of the respondents reported having at least adequate field equipment, the main constraints for the other respondents were lack of funding, lack of irrigation and lack of basic equipment. Other constraints identified for facilities and equipment included the lack of basic equipment with a dedicated space for cleaning seed; no seed dryer; no dehumidifier; and a general lack of funds for upgrading the basic facilities and equipment for genebank operations.

In the future, genebanks will need to consider their carbon footprint and how to reduce the routine costs of their power requirements for securing the long-term conservation of their collection. The shift to alternative energy supplies, such as solar power, could address this need, as could investment in energy-efficient equipment for new or replacement purchases. Four of the respondents have already shifted to solar power for the whole genebank or for a specific facility in the genebank. One respondent indicated that all procurement had to meet energy-efficiency targets, and 11 reported energy efficiency as a criterion for procurement of equipment.

Respondents were also asked about their access to the specific types of facilities, equipment or field space needed to allow them to meet international standards for their routine operations and secure conservation of the accessions (Figure 9.3). Nearly 60% of the respondents reported having separate work areas for seed handling and a dedicated laboratory with staff skilled in seed viability training. Only about one-third of respondents have a dedicated seed health testing laboratory. Half of the respondents have a low-temperature seed dryer and work areas for seed packaging that minimize fluctuations on seed moisture content during packaging. These responses indicate that many genebanks lack the necessary space, facilities and equipment to meet international standards for conserving orthodox seeds.

For many of the millet crops, secure regeneration requires access to an appropriate site for regeneration and to facilities that make it possible to regenerate difficult accessions or those in need of urgent regeneration. While more than 80% of respondents do have access to appropriate sites for regeneration, about 40% do not have access to an appropriate site for regeneration of accessions that have very low seed viability or quantity or that are difficult to grow.

The respondents were asked about the written procedures and protocols used in the genebank's routine operations. A number of respondents indicated that they followed the FAO (2014) international genebank standards, which are not written procedure or protocols but recommendations. Half of the respondents reported using Rao et al. (2006) and seven reported using an earlier manual by Hanson (1985). Several of the genebanks use more than one of the sources listed in Table 9.2. About one-quarter of respondents have their own genebank operational manual and/or written standard operating procedures for key processes, and have implemented a quality management system.

Finally, the survey asked if the genebanks were engaged in research on conservation or if they had the expertise to do conservation research in the future. The question listed four possible research areas: to improve protocols, to increase efficiency of conservation operations, to increase security of conservation, and to address crop-specific constraints for conservation such as seed dormancy, seed health, seed longevity, etc. Only three respondents reported no ongoing research or capacity to do conservation research. Fifteen respondents have ongoing research in at least one of these areas, especially research to increase the efficiency of conservation. Seven respondents reported having the interest and capacity to do conservation research in these four areas, but had no research underway. Overall, the majority of respondents do have ongoing research or the capacity to do future research to increase efficiency and improve protocols.

According to the international standards for safety duplication (FAO 2014), accessions that are original for a collection should be safety duplicated at a site that is geographically distant under conditions that are equal to or better than those of the original genebank. "Geographically distant" is viewed as most distant if outside the country. The safety duplication should be done in a way that maintains the integrity of the original sample. When possible, this is best done through a black box arrangement where the accessions are only conserved by the host institution and the monitoring and replacement of low viability seed are done by the original institution. It is generally not seen as secure practice to have the accessions regenerated and managed actively by the host institution unless the risk to genetic integrity is managed and monitored. Survey respondents were asked to indicate the proportion of their millet crop accessions that were conserved in safety duplication sites. The sites listed in the survey were Svalbard Global Seed Vault, an institution outside the country in a black box arrangement, an institution outside the country but dynamically managed by the host institution, in the same country at another institution, or in the same country but at another research site within the same institution.

Table 9.2 Sources of procedures and protocols used for routine operations in the genebanks surveyed.

Source of procedure or protocols	Number of respondents
No written procedures or protocols	5
Hanson, J. 1985. Procedures for handling seeds in genebanks. (Practical manual for genebanks no. 1). Rome, Italy: International Board for Plant Genetic Resources (IBPGR).	7
Rao, N.K., Hanson, J., Dulloo, M.E., Ghosh, K., Nowell, D., Larinde, M. 2006. Manual of seed handling in genebanks. (Handbooks for genebanks no. 8). Rome, Italy: Bioversity International.	13
Institute's own genebank operational manual	7
Written and verified standard operating procedure (SOP) for key processes	7
Quality management system (QMS)	7

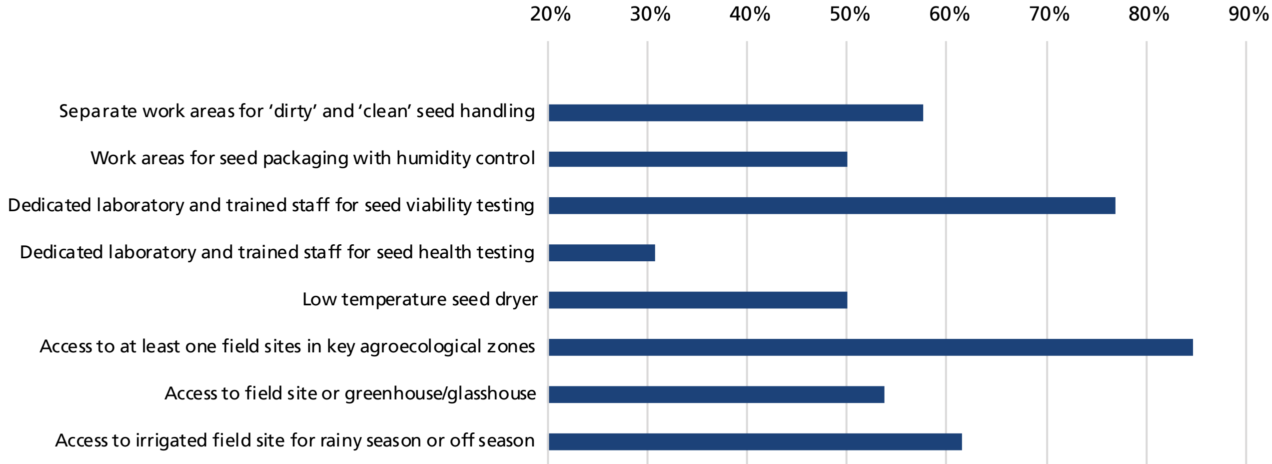


Figure 9.3 Percentage of respondents who reported having certain facilities, equipment or access to space.

From the results (Figure 9.4), it is clear that less than a quarter of the accessions conserved *ex situ* for these millet crops are safety duplicated in any site outside the original institute. The highest percentage of accessions are located outside of the country and managed actively by the host institution. About 20% of millet crop accessions are safety duplicated in the Svalbard Global Seed Vault. A similar percentage are safety duplicated at another research site in the same institution in the same country as the original collection. Five institutions have no safety duplication for any of their millet crops, 13 have safety duplication at one site, four have safety duplication at two sites and one has safety duplication at three sites. Only 12% of the accessions of millet crops conserved globally are safety duplicated both in the Svalbard global Seed Vault and in an institute outside the host country. Safety duplications also require a legal agreement that clearly states the terms and conditions. Respondents reported having legal agreements, but these were mainly with Svalbard Global Seed Vault (its deposition agreement), as well as four institution-specific agreements. The current system for *ex situ* conservation of millet crop is at risk given the high proportion of its diversity that is not safety duplicated.

In summary, the status of *ex situ* conservation for millet crops globally was assessed from a survey of about 50% of the institutions that conserve these crops. The current global system is not secure, efficient or rational; many gaps and vulnerabilities are apparent in key routine operations and facilities for some collection holders, although not for all. These gaps are related to knowledge on the viability and health of the conserved seeds as well as management information. Globally, there are inadequacies related to the regeneration of accessions that are losing viability and to the multiplication of seed for distribution. These inadequacies have already led to insufficient seed to meet distribution requests. Collection holders who responded to the survey reported having issues with their key facilities and equipment for conservation and routine operations. Other inadequacies are related to the use of the best and most efficient procedures and protocols through standard operating procedures, quality management systems and conservation research. Finally, the lack of safety duplication for more than three-quarters of the accessions conserved globally is a key vulnerability that needs to be addressed in the future.

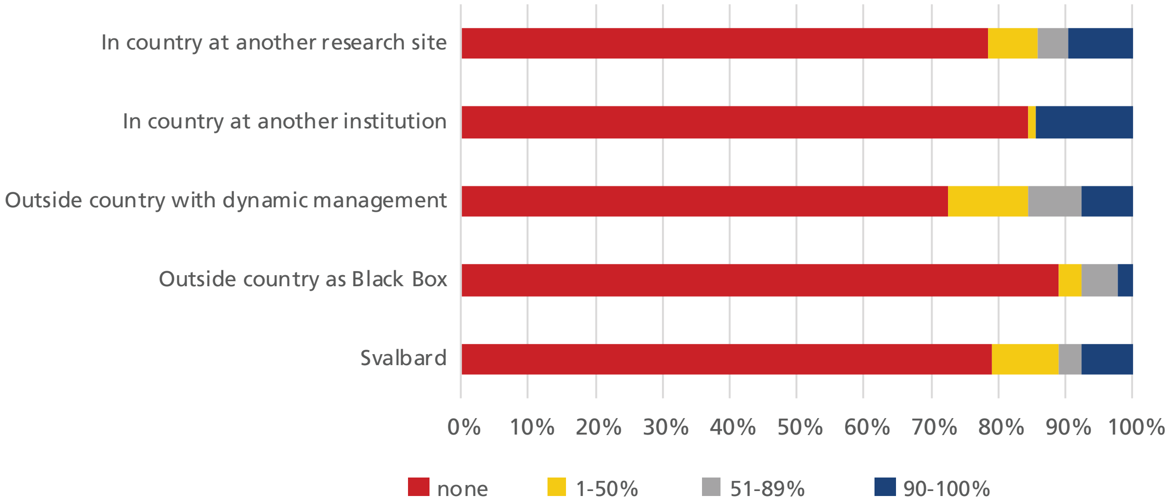
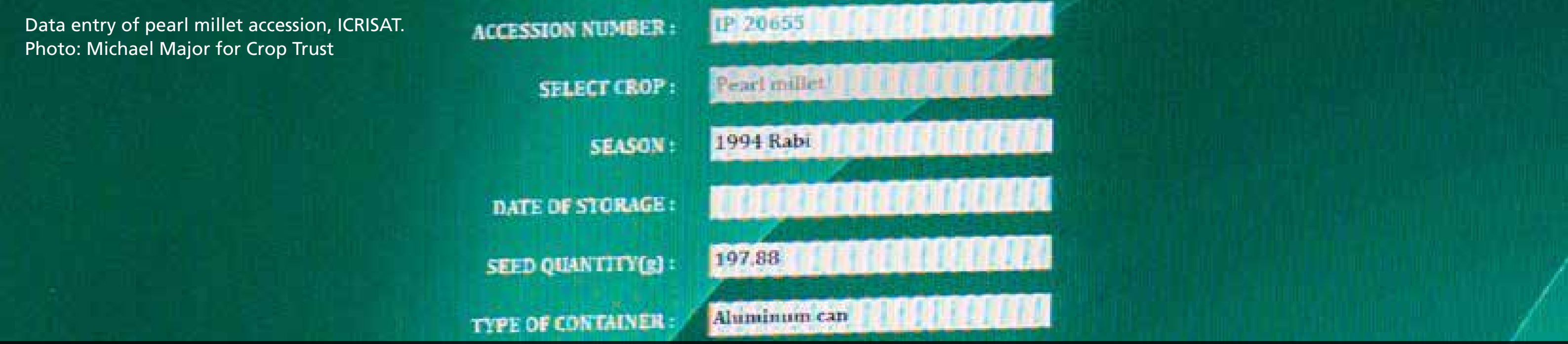


Figure 9.4 Proportion of respondents that reported having 0%, 1–50%, 51–89% or 90–100% of their accessions of millet crops in a safety duplication site.



Data entry of pearl millet accession, ICRISAT.
Photo: Michael Major for Crop Trust

10 STATUS OF *EX SITU* COLLECTIONS: DOCUMENTATION

The FAO (2014) international genebank standards for documentation recommend that "passport data of 100% of the accessions should be documented using FAO/Bioversity multi-crop passport descriptors." Survey respondents were asked about the type of data they had on their accessions (Figure 10.1). More than 80% of respondents have passport and characterization data, but less than 25% have images of their accessions, evaluation data or genotype profiles. Only three respondents have genotyping data for accessions. Figure 10.1 shows the extent to which passport data and characterization data are captured by respondents. The questionnaire did not explore whether respondents use FAO/Bioversity passport descriptors. Across all respondents and crops, the passport data of 66% of accessions are documented.

Across all respondents and crops, 38% of accessions have been characterized for minimal traits, but the characterization data are available in a searchable database for only 11% of accessions (Figure 10.1). The characterization traits use standard descriptors for all crops except little millet, teff and fonio, for which there is no international set of standard descriptors. These findings indicate that much of the characterization data are only available in hardcopy.

Accession-level information is available to users via a range of approaches. About 80% of respondents share information internally within their own institution through a written catalogue or direct interaction with the curator. Less than 50% of the institutions share their accession-level information publicly in a searchable online database and mainly through Genesys. A review of the websites used to share information on their collections online in a dedicated website found for some of the genebanks that the accession level information shared was limited, mainly shared in summary tables, or had limits to the number of records that could be viewed or downloaded. To fully utilize the websites would require prior knowledge of the accessions conserved so while this is a great start to addressing the needs of the users to understand the nature of the diversity of the accessions conserved in the collections, it is not adequate for sharing specific information on accessions to allow for use. Thus, users' access to accession-level information is still limited, which could hinder the use of the accessions of these millet crops.

The FAO (2014) standards also address storage of all data generated in the genebank, both management data and data associated with accessions. The recommendation is: "All data and information generated in the genebank relating to all aspects of conservation and use of the material should be recorded in a suitably designed database." A genebank's information system could be one designed by the institute itself, such as that of the Genebank Project, NARO, in Japan or it might have been developed regionally, such as the SPGRC Documentation and Information System (SDIS). There are also international efforts to develop

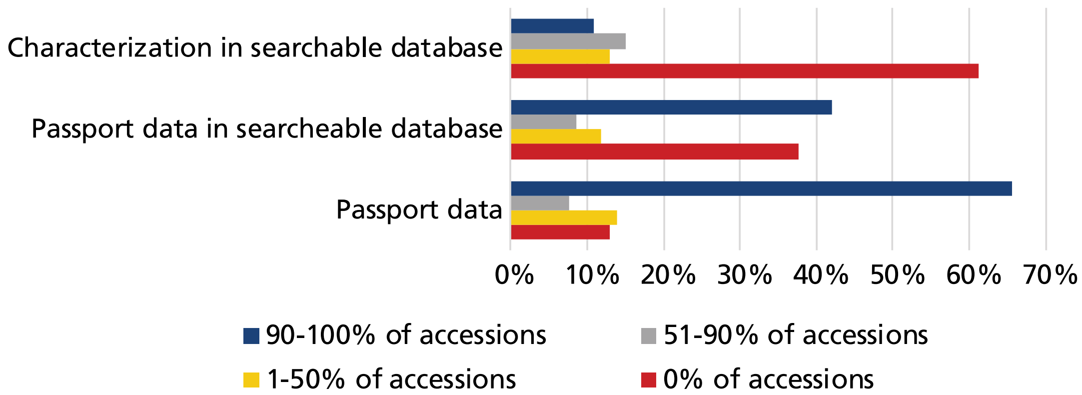


Figure 10.1 Proportion of respondents that have none of the accessions, 1–50% of accessions, 51–90% of accessions, or 90–100% of accessions with passport data; passport data in a searchable database; or characterization data in a searchable database. The *y* axis indicates the percentage of respondents (i.e. genebanks). The color of the bars indicates the proportion of accessions.

a genebank information system that can be adapted to individual genebanks, including the USDA's GRIN-Global, which has been adopted by several other national genebanks. Adopting a suitable information system is a very important step toward increasing the security and efficiency of conservation through better monitoring and reporting. Furthermore, a barcoding system will reduce the risk of mislabeling and better protect the genetic integrity of the accessions.

To optimize these information systems, genebanks must reconsider their processes and procedures. Genebanks in the USDA system and the CGIAR international collections have focused on accommodating new tools as opportunities to increase efficiency, including through barcoding, the adoption of electronic tablets and the automation of certain key tasks. In our survey, six respondents reported using barcoding to some degree, and five reported using electronic tablets for data capture to some degree.

To determine the extent to which genebank information management systems are being used for conservation of millet crops and information sharing, the survey asked respondents about their approaches to data capture and use for monitoring, decision making or information sharing. Although it is recommended that data be recorded for some routine operations, such as seed health status and, to a lesser degree, determination of 100/1000 seed weight and multiplication history, that is not always the case. Survey respondents' approaches to data capture are summarized in Table 10.1. From 8–24% of the respondents maintain records written in field books, laboratory logbooks, and/or datasheets. In some cases, these are handwritten records that are then also entered into a database, but the majority of respondents enter data on inventory, seed viability, and characterization directly into an electronic database. The exception is data on seed health testing, for which most respondents record no data. For other routine operations, 32–44% of respondents reported recording data in a database within the unit or a genebank information system.

Eight respondents reported that they were adopting or planning to adopt GRIN-Global, three respondents reported using the SESTO system and one respondent reported using an institution-developed system. These findings indicate that use of genebank management information systems is increasing; the adoption of these systems will lead to more secure and efficient operations.

Genebanks' efforts to adopt genebank information systems should continue and should receive support, as this increased documentation will lead to more opportunities to share accession-level information, through global platforms such as Genesys, via institutes' own websites or both. Databases will become more secure, as they can be backed up on the cloud or in a separate server. Although the survey did not ask about the security of databases, it is an important aspect of a genebank information system that needs to be considered, as databases need to be backed up frequently. One option for passport and characterization data is to upload them onto Genesys for backup and sharing. Existing accession-level sharing platforms, such as Genesys, employ a data-sharing agreement with contributors. These practices need to be considered more widely to allow greater user access to accession-level information. The USDA-ARS in the USA and NARO in Japan have open, transparent sharing of a limited amount of relevant passport data. Users can easily download these data to facilitate the selection of accessions, although NARO does limit the number of accessions that can be viewed or downloaded at one time. Globally, users' access to key accession-level information needs to be increased, in order to facilitate use.

Table 10.1 Survey respondents' approaches to data capture for routine operations.

Routine operation	No data taken (% of respondents)	Record in field books, laboratory logbook and/or data sheets (% of respondents)	Record and/or enter into laboratory or unit database (% of respondents)	Record, and/or enter into unit database and/or a genebank information system (% of respondents)
		% of respondents		
Inventory	0	16	28	56
Seed viability	12	16	20	52
Seed health status	68	12	12	8
Seed number	40	8	12	40
Packet weight	28	20	16	36
Regeneration	24	20	12	44
Multiplication	32	24	12	32
Characterization	12	20	16	52
Distribution	12	24	20	44

Screening crop wild relatives of finger millet for resistance to blast, Maseno University in Western Kenya. Photo: Michael Major for Crop Trust

11 STATUS OF *EX SITU* COLLECTIONS: USE

The survey requested information on the distribution of accessions to users, in terms of the type of user, the frequency of distribution, the main use of the accession, any constraints to distribution or restrictions on use, the exchange of accession-level information, and feedback mechanisms with users. All respondents reported distributing to users within their institute and nationally, but only about 50% distribute internationally with an SMTA (standard material transfer agreement) or a government- or institution-mandated MTA. Fonio and teff are not listed in Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which means their ABS status is less clear in terms of facilitated access through the Plant Treaty. For fonio, four respondents, who together conserve about 34% of the total accessions globally, distribute to users outside the country using an MTA. For teff, three respondents, who collectively conserve only 5% of global accessions, distribute accessions internationally using an SMTA. Access is generally restricted to research or repatriation. A few respondents indicated that there were more restrictions in the case of commercial uses, and one respondent reported that they could not distribute to farmers directly.

The distribution of accessions internationally (and sometimes nationally) requires the following: an adequate procedure for obtaining agreement to the terms and obligations through an SMTA or MTA; a

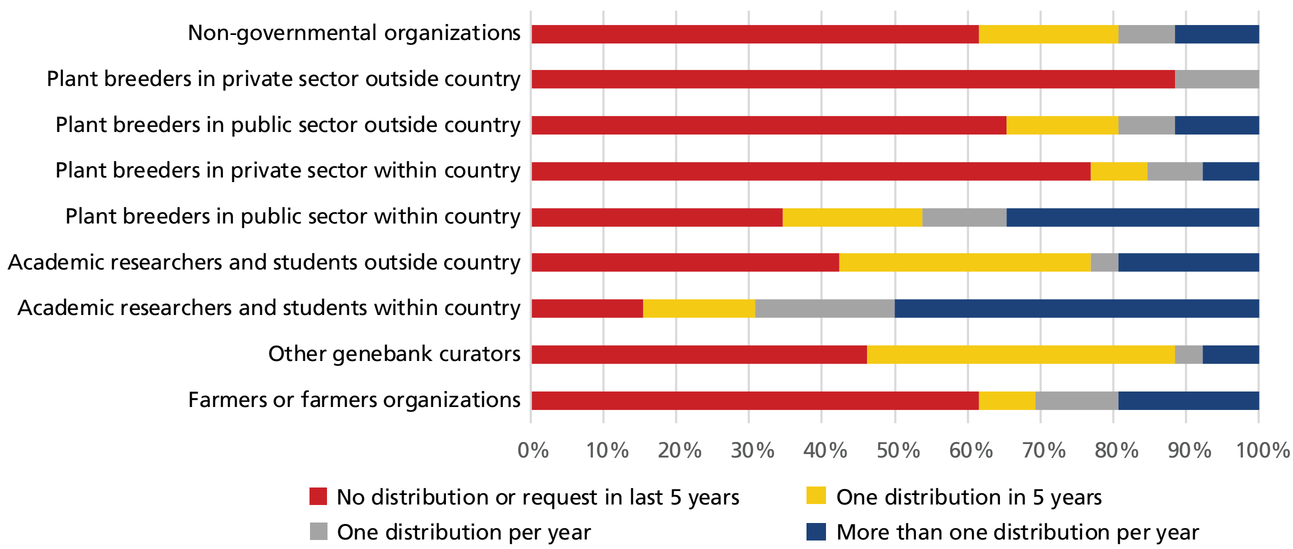


Figure 11.1 Frequency of distribution to various types of user, by proportion of respondents (no distribution or no requests in the past 5 years; one distribution in the past 5 years; one distribution per year; more than one distribution per year).

Table 11.1 Types of feedback that respondents solicit from users of accessions.

Specific areas of feedback from users	Number of respondents
Timeliness of the distribution	9
Helpfulness of information or advice from genebank staff in selection of accessions	8
Quality of samples sent	12
Quality of packaging used	6
Quality and usefulness of the accession-level information received	6
Usefulness of the accessions received	14
Sharing of reports or publications on any specific research results derived from the evaluation or use of the accessions received	14
Sharing of evaluation or characterization datasets	12
Variety releases, adoption studies or case studies from the use of an accession received	7

phytosanitary certificate to ensure samples are free of biotic threats or stresses for the importing country; appropriate packaging to secure and maintain the quality of the seed during transportation; and shipment through the appropriate route. The respondents were asked if their procedures and supplies were adequate for distribution. All but one of the respondents reported having adequate processes in place to manage the SMTA and/or MTA; the main issue for the other respondent was the lack of national legislation to facilitate this process. Seventeen respondents have adequate processes to obtain phytosanitary certificates; for the others, the main issues are related to costs or administrative obstacles in obtaining certificates from authorities. Some reported that the high cost was their main reason for not dispatching internationally, but one respondent said they charge the cost to the requestor. Packaging of seeds was not an issue for 17 of the respondents; for the other nine, packaging was inadequate mainly due to difficulties in getting appropriate packaging materials locally. Finally, more than half of the respondents reported that procedures for shipping were inadequate because of costs and difficulties in complying with regulations. These factors could be major constraints for international distribution as well.

The survey requested information on the frequency of distribution to nine types of user (Figure 11.1). Results for respondents who reported no distribution were merged with those who reported no distributions in the past 5 years. All respondents reported very few distributions to certain user types, such as national and international plant breeders in the private sector. This may be due to policy restrictions, or to low commercial interest in the millet seed sector. In addition, more than 60% of respondents reported no distribution to, or requests from, farmers, NGOs or public plant breeders outside their country. The main users of the collections were other genebank curators, academic researchers/students nationally and internationally, and national public plant breeders that were mainly from their own institution.

Finally, the survey asked how respondents follow up with users, or solicit feedback on the quality and use of the accessions received (Table 11.1). About 50% of the 26 respondents solicit feedback on the quality of the samples dispatched, the usefulness of the accession received, sharing of reports or publications, and sharing of characterization or evaluation datasets. Very few of the respondents solicit feedback on the quality of the packaging or the accession-level information shared. Fifteen respondents reported using informal feedback through email, phone or meeting, but, generally, no formal surveys are used. Respondents said they used the feedback to improve the quality of their seed and services and that feedback offered an opportunity to incorporate any additional characterization or evaluation data that were shared. Feedback is also used for reporting on the use of accessions distributed or the value of collections. The collation of research publications is used to enhance future research by sharing research results derived from the germplasm distributed.

Generally, distribution of millet crops occurs most often within institutions or nationally. International distribution is hampered by policy, cost of distribution and complex administrative procedures. The main users of millet crop collections are nationally based researchers and other genebank curators. The lack of public or private sector breeding programs for most of these crops has resulted in few users for these collections. Procedures to solicit feedback from recipients should be formalized and used to improve the quality of seed and services, to better understand users' interest in accessions and to communicate the value of the accessions and collections more widely.

Breeder and farmer review finger millet in field in Kakamega County, Kenya. Photo: Michael Major for Crop Trust

12 STATUS OF *EX SITU* COLLECTIONS: LINKS TO USERS

Links between *ex situ* collection holders and between collection holders and users are critical for long-term conservation and use. The survey explored the degree and diversity of these interactions by considering the types of activities and partnerships the collection holders had experienced for both conservation and use. As shown in Figure 12.1, the majority of activities listed are conducted with other *ex situ* collection holders, both nationally and internationally, and with local community seedbanks. Overall, 23 of the 26 respondents had joined with other *ex situ* collection holders to undertake these activities. Only one respondent reported receiving additional support to take part in the activity. When asked if the frequency of joint activities were increasing or decreasing, seven respondents indicated they were decreasing, and eight respondents indicated they were increasing. Only four respondents have taken part in joint activities with on-farm conservation sites, and two respondents have taken part in joint activities with *in situ* conservation sites; these activities focused on safety duplication, training and collection. Overall, these results indicate a low level of interaction with more locally focused conservers, which is an area that needs to be strengthened, given that many millet crops are still conserved primarily in local farmers' fields or in community seedbanks. Links to *in situ* conservation sites and protected sites for wild relatives are also very weak, which indicates a risk for wild relatives that are under threat in these sites. Such links also offer an opportunity to enhance partnerships between experts on conservation and experts on crop diversity. Links and partnerships need to be strengthened for all the other site-specific conservers.

The survey also explored the links and extent of activities between collection holders and various types of users (Figure 12.2). The majority of respondents reported having undertaken joint activities with national breeders and other researchers in a national program. These activities focused on seed multiplication, training and collection. Very few of the respondents had undertaken activities involving the private seed sector; of these, most interactions focused on research, field days, demonstration plots, participatory evaluation and seed multiplication. These results are likely due to the low level of private sector involvement with millet crops, but it is a type of partnership that should be strengthened in the future. In general, in only about one-third of cases involving activities with researchers had the respondent received additional support for the project; for activities involving the private sector, no respondents received additional support. Overall, more respondents indicated an

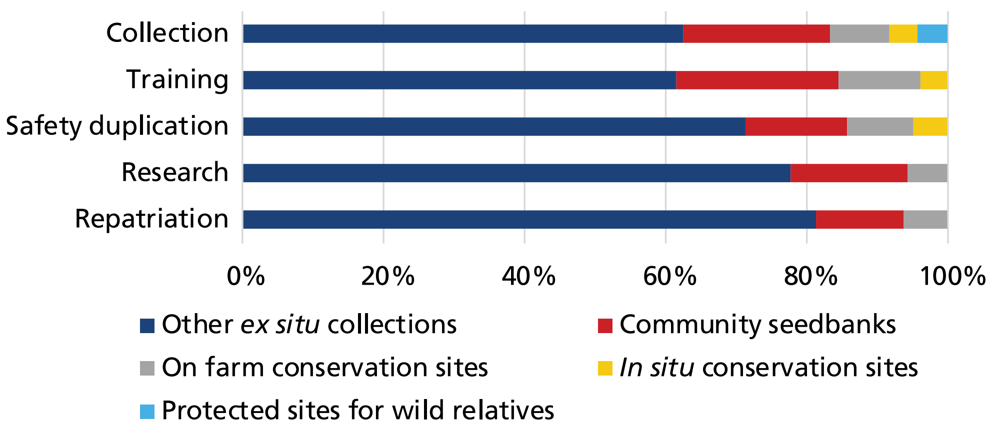


Figure 12.1 Proportions of respondents reporting interactions with partners for repatriation, research, safety duplication, training and collection.

increased level of activities with researchers than with any other type of user.

The survey also explored the extent of respondents' activities with the local direct users of their accessions. Overall, more respondents have worked with individual farmers and community groups than with researchers (Table 12.1). Such local activities focused mainly on participatory evaluation, demonstration plots and field days; training and seed multiplication were less common activities for local farmers and community groups. Across all activities, 60% of respondents reported receiving additional support for conducting activities with farmers' associations, community groups and NGOs, with 40% reporting additional support for activities involving individual farmers. The vast majority of respondents indicated that these activities were increasing. Overall, the extent of direct engagement of collection holders with local users is very encouraging for these millet crops, especially the level of collaborative research being undertaken. The majority of these millet crops are still mainly grown by local farmers for their own or local consumption. Much of the success in breeding these crops has come from direct selection from genebank accessions or farmers' varieties (Dwivedi et al. 2012; Goron and Raizala 2015; Sood et al. 2015; Assefa et al. 2017; Ayenan et al. 2017; Gomashe 2017; Habiyaremye et al. 2017; Yadav et al. 2017; Renganathan et al. 2020; Vetriventhan et al. 2020). Thus, collection holders' engagement with local farmers, directly or indirectly, will create more opportunities both to share accessions that are already conserved and to collect and conserve more of the germplasm that these farmers hold. This is an opportunity both to secure genetic resources that are at risk of genetic erosion or loss in the field and to contribute to efforts to improve the crops for climate change adaptation, rural development and food security.

While the results indicate that *ex situ* collections actively engage with each other, with the research community and with local farmers or communities, there are very few networks or collaborative initiatives that engage with respondents globally, across crops or for individual crops. ICRISAT, as a CGIAR center with an international collection of millets, has taken the lead on actively engaging with partners for the crops they conserve, and IRD continues to engage with countries that conserve fonio and pearl millet. Other regional networks include the SADC Plant Genetic Resources Centre (SPGRC), which involves all collection holders for pearl millet and finger millet, and the European Cooperative Programme for Plant Genetic Resources (ECPGR) for European collection holders that conserve proso millet. However, there are few international platforms for collaboration on millet crops, except for a few project-specific sequencing and genotyping initiatives that have involved global coalitions. One of these, which is ongoing, is the African Orphan Crops Consortium, which is focusing on the genome sequencing of fonio, teff and finger millet.

Table 12.1 Numbers of respondents who have conducted activities with farmers directly or through farmers' association, community groups, NGOs and extension services.

Activity	Individual farmers	Farmers' associations, community groups or NGOs	National or local extension services
Repatriation	1	1	0
Seed multiplication	6	12	3
Participatory evaluation	9	18	7
Demonstration plots	10	17	6
Field days	10	17	8
Research	6	6	2
Training	8	13	6
Collection	2	1	2

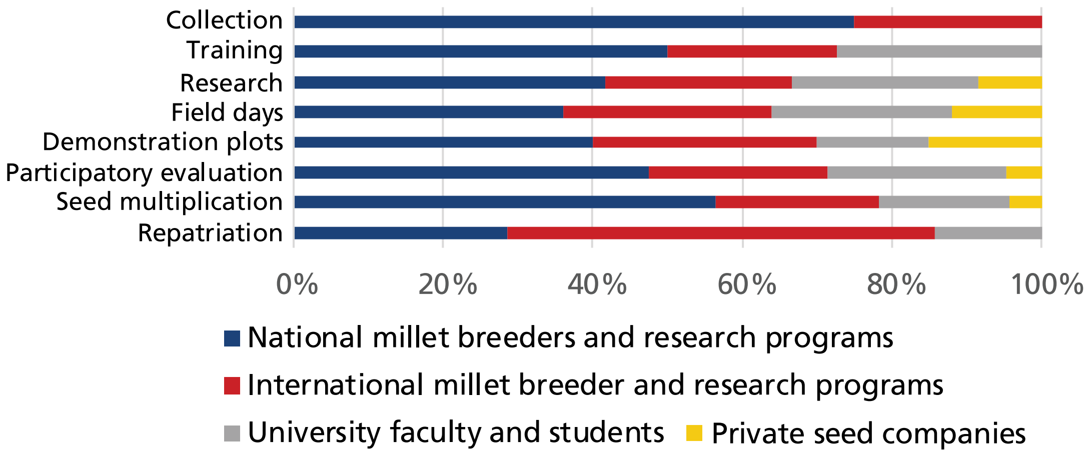


Figure 12.2 Proportions of respondents reporting joint activities with international and national research users.

Mature panicles of *Panicum miliaceum*, University of Nebraska high plains agricultural lab. Photo: Jschnable/Wikimedia

13 STATUS OF *EX SITU* COLLECTIONS: VULNERABILITY

Previous sections of this strategy have identified concerns related to priority needs for addressing vulnerabilities in the conservation of genetic diversity in collections; secure, efficient routine operations; genebank facilities and equipment; users' access to accession-level information; user engagement; and partnership opportunities. These areas are all possible sources of risk for long-term conservation and use, both for individual genebanks and for the global conservation system. Other possible areas of risk are inadequacy in staffing, poor planning for staff succession, inconsistent financial support, and lack of attention to management and risk mitigation.

Staff numbers and level of expertise are adequate for the vast majority of the respondents for routine operations and meeting distribution requests. Only about half of the respondents reported having adequate staff and expertise for information management. For all three areas, a high number of respondents indicated that the training of staff was inadequate. Training needs reported included specialist training

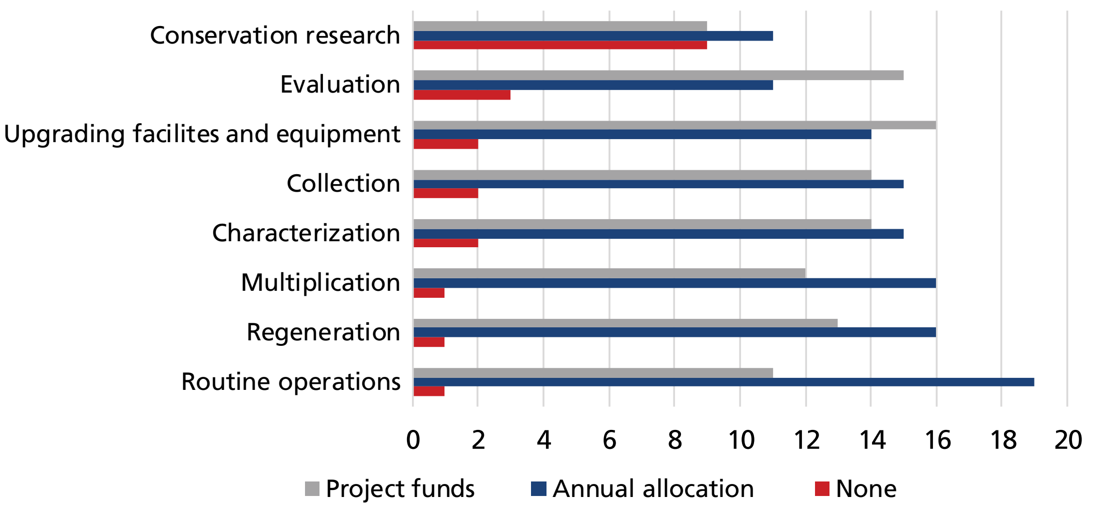


Figure 13.1 Number of respondents that reported receiving no funding, annual allocation, project funding for various activities.

such as seed physiology and data analysis; however, no respondents reported a need for genebank management or general genebank training. These latter areas were the focus for training in the previous strategies for pearl millet and finger millet (Mather and Upadhyaya 2012a; Mather and Upadhyaya 2012b).

Respondents were asked about funding sources for the genebanks and their activities, as well as the status of these financial resources. For 21 of the 26 respondents, the majority of funding comes from government; of the remaining five, three are mainly supported by international donors, one receives only specific project funding for conservation of accessions and one receives funds from the private sector. Two respondents reported receiving additional support from income that their institute generated from production, one from breeding programs and two from projects.

Funding sources for routine operations and the upgrade of facilities/equipment are shown in Figure 13.1. Annual and project funds are available for all activities, except, in the case of nine respondents, for conservation research. An annual allocation is the sole funding source for routine operations, regeneration and multiplication for about 50% of the respondents. For multiplication, characterization and collection, a nearly equal number of respondents receive only annual or project funding. Activities such as evaluation and the upgrade of facilities and equipment seem to be more dependent upon additional specific funding. A quarter or less use both annual allocation and project funds for all their activities.

Altogether, respondents' dependence on project funding for all activities could result in insecurity and uncertainty for conservation operations and lead to large backlogs. Respondents' dependence on project funding for activities such as multiplication, characterization, evaluation, collection and upgrades suggests a low certainty of investment in enhancing use, securing genetic resources at risk and securing conservation through adequate infrastructure and equipment when it is needed. One approach to addressing this situation is to increase advocacy targeting more annual funding and more safety duplication to ensure that collections are secured. The establishment of a global competitive project fund to address urgent shortfalls in funding for routine operations and necessary upgrades should also be considered over the longer term, as an action for the global system.

Identifying risks to collections and making risk mitigation plans that can be annually monitored are key aspects of a quality management system, as recommended in the FAO (2014) international genebank standards. Only six of the 26 respondents have a risk management plan that is monitored. The primary risks identified by the respondents are:

- fire, power outages, storms, theft, vandalism and national disasters;
- pest damage;
- uncertain and inadequate funding for staff and their training;
- uncertain and inadequate funding for equipment purchase, repair and maintenance;
- uncertain and inadequate funding for infrastructure construction, repair and maintenance;
- erratic power supply;
- lack of a long-term storage freezer or unit;
- obsolete or poorly maintained storage equipment;
- inadequate representation of national diversity;
- mistakes and mix-up of seeds because of handwritten labels;
- loss of viability because of an inadequate level of regeneration;
- inadequate safety duplication'
- large regeneration backlogs;
- inadequate management and security at field sites;
- low level of characterization, which is needed to improve use and conservation;
- accessions are not accessible;
- insufficient seed for distribution;
- no backup of genebank data; and
- no plans for staff succession.

Less than half of the respondents identified pest and disease concerns for seed storage and distribution as a risk, but 15 of the 26 identified biotic risks during regeneration, mainly disease or pathogens.

Pearl millet. Photo: Neil Palmer/CIAT

14 STATUS OF *EX SITU* COLLECTIONS: CONSTRAINTS AND OPPORTUNITIES

The respondents were asked to list the major limitations affecting the management and use of their millet collections. The major limitations identified for conservation, documentation, use and partnerships were:

Conservation

- Inadequate financial resources for: routine operations; conservation facilities; upgrades for obsolete, aging or inadequate conservation facilities and equipment; improving processes such as regeneration, multiplication, characterization and evaluation
- Aging accessions with decreasing seed viability, which is leading to increased demand for viability testing and regeneration, especially for large collections
- Insufficient funds for conservation research
- Limited quantity and quality of crop wild relatives, which are difficult to conserve and regenerate
- Difficulties producing high-quality seed of sufficient quantity for long-term conservation and distribution to a wide array of users
- Inadequate seed health testing
- Inadequate safety backup
- Lack of a quality management system with written, accurate standard operating procedures for key routine operations

Documentation

- Need for database upgrades and digitization of accession level information and genebank management information
- Generally poor access to accession-level information across all these millet crops
- Limited accession-level information with incomplete passport, characterization, genotyping and evaluation data
- Lack of accession-level information that meets users' needs
- Lack of online searchable databases that are shared through a widely available platform such as Genesys or an institution website

Use

- Complex and costly international distribution requirements with expensive, complicated phytosanitary and customs procedures
- Limited breeders/researchers and resources with a focus on millet crops
- Limited expertise and partnership opportunities for collaboration to promote use
- Low national and international priority of millet crops due to their low value, low productivity and intensive labor requirements, which is leading to further marginalization of the crop and its abandonment by farmers and the market
- Limited diversity in existing collections, with few opportunities to expand due to crop losses in country or to very strict import restrictions hampering germplasm exchange
- General lack of awareness about the conservation and sustainable use of crop biodiversity, *ex situ* collections and their potential use
- Policy issues related to access and benefit sharing (ABS)

Partnerships

- Weak or no international or national network for research/genetic resources within and across the millet crops
- Lack of international partners to conduct research into these minor or local crops
- Limited quantity of seed available to distribute directly to farmers for their own use of to rapidly respond to the need for repatriation or restoration after losses caused by disaster or abandonment of the crop
- Lack of partnership opportunities and limited commitment by communities and local stakeholders in conservation and sustainable use of genetic resources

The genebanks were asked to identify areas where they were doing well. Overall, the areas in which some respondents considered they were doing well were areas in which other respondents reported having difficulties. Thus, there are opportunities amongst these respondents to collaborate more closely to take advantage of the experience and expertise of some genebanks to address the constraints of others across the millet crops. The creation of a platform or network across millet crops through which genebanks could share their experiences, ask and offer advice, and undertake capacity building would be of benefit to all those in the global system.

Respondents were also asked to rate the status of various factors that influence whether the long-term conservation and use of their collections is secure, cost effective, rational and sustainable (Figure 14.1). For six of these factors—all related to distribution, use of collections and engagement with users—very few of the respondents reported that the status was declining. Four factors were reported by 11–13 of the respondents to be declining or stable; three of these factors are related to support for the collections and the other to the status of regeneration. These findings indicate that the key consideration for future actions of many of these genebanks is the need for reliable annual support, especially for ensuring more secure conservation and for expanding collections, to better meet users' needs. Given the status reported for safety duplication in the survey, it is interesting that most of the respondents viewed off-site duplication as stable or improving. This might be due to the lower priority given this issue for the respondents.

Finally, the respondents were asked to identify key aspects of their collections that would be important for future users. Some of the key aspects described were:

- The conservation of, and access to, diversity of these locally important crops for smallholder farmers, as they face more challenges related to production and land use, will lead to increased opportunities for direct use and for restoration when farmers lose or temporarily abandon the crop.
- Most of the accessions are unique, exhibit wide diversity and adaptation to a wide range of agroclimatic conditions nationally, and are a main source for initial breeding stock, especially for new breeding programs with a need for variation.
- Landraces and wild species can be explored as potential sources of resistance to biotic and abiotic stresses, for use in crop improvement programs aimed at developing new varieties.
- Conservation and availability of a range of accessions of wild species and subspecies related to the cultivated crops (crop wild relatives) that could be used to identify useful traits, particularly for abiotic stresses.
- Mostly unique indigenous collections that users have not yet explored or exploited.
- Accessions collected from a range of agroecological zones and farming systems, with an interesting range of adaptability.
- All the lines, populations and varieties developed by regional or national breeding programs are conserved and available in the collection.
- Varieties developed directly from accessions conserved in our genebank can be released as varieties to support food and nutrition security, following evaluation by farmers and breeders.
- Facilitated access to diversity for breeding/research; access for farmers of traditional varieties, and access for international users through the ITPGRFA.
- Diversity in the collection will be used as a source of healthy food and technical products, as there is increasing focus on the value-added aspects of these crops.
- Most of the millet crops are heat and drought tolerant, so climate change may make millets more relevant and productive for new, marginal environments; these *ex situ* collections will be critical for their improvement.

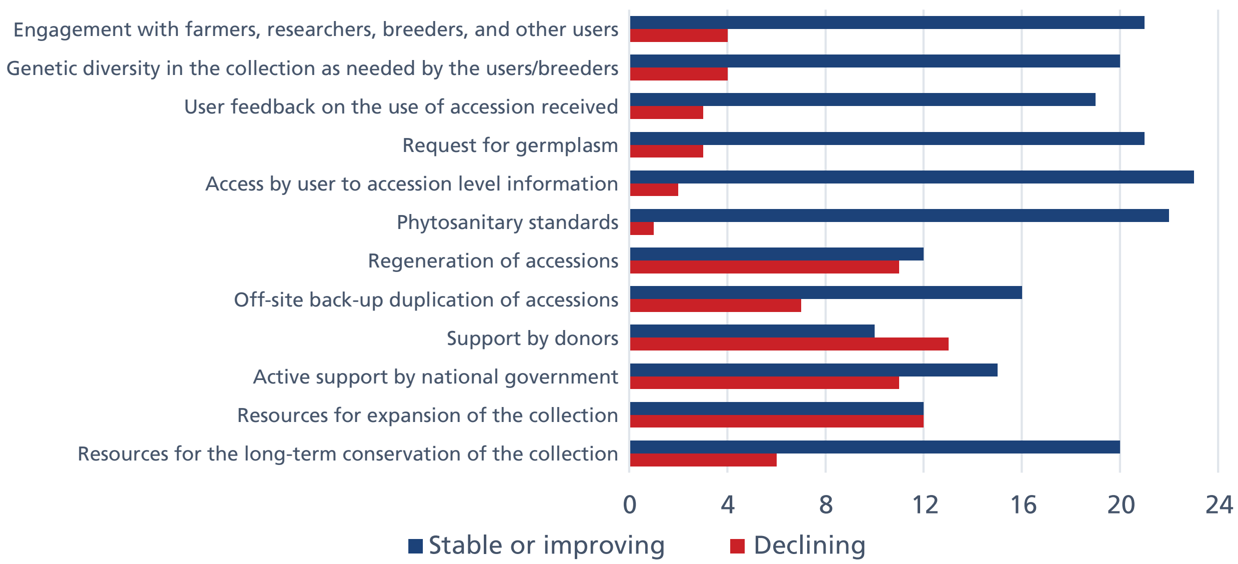


Figure 14.1 Proportion of respondents' assessment of the status of their millet collections (declining or stable or improving), in relation to key considerations for the genebank in the future.

Farmer in southern Senegal shows white fonio (*Digitaria exilis*). Photo: Richard Nyberg, USAID

15 GLOBAL STRATEGY FOR THE *EX SITU* CONSERVATION AND USE OF MILLET CROP GENETIC RESOURCES

This global strategy for the conservation and use of nine millet crop genetic resources draws on the background study on the importance of the millet crops, the history of millet crops and the value of the genetic resources for users. Also considered were the analyses of the quality and adequacy of the diversity conserved based on data retrieved from various databases with accession-level information on collections, and the assessment of the status of the current conservation system based on survey responses from about 50% of the institutions that conserve these crops that account for about two-thirds of the accessions conserved globally. The survey findings provided insights into the current status of millet collections on a global scale, with some notable deficiencies for crops such as foxtail millet, proso millet and Japanese barnyard millet.

The current global system is not secure, efficient or rational, and is characterized by constraints and vulnerabilities for some collection holders, although not all. Globally, there is a backlog both in the regeneration of accessions that are losing viability and in the multiplication of seed for distribution. This backlog is already resulting in insufficient seed to meet distribution requests. Collection holders who responded to the survey reported constraints with the key facilities and equipment for storage and for routine operations. Constraints were also identified in routine operations aimed at ensuring the use of the most efficient and secure procedures and protocols through SOPs, QMS and research. Finally, the lack of safety duplication for more than three-quarters of the accessions conserved globally is a key vulnerability that needs to be addressed in the future.

Currently, there is limited availability of and access to accession-level information for users through online, searchable platforms. Much of the genebank information and accession-level information is still not digitized or exists only within internal databases. The wider adoption of genebank information systems, such as GRIN-Global, will not only increase monitoring and efficiency of management, but will also enable more online sharing of accession-level information and better backups of documentation. It will also allow for greater linking of collections within the global system to enhance use and to better secure conservation.

Generally, distribution of millet crop germplasm tends to occur primarily within the institution or nationally. International distribution is hampered by policy, cost of distribution and complex administrative procedures. The main users of millet crop collections, after other genebank curators, are nationally based researchers. The lack of public or private sector breeding programs for most of these crops has led to low numbers of research users for these collections. Efforts to solicit feedback from recipients should be formalized and the feedback used to improve quality of seed and services, to better understand users' interest in accessions and to communicate the value of the accessions and the collection more widely.

For most of the collection holders, the current global system of conservation and use is generally insecure, with inefficient and poorly resourced operations, limited availability of seed to all users, limited sharing of accession-level information with users, and limited engagement of conservers and users globally, nationally and locally. This is not the sustainable, rational, secure and cost-effective system that is needed for long-term conservation and use of these very important cereal crops. Some of these weaknesses are due to the low priority given to these crops by international donors, national governments, public and private researchers, local authorities, local farmers, local and urban markets and consumers. This decline in priority is a risk not only to *ex situ* conservation but also to the continued conservation of diversity in farmers' fields.

The current global system for the conservation and use of millet crops consists of the following:

- Local farmers and households who conserve and manage the majority of these crops' diversity.
- Natural areas where the majority of the diversity of wild relatives is still conserved.
- One international genebank, ICRISAT, which conserves a large collection of pearl millet, finger millet, foxtail millet, proso millet, barnyard millet, kodo millet and little millet, and which receives long-term support from the Global Crop Diversity Trust for secure conservation and wide availability of accession-level information and seed for users.
- A few key national collection holders in the center of diversity that conserve mainly unique local diversity for one or a few millet crops with uncertain national support for conservation and breeding/research but with greater opportunities for local engagement with users for conservation and use.
- A few other national collections that are located outside the center(s) of diversity that conserve accessions that are duplicates of those held by others and that are conserved more securely, with greater availability of accession-level information and seed for a wide range of users; however, their support is national and, as national priorities change, they face an uncertain future for conservation and use given the decline in engagement with users.

The current global conservation system does have some advantages that can be built upon. There are commonalities amongst these millet crops in terms of conservation, productions, use, and local value can be built upon by a global, across, millet crop collaboration. This collaboration should also be expanded to include sorghum. A large millet crop that has had much more investments into breeding, research, and use of genetic resources but shares many of these same constraints to conservation and use. For example, for all crops except teff and fonio, there are genebanks with experience and expertise that other conservers can turn to for help and guidance, in their efforts to meet international standards. These genebanks, such as ICRISAT, can also serve as conveners in global efforts to increase security of conservation, adopt new technology and methods, enhance capacity and expertise on millet crops and collectively address some of the major constraints in the shift to a more sustainable global system. These genebanks can also take on leadership in advocacy and communication on the importance of conservation and use of millet crop diversity, with much of the focus on what is being done more nationally and locally by other conservers in the system. Other advantages in the current system are related to the national and local nature of conservation, which means value-added research and development can directly utilize local germplasm with the involvement of local farmers and consumers.

The main disadvantages of the current system are the lack of committed annual support for conservation of these crops in many of the national genebanks, the general lack of knowledge on the diversity that is conserved, the low level of support for research into millet crops, and the vulnerability of much of the diversity to loss, both *ex situ* in genebanks as well as in the field or in natural areas. The purpose of this strategy is to recommend priority actions to shift from the current system to a global system of conservation and use that is more secure, rational, cost-effective and engaged with users. These recommended actions will be used by the Crop Trust and others to identify key investments needed to secure conservation and use for the long term.

In 2012, global *ex situ* conservation strategies for finger millet and pearl millet were completed (Mathur and Upadhyaya 2012a; Mathur and Upadhyaya 2012b). Each of these strategies involved a survey on the status of conservation and use to determine the state of global conservation. The conclusions and some of the key issues identified for those two crops were similar to the present findings for all the millet crops, including the following:

- There were several key constraints to secure and effective conservation, such as limited safety duplication, a need for urgent regeneration, irregular seed viability monitoring and poor storage infrastructure.
- In general, there was limited sharing of accession-level information with users.
- There was limited availability of accessions to international users, except for a few collections such as ICRISAT and USDA-ARS.
- Only a fraction of the accessions of the two millet crop accessions conserved in genebanks were used in crop improvement programs; the main reasons for this low use were the poor quality of the evaluation data and the very limited sharing of accession-level information.
- A few collection holders have identified and made available core collections or trait-specific subsets to facilitate increased use of genetic resources.
- There was a lack of effective links to users due to poor information flow between genebanks and users, poor level of engagement between genebanks and crop-based research institutes, and poor links between genebanks and in situ/on-farm conservation efforts.

For the previous strategies, surveys were followed by a workshop for pearl millet and for finger millet to discuss the various conclusions of the survey and identify key recommendations for each crop separately. In general, the main recommendations from the workshops were to:

1. Address gaps in passport information for accessions in specific collections
2. Identify significant collection holders that could be designated as reference collection centers for the global system
3. Identify potential partners for conservation services
4. Identify key gaps in diversity that need to be urgently addressed with collection, such as wild relatives in the secondary and tertiary genepool in Asia and in the primary genepool in Africa
5. Adopt GRIN-Global or other genebank information management system that will enhance sharing of accession-level information through Genesys
6. Evaluate and share generated data of mini-core collections from ICRISAT
7. Secure safety duplication for all unique accessions through national facilities, regional genebanks, CGIAR genebanks and Svalbard Global Seed Vault
8. Support countries to address policy and technical constraints to exchange germplasm
9. Strengthen networks with regional collaborative programs, increase collaboration between India and Africa for both crops
10. Increase links to civil society organizations and researchers in health and nutrition
11. Increase the effectiveness of links to users with sharing of better-quality accession level information
12. Encourage more active engagement with researchers and breeders to demonstrate and develop material that meets their needs
13. Undertake capacity building in key areas related to secure conservation, documentation and genebank management.

The workshops for both millet crops identified key steps to address these recommendations. Most of these were actions that individual collection holders could take in relation to securing conservation, filling collection gaps, meeting internationally agreed genebank standards, and increase evaluation and use of the accessions in their collection. Opportunities for collective actions globally were identified in terms of policy guidelines and capacity building. No clear leadership or resources was identified to implement the either of the two global strategies but there have been some steps taken, with support of the Crop Trust, to regenerate 1519 pearl millet accessions and 2637 finger millet accessions that were at risk of loss at National genebanks. In addition, 1113 pearl millet and 1250 finger millet accessions at risk of loss were regenerated and conserved at ICRISAT for national collection holders. There has also been increased evaluation and use of core subsets (Vetriventhan et al, 2020). Thus, some of the collection holders have made progress in addressing constraints identified for action.

Millet field in Asia. Photo: Stefano Padulosi/Bioversity International

16 RECOMMENDED PRIORITY ACTIONS

A global strategy must identify the key priority actions that need to be taken, who should be involved and what kind of resources will be required. This is best done through consultation, such as the workshops in 2012. In the meantime, to enable the discussion, three strategic objectives are identified based on the survey, with the key activities:

1. Secure conservation of millet crop genetic resources for the long term:

    a. Address insecurity in *ex situ* conservation due to suboptimal routine operations, facilities and safety duplication.
    b. Address risks to unique diversity still being conserved in farmers' fields and in natural areas.
    c. Address constraints to global engagement between conservers and between conservers and users.
    d. Increase advocacy and communication on the importance of millet crops and their conservation to the public, local governments and communities, policymakers and other research communities to increase awareness and financial support and reduce the decline in production, research and conservation.

2. Increase the availability and exchange of germplasm:

    a. Address constraints to distribution due to insufficient seed quantity, quality and viability.
    b. Address policy bottlenecks to distribution.

3. Increase the use of the conserved genetic diversity;

    a. Increase access to accession-level information, preferably by making it available online to all users.
    b. Increase evaluation and genotyping, with results openly shared with users.
    c. Establish and make available core collections or other subsets to facilitate use.
    d. Increase genebanks' engagement with researcher and farmer.

Addressing the key activities in these three strategic objectives will facilitate the development of a more sustainable, longer-term and rational global system for conservation and use. The first steps in addressing these global objectives will be to build a global collaboration across all nine millet crops with committed leadership to facilitate the use of dedicated financial resources to implement collective and individual activities, both from increased annual allocations and from more targeted specific funds. Thus, taking lessons from the previous strategy, three priority actions have been identified from this 2020 survey and the background study for the initial implementation of the strategy.

Priority Action 1: Establish a global platform for the engagement of key collection holders and main users across the millet crops

A platform that enables conservers and users of millet genetic resources to communicate and collaborate is necessary. Any such platform will need to link the key collection holders, key users and other stakeholders. It will allow *ex situ* collection holders and users to share experiences; collectively improve conservation practices; establish quality management system protocols, processes and standards; offer each other capacity-building opportunities; and address the needs for safety duplication, adoption of genebank information systems and sharing of accession-level information that meet the needs of users. This platform could also be used to address the declining support for specific collections or local diversity in farmers field or diversity of wild relatives in natural areas that are at risk of loss due to natural disasters, declining perceived importance of the crop, loss of resources, loss of expertise and other threats that might require an urgent response. The platform could also serve as a source of experts when needed, as in the targeting of key gaps in diversity for collection or re-collection or facilitating collective research to enhance production and use. This platform could be mainly operated virtually with in-person meetings when funds are available.

ICRISAT leads the Smart Food Initiative (Smart Food, 2022a) that has an objective to diversify the production, marketing, and consumption of millets across Asia and Africa. It has an initial focus on pearl millet, finger millet, and sorghum but there is an indication that the longer-term intention is to cover all the millet crops. Smart Food indicates that its objective is to bring these food crops into the mainstream through communications, advocacy, market development, increasing consumer demand, ensuring links to smallholder farmers and rural communities, and filling the gaps in knowledge on nutrition, health, processing, and marketing. Smart Food has also indicated a commitment to the promotion of millets through the 2023 International Year of Millets (Smart Food 2022b). The key conservers of the nine millet crops and sorghum genetic resources are the same smallholder farmers and rural communities that are the focus for the Smart Food activities, and these are key resources for long term production and consumption. Thus, the expansion of the Smart Food Initiative to include a focus on activities related to the long-term conservation and use of millet genetic resources would clearly link these two key aspects of moving these crops into the mainstream. This would facilitate the establishment of this global platform with a focus on key users beyond the small number of breeder/researchers for these crops. ICRISAT, through the Smart Food Initiative and the genebank, as well as some of the key national collection holders could initially convene this platform. The establishment of the platform with a global workshop and key initial activities could be part of the actions planned for the International Year of Millets in 2023.

Priority Action 2: Establish a fund with a competitive grant scheme to increase resources for upgrades and secure conservation for key national collection holders in the center of diversity

A number of priority needs have been identified in term of routine operations, facilities, equipment and procedures where there are backlogs or a significant need for upgrades. Many of these are due to genebanks' reliance on short-term specific project funds that are not guaranteed and that seem to be declining. Financial support for long-term conservation and use is not a priority for many donors, and the minor nature of millet crops has resulted in few opportunities for funding to address these gaps. The lack of global action to address these collection-specific constraints is a risk for the conservation of a high proportion of the unique diversity of many of these crops. The development of a global fund with a competitive grant scheme, through which collection holders can apply for project funds, would enable them to address these key priority actions. The fund could be set up to require complementary funds from the government for a specific project and a commitment to increased annual allocation to secure long-term conservation of this key diversity, which has significant national value.

There is a general need to upgrade operations, documentation and efficiency of conservation through more sharing of accession-level data online through platforms such as Genesys and the adoption of a quality management system. The collective action of most of the major collection holders would be an opportunity to share resources, experiences, and capacity globally. Thus, there is a need to ensure the collaborative platform has an important role in setting priorities and targets for projects, collaborating on projects together, monitoring projects and communicating the results.

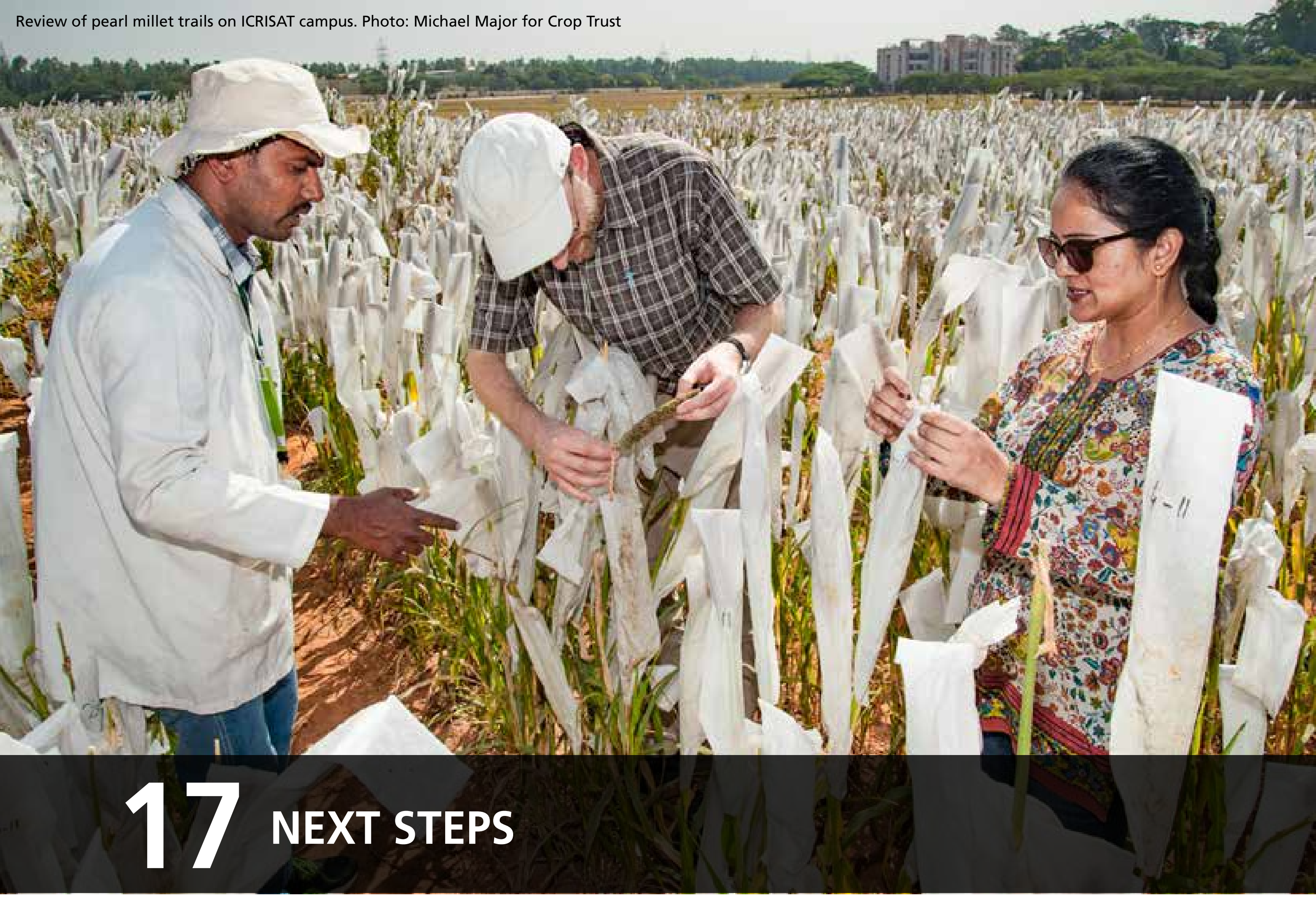
While national distribution seems to be constrained mostly by lack of knowledge of accessions and inadequate seed availability, international distribution is further constrained by policies, as well as by the cost and complexity of shipment with the need for phytosanitary certificates and appropriate packaging. It may be necessary to explore options to cover these costs or to transfer the charges to the requestor of the germplasm. A global approach could be taken to facilitate international shipments, as is done to support shipments to Svalbard Global Seed Vault for some depositors. This could be supported by the global fund.

Priority Action 3: Enhance knowledge, conservation, and use of the unique diversity of millet crops that is still found in the field or in natural areas

There is a need to expand the collaboration of *ex situ* collections, on-farm conservation sites, community seedbanks, and *in situ* and protected sites to secure the global diversity of these millet crops and their wild relatives. This can be achieved through better linking of global and national initiatives to ensure support for *ex situ* collection holders' to increase engagement with farmers, farmers' associations, community groups, NGOs and national extension services, given the limited number of millet breeders, and research on millet and private seed sector interest. Greater engagement will facilitate local access to these key genetic resources and secure *ex situ* conservation with collection and safety duplication.

A strong advocacy plan should be developed to create enabling policies to promote and enhance the on-farm maintenance of millet genetic resources. There is a need to carry out systematic surveying and inventorying of varietal diversity of the millets in farmers' fields and in the wild. It is further recommended that a global conservation planning exercise be carried out to determine key priority sites that would be targeted for conservation through collection and detailed *in situ* conservation interventions, including the creation of genetic reserves for millet genetic resources. This should include an early warning monitoring system for tracking the loss of millet genetic diversity from farmers' fields and the wild.

To facilitate the required actions, there needs to be investment in securing the diversity of these millet crops *in situ* in the most important centers of diversity; to collect and conserve a sample of this diversity in a key *ex situ* collection; and to collaborate with national and local authorities to ensure their long-term commitment. The funding for the plan could come from the global fund in Priority Action 2, or it could come from additional funds, but it must draw on lessons from past efforts at on-farm or *in situ* conservation to ensure the sustainability of the effort.



Review of pearl millet trails on ICRISAT campus. Photo: Michael Major for Crop Trust

17 NEXT STEPS

The next step in the implementation of this global strategy will be to hold a consultation workshop on the global strategy and the proposed priority actions. The link of this workshop with ICRISAT, through the Smart Food Initiative, as well as some of the key national collection holders and with any global workshop or key activities planned for the International Year of Millets in 2023 should be considered. NARO in Japan, Chinese Academy for Agricultural Sciences (CAAS) in China and VIR in Russia should be engaged in the planning process.

Holding the workshop in China should also be considered to further engage an important center of diversity for several millet crops. Or this workshop should be held at ICRISAT, given its international focus on most of the millet crops. The consultation workshop will allow for the establishment of the global platform, sharing knowledge on the millet crops conservation and use efforts, enhance global communications on the urgent needs for securing conservation and the long-term benefits of use of genetic resources, and further develop an implementation plan, with details on the estimated cost and who will be involved.

Key stakeholders in the millet crops value chain should be included, such as the collections holders who have participated in the strategy development, breeders/researchers from universities, national research programs, NGOs such as the M.S. Swaminathan Research Foundation (MSSRF) and the private sector.

Finally, the participants should include staff from the Crop Trust, the ITPGRFA and key donors who have a priority for investments in millet crops. The total attendance would be about 60–80 participants, with the cost dependent upon the type of workshop held and its link to other ongoing international meetings.

18 ABBREVIATIONS AND ACRONYMS

ABS	Access and benefit sharing
CAAS	Chinese Academy for Agricultural Sciences
CWR	crop wild relatives
DRC	Democratic Republic of the Congo
ECPGR	European Cooperative Programme for Plant Genetic Resources
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environmental Facility
GRIN	Germplasm Resource Information Network
IRD	Institut de recherche pour le développement
IBC	Institute of Biodiversity and Conservation
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute for Tropical Agriculture
IPGRI	International Plant Genetic Resources Institute
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
LI-BIRD	Local Initiatives for Biodiversity, Research and Development
MSSRF	M.S. Swaminathan Research Foundation
MTA	material transfer agreement
NARO	National Agricultural Research Organization
NGO	nongovernmental organization
QMS	quality management system
SDIS	SPGRC Documentation and Information System
SPGRC	SADC Plant Genetic Resources Center
SMTA	standard material transfer agreement
SOP	standard operating procedure
USDA-ARS	United States Department of Agriculture – Agricultural Research Service
VIR	N. I. Vavilov Institute of Plant Genetic Resources

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ANNEXES

Annex I. Taxon of *Pennisetum* or *Cenchrus* genus with number of accessions[1]

Taxon	Number of accessions
Cenchrus Americanus (L.) Morrane (syn Pennisetum glaucum (L.) R. Br.)	43318
Pennisetum violaceum (Lam.) Rich.	6634
Cenchrus ciliaris L.	4203
Pennisetum sp.	2633
Cenchrus orientalis	1543
Cenchrus purpureus (Schumach.) Morrone	479
Cenchrus pedicellatus (Trin.) Morrone	350
Cenchrus setigerus Vahl	348
Cenchrus polystachios (L.) Morrone subsp.polystachios	282
Pennisetum pycnostachyum Stapf& C. E. Hubbard	120
Cenchrus unisetus (Nees) Morrone	93
Cenchrus polystachios (L.) Morrone	92
Cenchrus sp.	72
Cenchrus clandestinus (Hochst. ex Chiov.) Morrone	71
Cenchrus ramosus (Hochst.) Morrone	68
Cenchrus setaceus (Forssk.) Morrone	52
Cenchrus prieurii (Kunth) Maire	50
Cenchrus mezianus (Leeke) Morrone	47
Cenchrus sphacelatus (Nees) Morrone	45
Cenchrus hybr.	41
Cenchrus geniculatus Thunb.	39
Cenchrus procerus (Stapf) MorroneMorrone (Stapf)	37
Cenchrus divisus (Forssk.) Verloove et al.	36
Cenchrus biflorus Roxb.	35
Pennisetum clandestinum Hochst. ex Chiov.	30
Cenchrus myosuroides Kunth	28
Cenchrus caudatus (Schrad.) Kuntze	24
Cenchrus purpurascens Thunb.	22
Cenchrus squamulatus (Fresen.) Morrone	22
Cenchrus stramineus (Peter) Morrone	22
Cenchrus sieberianus (Schltdl.) Verloove	19
Cenchrus trachyphyllus (Pilg.) Morrone	19
Cenchrus hohenackeri (Hochst. ex Steud.) Morrone	17

[7]. DONORNUMB and DONORCODE information from passport data was used to identify duplicates. In most cases it is not possible to identify duplicates from passport data as the DONORNUMB and DONORCODE are often not recorded.

Taxon	Number of accessions
Cenchrus longisetus M. C. Johnst.	16
Cenchrus flaccidus (Griseb.) Morrone	15
Cenchrus echinatus L.	13
Cenchrus pennisetiformis Hochst. &Steud.	12
Cenchrus massaicus (Stapf) Morrone	10
Cenchrus mitis Andersson	8
Pennisetum schweinfurthii Pilg.	7
Cenchrus brownii Roem. &Schult.	6
Cenchrus spinifex Cav.	6
Cenchrus pilosus Kunth	5
Cenchrus tribuloides L.	5
Pennisetum hybr.	3
Pennisetum polystachion subsp. atrichum (Stapf& C. E. Hubb.) Brunken	3
Cenchrus hordeoides (Lam.) Morrone	2
Cenchrus lanatus (Klotzsch) Morrone	2
Pennisetum basedowii Summerh. & C. E. Hubb.	2
Cenchrus dowsonii (Stapf& C.E. Hubb.) Morrone	1
Cenchrus elegans (Hassk.) Veldkamp	1
Cenchrus latifolius (Spreng.) Morrone	1
Cenchrus longispinus (Hack.) Fernald	1
Cenchrus longissimus (S.L.Chen&Y.X.Jin) MorroneMorrone (S.L.Chen&Y.X.Jin)	1
Cenchrus nervosus (Nees) KuntzeKuntze (Nees)	1
Cenchrus petiolaris (Hochst.) Morrone	1
Cenchrus pseudotriticoides (A.Camus)	1
Cenchrus riparius (Hochst. ex A.Rich.) MorroneMorrone (Hochst. ex A.Rich.)	1
Cenchrus schweinfurthii (Pilg.)	1
Cenchrus shaanxiensis (S.L.Chen&Y.X.Jin) MorroneMorrone (S.L.Chen&Y.X.Jin)	1
Pennisetum bambusiforme (E. Fourn.) Hemsl. ex B. D. Jacks.	1
Pennisetum longistylum Hochst. ex A. Rich.	1

Annex II. Accessions of pearl millet landraces in the Diversity Tree that are conserved in genebanks

Number of accessions of pearl millet landraces from specific countries (rows) and regions of the world that are important in the Diversity Tree that are conserved in individual genebanks (columns).

Region in the Diversity Tree	ISO code	BWA015	EGY087	ERI003	ESP004	ETH085	IND001	KEN212	LBY006	LKA036	MLI070	MLI087	MMR015	MWI041	NAM006	NGA010	PAK001	SDN002	SEN002	SEN075	SWZ015	TZA016	UGA132	ZAF060	ZAF062	ZMB048	ZWE049	IND002	ETH013	ZMB030	ARE003	CAN004	DEU146	ITA436	JPN183	USA016	IRD
West Africa	BEN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	182
West Africa	BFA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	950	0	0	0	0	0	0	0	116	472
West Africa	CIV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	306
West Africa	GHA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	420	0	0	0	0	0	0	0	0	0
West Africa	GIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71
West Africa	GMB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0
West Africa	MLI	0	0	0	0	0	0	0	0	0	474	218	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1086	2	0	0	0	0	0	0	0	982
West Africa	MRT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
West Africa	NER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1873	1	0	0	0	0	0	0	8	570
West Africa	SEN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	352	22	0	0	0	0	0	0	0	387	0	0	0	0	0	0	0	0	357
West Africa	SLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	0	0	0	0	0	0	0	0	0
West Africa	TGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	520	0	0	0	0	0	0	0	0	0
Middle Africa	CAF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	58
Middle Africa	CMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	912	0	0	0	1	0	0	0	5	144
Middle Africa	NGA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	605	0	0	0	0	0	0	0	0	0	0	0	2409	0	0	0	5	0	0	0	0	0
Middle Africa	TCD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106	0	0	0	0	0	0	0	0	0
Middle Africa	YEM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	308	4	0	0	0	0	0	0	0	0
East Africa	ERI	0	0	195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
East Africa	ETH	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
East Africa	KEN	0	0	0	0	0	0	114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	0	0	0	0	0	0	0	44	0
East Africa	SDN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2410	0	0	0	0	0	0	0	0	0	1066	0	0	0	0	0	0	0	0	0
East Africa	SOM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
East Africa	UGA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	112	0	0	0	0	0	0	0	0	0
South of Congo Basin	AGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	59	0	0	0	0	0	0	0
South of Congo Basin	BWA	114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	0	87	0	0	0	0	0	0	0
South of Congo Basin	COD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0
South of Congo Basin	COG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0
South of Congo Basin	MOZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0
South of Congo Basin	MWI	0	0	0	0	0	0	0	0	0	0	0	0	53	0	0	0	0	0	0	0	0	0	0	0	0	0	317	0	41	0	8	0	0	0	1	0
South of Congo Basin	NAM	0	0	0	0	0	0	0	0	0	0	0	0	0	1494	0	0	0	0	0	0	0	0	0	0	0	0	1155	0	1282	0	0	0	0	0	0	0
South of Congo Basin	SWZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
South of Congo Basin	TZA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	490	0	18	0	0	0	0	0	0	0
South of Congo Basin	ZAF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	47	0	0	152	0	0	0	0	0	0	0	0	0
South of Congo Basin	ZMB	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	297	0	181	0	213	0	1	0	0	0	0	0
South of Congo Basin	ZWE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1029	1595	0	83	0	0	0	0	0	323	0
North Africa	DZA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	50	10
North Africa	EGY	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
North Africa	LBY	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0
North Africa	MAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	1	0	4	0
North Africa	TUN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	2	28	0	0	0
Southwest Asia	IND	0	0	0	0	0	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6064	0	0	0	0	0	0	0	0	0
Southwest Asia	MMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0
Southwest Asia	PAK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	378	0	0	0	0	0	0	0	0	0	0	158	0	0	0	0	0	0	0	0	0

Annex III. Landrace accessions of *Eleusine coracana* subsp *coracana* conserved in various collections

The number of landrace accessions of *Eleusine coracana* subsp *coracana* by country of origin (rows) that are conserved in the various collections (columns). Data from Genesys, FAO-WIEWS, and USDA-GRIN.

Landraces from:	AUT001	BWA015	ERI003	ETH085	IND001	IND002	KEN212	LKA036	MWI041	NPL069	TZA016	UGA132	USA016	ZAF060	ZAF062	ZMB030	ZMB048	ZWE049	Aggregated
Botswana	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	16
Burundi	0	0	0	0	0	10	1	0	0	0	0	0	0	0	0	0	0	0	11
Central Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DRC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eritrea	0	0	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
Ethiopia	10	0	0	1048	0	31	25	0	0	0	0	0	0	0	0	1	0	0	1115
Kenya	0	0	0	0	0	1341	1397	0	0	0	0	56	0	0	0	0	0	0	2794
Malawi	0	0	0	0	0	241	99	0	168	0	0	0	0	0	0	79	0	0	587
Mozambique	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Rwanda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	1379	7	0	0	0	0	84	0	0	0	0	0	0	1470
Tanzania	0	0	0	0	0	60	20	0	0	0	357	11	0	0	0	223	0	0	671
South Africa	0	0	0	0	0	1	0	0	0	0	0	0	0	2	411	0	0	0	414
South Sudan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zambia	0	0	0	40	0	142	74	0	0	0	0	0	0	0	0	356	31	0	643
Zimbabwe	0	0	0	297	0	1131	258	0	0	0	0	0	1	0	0	0	0	782	2469
Nepal	0	0	0	0	0	1042	0	0	0	717	0	0	0	0	0	0	0	0	1759
India	0	0	0	0	170	1220	1	0	0	0	0	0	1	0	0	0	0	0	1392
Sri Lanka	0	0	0	0	0	18	0	403	0	0	0	0	0	0	0	0	0	0	421

Annex IV. Metrics of the results of pearl millet landrace spatial gap analysis

Metrics of the results by country of the pearl millet landrace spatial gap analysis (CGIAR Genebank Platform. 2020). Countries are ordered in descending order of the gap average area.

Country	ISO2	gap area average in km²	coverage in %
India	IN	636502	72.6
Mexico	MX	219444	38.6
Angola	AO	161205	28.2
Mozambique	MZ	157461	50.6
Sudan	SD	141518	77.6
Bolivia	BO	138897	52.6
Nigeria	NG	133056	80.6
South Sudan	SS	133000	30.8
Pakistan	PK	125290	58.4
Zambia	ZM	115417	73.1
Guinea	GN	103366	9.6
Chad	TD	100271	55.3
Peru	PE	83801	28.8
Ethiopia	ET	72436	12.7
Paraguay	PY	65946	65.4
Argentina	AR	65509	58.6
United Republic of Tanzania	TZ	59008	70.2
Zimbabwe	ZW	55851	80.5
Australia	AU	53842	63.3
Yemen	YE	49776	64.8
Mali	ML	40238	89.4
Ecuador	EC	34242	67.2
United States of America	US	33884	38.3
Mauritania	MR	28280	47.4
Niger	NE	27908	85.4
Guinea-Bissau	GW	27251	6.2
Democratic Republic of the Congo	CD	26943	69.4
Senegal	SN	23571	82.6
Cameroon	CM	22884	80.7
Ivory Coast	CI	21946	51.3
Japan	JP	16959	1.4
Burkina Faso	BF	16887	90.3
Eritrea	ER	16610	42.8
Brazil	BR	16453	60
South Africa	ZA	14888	72.2
Costa Rica	CR	13438	8.6
Sierra Leone	SL	12906	56.2
Ghana	GH	11827	83
Guatemala	GT	11204	72.4
Benin	BJ	10956	85.4
Dominican Republic	DO	10023	29.2
Malawi	MW	9952	85.7
Central African Republic	CF	9622	82.8
Botswana	BW	9454	76.8
Morocco	MA	9330	20.4
Oman	OM	9120	46.6
Namibia	NA	8971	81.2
Honduras	HN	8586	71.8
Indonesia	ID	8402	25.8
Saudi Arabia	SA	7964	52.9
Algeria	DZ	6472	8
Somalia	SO	5614	7.3
Cuba	CU	4984	48
United Arab Emirates	AE	4857	47
Sri Lanka	LK	4469	28.8
Kenya	KE	4352	91.2
Afghanistan	AF	3939	73.8

Country	ISO2	gap area average in km²	coverage in %
Philippines	PH	3899	70.6
South Korea	KR	3608	11.8
Puerto Rico	PR	3412	23.5
El Salvador	SV	3335	80
Uganda	UG	3333	88.7
China	CN	2991	52.4
Thailand	TH	2750	78.6
Spain	ES	2678	38.2
Vietnam	VN	2298	41.5
Tajikistan	TJ	2107	89
Gambia	GM	2056	76.3
Egypt	EG	1899	0.5
Haiti	HT	1787	62.8
Chile	CL	1441	36.6
Iran	IR	1371	62.2
Nicaragua	NI	1248	92.8
Armenia	AM	1236	69.4
Nepal	NP	1083	47.9
Cabo Verde	CV	1067	0
Colombia	CO	947	55.1
Togo	TG	704	97
Libya	LY	703	0
Uruguay	UY	701	63
Cambodia	KH	697	45.4
Madagascar	MG	683	4.5
Azerbaijan	AZ	668	19.4
Somaliland	SX	506	50
Turkey	TR	486	48.4
Syria	SY	434	42.8
Portugal	PT	403	5
Lebanon	LB	381	61.6
Israel	IL	336	26
Republic of the Congo	CG	275	0
Italy	IT	245	26.9
Myanmar	MM	243	14.2
Uzbekistan	UZ	236	81.5
Djibouti	DJ	225	35.6
Tunisia	TN	209	71.5
Venezuela	VE	207	65.1
Papua New Guinea	PG	179	0
Belize	BZ	178	50
Jamaica	JM	128	40
Laos	LA	120	50
Malta	MT	76	0.1
Taiwan	TW	72	0
eSwatini	SZ	67	96.3
Cyprus	CY	60	41.9
Mauritius	MU	56	41
Greece	GR	53	8.6
Kyrgyzstan	KG	33	86.2
Rwanda	RW	32	67.2
Burundi	BI	32	97.4
Bangladesh	BD	29	0
New Zealand	NZ	29	0
Malaysia	MY	26	0
Georgia	GE	24	50
Palestine	PS	18	0
Liberia	LR	16	10.6

Annex V. Metrics of the finger millet landrace spatial gap analysis

Metrics of the results by country of the finger millet landrace spatial gap analysis (CGIAR Genebank Platform. 2020). Countries are ordered in descending order of the gap average area.

Country	ISO2	gap area (avg estimate) in km²	coverage %
India	IN	226770	76.8
Mozambique	MZ	129222	60.8
United Republic of Tanzania	TZ	120556	55.4
Japan	JP	119854	30.6
Zambia	ZM	109380	71.8
Peru	PE	99648	16.8
Democratic Republic of the Congo	CD	99585	54.4
Zimbabwe	ZW	49006	83.4
China	CN	37918	47.1
Ethiopia	ET	35621	67.6
Bolivia	BO	34770	19
South Africa	ZA	27041	40
Kenya	KE	17874	86.5
Australia	AU	14325	0.6
Malawi	MW	14108	82.7
South Sudan	SS	13012	75.1
Rwanda	RW	12195	44.4
Angola	AO	12043	27.4
Guatemala	GT	11888	32.6
Madagascar	MG	11581	41.1
Mexico	MX	8299	88.3
Ecuador	EC	7904	11
Sri Lanka	LK	7752	83.8
Uganda	UG	7506	95.8
Venezuela	VE	4672	45.8
Burundi	BI	2922	88.2
Yemen	YE	2764	40.2
Chile	CL	2676	22.2
Nepal	NP	2481	87.1
Bhutan	BT	2464	81
Argentina	AR	2420	25
Lesotho	LS	1992	23
Brazil	BR	1711	12.3
Honduras	HN	1708	48.8
Indonesia	ID	1540	13.2

Country	ISO2	gap area (avg estimate) in km²	coverage %
Vietnam	VN	1395	37
United States of America	US	1367	9.6
France	FR	1050	2
Botswana	BW	1010	62.6
Costa Rica	CR	905	8.5
Philippines	PH	808	11.2
Dominican Republic	DO	761	28.8
El Salvador	SV	725	37.4
Haiti	HT	637	19.8
Colombia	CO	599	41.2
Pakistan	PK	433	18
Nigeria	NG	414	89.2
Namibia	NA	391	13.8
Malaysia	MY	330	3.1
Taiwan	TW	300	72.2
Myanmar	MM	174	21.3
Bangladesh	BD	158	25.8
Laos	LA	121	33.4
Somalia	SO	110	87.8
Italy	IT	103	22.4
eSwatini	SZ	98	91
Central African Republic	CF	97	66.4
Ghana	GH	94	22
Egypt	EG	83	10
Jamaica	JM	66	13.3
Cambodia	KH	63	25
Saudi Arabia	SA	60	66.6
Nicaragua	NI	52	50
Cameroon	CM	43	73
Benin	BJ	32	25
Sudan	SD	31	25.2
Mauritius	MU	30	25
Oman	OM	22	29.8
Mali	ML	10	50
Guinea	GN	1	99.9

Annex VI. Red list assessment of millets CWR

Red list assessment of millets CWR [Source : IUCN Red list Species information system as at 21 April 2020]
LC: Least concern, VU: vulnerable, DD: Data deficient, EN: Endangered, CR: Critically endangered.

Taxon	IUCN Red List	Taxon	IUCN Red List
***Pennisetum glaucum* – Pearl millet**			
***Pennisetum orientale* Rich.**	LC	***Pennisetum squamulatum* Fresen.**	**DD**
***Pennisetum purpureum* Schumach.**	LC	*Cenchrus platyacanthus* Andersson	LC
Odontelytrum abyssinicum Hack.	LC	*Panicum polystachion* (L.) Schult.	LC
Cenchrus agrimonioides Trin.	EN	*Cenchrus prieurii* (Kunth) Maire	LC
Cenchrus agrimonioides var. *agrimonioides*	EN	*Cenchrus pseudotriticoides* (A.Camus) ined.	EN
Cenchrus agrimonioides var. *laysanensis* F.Br.	EX	*Pennisetum setaceum* (Forssk.) Chiov.	LC
Pennisetum basedowii Summerh. & C.E.Hubb.	LC	*Cenchrus setiger* Vahl.	LC
Pennisetum ciliaris L.	LC	*Cenchrus sieberianus* (Schltdl.) Verloove	LC
Pennisetum clandestinum Hochst. ex Chiov.	LC	*Pennisetum sphacelatum* (Nees.) T.Durand & Schinz	LC
Cenchrus flaccidus (Griseb.) Morrone	LC	*Pennisetum stramineum* Peter	LC
Pennisetum thunbergii Kunth	LC	*Pennisetum trachyphyllum* Pilg.	LC
Pennisetum hohenackeri Hochst. ex Steud.	LC	*Pennisetum unisetus* (Nees) Benth.	LC
Pennisetum hordeoides (Lam.) Steud.	LC	*Panicum violaceum* (Lam.) Rich.	LC
Pennisetum latifolium Spreng.	LC	*Pennisetum frutescens* Leeke	LC
Pennisetum macrourum Trin.	LC	*Pennisetum natalense* Stapf	LC
Pennisetum massaicum Stapf	DD	*Cenchrus pennisetiformis* Steud.	LC
Pennisetum pedicellatum Trin.	LC	*Pennisetum mezianum* Leeke	LC
***Eleusine coracana* – Finger millet**			
Eleusine africana Kenn. -O'Byrne	LC	*Eleusine intermedia* (Chiov.) S.M.Phillips	DD
Eleusine floccifolia Spreng.	LC	*Eleusine kigeziensis* S.M.Phillips	DD
Eleusine indica (L.) Gaertn.	LC	*Eleusine tristachya* (Lam.) Lam.	LC
***Digitaria exilis* – Fonio**			
Digitaria appropinquata Goetgh.	DD	*Digitaria junghuhniana* (Steud.) Henrard	LC
Digitaria balansae Henrard	LC	*Digitaria megasthenes* P.Goetgh.	EN
Digitaria curtigluma Hitchc.	LC	*Digitaria patagiata* Henrard	VU
Digitaria curvinervis (Hack.) Fernald	LC	*Digitaria phaeotricha* (Chiov.) Robyns	LC
Digitaria duthieana Henrard ex Bor	DD	*Digitaria sacculata* Clayton	DD
Digitaria fuscopilosa Goetgh.	DD	*Digitaria siderograpta* Chiov.	LC
Digitaria stenostachya Hughes	LC		
***Echinochloa esculenta* – Barnyard millet**			
Echinochloa colona (L.) Link.	LC	*Echinochloa pyramidalis* (Lam.) Hitchc. & Chase	LC
Echinochloa crus-galli (L.) P.Beauv.	LC	*Echinochloa walteri* (Pursh) Heller	LC
Echinochloa frumentacea (L.) Link	LC	*Echinochloa picta* (J.Koenig) P.W.Michael	LC
***Eragrostis tef* – Teff**			
Eragrostis aethiopica Chiov.	LC	*Eragrostis orthoclada* Hack.	LC
Eragrostis ambleia Clayton	VU	*Eragrostis perbella* K. Schum.	VU
Eragrostis astreptoclada Cope	LC	*Eragrostis prolifera* (Sw.) Steud.	LC
Eragrostis coarctata Stapf	LC	*Eragrostis pseudopoa* C.E. Hubb.	EN

Taxon	IUCN Red List	Taxon	IUCN Red List
Eragrostis concinna (R.Br.) Steud.	LC	*Eragrostis pubescens* (R.Br.) Steud.	LC
Eragrostis condensata (J. Presl) Steud.	LC	*Eragrostis pusilla* Hack.	LC
Eragrostis conertii Lobin	DD	*Eragrostis saxatilis* Hemsl.	EN
Eragrostis desolata Launert	LC	*Eragrostis scabriflora* Swallen	LC
Eragrostis episcopulus Lambdon, Darlow, Clubbe	CR	*Eragrostis sericata* Cope	LC
Eragrostis fosbergii Whitney	CR	*Eragrostis silveana* Swallen	LC
Eragrostis hondurensis R.W.Pohl	LC	*Eragrostis stolonifera* A. Camus	EN
Eragrostis hypnoides (Lam.) B.S.P.	LC	*Eragrostis subglandulosa* Cope	LC
Eragrostis japonica (Thunb.) Trin.	LC	*Eragrostis subsecunda* (Lam.) E. Fourn.	LC
Eragrostis leptotricha Cope	DD	*Eragrostis unioloides* (Retz.)	LC
Eragrostis muerensis Pilg.	CR	*Eragrostis usambarensis* Napper	VU
***Panicum miliaceum* – Proso millet**			
Panicum acostia R.D.Webster	EN	*Panicum pearsonii* F.Bolus	CR
Panicum acuminatum Sw.	LC	*Panicum pilgerianum* (Schweick.) Clayton	LC
Panicum comorense Mez	LC	*Panicum pinifolium* Chiov.	VU
Panicum effusum R.Br.	LC	*Panicum pleianthum* Peter	NT
Panicum gilvum Launert	LC	*Panicum pole-evansii* C.E.Hubb.	LC
Panicum glaucocladum C.E.Hubb.	LC	*Panicum pseudowoeltzkowii* A.Camus	LC
Panicum hippothrix K.Schum. ex Engl.	LC	*Panicum repens* L.	LC
Panicum joshuae Lambdon	VU	*Panicum rigidum Balf.*f.	LC
Panicum lukwangulense Pilg.	LC	*Panicum scabriusculum* Elliott	LC
Panicum millegrana Poir.	LC	*Panicum shinyangense* Renvoize	DD
Panicum mlahiense Renvoize	LC	*Panicum socotranum* Cope	CR
Panicum niihauense H.St.John	CR	*Panicum strigosum* Muhl. ex Elliott	LC
Panicum nudiflorum Renvoize	EN	*Panicum sumatrense* Roth	LC
Panicum nymphoides Renvoize	DD	*Panicum vollesenii* Renvoize	VU
***Paspalum scrobiculatum* – Kodo millet**			
Paspalum acutifolium León	NT	*Paspalum galapageium* Chase	LC
Paspalum azuayense Sohns	EN	*Paspalum longifolium* Roxb.	LC
Paspalum canarae (Steud.) Veldkamp	LC	*Paspalum maculosum* Trin.	LC
Paspalum clavuliferum C.Wright	LC	*Paspalum pleostachyum* Döll	LC
Paspalum conjugatum P.J.Bergius	LC	*Paspalum repens* P.J.Bergius	LC
Paspalum densum Poir.	LC	*Paspalum riparium* Nees	LC
Paspalum distichum L.	LC	*Paspalum rugulosum* Morrone & Zuloaga	VU
Paspalum distortum Chase	LC	*Paspalum scrobiculatum* L.	LC
Paspalum galapageium var. *galapageium*	LC	*Paspalum soboliferum* Chase	EN
Paspalum galapageium var. *minoratum* Chase	LC	*Paspalum squamulatum* E.Fourn.	LC
Paspalum vaginatum Sw.	LC		
***Setaria italica* – Foxtail millet**			
Setaria cernua Kunth	LC	*Setaria paspalidioides* Vickery	LC
Setaria parviflora (Poir.) M. Kerguelen	LC	*Setaria setosa* (Sw.) P.Beauv.	LC

Annex VII. Survey sent to genebanks holding millets collections

ORGANIZATION INFORMATION

1.1 Name and address of organization holding/maintaining millet collection

Address:	
City:	
Postal Code:	
Country:	
Web site:	

1.2 Manager or Curator in charge of the millet collection:

Name:	
Email:	

1.3 Name of respondent to this questionnaire if not as above

Name:	
Contact details:	
Date of response:	

1.4 Additional key contact person for the millet collections

Contact details:	
Email	

1.5 Please describe the organization:

Governmental Institution	
Governmental program or department	
University	
Private organization	
NGO or charity	
Other: please describe:	

1.6 Does the genebank or collection operate under a national conservation strategy, policy, or plan? If yes, please specify?

1.7 Who has the most influence on the priorities for your genebank objectives, species focus, and activities?

The curator (s) of the collection	
The management of the Institute or Department	
A governing committee	
A stakeholder committee	
Other (please specify)	

Composition of the Collection

2.1 The year the collection was established:

2.2 The collection has:

	When established	Today
The total number of accessions		
The total number of millet crop accessions		

2.3 The main purpose of the collection includes:

	When established	Today
Long term conservation for national government		
Academic or educational use		
Working collection for National or University breeding/research program		
Working Collection for Private breeding/research program		
Other (please specify below)		

Please specify any other main purpose:

2.4 What is the current composition of the accessions in the specific millet crops overall and in the various accession types?

Crop	Total No. of accessions	Landraces or farmer's varieties collected in country	Landraces or farmer's varieties acquired from outside country	Old cultivars and released varieties	Research or breeding advances lines, populations or genetic stocks	Wild relatives
		Number of accessions				
Pearl Millet						
Foxtail Millet						
Finger Millet						
Proso Millet						
Kodo Millet						
Barnyard Millet						
Little Millet						
Tef						
Fonio						
Job's Tears						
Brown Top Millet						
Guinea Millet						

2.5 Please indicate the number of millet crop accessions that have been:

	Crop and Number of accessions
How many accessions have been lost from the collection in the past 10 years?	
How many of these accessions have been replaced with a re-collection or repatriation from others?	
How many accessions have been collected in the past 10 years?	

2.6 To what extent do you consider the millet crop accessions in your collection to be unique and not duplicated extensively elsewhere (i.e. EXCLUDING safety-duplication)?

Crop	100% unique	More than 50% unique	Less than 50% unique	0% unique
Pearl Millet				
Foxtail Millet				
Finger Millet				
Proso Millet				
Kodo Millet				
Barnyard Millet				
Little Millet				
Tef				
Fonio				
Job's Tears				
Brown Top Millet				
Guinea Millet				

2.7 In the past, has your Institution been involved in any joint mission with other international or national institutions to collect millet germplasm? If yes, please describe?

2.8 Can you describe any core collection or other trait specific subsets of accessions that has been established for the collection? Is this being distributed or requested by users?

2.9 Have the significant gaps or redundancies in diversity, or national or regional representation, or for specific traits in the collection been determined? How?

2.10 What are your priority gaps to fill specifically and how?

CONSERVATION OF THE COLLECTION

3.1 What is the status of conservation for the collection?

Crop	Accessions in long term storage	Accessions in medium term storage	Accessions with baseline seed viability	Accessions with baseline seed health status	Accessions with baseline seed number	Accessions that have been regenerated	Accessions that have been multiplied
	% of accessions						
Pearl Millet							
Foxtail Millet							
Finger Millet							
Proso Millet							
Kodo Millet							
Barnyard Millet							
Little Millet							
Tef							
Fonio							
Job's Tears							

Crop	Accessions in long term storage	Accessions in medium term storage	Accessions with baseline seed viability	Accessions with baseline seed health status	Accessions with baseline seed number	Accessions that have been regenerated	Accessions that have been multiplied
	% of accessions						
Brown Top Millet							
Guinea Millet							

3.2 Please check all that apply to best describe your facilities and approaches for conservation:

The long-term, medium-term, and short-term storage facility for collection has:

	Long term	Medium term	Short term
Cold storage unit			
Individual freezers			
Air-conditioned room			
Air-conditioned room with dehumidifier			
Back-up generator			
Other (please specify)			

What type of packaging is used for long term, medium term, and short-term storage?

	Long term	Medium term	Short term
Sealed Aluminum packs			
Sealed and vacuum-packed aluminum packs			
Plastic containers			
Glass containers			
Paper envelopes or bags			
Cloth bags			
Others (please specify)			

The temperature and relative humidity in the long-term, medium term, and short-term storage units are monitored by

	Long term	Medium term	Short term
Internal temperature monitors			
External temperature monitors			
Internal relative humidity monitors			
External relative humidity monitors			
External sounding alarms			
Automated monitoring system with link to security or curator			
Daily visit by genebank staff or security staff			
Others (please specify)			

The genebank facilities include:

Separate work areas for ‘dirty’ and ‘clean’ seed handling procedures	
Separate work areas for seed packaging for storage and distribution with relative humidity control	
Dedicated laboratory and trained staff for seed viability testing	
Dedicated laboratory and trained staff for seed health testing	
Low temperature seed dryer	
Access to at least one field sites in key agroecological zones for regeneration and multiplication	
Access to field site or greenhouse/glasshouse near genebank for regeneration and multiplication	

Access to irrigated field site for rainy season or off season for regeneration and multiplication	
Other (please specify)	

3.3 What is the average age, status, and main constraint for upgrading or improving the key conservation facilities and equipment?

Item	Average age	Status			Main constraint to improvement
		Excellent	Adequate	Inadequate	
Genebank building and facilities					
Storage facilities					
Laboratory facilities					
Laboratory equipment					
Field equipment					
Generator					
Other (please specify)					

3.4 Does the genebank make use of any alternative energy option, such as solar panels, to power a portion of the electricity needs for seed storage or seed processing? If yes, please be specific.

3.5 Does the genebank give a priority to energy efficiency in the procurement of new and replacement facilities and equipment? If yes, please be specific.

3.6 Are there any constraints to duplicating the collection elsewhere outside your country? If yes, please specify.

3.7 What is the status of safety duplication?

Crop	Accessions safety duplicated in Svalbard	Accessions safety duplicated in a black box arrangement outside country	Accessions safety duplicated in another collection in the country	Accessions safety duplicated in another research site in the country	Accessions safety duplicated in another collection outside the country
	Number of accessions				
Pearl Millet					
Foxtail Millet					
Finger Millet					
Proso Millet					
Kodo Millet					
Barnyard Millet					
Little Millet					
Tef					
Fonio					
Job’s Tears					
Brown Top Millet					
Guinea Millet					

3.8 Do all the safety duplication sites have formal agreements to establish terms and obligations?

3.9 Can you generally describe the terms of conservation and the obligations for both organizations in any formal or informal agreement for safety duplication?

3.10 The genebank utilizes written procedures and protocols from (Check all that apply):

No written procedures or protocols	
Hanson (1985) Practical Manual for Genebanks No. 1: Procedures for the handling seed in genebanks. IBPGR	
Rao NK, Hanson J, Dulloo ME, Ghosh K, Nowell D and Larinde M. 2006. Manual of seed handling in genebanks. Handbooks for Genebanks No. 8. Bioversity International, Rome, Italy.	
Institutes Genebank Operational Manual	
Written and verified Standard Operating Procedure (SOP) for key processes	
Quality Management System	
Other (Please specify)	

3.11 Do you have ongoing research or the resources and expertise to do research in the future on the conservation of the crop or its wild relatives, such as (Check all those that apply)?

	Ongoing research	Future research need
Improve procedures or protocols		
Increase efficiency of conservation		
Increase security of conservation		
Address crop specific constraints, such as seed dormancy, seed heath, seed longevity, etc.		
Others (please specify)		

INFORMATION MANAGEMENT

4.1 What is the status of accession level information in your collection?

Crop	Accessions with passport data	Accessions with passport data in searchable database	Accessions that have been characterized with a minimum number of traits	Accessions with characterization data in searchable database
	% of accessions			
Pearl Millet				
Foxtail Millet				
Finger Millet				
Proso Millet				
Kodo Millet				
Barnyard Millet				
Little Millet				
Tef				
Fonio				
Job's Tears				
Brown Top Millet				
Guinea Millet				

4.2 The information/database is (check all that apply):

Public	
Internal	
Available by written catalog or by contacting the curator	
Available and searchable online within the institute	
Available and searchable online outside the institute	

4.3 The accession level information/database provides data about (check all that apply):

Passport	
Taxonomy	
Characterization	
Genotypes	
Images	
Other (Please specify)	

4.4. Where is various accession level management data recorded, used and shared?

Operation	Recorded in field books, laboratory logbook, and/or data sheets	Enter into internal database in the laboratory or unit	Enter into database for electronic genebank information management system
Inventory			
Seed viability test and retest			
Seed or plant health status			
Seed number			
Packet weight			
Regeneration			
Multiplication			
Characterization			
Distribution			

4.5 Do you use barcoding for managing the identity of the accessions? In what operations?

4.6 Has the genebank automated any of the seed handling processes or data collection (such as using electronic tablets for data collection)? If yes, please describe what process is now being done with automation.

4.7 If you use an electronic information system for managing the collection and sharing accession level information, is it adequate to meet the needs of the genebank and users? If not adequate, what are the plans to upgrade or improve this system?

DISTRIBUTION

5.1 Are the accession in the collection available for use to requestors:

Crop	Within the institute	Nationally	Internationally	% of accession available with an SMTA
Pearl Millet				
Foxtail Millet				
Finger Millet				
Proso Millet				
Kodo Millet				
Barnyard Millet				
Little Millet				
Tef				
Fonio				
Job’s Tears				
Brown Top Millet				
Guinea Millet				

5.2 Do you have any restrictions on who can receive materials? If yes, please specify

5.3 Do you have adequate procedures in place for distribution:

	Adequate	Inadequate	Main constraints
MTA or SMTA			
Phytosanitary certification			
Packaging			
Shipping			
Other, please specify:			

5.4 For the following users, how would you describe the frequency of distribution of accessions of millet crops in the past 5 years?

	More than one distribution per year	One distribution per year	One distribution in 5 years	No request in last 5 years
Farmers or farmers organizations				
Other genebank curators				
Academic researchers and students within country				
Academic researchers and students outside country				
Plant breeders in public sector within country				
Plant breeders in private sector within country				
Plant breeders in public sector outside country				
Plant breeders in private sector outside country				
Non-governmental organizations				
Other (specify below)				

5.5 Do you routinely follow-up and solicit feedback from recipients on the quality and use of the accession received (Check all that apply):

Timeliness of the distribution	
Helpfulness of information or advice from genebank staff in selection of accessions	
Quality of samples sent	
Quality of packaging used	
Quality and the usefulness of the accession level information received	
Usefulness of the accession received	
Sharing of report or publication on any specific research result from the evaluation or use of the accession received	
Sharing of evaluation or characterization data sets	
Variety releases, adoption studies or case studies from the use of an accession received	
Other feedback (Please specify)	

Is this a formal survey or informal process?

How do you use the feedback obtained?

STAFF AND TRAINING

6.1 What is the number of staff allocated for the conservation and distribution of the collections?

6.2 Is the number of staff, level of expertise, and training adequate:

	Number of staff	Level of expertise	Training
To meet the needs for the routine annual operations for conservation			
To meet the request for annual distribution			
To address the needs of users for accession level information			

If inadequate, how is this being addressed?

6.3 Is there adequate retention of trained staff? Explain

FUNDING

7.1 Who provides most or all of the annual recurrent costs for the conservation of the collection?

7.2 Are there other sources of funds or significant revenue producing activities used to support the conservation of the collection? If yes, what percentage of the collection cost is covered by these activities?

7.3 What is the status of funding for the main conservation and use activities and who is providing this?

	Source of funds		Status of funding		
Operation	Annual allocation	Project funded	Increasing	Stable	Decreasing
Annual routine conservation activities					
Regeneration					
Multiplication					
Characterization					
Conservation Research					
Evaluation					
Collection					
Upgrade facilities or equipment					

RISK MANAGEMENT

8.1 Has there been a risk assessment done specifically for the genebank? Who is in charge of the assessment of risk and the development of a risk management plan for the institute and genebank?

8.2 Is the risk assessment and management plan reviewed on an annual basis? How? By whom in the genebank? By whom in the Institute?

8.3 What are the primary threats to the collection?

8.4. What are the primary disease/pathogen concerns for?

Seed storage	
Distribution	
Regeneration/multiplication	

EVALUATION

9.1 Has your millet crops collection at least partially been evaluated/screened for biotic and abiotic stresses? Has there been any genotyping or marker studies conducted on your millet crops collection?

	Biotic stresses	Abiotic Stresses	Genotyping or marker studies	Data publicly available?
Partial				
Core collection				
Focused trait specific subsets				
Majority of the complete collection				

If yes, please list the specific crop and specific biotic or abiotic stresses that have been evaluated?

9.2. Does your genebank conserve the data generated from the phenotypic or genotypic characterization or evaluation of the accessions by others? Please describe how this is formally or informally requested.

USE AND PARTNERSHIPS

47. What is the genebank's experience with various other collection holders?

Type of user	Repatriation	Research	Safety duplication	Training	Collection	Other (please specify below)	Does the genebank receive additional support for joint activities	Is the level of activities increasing or decreasing?
Other national *ex situ* collection holders								
Other regional or international *ex situ* collection holders								
In situ conservation sites								
On farm conservation sites								
Community seedbanks								
Protected sites for wild relatives								

48. What is the genebank's experience with the various users?

Type of user	Repatriation	Seed multiplication	Participatory evaluation	Demonstration plots	Field Days	Research	Training	Other (please specify below)	Does the genebank receive additional support for joint activities	Is the level of activities increasing or decreasing?
Individual farmers										
Farmers associations or community groups										
NGO										
National research programs										
National millet breeders										
International research programs										
International millet breeders										
University faculty and students										
Private seed companies										
National or local extension services										

SUMMARY

11.1 In general, please indicate the current status of the millet crop collection as a whole for the following considerations

	Improving/increasing	stable	regressing/declining
Resources for the long term conservation of the collection			
Resources for expansion of the collection			
Active support by national government			
Support by donors			
Off-site back-up duplication of accessions			
Regeneration of accessions			
Phytosanitary standards			
Access by user to germplasm information (passport, characterization, evaluation)			
Request for germplasm			
User feedback on the results from the use of accession received			
Genetic variability in the collection as needed by the users/ breeders			
Direct engagement with farmers, researchers, breeders, and other users			

11.2 Please list the 3 major limitations you are facing in the management of the collection

11.3 Please describe the main importance of your ex situ collection of millet crops for use in the future?

11.4 What are the 3 most important factors limiting the use of the millet crop accessions in your collection?

11.5 Please describe up to 3 areas where your collection is doing well?

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Annex VIII. Selected metrics on millets and maize (as comparison)

This annex was written by Dr. Felix Frey, International Consultant, Global Crop Diversity Trust

Khoury et al. (2022) compiled a comprehensive dataset as part of a project funded by the International Treaty on Plant Genetic Resources for Food and Agriculture and the Crop Trust, led by the International Center for Tropical Agriculture (CIAT). The aim was to introduce five normalized reproducible indicators to serve as an evidence base for use when prioritizing actions on the conservation and use of plant genetic resources for food and agriculture. The indicators encompass metrics associated with the USE of a crop (Global importance), the INTERDEPENDENCE between countries with respect to genetic resources, the DEMAND among researchers for genetic resources, the SUPPLY of germplasm by genebanks and the SECURITY of germplasm conservation. Graphs of the indicator results are publicly available on an interactive website. To generate the five indicators, Khoury et al. (2022) collected a comprehensive dataset from multiple sources. We do not present those indicators here, but rather discuss the underlying raw data to shed light on the aspects represented by the indicators.

To put numbers into context, we compare millet crops with maize (Table 1). The crops are comparable with respect to type of growth, propagation and use. Millet crops as well as maize are annual grasses used as cereals. They originate from the tropics or subtropics and are produced widely throughout the globe, both for human consumption and animal feed. The nine millet crops we discuss here span eight genera and 11 species (Table 2 and 3). Genus and species names of maize are *Zea* and *Z. mays,* respectively. FAOSTAT reports seven millet crops (pearl millet, finger millet, foxtail millet, proso millet, little millet, teff, kodo millet, Japanese/barnyard millet) in a combined category named "Millets", where fonio (*Digitaria exilis* & *Digitaria iburua*) is reported in a separate "Fonio" category.

The metrics for "Global production," "Food supply" and "Quantity exported globally" under the indicator domain "Crop use" are annual average values drawn from FAOSTAT for the years 2010–2014 (Khoury et al. 2022). The percentage of countries producing and consuming (being supplied with) the crop is calculated as the number of countries, where the respective crop is within the top 95% of most important crops divided by the number of countries that report respective numbers (can be different between metrics and crops).

The global production of millet crops is about 29 million tons annually, which is 3% of the global maize production (about 917 M t). The quantity of food supply by millet crops, i.e. the average global consumption, is about 9 g/cap/day, which is about 19% of global maize supply as food source (49 g/cap/day). This means millet crops' food supply is relatively high, compared to its production. This is putatively due to the fact that millets are mainly used for human consumption, where maize is not only used as a food source, but also as feed, to produce bioenergy, and as a raw material for industry purposes (Ranum et al. 2014). The percentage of countries in the world producing millet crops ranges from 4 (fonio) to 41% (Across all millets without fonio). Maize is produced in 81% of countries in the world, which is almost twice the number of countries that produce millet crops. Millet consumption is common in 32% of the worlds' countries (across all millets without fonio), where maize is consumed in 99% of countries. Export of maize is more important than export of millets. About 13% of produced maize is exported (120,837,238 t), where only around 1% of produced millets (354,883 t) are exported.

The crop use metrics with respect to research were assessed using a manual search on Google Scholar, searching for the respective genus or species in the titles of publications, including patents and citations, between the years 2009 and 2019 (Khoury et al. 2022). Search hits on Google Scholar indicate the level of scientific interest in a crop. The genus names of the different millet crops (Table 2) are found in 12,819 publication titles, which is about 78% of the publication titles including the maize genus *Zea* (16,400), a relatively high number compared to production of millets. However, we must take into account that millet crops encompass eight genera, whereas maize includes only one. The scientific species names of the millet crops (Table 2) appear in the titles of 4,002 publications, where pearl millet (1,374) and finger millet (907) account for the majority of publication titles. The maize species name *Zea mays* is included in 16,300 publications titles. If related to the comparison of production between millet crops and maize, presented previously, millet crop research is thus highly overrepresented when compared to maize research.

Khoury et al. (2022) defined interdependence as a measure for the degree of dependence of the global cultivation and use of a certain crop from germplasm present at the primary centers of diversity of the respective crop. Primary centers of diversity are not represented by countries, but by 23 agroecological zones (Khoury et al. 2016), as crop diversity does not follow national borders but rather climatic and agroecological boundaries. Interdependence is high in crops that originate from a small area and are cultivated and used globally. For production, interdependence is calculated by dividing a crop's production outside the primary center of diversity by the global production. If all production is outside the primary center of diversity, interdependence would be 100%. For food supply, interdependence is calculated by dividing the food supply by the world average. Food supply outside can be higher than that inside the primary centers of diversity and thus also higher than the global mean. Therefore, interdependence with respect to food supply can be above 100%. Primary centers of diversity of millet crops are located in South, East and South-East Asia as well as South, East and West Africa and North Eastern Europe (Table 2). Millet crop production (except fonio) is focused mainly on India, followed by Niger and China (FAOSTAT 2021A).

Table 1 Selected metrics collected by Khoury et al. (2021) for millet crops and maize, subdivided by indicator domain

Metric	Millets (Sum / Range)	Maize	Millets / Maize
Crop use			
Global production [tons] (Across all millet species)	28,813,720	917,517,036	3%
Food supply (Amount consumed) [g/capita/day] (Across all millet species)	9	49	19%
Percentage of countries producing crop * (Across all millet species w/o Fonio)	41%	81%	50%
Percentage of countries consuming (being supplied with) crop * (Across all millet species w/o Fonio)	32%	99%	33%
Quantity exported globally [t] (Across all millet species)	354,883	120,837,238	0%
Number of publications between 2009-2019, including patents and citations, searching title of publication (Google scholar search hits) for genus ** (Across all millet species)	12,819	16,400	78%
Number of publications between 2009-2019, including patents and citations, searching title of publication (Google scholar search hits) for species *** (Across all millet species)	4,002	16,300	25%
Interdependence			
Interdependence of global production from germplasm from primary centers of diversity [0-1] **** (Range across all millet species)	0-94%	97%	
Interdependence of global food supply from germplasm from primary centers of diversity [0-1] **** (Range across all millet species)	21-114%	89%	
Demand			
Accessions distributed from gene banks (Annual average 2014–2017) (Across all millet species)	13,268	49,148	27%
Variety releases in 5 years (2014-2018) (Across all millet species)	540	126,232	0.5%
Supply			
Number of accessions in *ex situ* collections of genus ** (Across all millet species)	165,482	213,337	78%
Number of accessions in *ex situ* collections of species *** (Across all millet species)	175,887	208,062	85%
Accessions of the genus ** available through Multilateral System (MLS) directly noted in databases [%] (Range across all millet species)	0-25%	20%	
Accessions of the species *** available through Multilateral System (MLS) directly noted in databases [%] (Range across all millet species)	0-4%	20%	
Accessions of the genus ** available through Multilateral System (MLS) indirectly by matching institute countries with party status [%] (Range across all millet species)	0-93%	69%	
Accessions of the species *** available through Multilateral System (MLS) indirectly by matching institute countries with party status [%] (Range across all millet species)	0-95%	69%	
Security			
Accessions of genus ** safety duplicated in Svalbard Global Seed Vault [%] (Range across all millet species)	5-27%	15%	
Accessions of species *** safety duplicated in Svalbard Global Seed Vault [%] (Range across all millet species)	7-53%	15%	
1-GINI index for equality of production across the world [0-1] ***** (Across millet crops w/o fonio)	0.03	0.03	
1-GINI index for equality of food supply across the world [0-1] ***** (Across millet crops w/o fonio)	0.03	0.15	

* Counting countries which list the crop as within top 95 % (FAOSTAT); Calculated as: Number of countries counting crop (top 95%) / Total number of countries (production 216, food supply 175)
** Millets: Genus names, Table 2; maize: Zea
*** Millets: Species names, Table 2; maize: Zea mays
**** Global metric / Metric at primary center of diversity
***** Relative equality of crop use across world regions (same regions as used in interdependence domain), high equality give high indicator value

As data for production of millet crops is reported in one category and can't be disaggregated (Table 3), an analysis comparing primary centers of diversity with main producing regions is not meaningful. For the case of fonio, the value of interdependence for production is practically negligible (0%), as main producers as well as the centers of diversity are exclusively situated on the African continent (FAOSTAT 2021A). The interdependence value of production for maize is 97%, where primary centers of diversity are in Andean South America, Central America and Mexico, and main producers are the United States of America and China (FAOSTAT 2021A). Consumption (food supply) of millet crops (except Fonio) is mainly focused on Indonesia, Germany and Bangladesh (FAOSTAT 2021B). As with production, data for food supply of millets (except fonio) can't be disaggregated for specific crops (Table 3) and an analysis comparing primary centers of diversity with main consuming regions is not meaningful. Fonio is consumed primarily in the Netherlands and France (FAOSTAT 2021B), resulting in a high value of interdependence with respect to food supply (91%). Maize has an interdependence for food supply value of 89%. This is putatively due to the fact that maize is commonly consumed globally with a relatively restricted center of diversity.

Demand for germplasm is defined by two metrics (Khoury et al. 2022): (1) the number of distributions of accessions by genebanks, as an annual average between 2014 and 2017 drawn from the Plant Treaty Information System; (2) the number of varieties released during the five years between 2014 and 2018, obtained from the International Union for the Protection of New Varieties of Plants (UPOV). There is a relatively strong use of millet crops germplasm reflected by the 13,268 accessions per year distributed by gene banks, which is about 27% of yearly distributions of maize accessions (49,148). However, for the development of new millet cultivars there's a different picture, where only 540 new varieties of millets were developed in a 5-year period, compared to the 126,232 cultivars of maize. In summary, germplasm supply of millet crops is on a relatively high level, but development of new cultivars is low, as it counts for less than 0.5% of new maize cultivars.

Khoury et al. (2022) illustrated the supply of germplasm by using the number of accessions available in *ex situ* collections around the world, with respect to the crop genus and the most important species of the respective crop. They also assessed the number of accessions (again with respect to genus and species) available under the multilateral system (MLS) of the Plant Treaty. This assessment was done first, directly, as notation (in MLS / not in MLS) in the public online databases Genesys, FAO WIEWS and GBIF. Secondly, the availability of accessions was assessed by considering whether the country hosting the institution that held the respective germplasm collection was a signatory to the Plant Treaty, in which case, the accession was regarded as available via the MLS. According to databases, global *ex situ* collections count a total of 165,482 accessions of millet crops when relating to the genus level. On the species level, 175,887 millet accessions are stored in genebanks (Table 2). In contrast to millets, the number of accessions accounting for the maize genus *Zea* is 213,337, where 208,062 accessions are attributed to the species *Zea mays*. Thus, a relatively high number of accessions of millets are conserved, compared to its global importance, mentioned above. However, we must consider that millet crops encompass eight genera and eleven species, whereas maize includes only one for each, genus and species. The millet crops pearl millet and finger millet as well as maize are listed in Annex I of the plant treaty

Table 2 Millet crops, corresponding genus, species, FAO stat category and origin

Crop	Genus	Species	FAO stat category	Origin
Pearl millet	*Cenchrus, Pennisetum* (synonyms)	*Cenchrus americanus/ Pennisetum glaucum* (synonyms)	Millet	West Africa, South Asia
Finger millet	*Eleusine*	*Eleusine coracana*	Millet	South and East Africa
Foxtail millet	*Setaria*	*Setaria italica*	Millet	South and East Asia
Proso millet	*Panicum*	*Panicum miliaceum*	Millet	South and East Asia, North Eastern Europe
Little millet	*Panicum*	*Panicum sumatrense*	Millet	South, East and South-East Asia
Teff	*Eragrostis*	*Eragrostis tef*	Millet	East Africa
Kodo millet	*Paspalum*	*Paspalum scrobiculatum*	Millet	West Africa, South and South-East Asia
Japanese / barnyard millet	*Echinochloa*	*Echinochloa frumentacea, Echinochloa esculenta*	Millet	South and East Asia
Fonio	*Digitaria*	*Digitaria exilis, Digitaria iburua*	Fonio (production/trade) / Cereals, Other (food supply)	West Africa

Table 3 Table of indicator values for species within millet crops

Metric	Pearl millet	Finger millet	Foxtail millet	Proso millet	Little millet	Teff	Kodo millet	Barnyard millet	Fonio
Crop use Global production [tons]				28,231,949					581, 770
Food supply (Amount consumed) [g/capita/day]				9					0.1
Percentage of countries producing crop *				41%					4%
Percentage of countries consuming (being supplied with) crop *				32%					NA
Quantity exported globally [t]				354,008					875
Number of publications between 2009-2019, including patents and citations, searching title of publication (Google scholar search hits) for genus **	3,800	1,210	1,430	2,840		692	1,110	1,080	657
Number of publications between 2009-2019, including patents and citations, searching title of publication (Google scholar search hits) for species ***	1,374	907	640	425	56	321	90	63	126
Interdependence Interdependence of global production from germplasm from primary centers of diversity [0-1] ****	NA	NA	NA	NA	NA	NA	NA	NA	0%
Interdependence of global food supply from germplasm from primary centers of diversity [0-1] ****	NA	NA	NA	NA	NA	NA	NA	NA	91%
Demand Accessions distributed from gene banks (Annual average 2014-2017)	5,986	1,452	971	1,503	1,368	1,382	337	212	57
Variety releases in 5 years (2014-2018)	116	27	121	234	0	14	0	28	0
Supply Number of accessions in *ex situ* collections of genus **	61,420	31,641	11,450	38,169		8,595	6,688	4,640	2,879
Number of accessions in *ex situ* collections of species ***	91,477	30,192	9,647	29,282	2,489	5,744	3,559	2,601	896
Accessions of the genus ** available through Multilateral System (MLS) directly noted in databases [%]	2%	0%	3%	3%		3%	10%	3%	25%
Accessions of the species *** available through Multilateral System (MLS) directly noted in databases [%]	0%	0%	1%	1%	0%	0%	2%	0%	4%
Accessions of the genus ** available through Multilateral System (MLS) indirectly by matching institute countries with party status [%]	91%	93%	0%	0%	0%	0%	0%	0%	
Accessions of the species *** available through Multilateral System (MLS) indirectly by matching institute countries with party status [%]	95%	94%	0%	0%	0%	0%	0%	0%	0%
Safety Accessions of genus ** safety duplicated in Svalbard Global Seed Vault [%]	27%	20%	19%	7%	5%	12%	18%	5%	
Accessions of species *** safety duplicated in Svalbard Global Seed Vault [%]	20%	20%	22%	9%	53%	7%	20%	28%	15%
1-GINI index for equality of production across the world [0-1] *****				0.03					0.01
1-GINI index for equality of food supply across the world [0-1] *****				0.03					0.11

* Counting countries which list the crop as within top 95% (FAOSTAT); Calculated as: Number of countries counting crop (top 95%) / Total number of countries (production 216, food supply 175)
** Millets: Genus names, Table 2
*** Millets: Species names, Table 2
**** Global metric / Metric at primary center of diversity
***** Relative equality of crop use across world regions (same regions as used in interdependence domain), high equality give high indicator value

(FAO 2009). The percentage of accessions available under the MLS, stated directly in respective databases of millet crops with respect to genus ranges from 0 (Finger millet) to 25% (Fonio). With respect to species, the percentage of accessions available under the MLS range from 0 (pearl millet, finger millet, foxtail millet, proso millet, little millet, teff, kodo millet and Japanese/barnyard millet) to 4% (fonio). In contrast 20% of maize accessions are available directly under the MLS, both on the genus and the species level. However, if counting accessions available indirectly by matching institute countries with party status, more than 90% of pearl millet and finger millet accessions can be made available. None of the other millet crops can be made available when matching institute countries with party status. In comparison, 69% of maize accessions are available when matching institute countries with party status, with respect to both genus and species.

Security of germplasm conservation is represented here by two metrics: safety duplication at the Svalbard Global Seed Vault (SGSV) and the equality of global distribution with respect to several crop use metrics. The numbers of accessions, by genus and species, safety duplicated were taken from the SGSV website and divided by the total number of accessions stored in global *ex situ* collections (see above), with the result giving the percentage of germplasm that is safety duplicated. To represent the equality of distribution across different agroecological regions of the world (Khoury et al. 2016), Khoury et al. (2022) used the reciprocal 1-Gini index with respect to the crop use metrics. The Gini index is the most commonly used inequality index (Gini Index 2008), known foremost for the quantification of global income inequality. The 1-Gini index, presented here, ranges from 0 to 1, where 0 reflects very unequal distribution across world regions and 1 reflects a completely equal global distribution across regions. It reflects the security of crop cultivation and use, where, for example, small indices of production and thus geographic restriction go hand in hand with a higher vulnerability of supply, as in the case of natural disasters. At the genus level, 5 (teff) to 27% (pearl millet) of millet accessions are safety duplicated at the SGSV, compared to 15% of all *ex situ* maize accessions, both at the genus and species level. At the species level the accessions of millet crops safety duplicated at the SGSV ranges from 7 (teff) to 53% (little millet). Equality of the distribution across the world's regions with respect to global production of millet crops (without fonio) is at about the same level of the equality of distribution for production of maize (0.03). With respect to food supply, maize is more equally distributed throughout the world, with a value of 0.15, whereas millet crops are more unequally distributed, with values of 0.11 for fonio and 0.03 for the rest of the millet crops.

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