Plant Genetic Resources: Characterization and Utilization

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M&E framework for sustainable PGRFA conservation in genebanks

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Abstract

The conservation of plant genetic resources for food and agriculture (PGRFA) is essential for global food and nutrition security, climate resilience and sustainable agriculture. This study presents a monitoring and evaluation (M&E) framework applied across 20 countries in the Global South to assess the state of *ex situ* PGRFA conservation. Using mixed methods, we collected quantitative and qualitative data on genebank performance, validated operational status, and identified specific needs of genebanks. Our findings demonstrate the practical use of this M&E framework for genebanks to assess efficiency and effectiveness in genebank management, while also guiding targeted capacity development and context-specific interventions to address persistent challenges. We recommend adopting the approaches described in this study, including genebank reviews and the review checklist, to support more systematic and evidence-based assessment of genebanks. Aligning national efforts with global conservation objectives will help generate actionable recommendations to strengthen genebanks and ensure the long-term conservation and availability of PGRFA.

Introduction

Plant genetic resources for food and agriculture (PGRFA) play a vital role in achieving and sustaining global food security and nutrition (Schmitz *et al.* 2023). Their value lies in the options they present for direct use as food and feed, for rehabilitation of degraded agricultural landscapes and natural habitats, for adapting crops to climate change and evolving pests

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and diseases, for enhancing productivity and nutritional value, and for improving the sustainability of agricultural systems.

However, factors such as socioeconomic changes, socio-political conflicts, land use changes, invasive species, extreme weather events and natural disasters threaten the diversity of PGRFA both in farmers' fields and natural habitats. PGRFA conserved in genebanks are also at risk of being lost forever due to funding uncertainty, inadequate infrastructure and limited staff capacity (Fu 2017, Khoury *et al.* 2022). For instance, many genebanks in developing countries have unreliable power supply, experience frequent power interruptions, and are vulnerable to typhoons, earthquakes or floods (Herbold and Engels 2023). This situation is exacerbated by ongoing political and financial crises, as seen recently in Lebanon (FAO 2025a), Sudan (FAO 2025b), Ukraine (FAO 2025c) and Yemen (FAO 2025d).

Countries worldwide have committed to conducting regular assessments to monitor the global status of conservation and use of PGRFA through the FAO State of the World's (SoW) PGRFA (FAO 1997, 2010, 2025e). These assessments are developed through inclusive, country-led processes under which national focal points, appointed by governments, provide their country reports through a dedicated reporting portal in the World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (WIEWS) (https://www.fao.org/wiews/en/).

The Crop Trust, an international organization established in 2004 by the Food and Agriculture Organization of the United Nations (FAO) and Bioversity International on behalf of CGIAR, works with genebanks to ensure the long-term conservation and availability of PGRFA for sustainable use. To achieve this, the Crop Trust provides funding, technical support and coordination through its projects and endowment fund, based on its Fund Disbursement Strategy (Crop Trust 2019) and receives policy guidance from the Governing Body of the International Treaty on PGRFA (Plant Treaty). This support helps genebanks effectively maintain their PGRFA collections, enhance operational efficiency and comply with the FAO's *Genebank Standards for Plant Genetic Resources for Food and Agriculture* (FAO 2014). Given funding constraints, there is a strong focus on making sure resources are used as efficiently as possible to achieve the Crop Trust's mission.

This paper draws on the findings of reviews of national genebanks facilitated by the Crop Trust in 20 countries between 2019 and 2022. The genebank reviews were conducted as a core project activity to assess current management practices, identify strengths and areas for improvement, and inform tailored support and capacity-building. They provide a baseline for monitoring progress over time and are integral to achieving the objective of enhancing genebank performance and accountability across projects. Taking into account the SoW reports, we present a systematic approach to assess the status of PGRFA conservation in developing countries. We describe the genebank reviews and present the review checklist in the annex as a supplementary file. We hope that the method and the rigor of analysis described below can support micro-level decision-making and complement macro-level policy-making in the global system for PGRFA conservation.

Background

In this section, we provide an overview of global and national genebank assessments, starting with the SoW reports on PGRFA. The first SoW, presented during the Fourth International Technical Conference on Plant Genetic Resources in Leipzig, Germany in 1996, identified crucial gaps and needs in PGRFA conservation from 154 country reports and resulted in a groundbreaking policy response: the first Global Plan of Action (GPA) on PGRFA (FAO 1997).

The second SoW was published in 2010 and revealed progress in conserving PGRFA but also highlighted ongoing challenges (FAO 2010). The report led to the development of the second GPA.

The third SoW, published in March 2025, called for actions to ensure the long-term financial stability of genebanks. Over 5.9 million accessions are reported to be conserved under medium- and long-term storage conditions across 852 national genebanks in 116 countries, as well as in four regional and 13 international genebanks (FAO 2025e). The third SoW also highlighted the need for continued support for safety duplication, regeneration, capacity development and quality management and information systems for genebanks.

The 1996 SoW was the first attempt to collate reliable data to assess the status of PGRFA conservation and use all over the world. The commitment to monitor and track progress through the indicators identified in the second GPA is crucial in assessing the progress of priority activities and their contribution to the targets on conservation, sustainable use and institutional and human capacities (FAO 2015).

Monitoring and evaluation (M&E) are important tools to provide decision-makers with indications of the extent of progress and achievement of intended results, as well as progress in the use of funds and resources (UNDP Evaluation Office 2002). Limited information on PGRFA hinders the capacity of decision-makers to assess current conservation efforts and identify effective interventions to mitigate PGRFA loss.

The global assessments, from the first to the third SoW, provide a valuable broad perspective, but their complexity and lengthy update cycles make them less helpful for guiding immediate action. To provide more rapid and specific updates, the Crop Trust started facilitating external reviews of international genebanks through the Genebanks CGIAR Research Program (Genebanks CRP) in 2012 (CGIAR 2014), as part of its M&E framework.

Genebank reviews were critical to the Genebanks CRP because they helped verify reports that contained important information on the performance of the genebanks and the status of the PGRFA collections they conserved. They highlighted each genebank's needs and priorities and allowed targeted recommendations tailored to each genebank's unique context to be developed. The information helped identify gaps in conservation and guided the planning of capacity development activities for the efficient use of funds and resources. The review findings also helped in formulating recommendations for priority actions and assessing the eligibility of the genebanks for long-term funding from the Crop Trust Endowment Fund. The Genebanks CRP led to the development of a performance management system for CGIAR genebanks, which contributed to the effective monitoring of genebank performance and the conservation status of PGRFA collections (Lusty *et al.* 2021). The CGIAR genebank reviews also inspired the development of the system of genebank peer reviews, successfully applied in Europe (van Hintum *et al.*, 2025a)

In 2019, the Crop Trust started a series of external reviews of national genebanks through its Seeds for Resilience project (SFR) (https://www.croptrust.org/work/projects/seeds-for-resilience/) to identify priorities for upgrading and funding. Following the model of the external reviews of the CGIAR genebanks, these national genebank reviews informed targeted equipment upgrades and tailored capacity development of genebank staff.

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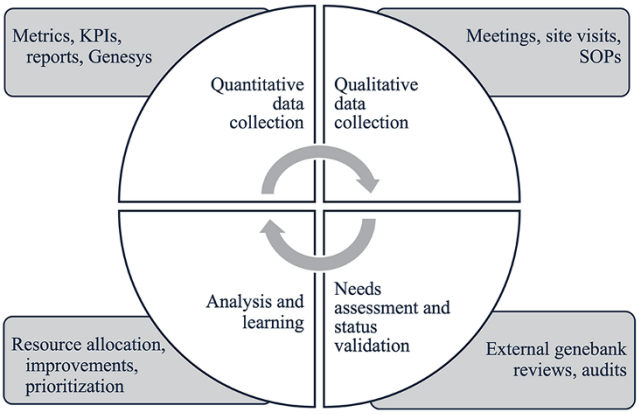

Figure 1. M&E framework for genebanks

In 2021, the Crop Trust's Biodiversity for Opportunities, Livelihoods and Development (BOLD) project (https://bold.croptrust.org/) adopted the same process for reviewing partner genebanks and invited experts who had participated in the reviews of CGIAR international genebanks and the SFR national genebanks to take part (Neate 2022). The reviews were carried out by 13 experts, forming a team of two to three members per country, to gather information on 15 national genebanks under the BOLD project. The national genebanks of 15 BOLD partner countries were reviewed in 2022 and all reports were finalized by mid-2023. The review findings and recommendations were fully accepted by partner genebanks and were used to prioritize project activities and make improvements in genebank operations.

Materials and methods

M&E framework for genebanks

The M&E framework for genebanks integrates quantitative data (metrics and KPIs reported annually, germplasm-related data uploaded to Genesys) with qualitative information from site visits, meetings and genebank standard operating procedures (SOPs). These inputs are complemented by periodic external reviews and audits conducted by subject-matter experts to assess performance, compliance with standards, and priority needs. Together, they provide a continuous feedback loop in which analysis of quantitative and qualitative data informs resource allocation, technical improvements, and capacity-building priorities, thereby strengthening genebank management and PGRFA conservation outcomes (Figure 1).

The M&E framework builds on experience from reviewing CGIAR genebanks. Lusty *et al.* (2021) described external reviews and validation of these collections, including SOP audits that led to Recommendation Action Plans. We extended this work by proposing a framework with clearly defined steps, offering a standardized approach to reviews across diverse contexts. The principles applied are consistent with the FAO genebank standards and relevant to national, regional, and international genebanks alike.

Genebank performance metrics and KPIs

A set of metrics and KPIs are tracked to assess genebank performance (Table 1 and Table S1). While reporting requirements may vary by project, the tables include the core data needed to evaluate performance across essential genebank operations. The metrics serve as quantitative measures of specific processes in genebank operations, while the KPIs are typically used for strategic decision-making and are aligned with institutional goals and targets. van Hintum *et al.* (2025b) proposed a set of mandatory and optional metrics that are straightforward to calculate and valuable for strengthening management and performance. Their contribution is complementary to this study, with considerable overlap in areas such as collection size and composition, documentation, conservation, safety duplication, availability and distribution. The M&E framework presented here integrates these metrics within a broader evaluation process to guide capacity-building and strategic decision-making. To promote transparency and accountability, partner genebanks (both national and international genebanks with active contracts with the Crop Trust) routinely report on their performance using these metrics and the progress in reaching targets for KPIs is monitored and evaluated regularly through site visits, meetings and external reviews.

The Crop Trust strategically uses the genebank KPIs, developed under the Genebanks CGIAR Research Program (CRP) (Lusty *et al.* 2021), to inform decisions on long-term funding support, aligned with its mission (Crop Trust 2004). The metrics, on the other hand, provide context for evaluating genebank performance but may not be directly linked to institutional targets. A mix of metrics can also be used to define certain KPIs. For instance, the KPI on availability requires that accessions be viable, available in the Multilateral System (MLS) of the Plant Treaty, disease/pathogen-free and with adequate quantity for distribution. Similarly, the KPI on safety duplication requires that seeds are conserved in long-term storage and duplicated in two geographically distant locations, one of which may be the Svalbard Global Seed Vault.

While different targets can be set within time-bound projects, the ultimate goal is for crop collections to be 100% available for immediate distribution, 100% safety duplicated and for all genebanks to have a quality management system (QMS) in place that guarantees that the collection is maintained based on procedures that comply with FAO genebank standards (FAO 2014). However, achieving 100% is rarely feasible in practice. Instead, a 90% threshold allows for some flexibility, considering the continuous flow and exchange of germplasm in genebanks.

Further, while evidence of a QMS is in place and levels of distribution are requested, quantitative targets are not specified for some indicators '*for various reasons including consideration of the kind of incentive that would be created*' (Lusty *et al.* 2021). Similarly, while there is no target for the number of people trained, the long-term partnership agreements of the Crop Trust with international genebanks require a commitment to capacity building with at least five partners from national agricultural research systems (NARS). Some metrics have also been changed or redefined through the years, taking into account new knowledge and improvements in data management.

External genebank reviews

The Crop Trust has facilitated numerous external reviews as one of the key components of the M&E framework for genebanks. The 20 national genebanks included in this paper, along with their corresponding World Information and Early Warning System on PGRFA (WIEWS) institute codes, are as follows:

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Table 1. Key performance indicators and targets for long-term funding support

Mission of the Crop Trust	Key performance indicators	Targets for long-term funding support
Promote the availability of plant genetic resources for food and agriculture	Number of accessions that are legally available for distribution Number of accessions that are available in the Multilateral System (MLS) Number of accessions that are physically available for distribution	**Target 1: Availability** 90% of collection clean of pathogens of quarantine risk, viable, and in sufficient quantity to be immediately available for national and international distribution from medium-term storage
Endeavor to safeguard collections of unique and valuable plant genetic resources for food and agriculture held *ex situ*	Number of accessions conserved as seeds in cold storage, as live plants in the field, and other plant materials in *in vitro* and cryopreservation. Number of accessions conserved in long-term storage (LTS) at two locations, and in the Svalbard Global Seed Vault (seed crops) Number of accessions conserved *in vitro* in slow growth conditions or in cryopreservation at two locations (clonal crops)	**Target 2: Safety duplication** a. For seed crops: 90% of collection in LTS at two locations and in the Svalbard Global Seed Vault b. For clonal crops: 90% of collection duplicated *in vitro* or in cryopreservation
Promote an efficient goal-oriented, economically efficient and sustainable global system of *ex situ* conservation in accordance with the International Treaty and the GPA.	Elements of QMS in place (science and operations, policy, risks, staff, equipment, infrastructure and reagents, user satisfaction, information management, supplies and services)	**Target 3: QMS** Eight elements of genebank QMS in place and regularly updated
Promote the regeneration, characterization, documentation and evaluation of plant genetic resources for food and agriculture and the exchange of related information	Number of accessions with passport data uploaded to Genesys Passport data completeness index (PDCI) Number of accessions with characterization and/or evaluation data uploaded to Genesys	**Target 4: Data availability and completeness** a. 90% of accessions uploaded to Genesys b. Average PDCI > 6
Promote national and regional capacity building, including the training of key personnel	Capacity building activities with NARS Number of participants, including key genebank staff, trained on performance areas related to above	**Target 5: Capacity building** Capacity building with at least five NARS (including other crop genebanks, regional/community organizations, and/or farmer groups)

- **Seeds for Resilience project**
  Ethiopia (ETH085), Ghana (GHA091), Kenya (KEN212), Nigeria (NGA010) and Zambia (ZMB048)

- **BOLD project**
  Azerbaijan (AZE015), Bhutan (BTN026), Cuba (CUB014), Ecuador (ECU023), Egypt (EGY087), Laos (LAO018), Lebanon (LBN020), Morocco (MAR088), Pakistan (PAK034), Peru (PER773), Sudan (SDN002), Tanzania (TZA016), Uganda (UGA528), Vietnam (VNM049) and Yemen (YEM061)

There are three phases in the review process: (1) before the site visit (collecting background information), (2) during and (3) after the site visit (report writing) (Table S2). A site visit, as part of the reviews, is an important component of M&E, adding value beyond what can be captured in written reports alone. While reports provide regular updates on activities and outputs, site visits allow for direct observation of operations and facilities and interactions with staff, offering a clearer picture of genebank management and operations.

Preparation for the review starts four to six months before the planned site visit. Genebanks are asked to complete a baseline questionnaire on technical, financial and institutional topics that helps prepare the reviewers and identifies critical areas that need probing during the site visit. The baseline questionnaire is available for download from the Crop Trust website (Crop Trust 2023). The GPA indicators and the FAO genebank standards (FAO 2014) guided the early development of the questionnaire, but it is continuously being reviewed and updated. The reviewers also conduct background research in preparation for the site visit.

The agenda for the site visits is typically planned for five days, which gives adequate time for reviewers to meet and interview key genebank staff, validate reported data, determine compliance with FAO genebank standards and identify priority recommendations for improvement. A Crop Trust staff member accompanies the review team as an observer and facilitates the interactions with genebank staff, and ensures that planned activities are on schedule and that the review focus stays on track.

At the end of the site visit, reviewers present key findings and preliminary recommendations to all genebank staff and institutional management. This is crucial because it confirms whether expectations are being adequately met. If misunderstandings occur, the real-time review allows for some clarifications and further investigations before the reviewers start writing the report.

The reviewers submit a draft report about a month after the site visit. The Crop Trust first reviews the report for clarity and completeness and to ensure recommendations are based on principles of scientific objectivity and technical feasibility. The review team incorporates the initial comments from the Crop Trust and then shares the report with the genebank. The genebank then reviews the report and corrects any factual errors. Additional information

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or justifications are requested by or provided to the review panel to support corrections. While there may be some recommendations that the genebank does not fully accept, often due to funding and capacity constraints, they are left in the review report to retain the independent nature of the reviews and to encourage complementary fundraising efforts. The reviewers submit a final report to the Crop Trust after incorporating the feedback from the genebank. The report template is available for download from the Crop Trust website (Crop Trust 2025).

Review checklist

The genebank review checklist presented in annex (Table S3) was developed through extensive consultations with subject-matter experts, facilitated by the Crop Trust. While previous reviews have used similar checklists to guide the process, it was first formally used for structured scoring and genebank evaluation in the BOLD project. The reviewers conducted a detailed needs assessment for each item in the checklist, fostering a systematic and consistent evaluation process. This approach facilitated constructive discussions among reviewers and contributed to the harmonization of the review methodology across 15 countries, despite the involvement of different sets of experts for each genebank.

The review checklist is organized around four main areas, supplemented by genebank performance metrics:

1. Genebank resources
2. Genebank management
3. Genebank operations
4. Enabling environment

These areas encompass the critical dimensions of genebank operations and management, ensuring a comprehensive and holistic evaluation of the genebank's capacity to fulfil its mandate of conserving PGRFA and making them accessible for use. This structured approach enhances the consistency and reliability of the review process, supporting the development of actionable recommendations.

Genebank resources

Genebank resources include staff, supplies, equipment, facilities, infrastructure and the composition of the collection. Reviewers evaluated whether the genebank had sufficient and skilled personnel to carry out its operations, along with the adequacy and condition of supplies and equipment. The infrastructure, such as storage chambers, seed processing areas and field stations, was examined for its suitability and state of maintenance. Reviewers also analysed the composition of the collection to ensure that it adequately represented the genetic diversity necessary for conservation and use of target genepools. Bramel *et al.* (2025) presents an extended analysis of the composition of PGRFA collections of the 20 reviewed genebanks.

Genebank management

In the domain of genebank management, reviewers examined QMS, risk management strategies and the overall efficiency of processes including information management. This included assessing the ability to identify and address backlogs in conservation and the effective use of information systems to ensure that accessions and seed lots progressed through workflows in an accurate, timely and efficient manner. QMS in genebanks provides the framework to develop 'a unique resource of documents, policies and scientific practices that comply with regulatory policy, genebank standards and other relevant standards' (Lusty *et al.* 2021). QMS supports the implementation of best practices, documentation and continuous improvement efforts to enhance the reliability, efficiency and transparency of genebank operations and management (van Hintum and Wijker, 2024). Reviewers evaluated whether systems for continuous improvement were in place and aligned with best practices in *ex situ* conservation, ensuring that the genebank was equipped to adapt to challenges and optimize its performance.

Genebank operations

Genebank operations include the adequacy of procedures and systems that support key activities. Reviewers assessed whether SOPs were established and if they were well documented and effectively implemented across the operations such as acquisition, seed processing, viability testing, conservation, regeneration, characterization, safety duplication and distribution. For conservation activities, for example, the reviewers examined whether the genebank adhered to established protocols for critical tasks such as packing samples into adequate containers or envelopes and which met FAO genebank standards (FAO 2014). Additionally, the reviewers assessed if written procedures, protocols and policies existed to verify that the genebank operated with clear guidelines that aligned with best practices and standards. Data and information management were also an integral part of these evaluations. Reviewers conducted a validation exercise to confirm that the data required for, and generated during each genebank activity was accurately recorded and systematically entered into the genebank's information system, and could be retrieved from it with ease.

Enabling environment

Finally, the reviewers assessed the institutional enabling environment, which includes critical aspects such as linkages with users, indirect cost charges, leadership effectiveness, policy frameworks, procurement processes and participation in the global system for *ex situ* conservation. Reviewers considered how well the genebank was integrated with external stakeholders and users, including breeders, researchers and policymakers, ensuring that its resources are effectively used. Financial sustainability and routine funding for genebank activities were explored, along with the clarity and efficiency of procurement processes. Leadership and institutional policies were evaluated for their role in fostering effective operations.

Needs scoring system

Reviewers for the BOLD project further assessed genebank needs using a structured scoring system (Table S4), assigning scores from 0 to 3 for each question. A similar scoring approach to assess compliance with quality assurance frameworks was previously applied in the reviews of CGIAR genebanks. A score of three signified critical issues or gaps that required major, immediate improvements. This scoring matrix, combined with the comprehensive review checklist, played a crucial role in harmonizing the review process across different review teams, genebanks and crops. By fostering consistency and uniformity, the approach enabled an objective and systematic assessment across countries, thereby enhancing the reliability and validity of the findings.

Moreover, the scoring system supported the prioritization of needs, ensuring that critical areas demanding urgent action were clearly identified. All areas receiving a score of three required

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reviewers to provide specific recommendations and immediately actionable suggestions for improvement. The approach can be used by genebanks themselves for a self-assessment of gaps and priority needs.

Results

This section presents key findings from the use of the described M&E framework for genebanks, validated in 20 partner countries. In some areas, data were available only from the 15 BOLD project partners; therefore, the five SFR project partners were excluded from specific analyses. The results combine quantitative metrics and qualitative insights to assess the effectiveness, challenges, and operational gaps in genebank performance. A structured needs assessment further highlights critical areas requiring targeted support to strengthen genebank operations and ensure long-term conservation of PGRFA. Hanson *et al.* (2025) present an extended discussion on the performance of national genebanks.

Quantitative assessment of genebank performance

Table 2 captures the genebank metrics reported by partners in 20 national genebanks in the Global South. Overall, these metrics provide partial insights into the global efforts in PGRFA conservation and highlight areas for improvement. Document reviews and on-site validation show that these partner countries hold and manage more than 459,000 accessions, showcasing the extensive efforts in *ex situ* conservation worldwide. The majority of the accessions are conserved as seeds (89%) and the rest are conserved in the field or *in vitro*.

The percentage of accessions included in the Multilateral System of the Plant Treaty (MLS, https://www.fao.org/plant-treaty/areas-of-work/the-multilateral-system/overview-mls/en/) reflects the commitment of countries to access and benefit sharing of genetic resources under the Plant Treaty. About half (47%) of the accessions conserved by partners are currently legally available in the MLS, and only about 21% of the total collection is physically available for distribution when considering viability status and the number of seeds available per accession. Low scores in this metric indicate challenges in regeneration and multiplication, storage limitations, lack of staff capacity for monitoring, or inadequate facilities. Seed viability above 85% is the benchmark for ensuring that stored seeds are viable. However, this threshold may not be appropriate for all crops. Species such as forage grasses, trees, and many wild relatives often have complex germination requirements, seed dormancy, and pose challenges in conducting reliable viability tests (Hay *et al.* 2021). The FAO genebank standards accommodate these differences by allowing flexibility in viability thresholds for specific accessions and wild species that do not normally reach high levels of germination, Nevertheless, our dataset indicates that most accessions conserved in partner genebanks are orthodox seeds and failed to meet this threshold, which could result from suboptimal multiplication, regeneration, or storage conditions, aging packaging materials, or inadequate monitoring.

The data collected on germplasm health reveals low percentages (5%) of health-tested materials across regions. This highlights significant gaps in ensuring that stored materials are clean and free from pathogens. While this does not pose problems for the distribution of germplasm within the country, some fungi present a significant risk of germplasm loss during storage (Martín *et al.* 2022). Nevertheless, the reviews also confirmed that many national genebanks collaborate closely with national phytosanitary agencies, particularly for the import and export of PGRFA.

Safety duplication rates remain low across countries, raising serious concerns about the potential loss of PGRFA, especially in regions prone to geopolitical instability or environmental stress. Schreinemachers *et al.* (2024) conducted a baseline assessment of vegetable seed collections in four Southeast Asian countries (Malaysia, the Philippines, Thailand and Vietnam) which confirmed these concerns. The study found that only 11% of collections are safety duplicated in other genebanks, and just 2% are backed up in the Svalbard Global Seed Vault.

Qualitative assessment of genebank performance

The qualitative assessment across partner genebanks reveals common challenges in staff capacity, documentation and quality management. There is a widespread lack of an established genebank QMS. Although some genebanks have foundational components such as seed conservation standards and basic manuals, these elements are often fragmented, incomplete, or not used. Many genebanks need to develop detailed, published SOPs, structured risk assessments and comprehensive staff succession plans.

To advance QMS implementation, genebanks across all regions require more rigorous documentation, improved protocols, structured processes and continuous staff training and succession planning, to support efficient genebank management and compliance with FAO genebank standards.

The BOLD genebank reviews also evaluated the availability and quality of data to support performance measurement (Table S5). The expert assessment of reviewers revealed that all 15 BOLD project partners face serious challenges in maintaining essential information on the viability and health of their collections. This highlights a major concern, underscoring the difficulty of verifying the status of crop collections conserved in many developing countries.

While many genebanks have uploaded accession-level data to Genesys and/or FAO WIEWS as part of reporting to the GPA, their institutional websites generally provide little information about their crop collections. Furthermore, despite adherence to data descriptor standards, characterization data is also often incomplete, which limits its usability for external stakeholders. Distribution data, when available, is typically stored in paper formats limiting accessibility and analysis. Additionally, user feedback mechanisms, when they exist at all, tend to be informal and unstructured, with minimal follow-up, reducing opportunities for genebank service improvements and insights into germplasm demand.

Needs assessment

We used the needs assessment scoring matrix (Table S2) to identify areas with critical issues or major gaps. Figure 2 presents the distribution of scores for each area of consideration, weighted by the number of questions or checklist items for the 15 BOLD project partners. The details by report checklist item are presented in the Annex.

The analysis confirmed critical gaps in: QMS, information management, efficiency of procedures, risk management, genebank routine funding, overall capacity in genebank management,

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Table 2. Status of genebank metrics, as of 2021

Areas	Themes	Metrics	Value	%
		Number of genebanks	20	
Genebank overview	Composition of the collection	Number of accessions in total	459,195	100%
		Number of accessions conserved as seeds	408,395	89%
		Number of accessions conserved *in vitro*	3,374	1%
		Number of accessions conserved in field genebank	41,597	9%
Genebank management	QMS	Number of genebanks with eight elements of QMS in place	0	0%*
	Information management	Number of accessions with minimum passport data publicly available (in searchable databases)	376,299	82%
		Number of genebanks with PDCI value >6	1	5%*
	Germplasm health	Number of accessions health tested	21,868	5%
Genebank operations	Conservation: seed processing, storage, and viability testing	Number of accessions with viability above 85%	113,513	25%
		Number of accessions with adequate seed number	102,951	22%
	Regeneration and Characterization	Number of accessions regenerated in the last five years	67,848	15%
		Number of accessions with characterization and/or evaluation data publicly available (in searchable databases)	138,340	30%
	Distribution	Number of accessions physically available for distribution	96,657	21%
		Number of samples distributed annually	22,960	5%
	Safety duplication	Number of (seed) accessions conserved in LTS	231,116	57%+
		Number of (seed) accessions safety duplicated inside the country	15,960	4%+
		Number of (seed) accessions safety duplicated at Svalbard or other site outside country	42,881	10%+
		Number of field accessions maintained in at least two locations	60	0%
Enabling environment	External linkages to users	Number of genebanks requesting regular feedback from genebank users	6	30%*
	Genebank routine funding	Number of genebanks with constant or increasing budget for genebank operations	8	40%*
	Policy	Number of accessions legally available in MLS	215,844	47%

% = percentage from total number of accessions (459,195).
* = percentage from total number of genebanks (20).
+ = percentage from total number of seed accessions (408,395).

safety duplication, monitoring performance indicators, field management and conservation activities (e.g. seed processing, storage, viability testing). Major issues present substantial challenges that need significant improvements to improve conservation processes, including staff management, acquisition, regeneration and characterization, and supplies, equipment, facilities and infrastructure. Immediate and substantial interventions are required to address these critical and major issues and ensure the effective functioning of genebanks.

Using the needs assessment scores, we can also group countries based on their needs, which helps prioritize resources and interventions (Table 3). This categorization ensures that support is directed where it is most crucial. For instance, countries with genebanks in the 'Low needs category have well-established operations that require minimal intervention. Support for these genebanks should focus on continuous improvement to ensure long-term sustainability, ensuring they remain efficient and effective in their conservation efforts'

On the other hand, genebanks in the 'Critical needs" category face severe and urgent challenges that threaten their ability to conserve and manage PGRFA, i.e., the materials in their collections are in danger of being lost, if not lost already. These genebanks require significant and immediate interventions to address issues such as inadequate funding, poor infrastructure and lack of trained staff. From our set of countries, four of 15 genebanks have 'Critical' and eight genebanks have 'High' needs requiring major support to conserve and manage their PGRFA. By identifying and categorizing these needs, stakeholders can allocate resources more strategically, ensuring that genebanks with the most urgent needs receive the necessary support to improve their operations and ensure the long-term conservation of PGRFA.

Overall, the scores are generally aligned with the gaps indicated in the quantitative and qualitative assessment of genebank performance. This detailed assessment was essential for identifying both strengths and areas for improvement, supporting informed

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Figure 2. Distribution of needs assessment scores*

decision-making and facilitating the development of targeted recommendations to enhance the genebanks' capacity for long-term conservation and efficient PGRFA management.

Discussion

Significant progress has been made in enhancing the global system for *ex situ* conservation of PGRFA. The numbers of accessions

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Table 3. Prioritization based on aggregate conservation needs from the review checklist

Ranking needs+	Definition	Number of countries identified*
I: Low needs (<100)	These genebanks are well-functioning. Support for these genebanks should focus on continuous improvement, ensuring long-term sustainability.	1
II: Moderate needs (100–149)	These genebanks are generally functional but require targeted support to optimize efficiency and enhance operations.	2
III: High needs (150–199)	These genebanks face significant challenges that hinder their effectiveness. They require substantial support to address key operational gaps.	8
IV: Critical needs (≥200)	These genebanks are in urgent need of intervention due to severe operational and resource constraints. They require immediate and comprehensive support to conserve and manage PGRFA.	4

+The maximum score possible is 300 for 100 questions. The groups were categorized based on total scores. *Includes only the 15 BOLD project partners.

and species conserved in long- and medium-term storage facilities has grown, including safety duplication at the Svalbard Global Seed Vault (FAO 2025e). However, many core challenges remain unresolved and the national genebank reviews have provided an indication of the work needed to improve conservation conditions across genebanks in developing countries (Hanson *et al.* 2025).

The genebank performance metrics reveal persistent challenges, including suboptimal storage conditions, inadequate documentation and information systems, limited capacity for regeneration and multiplication, low levels of safety duplication and insufficient monitoring of seed health and viability. Many accessions remain unavailable for immediate distribution, as a result of insufficient quantity and poor quality for effective use, or are at risk of being lost forever. Each of these gaps points to a clear pathway for action: upgrading storage facilities, enhancing seed viability and health monitoring, strengthening data systems, expanding regeneration capacity and increasing safety duplication.

These issues hinder the ability of genebanks to meet the growing demands of users and crop improvement programs. Compounding these challenges, climate change and emerging technologies introduce new complexities to the conservation landscape, making the safeguarding of PGRFA even more urgent for immediate and future food security (Gollin 2020; Engels and Ebert 2021).

The M&E framework for genebanks described here plays a crucial role in assessing and validating the status of genebanks, ensuring they meet their conservation objectives. It directly addresses two key recommendations of the '2022 Background Study' in the implementation of Articles 5 and 6 of the International Treaty: '*conducting regular assessments of gaps, needs, and challenges in the conservation and sustainable use of plant genetic resources at national and regional levels, and developing national and region-specific studies to improve the implementation of Articles 5 and 6 of the International Treaty*' (FAO 2022). These reviews promote transparency and accountability in the management of valuable PGRFA, while simultaneously highlighting strengths and identifying areas for improvement.

While the challenges in genebank management and PGRFA conservation are already widely recognized, the M&E framework for genebanks offers a method to uncover deeper understanding of the unique contexts in which genebanks operate. The structured site visits by external experts allowed the development of tailored recommendations that tackle root causes of challenges and avoid generic solutions. Direct engagement with staff – managers, technical personnel and field workers – fostered open dialogue, enabling the sharing of insights, challenges and successes that may not be reflected in written reports. Additionally, site visits provided invaluable opportunities for capacity building, as reviewers, who are experts in diverse relevant fields, delivered real-time feedback, shared best practices and recommended immediately actionable steps to promptly address identified gaps.

Importantly, external reviews aim to complement and verify reported data, ensuring accuracy and reliability of findings. By directly observing infrastructure, processes and records, site visits uncover issues that may not be apparent from quantitative or self-reported data. Operational inefficiencies, outdated equipment or inadequate staffing often only come to light through on-site assessments. These visits allowed the validation of quantitative data and qualitative evaluations of critical factors such as staff expertise, organizational culture and adherence to procedures, which are essential to the success of genebanks but difficult to quantify. Often the findings also revealed issues that the genebank managers were not aware of.

Following the reviews, the findings are used to guide tailored technical support, capacity-building activities, and workplans for each genebank. The review reports have also supported genebanks in justifying funding requests and enhancing government support. While the KPIs and metrics in the framework align with FAO genebank standards, it is important to note that some targets, such as the 90% thresholds presented, are aspirational and may not be achievable in the short term given the diverse contexts and resources of partner genebanks. Short-term projects should establish their own interim targets or milestones, which serve as incremental steps toward these long-term goals. This approach allows for realistic and flexible progress monitoring tailored to each genebank's circumstances.

While the M&E framework described in this paper has helped bring structure to the genebank reviews, we acknowledge that our findings are based on a limited sample of genebanks from 20 countries in the Global South – out of 852 national genebanks across 116 countries. All materials used in the genebank reviews, including the baseline questionnaire, review checklist, and report template, are regularly updated based on feedback from subject-matter experts. The more we understand the conservation and management of PGRFA collections, the better equipped we are to monitor and evaluate genebank performance and identify critical gaps in *ex situ* conservation.

Conclusion

The M&E framework for genebanks, described in this study and applied to 20 genebanks, has demonstrated to be an effective

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mechanism for assessing, monitoring and improving genebank operations. It validates the long-term availability and security of the collections and also provides actionable recommendations tailored to the specific needs of each genebank.

The adoption of a structured external review process, supported by the review checklist, site visits and comprehensive reporting, enables genebanks to prioritize upgrades, address operational inefficiencies and enhance their capacity to conserve and share PGRFA. The baseline questionnaire and the review checklist can be used both by genebanks for self-assessment and by experts conducting reviews of genebanks. We believe this will enable a more systematic assessment of genebanks and help address the critical challenges in PGRFA conservation.

Ultimately, such an M&E framework for genebanks promotes a culture of transparency and accountability by providing clear assessments of how PGRFA are managed and conserved, thereby fostering trust among stakeholders and donors. The comprehensive evaluation of genebank performance plays a critical role in ensuring an effective, goal-oriented, economically efficient and sustainable global system of *ex situ* conservation through the effective management of PGRFA. While external reviews and needs assessments are not solutions in themselves, they offer valuable guidance on the optimal use of limited financial resources, enabling genebanks to achieve their long-term conservation goals and support the evolving needs of global agriculture.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1479262125100336.

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