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Identifying gaps and challenges for conserving crop diversity in genebanks: Lessons from the reviews of national genebanks

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Research Article

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Abstract

This study examined data from 20 national genebanks in Latin America and the Caribbean, Africa, the Near East and Asia to identify similarities and differences in genebank operations and processes, funding and facilities, as well as opportunities to strengthen their contributions to the global system of crop conservation and use. Data on genebank performance metrics were collected and used to assess compliance with FAO Genebank Standards. This enabled the analysis of trends in *ex situ* conservation of major food crops, locally important crops and crop wild relatives across national genebanks and the identification of shared challenges and opportunities to improve genebank operations and address funding gaps. All genebanks in the study failed to meet quality management standards and performance goals for the effective management of crop collections. The most pressing challenge for all national genebanks was the management and safety duplication of highly diverse collections in both seed and field genebanks, often with limited information available to guide best conservation practices. A further critical constraint was the fluctuating and often insufficient funding to support the wide range of tasks needed to secure and use this valuable national crop germplasm.

Introduction

There are more than 869 genebanks in 116 countries that hold nearly six million accessions of the major crops, local and opportunity crops and crop wild relatives that contribute to food security and are reported through the World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (WIEWS) (FAO 2024).

They form the core of global conservation efforts aimed at achieving the United Nations Sustainable Development Goal (SDG) 2 to 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture.' In particular, Target 2.5 emphasizes maintaining the genetic diversity of crops in soundly managed genebanks at the national, regional and international levels and promoting access to and fair and equitable sharing of benefits arising from their use (United Nations 2025). The Global Plan of Action for Plant Genetic Resources for Food and Agriculture, working through the FAO Commission on Genetic Resources for Food and Agriculture (FAO Commission) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), all support reaching this SDG 2.5. National genebanks were established and funded by their respective governments to conserve their local crop diversity in medium- and long-term *ex situ* storage. However, declining funding trends, insufficient overall funding and uncertainty of funding for crop diversity conservation raise serious concerns about the ability of genebanks to sustain their commitments to long-term conservation (Herbold and Engels 2023).

National genebanks form the basis of a global network of genebanks that contribute to a global conservation system, storing 84% of global plant resources (FAO 2025a). They work closely with international and regional genebanks. Engels and Ebert (2021) provided a working definition of the global conservation system as:

> A long-term global plant agrobiodiversity conservation system of well-defined national and international *ex situ* seed, tissue and plant collections that is managed under agreed genebank quality management standards and in harmony with the prevailing political framework regarding access and benefit sharing, and that aims at safe, effective, efficient and rational long-term conservation and facilitating use by making high-quality accession-level information available.

While this study focuses on national genebanks, the global conservation system includes other institutions, such as botanic gardens, *in situ* conservation areas, national parks, universities and national agricultural research centres, which also conserve and use crop diversity. Engels and Ebert (2024) concluded that the current global system could be further strengthened by adopting new approaches and technical developments (genomics, information technology), complementary conservation approaches (*in situ*, on-farm, home gardens) and increased collaboration at national, regional and global levels with the private plant breeding sector and botanic garden community.

A core requirement of a global system of genebanks is that the accessions in their care are conserved under conditions that support the maximum longevity of the germplasm and represent significant crop diversity that is made available for sustainable use through partners for plant breeding and agricultural development. Adherence to the FAO Genebank Standards (FAO 2014) ensures that genebanks are applying the latest scientific knowledge to inform conservation decisions as set out in the practical guides (FAO 2022a, 2022b, 2022c), thereby safeguarding crop diversity and demonstrating their commitment to the global conservation system. The guidance in the FAO Genebank Standards helps genebanks to define targets for genebank operations and performance metrics to measure progress towards those targets (Lusty *et al.* 2021; van Hintum *et al.* 2025). Lusty *et al.* (2021) described a performance management system for the international genebanks of the Consultative Group on International Agricultural Research (CGIAR) that uses five key performance indicators to assess progress towards targets for germplasm availability, quality management, data completeness and availability and safety duplication. These indicators are underpinned by some 200 performance metrics that capture information across all aspects of genebank operations (Lusty *et al.* 2021). van Hintum *et al.* (2025) proposed using 10 mandatory and 38 optional metrics to address the size and composition of the collection, data and documentation, conservation, availability and distribution. The ultimate goal is to have all accessions securely conserved and safety duplicated for the long term, fully documented and available for sustainable use (Jamora *et al.* 2025).

National genebanks play a key role in the conservation and sustainable use of crop diversity, maintaining local farmer varieties of a wide range of crops considered important for national food security and agricultural development (Engels and Ebert 2024). This includes many minor crops that continue to be grown in home gardens or by smallholder farmers and make a major local contribution to nutritional security. It has long been recognized that farmer varieties are highly diverse and well-adapted to local agroecological conditions, having been selected by farmers over hundreds of years (Bennett 1970). Farmer varieties stored in national genebanks have enormous potential to contribute to sustainable agricultural systems and the transformation of local food systems (Borelli *et al.* 2020). In addition, national genebanks play a key role in the restoration of farmer varieties that have been lost from cultivation and in the dissemination of germplasm to farmers and community groups to support conservation through use and cultural and religious use (Borelli *et al.* 2020).

Genebank operations face numerous challenges that threaten the long-term conservation of plant genetic resources as outlined by the ITPGRFA (FAO 2022d). The 2022 background study on the implementation of Articles 5 and 6 of the ITPGRFA summarized the main challenges self-identified by genebanks in the conservation and sustainable use of PGRFA by region (FAO 2022a). Recurring themes included the lack of national inventories and information systems, limited seed storage facilities and capacity for regeneration and viability monitoring, and resource constraints for adopting new and emerging technologies. Crop wild relatives, non-economic and minor crops have been neglected, with limited research and poor representation among accessions conserved in national genebanks. These critical challenges align with those identified by Fu (2017) in his review of published reports, reviews, news, personal communications and observations on the global genebank development. A critical issue is chronic underfunding, which limits the ability of many genebanks to maintain their collections effectively. This funding shortfall leads to regeneration backlogs, delays in seed viability testing and risks to the genetic integrity of stored germplasm. Further challenges include a lack of professional training for conservation, insufficient research into advanced storage technologies and the vulnerability of genebanks to natural disasters, conflicts and system failures. Compounding these issues is the lack of political support, which has diluted the focus on conservation policies and weakened stakeholder engagement.

The Global Crop Diversity Trust (Crop Trust) has been working with both international and national crop genebanks for several years. These partnerships provide the opportunity to use a common approach to data collection across different genebanks to verify gaps and challenges in optimizing genebank operations and meeting genebank quality management standards to facilitate more efficient and effective conservation of crop diversity. The opportunity to conduct a broad assessment is relatively rare because most studies are crop-, country- or genebank-specific, making it difficult to identify trends.

The objective of the study was to evaluate the status of genebank operations, facilities, equipment and staffing using common assessment criteria to prioritize upgrading needs for each genebank to meet performance targets, identify challenges and focus on opportunities to optimize the efficient and effective *ex situ* conservation and use of crop diversity.

Materials and methods

This study focused on 20 genebanks participating in the Seeds for Resilience (SFR) and the Biodiversity for Opportunities, Livelihoods and Development (BOLD) projects, both coordinated by the Crop Trust. Partners in the projects were selected based on their geographical location and spread, the importance and level of risk associated with the loss of their collections and their prior involvement in the crop wild relative (CWR) project, also coordinated by the Crop Trust, to strengthen their abilities to conserve and use this material effectively. The study included genebanks from Azerbaijan, Bhutan, Cuba, Ecuador, Egypt, Ethiopia, Ghana, Kenya, Laos, Lebanon, Morocco, Nigeria, Pakistan, Peru, Sudan, Tanzania, Uganda, Vietnam, Yemen and Zambia. The countries targeted in the study are all members of the FAO Commission and have national focal points (FAO 2025b). All but two are also contracting parties to the ITPGRFA (FAO 2025c) and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (CBD 2025).

Data were collected from each genebank using a structured questionnaire that covered different areas of genebank operations and the status of 21 performance metrics, as described in Jamora *et al.* (2025). The metrics serve as quantitative measures of the status of specific processes in genebank operations that meet the FAO Genebank Standards (FAO 2014), while the targets are typically aligned with institutional goals and crop biology, as described in Jamora *et al.* (2025). Not all metrics can be assigned numeric targets because of their dependency on external factors. For example, the composition and size of the collection are variable and

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related to the crop diversity within the country, while the number of accessions distributed depends on user demand. The number of accessions regenerated in any year is related to the age of the collection, storage conditions, longevity and distribution rate. Setting arbitrary targets can lead to inefficient use of scarce resources to meet them. Therefore, these metrics are listed as ‘no target’ and reported as numbers per year (Table 1). An in-depth investigation was conducted on-site and virtually to obtain any missing details or clarifications. Jamora *et al.* (2025) present the full methodology for data collection. Genebanks identified their major achievements and challenges faced in crop conservation. In all but one location, where access was difficult due to security issues and further discussions were held off-site, the review panels made verification visits to genebanks to observe genebank operations and collect additional or updated information on the genebank, operations, administration and policies. This information was used to assess the status of performance metrics, determine progress towards targets and gain a better understanding of the challenges and potential opportunities that could be realistically realized through upgrading. Verified information from the questionnaires and site visits was included in the review report for each country (Jamora *et al.* 2025).

Data collected from genebanks were normalized and transformed based on criteria to classify the status of each metric in relation to performance targets and FAO Genebank Standards (Table 1). The figures were used to provide a snapshot of the global efforts in genetic resource conservation and highlight critical areas with issues and gaps for improvement. Data were further analyzed through frequency distributions to identify trends in genebank operations and common gaps and challenges towards meeting targets across the genebanks in the study. Special attention was given to identifying opportunities and challenges that determined how these genebanks contributed to the global conservation system of crop germplasm and its sustainable use.

Results

The data indicated large variations in the numbers of accessions maintained, safety duplicated and distributed in the target genebanks (Table 2). The countries in the study hold and manage more than 459,000 accessions in *ex situ* conservation. All genebanks in the study had seed storage as their main conservation form, with 89% of accessions stored as seeds. Sixteen genebanks managed approximately 41,600 accessions of clonally propagated crops in field genebanks, and nine genebanks also had *in vitro* facilities to conserve 10% of the accessions of these crops as a complementary method of conservation with the field genebank.

The genebank metrics were used to assess how effectively the genebanks fulfil their role in conserving and sustainably using crop diversity, as well as their compliance with the FAO Genebank Standards (Table 3). Only five genebanks in the study reported testing the viability of over 90% of their accessions, and only 25% of the seed accessions tested met the 85% viability threshold.

Health testing was another critical concern, with only five genebanks in the study conducting health testing. While many national genebanks reported collaborating closely with national phytosanitary agencies, particularly for the import and export of genetic materials, the dataset revealed that only 5% of accessions were currently health-tested.

Safety duplication within the country was a significant or critical issue for 19 of the genebanks in the study, with only 4% of accessions conserved as seeds being safety duplicated within the country, and 10% of accessions in Svalbard or another site outside the country. It was even more concerning for field collections, where only one of the 16 field genebanks reported maintaining 60 accessions in two locations. These low safety duplication figures raise significant concerns about the risk of losing plant genetic resources, particularly in regions vulnerable to geopolitical instability or environmental challenges (Table 3). The percentage of safety duplication was higher for seed crops and for genebanks in Asia, with 36% of accessions duplicated from genebanks in the study located in Asia compared to less than 8% in genebanks in the study in other regions. This is due to genebanks with rice germplasm having materials conserved at the International Rice Research Institute (IRRI) in the Philippines.

Across regions, there was a widespread lack of an established quality management system (QMS), with only 6 of the 20 genebanks having elements of QMS in place. Although genebanks have foundational components, such as seed conservation standards, basic manuals and health and safety protocols, these elements are often fragmented or incomplete, and there are substantial gaps in structured documentation and consistent quality management practices, including a lack of standard operating procedures (SOPs). Only two genebanks reported having SOPs, and these covered only a limited set of operations. To align with FAO Genebank Standards, SOPs, structured risk assessments and comprehensive staff succession plans are needed in all genebanks for all genebank operations.

Availability was an issue in 14 of the genebanks, with less than half (47%) of the accessions conserved by partners legally available in the MLS. When considering viability status and the number of seeds per accession, only 21% of genebank accessions were available for distribution.

Challenges faced by national genebanks that constrain their ability to meet genebank quality management standards and the genebank metrics were found to be similar across countries (Table 4). The most important challenge faced by all genebanks in the study was the complexity of managing highly diverse collections of multiple crops in both seed and field genebanks. These collections often include local and neglected crops and CWRs, for which there is little information available to guide the selection of the best conservation practices.

Another major challenge was competition for funding with national priorities, including responses to climate change and the COVID-19 pandemic, which led to fluctuating and often insufficient resources for the numerous tasks required to secure and use the germplasm in 12 of the genebanks studied. Despite a national focus on meeting the SDGs and the recognition of the role of the national genebanks in the conservation of crop diversity and improvement, financial support for national genebanks was inconsistent from year to year (Fig. 1). All relied on project funding to fill the gaps and allow for continuity of operations, improve infrastructure, upgrade equipment, or perform more than the basic operations of germplasm storage and distribution.

Discussion

The 20 partners in the BOLD and SFR projects selected for this study are national genebanks across different regions. They conserve a wide range of crops, including small and large collections stored in seed, field, and *in vitro* genebanks, located both within and outside centres of diversity for the crops. Many of these genebanks have been established between 18 and over 40 years ago, with different levels of infrastructure and funding. The results

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Table 1. Assessment criteria used to evaluate the status of genebank metrics towards meeting targets

Areas	Themes	Relevant FAO Genebank standards	Metrics	0 = Meets target	1 = Minimal issues and gaps	2 = Significant issues and gaps	3 = Critical issues and gaps
Genebank overview	Composition of the collection		Total number of accessions Number of accessions conserved as seeds	No target	Nearly 100% seed	Seed and field	Seed, *in vitro*, and field
			Number of accessions conserved *in vitro*				
			Number of accessions conserved in field genebank				
Genebank management	Efficiency of procedures	4.10.1 A genebank should have a risk management strategy in place that includes *inter alia* measures against power cut, fire, flooding and earthquakes. 4.10.2 A genebank should follow the local Occupational Safety and Health requirements and protocols where applicable. 4.10.3 A genebank should employ the requisite staff to fulfil all the routine responsibilities to ensure that the genebank can acquire, conserve and distribute germplasm according to the standards.	Elements of QMS in place	Eight elements	Greater than four elements with reviews	Greater than one element but no reviews	0–1 element
	Information management	4.7.2 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	Number of accessions with minimum passport data publicly available (in searchable databases)	90–100%	71–89%	36–70%	0–35%
		4.7.1 Passport data of 100 percent of the accessions should be documented using FAO/bioversity multi-crop passport descriptors.	Average PDCI value	Greater than six	3–5.99	1–3	none
	Germplasm health		Number of accessions health tested	90–100%	71–89%	36–70%	0–35%
Genebank operations	Conservation: seed processing, storage, and viability testing	4.3.2 The initial germination value should exceed 85 percent for most seeds of cultivated crop species. For some specific accessions and wild and forest species that do not normally reach high levels of germination, a lower percentage could be accepted.	Number of accessions with acceptable viability (above 85%)	90–100%	71–89%	36–70%	0–35%
			Number of accessions with adequate seed number				
	Regeneration and characterization	4.4.1 Regeneration should be carried when the viability drops below 85 percent of the initial viability or when the remaining seed quantity is less than what is required for three sowings of a representative population of the accession. The original sample should be used to regenerate those accessions.	Number of accessions regenerated in the last 5 years	No target	More than 5%	2–5%	0–1%

(*Continued*)

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Table 1. (*Continued.*)

Areas	Themes	Relevant FAO Genebank standards	Metrics	0 = Meets target	1 = Minimal issues and gaps	2 = Significant issues and gaps	3 = Critical issues and gaps
		4.7.2 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.	Number of accessions with characterization and/or evaluation data publicly available (in searchable databases)	90–100%	71–89%	36–70%	0–35%
	Distribution	4.8.4 For most species, a sample of a minimum of 30–50 viable seeds should be supplied for accessions with sufficient seeds in stock. For accessions with too little seed at the time of request and in the absence of a suitable alternative accession, samples should be supplied after regeneration/multiplication, based on a renewed request. For some species and some research uses, smaller numbers of seeds should be an acceptable distribution sample size.	Number of accessions physically available for distribution	90–100%	71–89%	36–70%	0–35%
		4.8.1 Seeds should be distributed in compliance with national laws and relevant international treaties and conventions.	Number of samples distributed annually	No target	1,001 or more	101–1,000	0–100
	Safety duplication	4.9.1 A safety duplicate sample for every original accession should be stored in a geographically distant area, under the same or better conditions than those in the original genebank.	Number of accessions conserved in LTS	90–100%	71–89%	36–70%	0–35%
			Number of accessions safety duplicated in the country				
			Number of accessions safety duplicated at Svalbard or other site outside the country				
			Number of field accessions maintained in at least two locations				
Enabling environment	External linkages to users	5.8.1 Passport data for all accessions should be documented using the FAO/bioversity multi-crop passport descriptors. In addition, accession information should also include inventory, map and plot location, regeneration, characterization, evaluation, orders, distribution data and user feedback.	Regular feedback from genebank users	Yes			No
	Genebank routine funding	4.10.3 A genebank should employ the requisite staff to fulfil all the routine responsibilities to ensure that the genebank can acquire, conserve and distribute germplasm according to the standards.	Annual budget for genebank operations	No target	Increasing, constant	Fluctuating	Decreasing
	Policy	4.8.1 Seeds should be distributed in compliance with national laws and relevant international treaties and conventions.	Number of accessions legally available in the MLS	90–100%	71–89%	36–70%	0–35%

Table 2. Genebanks in the study and status of conservation and use

Genebank			**Conservation***					Sustainable use		
Country	FAO WIEWS code	Year established	Number of genera	Number of accessions conserved as seed	Number of accessions conserved *in vitro*	Number of accessions conserved in field	Number of accessions safety duplicated	Number of samples distributed over last 5 years	Regular feedback from users	Linkages to users+
Azerbaijan	AZE015	2003	498	7,839	0	1,527	2,032	3,534	No	1
Bhutan	BTN026	2005	60	3,327	0	0	3,327	599	Yes	1
Cuba	CUB014	1982	296	3,024	6	332	0	77	Yes	1
Ecuador	ECU023	1990	446	16,736	997	8,415	168	**	No	1
Egypt	EGY087	2004	251	40,208	42	250	0	331	No	2
Ethiopia	ETH085	1976	336	67,162	0	6,488	0	36,236	No	1
Ghana	GHA091	1964	413	3,760	249	453	185	812	No	2
Kenya	KEN212	1988	936	51,197	0	166	2,807	8,237	No	2
Laos	LAO018	1995	67	14,962	0	195	13,000	895	No	3
Lebanon	LBN020	2013	509	2,345	0	0	2,247	981	No	2
Morocco	MAR088	2003	341	71,783	0	0	983	1,612	No	2
Nigeria	NGA010	1987	149	10,627	26	1,210	920	4,697	No	2
Pakistan	PAK001	1980	391	40,579	20	293	6,931	44,062	Yes	2
Peru	PER012	1986	264	4,659	1,357	10,514	393	391	No	2
Sudan	SDN002	1995	120	16,739	0	538	6,477	2,831	Yes	2
Tanzania	TZA016	1991	544	9,151	20	83	4,739	2,454	No	1
Uganda	UGA132	2004	100	4,184	0	0	2,105	1,293	Yes	2
Vietnam	VNM049	1986	218	27,006	657	10,860	7,786	5,144	Yes	1
Yemen	YEM053	2002	152	6,769	0	173	1,481	0	No	2
Zambia	ZMB048	1989	254	6,338	0	100	3,260	612	No	2

* accessions may be stored in more than one conservation type; **, data not available; +1, minimal issues; 2, significant issues; 3, critical issues.

Table 3. Numbers of genebanks in the study facing critical issues

Area	Metrics	0 = **Meets target**	1 = Minimal issues and gaps	2 = Significant issues and gaps	3 = Critical issues and gaps
Genebank overview	Number of accessions in total	No target	9 (Nearly 100% seed)	7 (Seed and field)	4 (Seed, *in vitro* and field)
	Number of accessions conserved as seeds				
	Number of accessions conserved *in vitro*				
	Number of accessions conserved in field genebank				
Genebank management	Elements of QMS in place	0	1	2	17
	Number of accessions with minimum passport data publicly available (in searchable databases)	10	5	2	3
	Average PDCI value	1	0	3	16
	Number of accessions health tested	0	0	1	19
Genebank operations	Number of accessions with viability above 85%	1	3	6	10
	Number of accessions with adequate seed number	1	2	3	14
	Number of accessions regenerated in the last 5 years	0	17	2	1
	Number of accessions with characterization and/or evaluation data publicly available (in searchable databases)	1	0	5	14
	Number of accessions physically available for distribution	1	2	3	14
	Number of samples distributed annually	No target	4	11	5
	Number of accessions conserved in LTS	9	2	2	7
	Number of accessions safety duplicated inside the country	1	0	1	18
	Number of accessions safety duplicated at Svalbard or other site outside the country	0	2	1	17
	Number of field accessions maintained in at least two locations	0	0	0	20
Enabling environment	Regular feedback from genebank users	6	0	0	14
	Annual budget for genebank operations	No target	8	8	4
	Number of accessions legally available in the MLS	1	3	5	11

Table 4. Challenges faced by the 20 national genebanks in the study

Area	Theme	Challenge	Genebanks facing the challenge (%)
Genebank overview	Collection composition	Complex operations to manage a wide range of species requiring seed, field and *in vitro* genebank facilities	100
		Minimum literature and knowledge about how best to conserve many minor crops and CWR	100
Genebank management	Data management	Non-adoption of genebank database system for passport and inventory data	40
		Reliance on paper files which takes a long time to extract data	40
		Data files not up to date with backlog of data entry from paper files	45
		Limited access to internet in some work areas and outside of capital city	50
Enabling environment	Staffing	Limited staff numbers and expertise to cover all genebank operations	50
		Limited training of staff in modern techniques	40
		Trained staff unable to apply what they learnt due to lack of equipment and supplies	50
	Infrastructure and equipment	Ageing infrastructure of genebanks established more than 20 years ago that is not eco-friendly and has high repair and maintenance costs	65
		Ageing and outdated IT systems and laboratory equipment cause frequent disruptions to activities	50
		Limited access to modern laboratory equipment and supplies to implement new areas of research such as genomics	40
		Limited access to spare parts and service contracts for equipment	70
	Budget support	Declining budget insufficient for essential operations	45
		Annual budget fluctuations constrain long-term planning	40
		Competition for funds with other national priorities	100

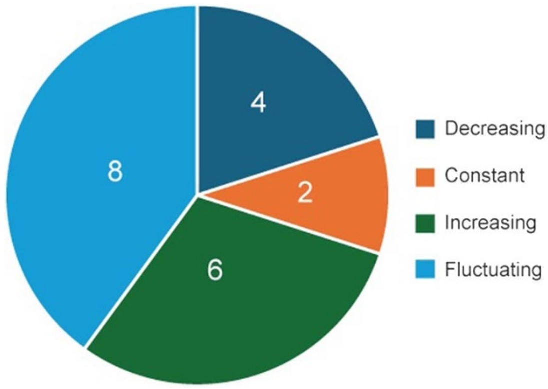

Figure 1. Funding trends in 20 national genebanks over the last five years.

provide an insight into the status, challenges faced and opportunities to contribute to global efforts in conservation and sustainable use of crop diversity for these 20 national genebanks. However, care should be taken in assuming similar challenges are applicable across national genebanks and other crop collections because of differences between institutions, crops and policies.

Conservation that complies with the FAO Genebank Standards requires that accessions be viable and in sufficient numbers to be available for use. The common challenge of insufficient resources for the many tasks involved in crop conservation was reflected in the progress towards targets measured by the genebank metrics. Low percentages of accessions meeting viability thresholds, health testing, availability for distribution and safety duplication indicate challenges and backlogs in regeneration and multiplication, storage limitations, lack of staff capacity for monitoring and/or inadequate facilities for both seed and field genebanks. The study confirmed the reality of the bottlenecks and challenges identified in the self-assessment from the ITPGRFA study on the implementation of Articles 5 and 6 of the ITPGRFA (FAO 2022d), as well as the strengths and weaknesses outlined by Engels and Ebert (2021) and the analysis by Fu (2017).

Lessons learnt from the study

Following Jamora *et al.* (2025), this section is structured around four main areas: genebank overview, genebank management, genebank operations and the enabling environment, which together encompass the critical dimensions of *ex situ* genebank conservation.

Genebank overview

Composition of the collection

The genebanks in the study conserved a wide diversity of globally and locally important crops to support national efforts in achieving food and nutritional security. However, many of these crop collections were represented by relatively low numbers of accessions, with a high proportion of genera represented by fewer than 10 accessions, which were conserved in only one institution (Bramel *et al.* 2025). Managing small numbers of accessions from a large number of crops with diverse plant biology and conservation procedures is complex and challenging, especially when incorporating CWRs (Hay and Probert 2013). Bramel *et al.* (2025) concluded that there was evidence that these genebanks needed to reconsider the composition of their collections, given the high cost but limited resources available for long-term *ex situ* conservation.

Genebank management

Quality management

All genebanks in the study were working towards improving quality management. The genebank QMS was developed to support genebanks to comply with the FAO Genebank Standards and is built on the science of conservation, including factors affecting seed longevity, cost-efficient ways to conserve genetic resources and use of the collections and consists of eight coordinated elements that cover science, policy, risk management, staffing, infrastructure/equipment, user satisfaction, information management and supplies (Lusty *et al.* 2021). All 20 genebanks were following national policies and laws on procurement, labour, health and safety in the workplace, with good scientific practices in place, including written protocols and procedures for routine activities. While none had yet established a fully functional QMS, and the absence of such systems was identified as a challenge, the existence of strong national regulatory frameworks provides a solid foundation for the future adoption and implementation of QMS in national genebanks. The assessment revealed common challenges in staff numbers and capacity, as well as minimal documentation and adherence to FAO Genebank Standards for all genebank operations. The establishment and routine use of SOPs and regular risk assessments are needed to create a more robust QMS framework. To improve QMS implementation, genebanks in all regions need better documentation, clear protocols, structured workflows and staff training. Succession planning is also essential to ensure efficient management and alignment with FAO Genebank Standards.

Information

Documentation and data management systems required more attention in all genebanks in the study, with no genebank having full passport and inventory data in a searchable data management system, although minimum passport data on 82% of accessions was publicly available in searchable databases, including WIEWS and Genesys. Good quality, well-managed and searchable data on genebank operations are important for accurate and timely decision-making. A common issue was a backlog of data entry, with eight of the genebanks in the study relying to some extent on data retained in paper copy, field books and data sheets. Searching for accession-level data is time-consuming, and paper data sheets may be lost or damaged. Data were also stored in Excel files, making it difficult to query, or genebanks had their own customized data management system that required external support to resolve problems or make improvements. Engels and Ebert (2024) recognized the weak information management systems and online accessibility of accession-level data in national genebanks as a challenge to rationalization, as well as to cost-efficient and effective conservation and use. Despite the increasing use of digital object identifiers for accessions to link accession-level data, the *Third Report on the State of the World's Plant Genetic Resources* concluded that progress in the area of documentation has been limited, and training is needed for data managers and genebank managers to adopt available improved data management systems (FAO 2025c).

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Germplasm health

The FAO Genebank Standards note the importance of health testing for acquisition and distribution. Plant diseases, especially fungi, have significant effects on seed quality and longevity during storage (Martín *et al.* 2022) and can lead to loss of accessions in field and *in vitro* genebanks. Considering the wide range of virus, fungal and mycoplasma diseases, whose severity varies with crop, the number of accessions that would need testing for multiple pathogens and the cost of testing, genebanks are reluctant or unable to use scarce resources for widespread testing. Only five genebanks in the study were doing health testing and only for a limited number of accessions and diseases. A lack of information on the health status is a concern for accessions of clonally propagated crops stored in field genebanks and seed crops during regeneration, as diseases can be transmitted between accessions, and severe disease attacks can lead to loss of genetic integrity and even loss of accessions (Martín *et al.* 2022). These results highlight significant gaps in ensuring that genetic materials are clean and free from pathogens for conservation. However, since most germplasm maintained in national genebanks is collected, regenerated and distributed within the country, there are few phytosanitary issues and concerns.

Genebank operations

Conservation: Seed processing, storage and viability testing

There was a backlog of viability testing among genebanks in the study, with only 25% of them having tested viability for more than 90% of their accessions. Inaccurate and insufficient viability data, resulting from unsuitable germination protocols and inadequate seed viability monitoring, could lead to the loss of accessions when longevity declines are not detected in a timely manner. It also constrains evidence-based decisions for assigning priority for regeneration and can lead to accessions being regenerated unnecessarily, with associated risks of loss of genetic integrity during the regeneration process.

Regeneration and characterization

The lack of progress and continuing backlogs in the regeneration of older accessions in this study were linked to declining budgets and the age of the accessions. Regeneration backlogs were recognized as an issue faced by genebanks in the *Second Report on the State of the World's Plant Genetic Resources* published in 2010 (FAO 2010), and remained an area of concern a decade later (Engels and Ebert 2021). Regeneration continues to be one of the main challenges identified in the most recent *Third Report on the State of the World's Plant Genetic Resources* (FAO 2025c). Although many genebanks have information on the number of accessions characterized and regenerated, this number remains low compared to the number of accessions stored as seeds and does not reflect the backlog of accessions waiting for regeneration and the urgency of clearing those backlogs before accessions are lost.

Distribution

While the number of accessions distributed varied among genebanks (ranging from less than 100 to over 44,000 over 5 years), 19 of the genebanks in the study distributed germplasm within the country to their national plant breeding programmes and universities, and had linkages with local communities to promote sustainable use. Distribution depends on user demand and, therefore, varies from year to year and cannot be compared between countries or crops. These numbers may not fully represent normal distribution rates because two of the years were within the period when the COVID-19 pandemic disrupted many research activities. The analysis also did not differentiate among different crops, legal frameworks or users to assess the use and impact of the distributed samples. Future studies should consider a more in-depth analysis by user type to better understand the principal users of germplasm by crop and the potential impact of the genebank. Metrics for measuring distribution excluding internal genebank use by region, user group and total number of distributions of an accession proposed by van Hintum *et al.* (2025), or the method used by Khoury *et al.* (2023) to determine demand using data on distribution under the SMTA of the ITPGRFA by crop, could be used for this assessment and analysis.

Safety duplication

Safety duplication in secure black box storage was the area with the least progress, including establishing safety duplicates within the country. This is substantiated by FAO (2025c), which concluded that many national genebanks have no or limited safety duplication. Only three of the genebanks in the study reported that more than 90% of their accessions were safely duplicated, and while 57% of accessions were stored in long-term storage, only 10% had been safely duplicated outside the country. This is likely linked to the backlog of accessions requiring regeneration to produce sufficient seeds with high viability for deposit, as well as the costs of safety duplication and concerns over access and rights to the material, even under a black box agreement where the depositor retains all rights to the germplasm. Given the importance of safety backup in a secure location, such as the Svalbard Global Seed Vault, as an insurance against national or man-made disasters and civil unrest, the low rate of safety backup needs addressing as soon as possible.

Enabling environment

External linkages to users

Fourteen of the genebanks were working directly with farmers and community groups and restored farmer varieties directly back to communities to enhance conservation through use. Farmer varieties that are well adapted to the environment were reintroduced to respond to climate change or user preferences. These 14 genebanks were partnering with local communities to restore and introduce vegetables and fruit trees in home gardens as part of national efforts to increase nutritional security. Some notable examples of restoration efforts to support healthy diets include vegetables in Cuba, tropical fruit trees in the Amazon region of Ecuador and potato germplasm in Peru. Several of the genebanks also reported restoration of culturally significant local varieties that were used in traditional ceremonies, including rice in Vietnam and potatoes in the Andes.

Resources

The resources needed to maintain a functioning genebank include staff, access to new technologies, infrastructure (including equipment) and sufficient budget.

Staffing

Limited staff numbers and expertise to cover all genebank operations were reported as a challenge by 10 of the genebanks in the study. Major constraints identified included the limited number of trained staff, challenges in retaining personnel due to more attractive employment opportunities in universities and the private sector, and insufficient staff capacity in both emerging technologies and core genebank operations.

Access to new technologies

Another common challenge faced by the surveyed genebanks was access to new technologies, with eight of the genebanks reporting a lack of trained staff, equipment and supplies. Adoption of new technologies can result in efficiency gains, allowing genebanks to provide a better service to users. Genebanks must leverage technological advancements to enhance genebank operations and meet the evolving needs of breeders and researchers (Engels and Ebert 2024). Staff learn new methods and technologies in training courses and PhD studies. Still, eight of the genebanks reported that after training, staff were unable to apply what they had learnt in their own genebank due to a lack of equipment and supplies. The high cost and limited availability of consumables were also reported as major barriers to adopting new technologies.

Recent progress in the generation of digital sequence information (DSI) through genotyping and sequencing whole genomes of plant germplasm collections provides new opportunities for studying diversity within and among genebank accessions (Anglin *et al.* 2025). DSIs can be used in genebank management to confirm taxonomy, genetic integrity and identity to discover potential errors, as well as understand the relationship between accessions and the amount of diversity captured within accessions of a species. Genomic data has the potential to be used to identify genetic gaps in the collection and for prioritization of unique germplasm by identifying duplicates and genetically similar accessions, which can then be removed from the collection to focus resources on more diverse genetic material (Hanson *et al.* 2024). Both genomic and phenotypic data are important to identify accessions with specific use traits, enabling users to select germplasm that best meets their needs, thereby increasing the value and driving the use of the germplasm (Anglin *et al.* 2025).

Infrastructure

All genebanks in the study were established more than 18 years ago, with infrastructure and equipment often older than 30 years. The genebanks in Cuba, Ethiopia, Ghana and Pakistan have been operating for more than 40 years. Infrastructure and equipment are ageing, and despite investment in maintaining and expanding facilities over the years, the cost of repair and maintenance of aging infrastructure is considerable. Older equipment may not be as efficient and may have a higher environmental footprint compared to newer models, necessitating replacement. New equipment is needed to support emerging technologies. Genebanks in the study took advantage of project funding or time-limited discretionary government funding to obtain new and additional equipment that had to be maintained in working order, often with a limited budget for equipment maintenance.

In addition, all genebanks in the study identified areas within the country for further acquisition of farmer varieties or CWRs to fill the gaps in their germplasm collection to fulfil their national conservation mandates. This is in addition to the need to improve curation of the germplasm already in *ex situ* conservation. As the germplasm collections grow to meet national priorities, facilities will need to be upgraded and increased to achieve quality management standards and handle larger collections. Current inflation and rising costs of labour and energy have resulted in national genebanks struggling to maintain and expand their facilities and infrastructure to keep pace with the growth of their collections and meet FAO Genebank Standards.

Budget

Budget constraints were the biggest challenge reported by all national genebanks. Annual budgets fluctuate, often with reductions in funding, making it difficult to plan priority activities. Only a few of the surveyed genebanks reported an increased budget in the years preceding the survey. Fluctuations and declining budgets were reported as resulting from competition for funds with national priorities for activities related to food security and climate change, as well as the overall funding situation, which is impacted by inflation and the growing size of collections requiring additional funding. The global COVID-19 pandemic also negatively impacted national budgets as funds were reallocated to the health sector to contain the global threat.

Opportunities to enhance contributions to global crop diversity efforts

National genebanks conserve the majority of the world's crop germplasm (FAO 2025c) and play a critical role in advancing crop diversity efforts as part of the global conservation system (Bramel *et al.* 2025). Staff at national genebanks bring valuable expertise in conserving neglected and underutilized crops, and in maximizing the use of limited resources. They also often employ innovative ways of problem-solving to ensure the survival of the accessions under their care.

A missed opportunity lies in providing more information on the value of germplasm conserved in national genebanks, which could help raise awareness of its importance and promote greater use. Although all genebanks responded to requests from plant breeders, farmers and communities, there was limited proactive engagement to highlight the potential of their accessions as a strategy for increasing germplasm use in national agricultural development.

An active programme of characterization and evaluation with rapid phenotyping and/or genotyping to learn more about the accessions, together with sharing that knowledge with users, would increase the opportunities for the genebank to support national agricultural and food security efforts. Making information about the use of the germplasm and its impact more widely available in national fora would enhance the awareness of the value of the genebank and provide the basis for sustainable funding.

National genebanks could also raise awareness of the value of their collections globally by making data available in WIEWS and/or Genesys and sharing germplasm internationally under the standard material transfer agreement of the ITPGRFA, for those crops in the multilateral system, or other suitable material transfer agreements.

Addressing staff skills through continuous improvement and capacity building would support the adoption of new technologies that can improve the efficiency of genebank operations. Regional staff exchange visits between genebanks with similar crops and languages could broaden staff experience and expertise. These exchanges would offer mutual benefits to participating genebanks. In addition, workshops focused on genebank processes can provide advanced training opportunities, enabling staff to share practical knowledge and strategies developed under conditions of limited

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facilities and resources, thereby enhancing their overall contribution to global conservation efforts.

The network of national genebanks participating in the FAO Commission and ITPGRFA is an important group for leading global efforts on the conservation and sustainable use of crop diversity. These international fora provide opportunities for shaping genetic resources policies, proposing studies aimed at improving and adopting technologies for improved genebank operations, information sharing and capacity building.

The ITPGRFA Benefit-Sharing Fund has already supported 100 projects, with 40 projects in 20 countries in the study (FAO 2025c). Participation as a contracting party to the ITPGRFA also gives access to apply for funds from the Emergency Reserve for Genebanks, jointly established by the Secretariat of the ITPGRFA and the Crop Trust, to mitigate an imminent threat to the collection where no available alternative financial support is available (FAO 2021). Project funding also offers opportunities for increased collaboration and capacity development in quality management, genebank operations, data management and genetic resources policy.

Conclusions

This study examined progress in using metrics and trends in operations, infrastructure and data management to evaluate alignment with the FAO Genebank Standards and conservation targets in national genebanks. It concluded that many genebanks still face significant challenges and share common issues that must be addressed to reach these performance targets and comply with quality management standards.

While facing many similar challenges and often working with an insufficient budget and aging infrastructure and equipment, national genebanks make a significant contribution to the global system of crop conservation and use. Their most notable role is in safeguarding the diversity of neglected and locally important crops and making this diversity available to breeders and farmers, thereby supporting national food and nutritional security.

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