Food and Agriculture Organization of the United Nations

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Practical guide for the application of the Genebank Standards for Plant Genetic Resources for Food and Agriculture

Conservation of orthodox seeds in seed genebanks

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Foreword

The international development community and governments are striving to achieve the Sustainable Development Goals (SDGs), including the eradication of hunger, by 2030. The imperative of generating and disseminating the solutions that work for farmers as means to achieve the SDGs provides the backdrop for FAO's Strategic Framework 2022-2031. The Strategic Framework aims to transform current sub-optimal agricultural and food systems to become more efficient, inclusive, resilient and sustainable as envisaged in its four aspirations: better production, better nutrition, a better environment and a better life.

With about 80 percent of food being plant-based, these efforts will benefit greatly from sustainable crop production systems, which generate increased yields of nutritious food with fewer external inputs than are currently the case, even under worsening climate change scenarios. One critical element of such systems is a diverse suite of progressively superior crop varieties that are input use-efficient, nutritious, adapted to target agroecologies, and resilient to biotic and abiotic stresses. Plant breeders need access to the widest possible spectrum of the sources of heritable variations in order to breed such crop varieties. Plant genetic resources for food and agriculture (PGRFA) – which include improved crop varieties, farmers' varieties/landraces and the wild relatives of crops – are the sources of such variations. The safeguarding of characterized and documented PGRFA in genebanks is a reliable means to ensure their availability to current and future generations – both for direct use and for research and plant breeding.

FAO and partners have been cognizant of the critical importance of effective genebank operations to sustainable crop production systems. In addition, in recognition of the global interdependence on PGRFA, facilitated through the exchange of germplasm, the need for the harmonization of genebank procedures has always been at the forefront of FAO's work on the conservation and sustainable use of PGRFA. This was why FAO, through its Commission on Genetic Resources for Food and Agriculture, published the *Genebank*

Standards for Plant Genetic Resources for Food and Agriculture (Genebank Standards) in 2014. The Genebank Standards provide international standards for *ex situ* conservation of PGRFA in seed genebanks, field genebanks, *in vitro* culture and cryopreservation.

Deemed a seminal reference material, one of the feedbacks provided by genebank practitioners was that the utility of the Genebank Standards would be enhanced through the development of companion volumes that detail the action steps of the genebank workflow in a sequential manner and provide guidance on the complex steps and decisions required. In response to this feedback, FAO developed the *Practical guide for the application of the Genebank Standards for Plant Genetic Resources for Food and Agriculture: Conservation of orthodox seeds in seed genebanks.* In addition, the *Practical guide for the application of the Genebank Standards for Plant Genetic Resources for Food and Agriculture: Conservation in field genebanks* and the *Practical guide for the application of the Genebank Standards for Plant Genetic Resources for Food and Agriculture: Conservation via* in vitro *culture* have also been developed.

These companion volumes, prepared in an easy to understand format, will be useful for genebank technicians as operational handbooks; for genebank managers as streamlined instructional materials; and for all interested in genebank operations, a handy reference material.

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Preface

The *ex situ* conservation of plant genetic resources for food and agriculture (PGRFA) in genebanks is aimed at safeguarding them for use by current and future generations – both directly by end users and as materials for research and plant breeding. Genebanks, therefore, ultimately contribute to sustainable crop production systems and hence, food security and nutrition. However, genebanks must be managed effectively in order to conserve these resources in optimal conditions and making them available for use.

Genebanks also play a major role in fostering global collaboration on PGRFA through germplasm exchange, including across national boundaries. The *Genebank Standards for Plant Genetic Resources for Food and Agriculture* (Genebank Standards), published in 2014, aimed at the harmonization of genebank operations, i.e. the storage of the accessions, their characterization and evaluation and the documentation of associated data, across genebanks and countries. The Genebank Standards set the benchmark for current scientific and technical best practices.

Addressing an identified need for the articulation of the stepwise activities of routine genebank operational workflows, the *Practical guide for the application of the Genebank Standards for Plant Genetic Resources: Conservation of orthodox seeds in seed genebanks* was developed. Endorsed by FAO's Commission on Genetic Resources for Food and Agriculture at its Eighteenth Regular Session in 2021, this practical guide presents the information contained in the Genebank Standards in a format that presents the action steps of genebank workflow in a sequential manner. The series of interrelated operations presented, are based on the underlying principles of genebank management, namely: identification of accessions; maintenance of viability; maintenance of genetic integrity during storage and regeneration; maintenance of germplasm health; physical security of collections; availability, distribution and use of germplasm; availability of information; and proactive management.

The sections included in this practical guide are: acquisition of germplasm; drying and storage; seed viability monitoring; regeneration; characterization; evaluation; documentation; distribution and exchange, safety duplication; and security and personnel. A summary diagram of the associated workflow and activities supports each of these operations. An additional section considers the suggested infrastructure and equipment for designing or modifying the facilities of a seed genebank. A final section provides a list of references to provide guidance and/or technical background on seed genebank operations and management. An annex identifies the potential risks associated with the different genebank operations and their respective proposed preventive measures.

This practical guide is part of a series of publications conceived as companion volumes to the Genebank Standards aimed at facilitating their more widespread application. Genebank managers may use the practical guide as a basis for the development of standard operating procedures, quality management systems or, simply, as a handbook.

1. Introduction

Bean diversity, CIAT

The majority of plant species, including many of the most important food crops, produce orthodox seeds that can be dried to a low moisture content and stored at low temperatures. Lowering seed moisture content and storage temperature extends the storage life of orthodox seeds.

Species that produce orthodox seeds and can therefore be conserved in seed genebanks include cereals, grain legumes, forages, most vegetables and some fruits. Most wild relatives of these crops also produce orthodox seeds, although they often require specialized treatment. Some crops that are usually propagated vegetatively, for example potato, also produce true seeds that are orthodox.

Seed genebanks are underpinned by the same principles as other genebanks, namely identification of accessions, maintenance of viability, maintenance of genetic integrity during storage and regeneration, maintenance of germplasm health, physical security of collections, availability, distribution and use of germplasm, availability of information and proactive management (FAO, 2014: Chapter 2).

The conservation of orthodox seeds in seed genebanks can be broken down into a series of interrelated operations (Figure 1). This practical guide presents practices and activities[1] critical to the underlying genebank principles in each operational area (Table 1). It outlines workflows for routine genebank operations for the conservation of orthodox seeds (Figure 2), and supports the application of the *Genebank Standards for Plant Genetic Resources for Food and Agriculture* (Genebank Standards) (FAO, 2014).[2] The purpose of this guide is to present the information contained in the Genebank

[1] Practices and activities follow best practices as outlined in the Genebank Standards.

[2] All standards referenced throughout the document are described in the FAO Genebank Standards.

Standards in a format that details the different actions of the genebank workflow in a sequential manner and thereby facilitate more widespread application of the Genebank Standards. Genebanks may use the activities outlined in this guide as a basis for the development of standard operating procedures (SOPs) (e.g. IITA, 2012) and quality management systems (QMS) (CGIAR Genebank Platform, 2021) for conserving germplasm collections, defining in detail how to carry out each activity.

This booklet only provides general guidance on the complex steps and decisions required when operating a seed genebank. Each genebank will have its own unique and special circumstances, and the efficient management of particular collections will require careful consideration and procedural adjustments based on experience. For detailed technical specifications for the steps outlined in this guide, genebank staff will need to consult various sources of information, a few of which are referenced in this booklet.

Figure 1. Major operations for the conservation of orthodox seeds in seed genebanks

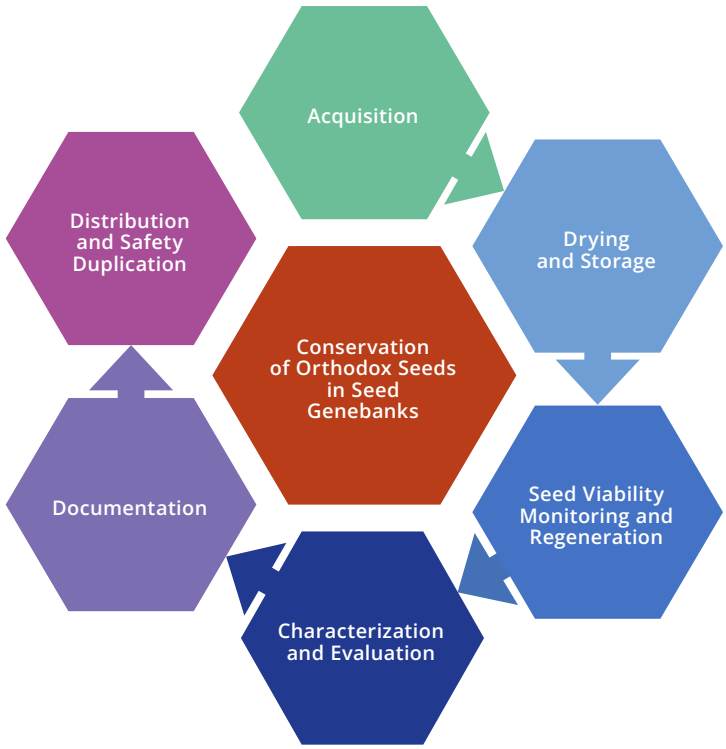
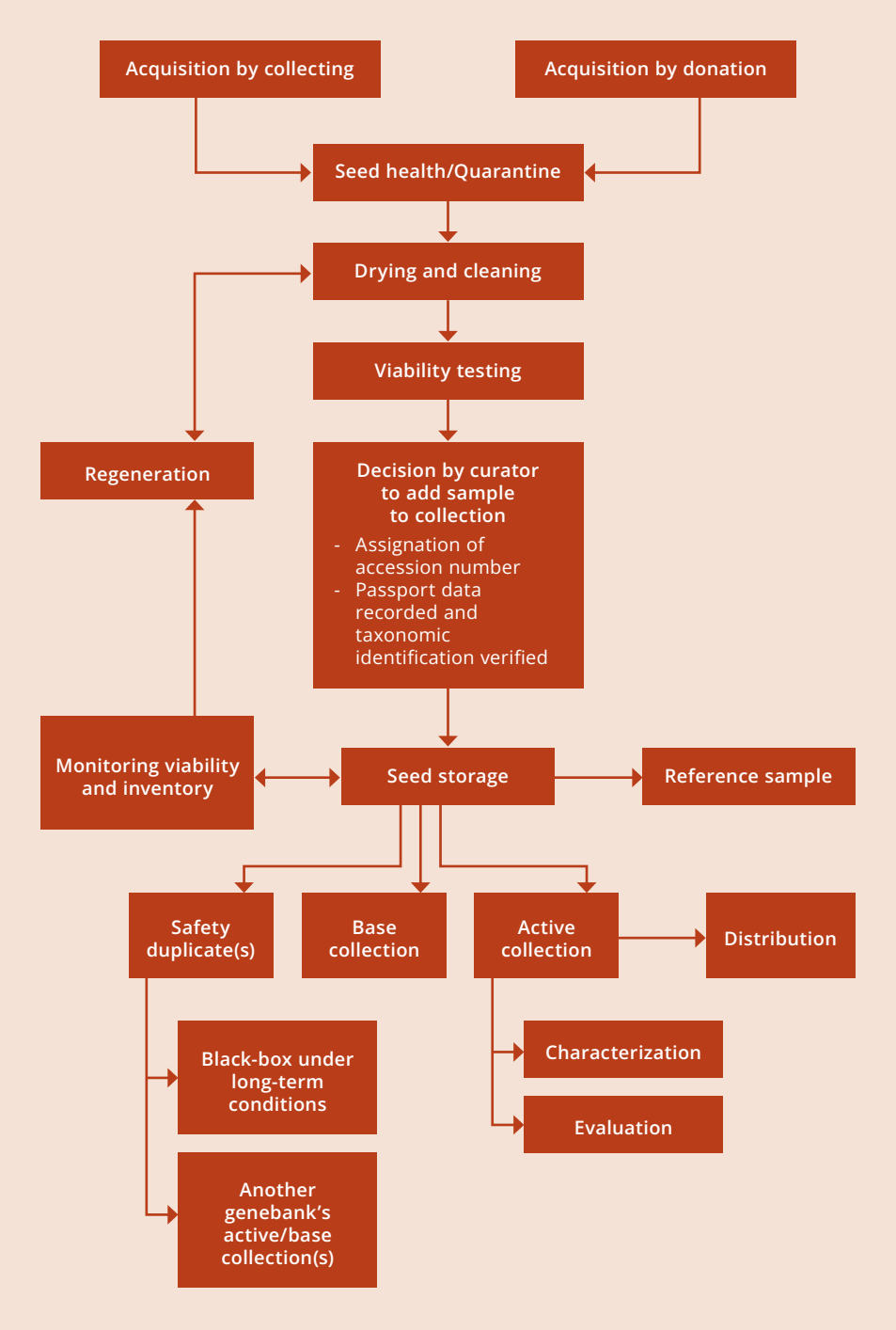


Table 1: Underlying principles and related genebank operations for seed genebanks

Genebank principle	Summarized genebank operations
Identity of accessions	Passport data collected and recorded Taxonomic identity verified Permanent and unique accession number assigned and used in all documentation Accessions handled carefully to avoid mixing, and all samples labelled and tracked through genebank operations and in storage
Maintenance of viability	Best practices followed and timing optimized during collection, regeneration, seed processing and transportation Storage conditions optimized and monitored Viability monitored regularly Regeneration undertaken when necessary
Maintenance of genetic integrity	Collection and maintenance of samples conducted in a manner that ensures they represent the original population as fully as possible Best practices followed during packing, regeneration and multiplication
Maintenance of germplasm health	Quarantine procedures undertaken when needed Best practices followed during collection, packing, regeneration and multiplication Contamination monitored and managed
Physical security of collections	Risk management strategy developed and implemented Appropriate genebank infrastructure in place and maintained Accessions safety duplicated and safety backed up
Availability and use of germplasm	Germplasm acquired and distributed according to legal and phytosanitary requirements Sufficient stocks and efficient and timely dispatch of samples Relevant documentation provided to recipients of genebank material
Availability of information	Genebank information management system in place Passport and accession-management data secured by regular data backups Passport and other relevant data available and accessible to external users, as far as possible
Proactive management of genebanks	Standard operating procedures developed and available to staff Data and information generated during genebank activities available to managers and staff Well-trained staff employed and protected by occupational safety and health measures Genebank staff capacities kept up to date, and training provided as necessary

Figure 2. Flow of germplasm in a seed genebank for orthodox seed conservation.
Note: Each step is associated with proper documentation.



2. Acquisition of germplasm

Collecting crop wild relatives, Nepal

The genebank is recommended to have documented policies and/or procedures, as applicable, for acquiring germplasm that include abiding by legal, phytosanitary and other regulations and requirements.[3]

✔ **Decisions to accept germplasm into a genebank's collection are guided by the institute's acquisition policy.**

The development of an acquisition policy ensures that collections remain manageable and meet users' needs (Guarino, Rao and Reid, eds., 1995).

- Genebank curators may interact with breeders, botanists and other scientists before deciding on new acquisitions. Institutes may also have a crop specific or general advisory committee in place.
- The health and viability status of collected or donated samples, availability of passport information (taxonomic identity, origin of the germplasm, etc.) and sample "uniqueness" (to avoid unnecessary duplicates) should also be considered in the decision-making process.

✔ **Germplasm added to the collection is legally acquired and accompanied by all relevant documentation.[4]**

The process of germplasm acquisition is governed by national and international regulationssuch as phytosanitary/quarantine laws, the International Treaty on Plant Genetic Resources for Food and Agriculture (Treaty) or the Convention on Biological Diversity (CBD) for genetic resources access (FAO, 2014).

- The genebank should communicate with the National Focal Points for the Treaty or other designated authorities on questions concerning germplasm acquisition.

[3] See Figure 3 at the end of this section for a summary diagram of the workflow and activities for the acquisition of germplasm.

[4] Standard 4.1.1.

✔ **A permanent and unique accession number is assigned to each sample added to the genebank collection.**
Once the curator decides to accept a sample into the genebank, a unique accession number must be assigned.
- A Digital Object Identifier (DOI) can also be requested from the Secretariat of the Treaty (FAO, 2021a). Both the accession number and the DOI remain with all material derived from the accession during all genebank handling.
- If donated material has an accession number assigned by the donor organization, a DOI, or both, keep these as alternative identifiers in the passport data. This is a critical means of ensuring the unambiguous association of information with the material.

✔ **Germplasm added to the genebank collection is accompanied by the associated data outlined in the FAO/Bioversity Multi-Crop Passport Descriptors.**[5]
It is recommended that all samples, whether obtained through collection missions or donation from other institutes, be accompanied by the associated data detailed in the FAO/Bioversity Multi-Crop Passport Descriptors (Alercia, Diulgheroff and Mackay, 2015).
- The association of data with the single accession must be clear, for example through the use of accession numbers and/or DOI.

✔ **All acquisition data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**
Consider the use of electronic devices to avoid transcription errors and for ease of uploading. Otherwise, the use of indelible ink (or pencil) and clear, legible writing are necessary when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

2.1 Germplasm acquired through collecting missions

✔ **A clear strategy for germplasm collecting missions is developed according to the institute's mandate.**
Setting collection priorities prior to any collection mission is essential. It is recommended that a collecting proposal be developed that clearly states the purpose of the collecting mission, the target location and the methodology. It may be appropriate and useful to:
- emphasize the importance of conducting inventories and gap analyses to prevent duplicates and of having a clear strategy for collecting missions that considers national inventories and gap analyses;
- establish a collaboration with an institute or experts from the targeted area and abide by regulations for collecting in that area; and

[5] Standard 4.1.4.

- plan the mission well in advance in order to ensure best practices and compliance with regulations and requirements.

✔ **Collected germplasm is legally acquired and accompanied by all relevant documentation.[6]**

The process of germplasm acquisition is governed by national and international regulations. The following information could assist in ensuring compliance with these regulations:

- The genebank should communicate with the appropriate designated authorities when there are questions regarding germplasm acquisition.
  - For collecting missions in other countries, it may be necessary to contact the National Focal Points for the Treaty or other designated authorities for germplasm acquisition.
  - For collecting missions in the genebank's country, it may be necessary to contact the national competent authority in order to ensure understanding of and compliance with national and local regulations.
- Collecting permits from national, regional or local authorities, as appropriate, may be required for collecting crop wild relatives or semi-domesticated germplasm in natural populations *in situ*.
- When collecting from farmers' fields/stores or community areas, including some natural habitats, prior informed consent (PIC) may be required and mutually agreed terms (MAT) (see CBD, 2018) determined, according to relevant national, regional or international laws and regulations.

✔ **The genebank abides by national, regional and international phytosanitary and any other import regulations and requirements from the relevant authorities.[7]**

When germplasm is moved there is a risk of accidentally introducing plant pests and diseases along with the host plant material. The following steps may help mitigate such risks while ensuring compliance with regulations and requirements:

- for materials collected in another country, obtaining a phytosanitary certificate from the provider country and an import permit from the relevant authorities in the genebank's country (see IPPC, 2021);
- passing collected samples through the relevant quarantine process before transferring them to the genebank, if required; and
- multiplying collected accessions with insufficient seed quantity in containment or in an isolated area, according to the advice of the national phytosanitary authority.

6 Standard 4.1.1.

7 Standard 4.1.1.

✔ **Collecting missions are scheduled at the optimum stage of maturity and seeds, spikes, pods, etc. are collected from visibly healthy plants, devoid of disease and insect pest infestations or other damage**

Genebank staff should consult specific sources of information depending on the target species to be collected. In order to prevent potential phytosanitary contamination, avoid, if possible, collecting dispersed seeds from the ground, soiled seeds or seeds infested with saprophytic or pathogenic fungi/bacteria or insects. This may not be possible with crop wild relatives, as they tend to shatter seeds easily.

✔ **Seeds, spikes, pods, etc. are collected from an appropriate number of individual plants while avoiding the depletion of the natural population targeted for collecting.**

The breeding system of the target species may be taken into consideration in order to define the number of plants to sample within a population and the number of seeds (see SGRP-CGIAR, 2011).

- To attain reasonable representativeness it is recommended to harvest seeds from at least 30 seed parents for cross-fertilizing species and 60 seed parents for autogamous species, if possible.[8]
  - If the source population is of sufficient size, it is recommended to collect enough seeds to avoid the need for an initial multiplication stage.[9]
  - As a general rule, collecting more than 20 percent of the available seeds of a wild population should be avoided in order to leave sufficient seeds for natural population renewal (Way, 2003).

✔ **Collected samples are labelled and are not mixed during handling.**

Use indelible ink or computer-generated labels (preferably with barcodes), if possible, on the collection receptacle to label the sample. Placing labels both inside and outside a seed packet is a good practice. Protecting inside labels from deterioration, for example by placing the label in a sealed plastic bag or using moisture resistant labels, is useful if the seed/plant material is not dry. It is recommended to keep a journal with all collection numbers assigned to each sample and additional information, as required.

✔ **Collected germplasm is accompanied by the associated data outlined in the FAO/Bioversity Multi-Crop Passport Descriptors.**[10]

A standardized collecting form is helpful for collecting the associated data for each sample obtained. Each sample is assigned a collection number so that the samples

[8] Standard 4.1.5.

[9] The Crop Genebank Knowledge Base suggests storing a minimum seed quantity of 3 000–4 000 for a genetically homogenous sample, and 4 000–12 000 for a genetically heterogeneous sample.

[10] Standard 4.1.4.

Box 1: Minimum passport data

As a minimum, collecting forms should contain:

- Collection number
- Collecting institute name/code
- Taxon name, as detailed/specific as possible
- Common crop name
- Location of collecting site
- Latitude of collecting site
- Longitude of collecting site
- Elevation of collecting site
- Date of collecting
- Biological status (wild, weedy, landrace, etc.)

can be linked to the collected information. Collecting the following information may be considered:

- Taxonomic identification at species and intraspecific levels, if possible, plant population type, habitat and ecology, soil conditions at the collecting site, GPS coordinates and photo images in order to provide curators and users of the germplasm with an understanding of its original context.
- Associated data for each sample obtained as detailed in the FAO/Bioversity Multi-Crop Passport Descriptors (Alercia, Diulgheroff and Mackay, 2015; see Box 1).
- Information on the origin of the germplasm, traditional knowledge, cultural practices, etc. if collecting from farmers' fields/stores.
- For any herbarium voucher specimen obtained as a reference from a population (for example wild species), it is important to use the same collection number as that of the collected sample and associate it with the accession number in the database.

✔ **The period between collecting and processing and then transferring to the genebank is as short as possible to prevent loss and deterioration of the material.**[11]

Initial viability is a major factor in seed sample longevity, and it is at a maximum at the time of harvest/collecting; viability declines as seeds begin to age. The sooner the newly harvested seed samples are placed in controlled drying conditions, the more likely it is that a high initial viability will be achieved (see seed viability monitoring section).

✔ **The choice of packaging material and transport allows for safe and timely delivery.**

The time needed for document processing, shipment/transit time and conditions (temperatures and/or humidity) are generally taken into account in order to ensure

[11] Standard 4.1.3.

that the material reaches the destination genebank in good condition. The following considerations could decrease the risk of germplasm loss after collecting missions:

Packaging

- Precautions should be taken to avoid risks of fungal or insect attacks during shipment.
  - If a pest has been observed and correctly identified, it may be necessary to apply pesticide before packing. Avoid any unnecessary chemical treatment, as it may be harmful to the collected samples. If treatments are applied, declare them on each seed package and in accompanying documentation.
  - The use of well-ventilated cloth bags is recommended.
- Use of rigid cushioned envelopes or insulated packaging should protect samples from crushing by mechanical mail sorters and deterioration.

Transport

- For long transit times by road, periodic aeration of the collected material may be necessary if the seeds/material are moist to prevent potential viability loss.
- Sending shipments using the fastest means possible, by airfreight or courier, should avoid exposure to adverse environmental conditions and deterioration of seed quality.
- Continuous tracking of the package, if possible, will ensure genebank staff are prepared to process the samples upon arrival at the genebank.

✔ **All incoming material is checked for damage/contamination in a designated reception area (e.g. seed health unit) and processed in a way that does not alter the physiological status.**

- Low-quality or contaminated seeds are not planted directly in the field.
- Quarantine measures are applied, as necessary.

2.2 Germplasm acquired through transfer/donation

✔ **Donated germplasm is legally acquired and accompanied by all relevant documentation.**[12]

- If the donating institute is from a country that is a signatory to the Treaty and the donated germplasm includes crops or species listed under Annex 1 of the Treaty (FAO, 1995), it is necessary to use a Standard Material Transfer Agreement (SMTA) (FAO, 2021b, c).
- If the donating institute is from a country that is not a Contracting Party to the Treaty or if the germplasm is not covered under Annex 1, a Material Transfer Agreement (MTA) is usually used (e.g. AVRDC, 2012), though an SMTA could also be used.

[12] Standard 4.1.1.

- For donations from institutions, plant breeders or other germplasm providers without an MTA, it may be useful for the genebank to have a donor agreement spelling out the conditions of germplasm transfer to the genebank.

✔ **Donated germplasm is accompanied by the associated data outlined in the FAO/Bioversity Multi-Crop Passport Descriptors.[13]**

It is recommended to request donors that samples be accompanied by the associated data detailed in the FAO/Bioversity Multi-Crop Passport Descriptors (Alercia, Diulgheroff and Mackay, 2015; see Box 1).

✔ **The genebank abides by national, regional and international phytosanitary and any other import regulations and requirements from the relevant authorities.[14]**

When germplasm is moved there is a risk of accidentally introducing plant pests and diseases along with the host plant material. The following steps may help mitigate such risks while ensuring compliance with regulations and requirements:

- for materials from another country, obtaining a phytosanitary certificate from the provider country and an import permit from the relevant authorities in the genebank's country (see IPPC, 2021);
- passing samples through the relevant quarantine process before they are transferred to the genebank, if required;
- checking donated material for treatment that may require special handling of the seeds, such as breaking dormancy; and
- regenerating donated accessions with insufficient seed quantity in containment or in an isolated area, according to the advice of the national phytosanitary authority.

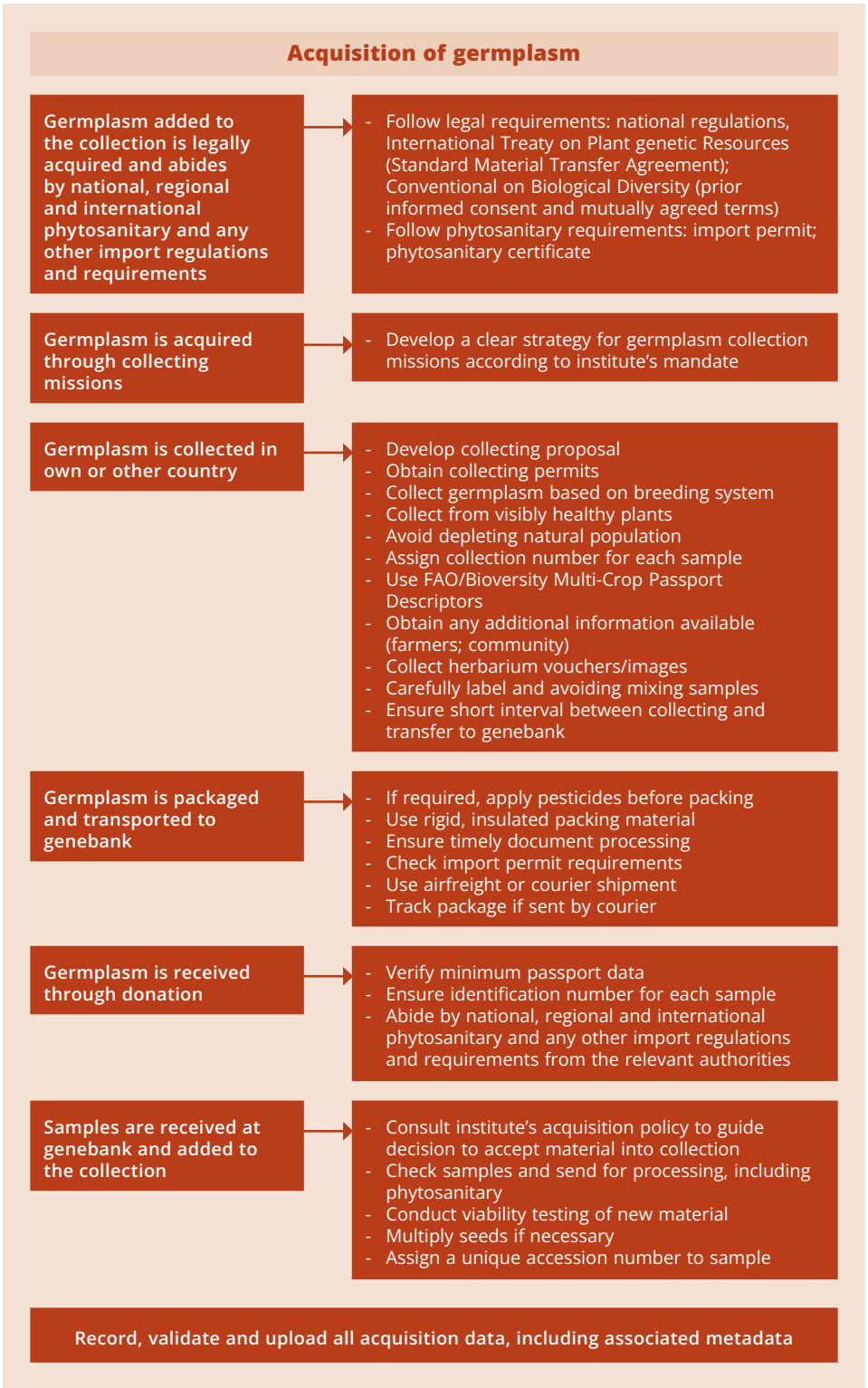
✔ **All incoming material is checked for damage/contamination in a designated reception area (e.g. seed health unit) and processed in a way that does not alter the physiological status.**

- Low-quality or contaminated seeds are not planted directly in the field.
- Quarantine measures are applied, as necessary.

[13] Standard 4.1.4.

[14] Standard 4.1.1.

Figure 3. Summary diagram of the workflow and activities for the acquisition of germplasm



3. Drying and storage

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Seed storage, Zambia Agriculture Research Institute

The genebank is recommended to have documented policies and/or procedures, as applicable, for introducing acquired germplasm into long-term and medium-term storage and to ensure sufficient numbers of seeds are available to satisfy requests for timely distribution.[15]

- ✔ **Collected samples are processed and undergo initial cleaning prior to drying.** Cleaning samples as part of the initial processing into genebanks is an essential component of sample management. Seeds should be extracted from fleshy and dry fruits, pods and spikes prior to drying. Dry material, particularly for seeds in dry pods or spikes, is threshed to remove seeds from the plant and to break up remaining plant material. If possible, an initial cleaning to remove broken dead seed is done prior to drying.

- ✔ **Seed samples are dried to optimum moisture content for storage.** It is recommended dry seeds to equilibrium in a controlled environment of 5–20 °C and 10–25 percent relative humidity.[16] The optimal moisture content for storage varies among species, but these conditions should ensure seeds of most species are dried to the optimal moisture content (around 3 percent for oily seeds and 7 percent for starchy cereal seeds). Available online tools can be used to check the equilibrium moisture content achieved under different drying conditions (RBG, 2018). Where a dedicated drying chamber or room is not available, seeds may be dried using a desiccant such as silica gel. It is helpful to:
  - determine the appropriate method for drying seeds, taking into account the type of sample (fleshy fruit, dry fruits or seeds), the number and size of samples

[15] See Figure 4 at the end of this section for a summary diagram of the workflow and activities for drying and storage.

[16] Standard 4.2.1.

to be dried at a time, local climatic conditions and the financial resources available (Rao *et al.*, 2006); and
- monitor drying using a digital moisture monitor, indicator silica gel or low-cost dial hygrometers, if available.

✔ **Seeds undergo a final cleaning prior to storage.**
Seeds are threshed to remove them from the remaining plant materials and cleaned to remove broken dead seed prior to storage.

✔ **After drying, samples meant for long-term storage are packaged under controlled conditions, in clearly labelled airtight containers.**[17]
Sealing samples in airtight containers ensures that seeds do not re-absorb moisture during storage. Packaging seeds under dry-room conditions or in an air-conditioned room where relative humidity is controlled is useful in order to maintain the moisture content of the seeds. Additional best practices include:
- filling the container to minimize the air gap above the seeds helps to prevent seeds re-absorbing moisture (ideally keep a range of container sizes to suit the volume of seeds in different accessions);
- using both an outer and an inner label (preferably barcoded) for each sample to ensure that the material is properly identified; and
- storing enough seeds for three regenerations (SGRP-CGIAR, 2010a).[18]

If enough seed and resources are available, it is recommended to package samples for safety duplication (see safety duplication section), seed germination testing (see seed viability monitoring section) and a reference sample (see below) at the same time.

✔ **Samples of long-term base collections are ideally stored at –18 °C.**[19]
A suitable temperature for long-term storage is –18 °C. If this technology is not available, sub-zero freezers that do not reach –18 °C are acceptable. For large germplasm collections, a single cold room may be more energy efficient than many standalone freezers. It is very important to have backup power supply for cold stores and freezers. Best practices include:
- avoiding entering cold rooms or opening freezers during any periods of power loss; and
- minimizing the time samples are at higher temperature (but allow containers removed from the cold room or freezer time to equilibrate to the external temperature before opening the container to avoid condensation forming on the cold seeds).

17 Standard 4.2.2.

18 The Crop Genebank Knowledge Base suggests storing a minimum seed quantity of 3 000–4 000 for a genetically homogenous sample, and 4 000–12 000 for a genetically heterogeneous sample.

19 Standard 4.2.3.

✔ **After drying, samples meant for medium-term storage are packaged under controlled conditions in clearly labelled, airtight and easily opened containers.**
Active collections kept in medium-term storage consist of germplasm that may be used for distribution, regeneration, characterization and evaluation. Best practices include:

- using both an outer and an inner label (preferably barcoded) for each sample to ensure that the material is properly identified;
- using indicator silica gel sachets in the container to monitor ingress of moisture; and
- storing enough seeds for distribution and regeneration (SGRP-CGIAR, 2010a).[20]

✔ **Samples of medium-term active collections are stored at refrigerated temperatures.**
Active collections may be stored in purpose-built refrigerated cold stores or commercial refrigerators, ideally at a temperature of 5–10 °C and a relative humidity of 15±3 percent.[21] It is very important to have backup power supply for cold stores and refrigerators. Best practices include:

- avoiding entering cold rooms or opening refrigerators during any periods of power loss; and
- minimizing the time spent at higher temperature (but allow containers to equilibrate to the external temperature before opening to avoid condensation forming on the cold seeds).

✔ **A small reference sample of seeds is kept separately for each accession.**
It is helpful to keep a reference seed sample for each accession in a "seed file", ideally of the most original sample available. If possible, approximately 50 viable seeds should be kept in a small plastic or glass vial or sealed plastic bag with both an outer and an inner label (preferably barcoded) to ensure that the material is properly identified.[22] Such a seed sample can be particularly useful for true-to-type verification of seed after regeneration of the accession.

✔ **All cleaning, drying and storage data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**
Data to consider include accession location (active/base, position within the cold chamber), number of seeds per location, initial moisture content (if available) and date of inclusion in the collection. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

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[20] The Crop Genebank Knowledge Base suggests storing a minimum seed quantity of 3 000–-4 000 for a genetically homogenous sample, and 4 000 –12 000 for a genetically heterogeneous sample.

[21] Standard 4.2.4.

[22] Standard 4.4.3.

Figure 4. Summary diagram of the workflow and activities for drying and storage

4. Seed viability monitoring

©Crop Trust/Neil Palmer

Rice germination, AfricaRice

The genebank is recommended to have a documented policy and/or procedure, as applicable, describing the viability[23] monitoring system used to detect falls in viability.[24]

- ✔ **Seed germination testing follows optimized and documented procedures.** It is important to use standard protocols so that viability monitoring tests are comparable, including over time, ideally using replicated testing procedures.[25] Many genebanks have developed in-house protocols. A number of resources can be found on-line:
  - The International Seed Testing Association (ISTA) (ISTA, 2021) and the Association of Official Seed Analysts (AOSA) (AOSA, 2021) publish germination testing procedures, including suggested substrate, optimum temperature regime, and special treatments that may be required to overcome dormancy.
  - Species-specific guidelines for viability testing are available via the Crop Genebank Knowledge Base (SGRP-CGIAR, 2010b).
  - Kew's Seed Information Database includes details of successful germination protocols for more than 12 424 wild species, including crop wild relatives (RBG, 2018).

- ✔ **Initial seed germination testing is conducted as soon as possible after obtaining the accession.[26]**
  All seed lots intended for storage in the genebank should be tested for seed viability. Such testing is particularly important if the seed source indicates that viability may be

[23] Viability is usually assessed by testing germinability, taking into account dormant seeds that are viable but do not germinate.

[24] See Figure 5 at the end of this section for a summary diagram of the workflow and activities for seed viability monitoring.

[25] See Section 4.3.

[26] Standard 4.3.1.

suboptimal. Well-timed testing provides important data to help inform management decisions about possible early regeneration of poor-quality accessions and minimizes the rate of viability decline between seed collecting and storage.

Some species have a period of primary dormancy and the germination protocol should ensure that dormancy does not confound the result. Older seeds may have secondary dormancy. Literature about specific methods to break seed dormancy must be consulted (see above).

✔ **The viability threshold is set as high as possible to ensure maximum longevity of the sample.**

Viability is an important factor in seed longevity, as seeds with high viability tend to survive longer in storage. The standard for minimum viability is generally set at above 85 percent seed germination.[27] A lower threshold may be acceptable for certain accessions that do not normally reach 85 percent[28] (for example, some forest and wild species). It may be helpful to consider the following:

- Most seeds that are collected at the optimum stage of maturity, handled appropriately and dried promptly should easily achieve an initial viability of ≥ 85 percent.
- For those accessions that do not normally reach high levels of seed germination, it is relevant to account for dormant but viable seeds. The use of alternative methods such as cut tests (RBG, 2015) or tetrazolium tests (RBG, 2014) should provide a more accurate estimate of the true viability of the accession.
  - Conducting a cut-test on seeds that have not germinated will help determine whether they seed are dead or diseased. It is recommended, however, to verify this by carrying out a cut-test on fresh seed from the same seed lot.

✔ **For seeds with very low viability, germinated seeds are planted directly for regeneration if necessary.**

If the viability is very low, the only way to rescue the accession may be to grow those seedlings that germinated during the viability test. In such cases, transplant germinated seeds directly into pots for growing in the greenhouse or growth chamber, if available. This situation should be prevented, if possible, in order to avoid compromising the genetic integrity of the original sample.

✔ **A monitoring system is in place to test the viability status of samples at regular intervals during storage.**

Viability monitoring aims to identify, as closely as possible, the time when viability has fallen to, or is approaching, the determined threshold for regeneration. Setting monitoring intervals is a compromise between the need to avoid wasting seed

[27] Standard 4.3.2.

[28] Standard 4.3.4.

and resources and the risk that valuable material may be lost if monitoring is too delayed or infrequent. The following practices may be considered:

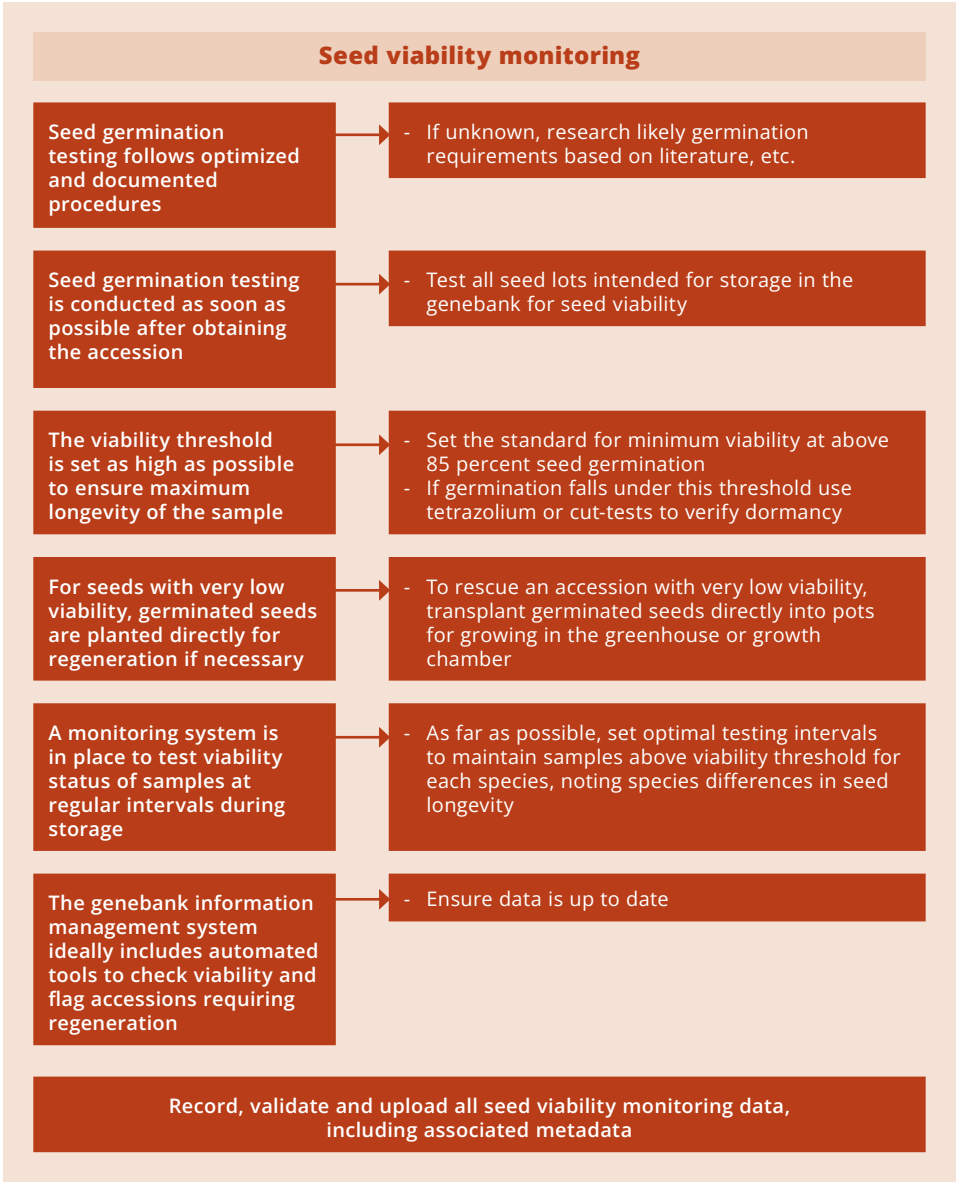
- determining, as far as possible, optimal testing intervals for maintaining samples above viability thresholds for each species, noting species differences in seed longevity (see for example, Ellis *et al.*, 2019; Nagel and Börner, 2010)
- ideally setting viability monitoring test intervals at one-third of the time predicted for viability to fall to the determined regeneration threshold, but not exceeding 40 years;[29]
- setting monitoring intervals for medium-term collections, to 5–10 years for short-lived species; and
- monitoring the viability of the base collection when samples in medium-term storage near the threshold set for regeneration (Hay and Whitehouse, 2017).

✔ **The genebank information management system ideally includes automated tools to check viability and flag accessions requiring regeneration.**

✔ **All seed viability monitoring data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**
Data to consider include dates of germination testing and procedure, number of dead or empty seeds, germination percentage, etc. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

[29] Standard 4.3.3.

Figure 5. Summary diagram of the workflow and activities for seed viability monitoring



5. Regeneration

Regeneration of faba bean, ICARDA Lebanon

The genebank is recommended to have a documented policy and/or procedure, as applicable, for regeneration[30] of germplasm, including step-by-step instructions for monitoring seed inventory and seed viability, field preparation, selection of accessions, sample size, sowing, crop management, pollination control, identity verification, harvest and post-harvest management and documentation.[31]

✔ **Seed inventory and viability are monitored regularly.**
The genebank information management system ideally includes automated tools for checking seed inventory and viability, and flagging accessions requiring regeneration. It is also important to take practical considerations into account in order to avoid planting an overwhelming number of accessions.

✔ **Accessions are regenerated when seed viability or seed quantity falls below the respective regeneration threshold**.
Regeneration is required if/when viability falls below the viability threshold or if seed stocks are insufficient to meet distribution requests. An initial regeneration may also be required for newly acquired acquisitions with low seed number. Suggested practices to consider include:

- regenerating when viability drops below 85 percent of initial viability;[32] and
- regenerating when the number of seeds remaining falls below that required for three sowings of a representative population of the accession.

30 Note that we are using the term regeneration to depict both multiplication and regeneration to align with the terms use in chapter 4 of the Genebank Standards.

31 See Figure 6 at the end of this section for a summary diagram of the workflow and activities for regeneration.

32 Standard 4.4.1.

✔ **Optimal regeneration practices are used to ensure sufficient and healthy seeds.**
Reducing the number of regeneration cycles is important to avoid risks. Suggested practices include:

- selecting a regeneration environment that is as ecologically similar as possible to the original collecting site to reduce potential selection pressures;
- paying special attention to the regeneration needs of wild species to avoid the complete or partial loss of poorly adapted accessions, for example by growing at alternative locations such as research stations, in greenhouses, or under shaded conditions, etc.;
- creating both hard and electronic copies of field maps developed before planting;
- clearly labelling regeneration plots (preferably with barcodes); and
- following appropriate crop-management practices, including land preparation, any pre-sowing treatments, planting time, plant spacing, irrigation, fertilizer application and pest, disease and weed control.

✔ **Optimal regeneration procedures are used to minimize risk to the genetic integrity of the accession.**
Understanding the genetics and structure of the genebank collection as a whole facilitates informed decisions about regeneration procedures, including species-specific requirements. Best practices to consider include:

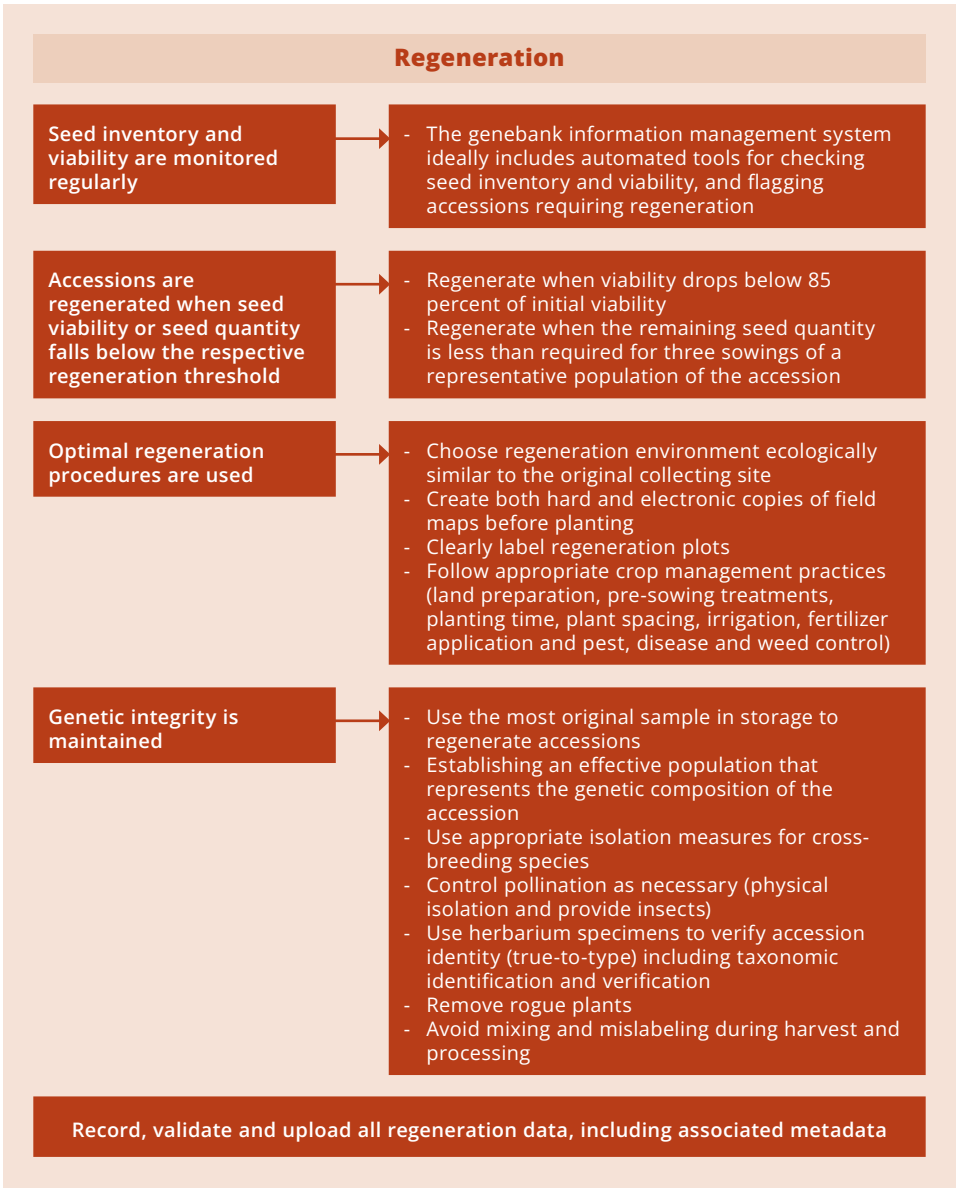
- using the most-original sample in storage to regenerate accessions for long-term storage and seeds from the active collection to regenerate accessions for medium-term storage (for a maximum of three cycles, after which a sample of the most-original seeds in long-term storage should be used);
- establishing an effective population that represents the genetic composition of the accession (for crop-specific information see SGRP-CGIAR, 2010c);
- controlling pollination as necessary, for example by taking the crop breeding system into account, which may require physical isolation and provision of pollinating services (insects);
- removing plants that are growing outside the planted rows;
- using herbarium specimens and images and reference seed samples, if available, to verify accession identity (true-to-type), including taxonomic identification and verification, and to fill any gaps in documentation;
- removing phenotypically different plants when there is absolute certainty that they are rogue plants derived from contamination of the original accession;
- if feasible, taking and storing images of plants and seeds during each regeneration for future reference;
- observing and recording phenotypic heterogeneity that may be based on genotypic heterogeneity
  - consider separating accessions into distinct accessions to ensure diversity is preserved and can be characterized and utilized more efficiently; and
  - record that the separated populations (new accession number/s) are derived from the original accession (see Lehmann and Mansfeld, 1957);

- adding a specific identifier to the seed lot after harvest that allows all generations of harvested seed lots to be traced to the original material obtained by the genebank;
- taking herbarium specimens and images during the growing season and a small seed sample at harvest to verify accession identity; and
- avoiding mixing and mislabelling during harvest and processing.

✔ **All regeneration data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**

Data to consider include planting and harvest dates, cultural practices used (spacing, weeding, irrigation, fertilizer, pesticide application, etc.) and dates when implemented, number of plants harvested, yield, etc. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

Figure 6. Summary diagram of the workflow and activities for regeneration



6. Characterization

©Crop Trust/Neil Palmer

Characterization of rice germplasm, AfricaRice

The genebank is recommended to have a documented policy and/or procedure, as applicable, for characterization of germplasm, including step-by-step instructions describing field designs, growth cycle stages during which characterization data are obtained, descriptors used (taxonomic, morphological, phenotypic, biochemical, nutritional, physiological and molecular), and the manner in which the data are collected and validated.[33]

✔ **Characterization data are obtained for as many accessions as possible and as soon as possible after acquisition.**
Ideally, all accessions should be characterized as soon as possible.[34] The sooner the information is available, the more likely the accession will be used. It is essential that staff be well trained in data recording and field work.

✔ **Characterization can be combined with regeneration.**
For self-pollinating species, accessions can be planted in proximity to each other. In outcrossing species, it is preferable to plant special characterization nurseries using proper isolation methods such as isolation tents. Best practices to consider include:

- using an augmented design, possibly replicated, with carefully chosen check (control) accessions or varieties, as they facilitate the generation of reliable characterization data (IPGRI, 2001);[35]
- creating both hard and electronic copies of field maps developed before planting; and
- clearly labelling plots (preferably with barcodes).

[33] See Figure 7 at the end of this section for a summary diagram of the workflow and activities for characterization.

[34] Standard 4.5.1

[35] See Section 4 of Chapter 6

It is advisable to characterize as many accessions as practically possible at the same time in order to increase efficiency.

✔ **Germplasm is characterized for a set of highly heritable morphological traits, and species-specific characterization procedures are based upon standardized and calibrated measuring formats and categories, following internationally agreed descriptor lists as much as possible.**[36]

The use of standardized crop descriptor lists and calibrated and standardized measuring formats enables the comparison of data across institutions and countries. A wide range of crop descriptor lists have been developed (for example by Bioversity International (2018), The International Union for the Protection of New Varieties of Plants (UPOV, 2011), and the National Plant Germplasm System (NPGS) of the United States of America (USDA-ARS, 2021). If there are no existing descriptor lists for a species, it is recommended to use Bioversity International's Guidelines for Developing Crop Descriptor Lists (Bioversity International, 2007). It may be helpful to consider:

- using reference accessions in the same field to facilitate scoring;
- using herbarium specimens and possibly digital high-quality voucher images to guide true-to-type identification, including taxonomic identification and verification, if needed;
- observing and documenting the homogeneity/heterogeneity of an accession is important; and
- taking measurements at the plant level rather than at the plot level for crops with high levels of variability in order to capture information about the variability between plants of the same accession.

In cases where an accession is heterogeneous, it may be preferable to split an accession into two or more different accessions that are phenotypically homogenous to facilitate characterization and utilization. If that is done, the composition of the original accession must be properly recorded and documented, and new accession numbers assigned to the newly defined accessions (see Lehmann and Mansfeld, 1957). For some purposes it may be necessary to create pure lines based on single plant offspring in self-pollinating plants (Diederichsen and Raney, 2008).

✔ **Molecular marker technologies and genomic tools for characterization are utilized if resources are available, complementing phenotypic characterization.**

Molecular markers help ensure the identity of plants and help identify mislabelled plants and duplications. They are also highly useful in detecting genetic diversity and parentages within and among accessions. Molecular markers are stable and detectable in all tissues. Molecular marker technologies include DNA-based markers and direct sequencing; determining the best method to use

[36] Standard 4.5.2

will depend on need and resources.[37] Molecular characterization may be outsourced to specialized laboratories.

✔ **All characterization data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**
Data to consider include planting and harvest dates, cultural practices used (spacing, weeding, irrigation, fertilizer, pesticide application, etc.) and dates when implemented, check accessions or varieties used, descriptors measured and results, dates recorded, staff responsible, laboratory techniques (molecular, etc.) and dates carried out. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

✔ **Relevant characterization data are made publicly available.**
Having selected data publicly available to potential germplasm users at genebank, country, regional and global levels will serve to enhance germplasm use (see documentation section). The publishing of characterization data is therefore highly recommended.

[37] A number of resources on molecular marker technologies are available online and in print. Please see further information/reading section.

Figure 7. Summary diagram of the workflow and activities for characterization

7. Evaluation

©CIAT/Georgina Smith

Evaluation of bean germplasm, CIAT Uganda

The genebank is recommended to have documented policies and/or procedures, as applicable, for the evaluation of germplasm, including step-by-step instructions describing seed sampling methodology, replicated multi-location, multiyear designs, growth cycle stages during which evaluation data are obtained, data collected (agronomic performance, biotic resistance, abiotic tolerance and nutritional), and the manner in which the data are analysed and validated. The methods/protocols, formats and measurements for evaluation should be properly documented, with citations.[38]

- ✔ **Evaluation data are obtained for as many accessions as practically possible through laboratory, greenhouse and/or field trials, as applicable.[39]**
  Ideally, all accessions should be evaluated to maximize their utility. In reality, genebanks are usually only able to evaluate subsets of their germplasm. It is therefore helpful to collaborate with national or international research organizations, with field stations in different agro-ecological environments, or with members of national or regional genetic resources networks. If germplasm is shared for evaluation purposes, it is recommended that a request be made for data to be sent back for inclusion in the genebank information management system.

- ✔ **Experimental designs with replicates are used and evaluations conducted in different environments and/or over multiple years.[40]**
  Traits measured during evaluation, such as yield and plant height, are mostly inherited through a large number of genes and therefore quantitative and subject to considerable environmental interaction. Consequently, they are more difficult to measure. Because of the strong genotype by environment

[38] See Figure 8 at the end of this section for a summary diagram of the workflow and activities for evaluation.

[39] Standard 4.6.2.

[40] Standard 4.6.3.

(G x E) interactions, traits such as yield (and its components) are site-specific. Best practices to consider include:

- defining and identifying check accessions or varieties to be included in the statistical design and used over time, as they facilitate comparisons of data collected across locations and years;
- working with plant breeders and other specialists (for example, virologists, entomologists, mycologists, plant pathologists, chemists, molecular biologists and statisticians) to agree on the traits to be evaluated, the accessions that will be tested and the experimental designs to be implemented;
- using appropriate screening protocols to make sure that internationally validated protocols are respected;
- creating both hard and electronic copies of field maps developed before planting; and
- clearly labelling plots (preferably with bar-codes).

✔ **Evaluation data are presented using appropriate methods.**
The use of standardized crop descriptor lists and calibrated and standardized measuring formats enables the comparison of data across institutions and countries (see characterization section).[41] Data are either presented as discrete values (e.g. scores for severity of disease symptoms or symptoms of abiotic stresses) or as continuous values (e.g. length, height, weight) based on measurements.

✔ **Molecular markers and genomic tools are used if resources are available.**
The use of molecular markers in strong linkage with an agronomic trait provides a fast and relatively inexpensive screening methodology for the evaluation of germplasm. Molecular markers are also highly useful in detecting genetic diversity and parentages within and among accessions. Molecular markers are stable and detectable in all tissues. Molecular marker technologies include DNA-based markers and direct sequencing; determining the best method to use will depend on need and resources.[42] If desired, work with molecular breeders to identify marker-trait associations.

✔ **All evaluation data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**
Data to consider include location, planting and harvest dates, cultural practices used (spacing, weeding, irrigation, pesticide application, etc.) and dates when implemented, number of replications, check accessions or varieties used, descriptor measured and results, dates recorded, staff responsible, laboratory techniques (molecular, etc.) and dates carried out. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information

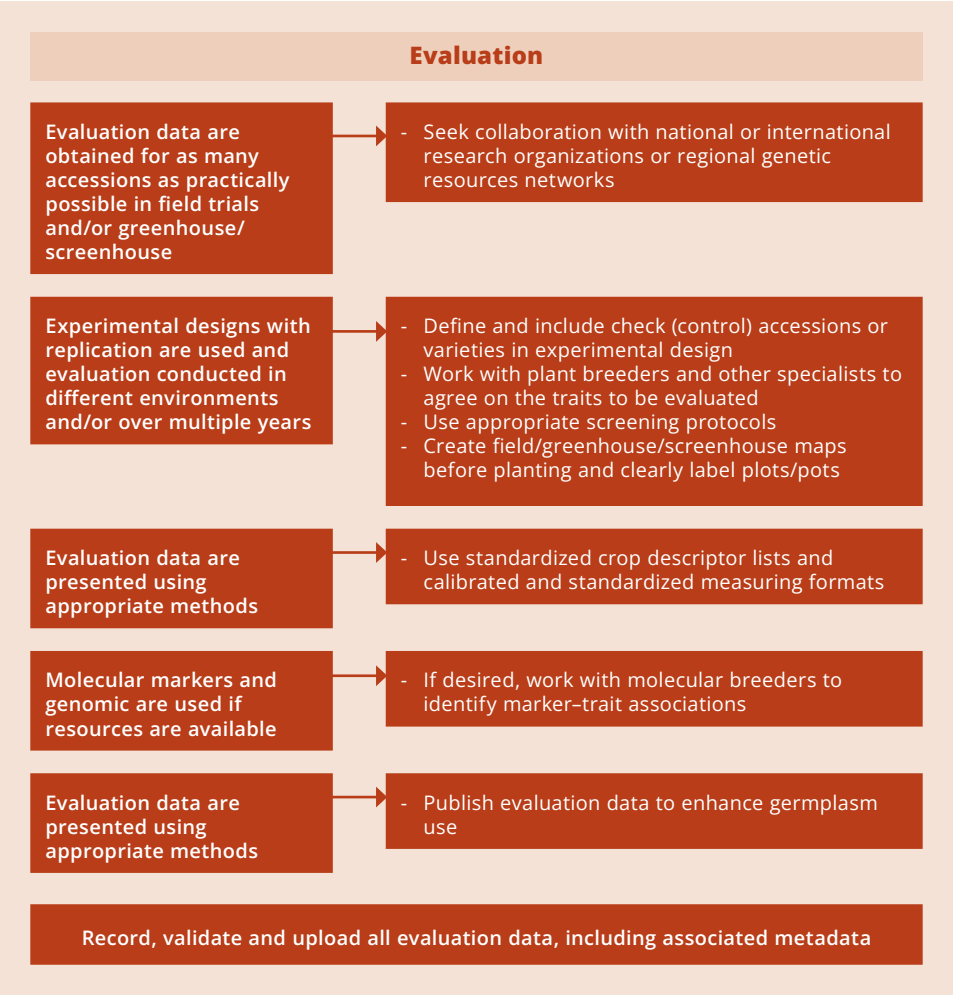
41 Standard 4.6.1.

42 A number of resources on the various molecular marker technologies available are available online and in print. Please see Further Information/Reading.

management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

✔ **Relevant evaluation data are made publicly available.**
Having selected data publicly available to potential germplasm users at genebank, country, regional and global levels will enhance their use (see documentation section). The publishing of evaluation data will also promote the use of the germplasm collection, especially by plant breeders.

Figure 8. Summary diagram of the workflow and activities for evaluation



8. Documentation

Data collection, IRRI

The genebank is recommended have a documented policy and/or procedure, as applicable, for managing genebank data and information, including data sharing guidelines.[43]

✔ **A suitably designed genebank information management system is used.**
The genebank information system is ideally designed to manage all the data and information generated relating to all aspects of the conservation and use of the germplasm stored in the genebank, including passport, characterization, evaluation, seed storage and management data and metadata. Built-in automated tools for checking seed-lot inventory and viability and flagging accessions requiring regeneration should be available.

GRIN-Global has been developed by USDA-ARS, the Global Crop Diversity Trust and Bioversity International to enable genebanks to store and manage information associated with plant genetic resources, and is freely available (GRIN-Global, 2021). Other systems include the AVRDC Vegetable Genetic Resources Information System (AVGRIS) (AVRDC, 2021), the German Genebank Information System (GBIS) (GBIS/I, 2021) and Alelo developed by the Brazilian Agricultural Research Corporation (Embrapa) (Embrapa, 2021).

✔ **International data standards are adopted to provide consistency in data shared among different information systems and programmes.**
Recording the passport data of accessions using FAO/Bioversity multi-crop passport descriptors (Alercia, Diulgheroff and Mackay, 2015) and the use of standardized, internationally agreed, crop-specific descriptors for characterization

[43] See Figure 9 at the end of this section for a summary diagram of the workflow and activities for documentation.

and evaluation[44] facilitate data exchange, and comparison of accessions across different countries and institutions. Passport data should ideally be available for all accessions in the genebank collection.[45] A unique and permanent accession number is a key element of proper documentation and identification and must be assigned to each accession upon its acceptance into the genebank collection. In addition, different seed lots or generations of seed accessions should be identified uniquely. The voluntary use of Digital Object Identifiers (DOIs) (Alercia, Diulgheroff and Mackay, 2015; FAO, 2021a) is an additional option for information sharing across different information systems and different communities but cannot replace the assignment of the genebank's unique and permanent accession number.

✔ **All data and information relating to all aspects of conservation and use of germplasm, including images and metadata, are validated and uploaded to the genebank information management system.**[46]
It is important to have staff trained in data recording and data entry in close collaboration with documentation officers and germplasm collection curators. It would be useful to have staff members that are assigned specific responsibility for managing the genebank information management system, including keeping data up-to-date at all times. It is recommended that genebank curators and documentation officers validate data before they are uploaded into the genebank information management system.

✔ **Mobile devices are used to capture data, if possible.**
The use of barcoding facilitates all aspects of genebank management, especially documentation.

✔ **Data recorded on paper are digitalized and measures are put in place to check hand-written and electronic data entries for transcription errors.**

✔ **Data are publicly available in a search-query database, if possible.**
Publishing data on the genebank holdings increases opportunities for use of germplasm and therefore adds to the value and prestige of genebanks. It may not be possible for all genebanks to maintain a web portal for external access to collection information. An option is to provide information through Genesys, an international global portal managed by the Global Crop Diversity Trust (Crop Trust, 2021). Genesys allows accession data from genebanks around the world to be shared, and facilitates the ordering of germplasm. It includes accession-level passport, characterization and evaluation data as well as environmental information associated with accession collecting sites. Another option for making the passport data of genebank accessions publicly accessible is provided by the

[44] See characterization and evaluation sections.

[45] Standard 4.7.1.

[46] Standard 4.7.2.

FAO World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (WIEWS) (FAO, 2021d). By serving as the data repository for the plant indicator of Target 2.5 of the Sustainable Development Goals (United Nations, 2021), WIEWS stores and publishes accession-level passport data for the largest global inventory of *ex situ* collections (FAO, 2021e).

✔ **Data are duplicated (backed-up) at regular intervals and stored at a remote site to guard against loss from fire, computer failure, data breach, etc.**

Figure 9. Summary diagram of the workflow and activities for documentation

9. Distribution

Seed distribution, NordGen

The genebank is recommended to have a documented policy and/or procedure, as applicable, for the distribution of germplasm, including the review process for checking for fulfilment of legal, phytosanitary and other regulations and requirements, and step-by-step instructions for consignment preparation, post-consignment follow-up and reporting to the Secretariat of the Treaty or a National Focal Point or other designated authority, as necessary.[47]

✔ **The genebank complies with national, regional and international regulations and agreements.[48]**

The process of germplasm distribution is governed by national and international regulations. The genebank should communicate with the appropriate designated authorities when there are questions regarding germplasm distribution. The following information should assist in ensuring compliance:

- The genebank should communicate with the Secretary of the Treaty or a National Focal Point or other designated authority if other countries are involved in germplasm distribution.
- If the genebank's country is a signatory to the Treaty and germplasm of crops or species listed under Annex 1 of the Treaty (FAO, 1995) are being distributed for the intended uses covered by the Treaty (i.e. research, breeding and training for food and agriculture), it is necessary to use an SMTA (FAO, 2021b; c).
- If the genebank's country is not a Contracting Party to the Treaty or if the germplasm is not covered under Annex 1, it is recommended that an agreement be reached with the recipient on the terms and conditions of germplasm distribution – covering, for example, the use and onward sharing of the material

[47] See Figure 10 at the end of this section for a summary diagram of the workflow and activities for distribution of germplasm.

[48] Standard 4.8.1.

or its derivatives, data reporting, etc. An MTA is usually used (e.g. AVRDC, 2012), though an SMTA could also be used.

✔ **A policy is in place for the number of seeds to distribute for any given species.** For most species, a sample of 100–200 viable seeds would be supplied for those accessions with sufficient seeds.[49]

- For accessions with too few seeds at the time of the request, and in the absence of a suitable alternative accession, samples are supplied after regeneration, based on a renewed request. For some species and for some uses, a smaller number of seeds is sufficient.
- If feasible, consider the distribution of samples with a mutually signed regeneration agreement. In this case, the requesting institute should have the necessary technical capacity and regeneration should be carried out under the supervision of staff from the genebank according to the genebank's protocols.

✔ **Required documentation is requested and obtained.**
Import permit regulations, which specify phytosanitary and any other import requirements, including packaging requirements, must be requested from the relevant national authority of the receiving country. Documents often required by the recipient country include a phytosanitary certificate, additional declarations, a certificate of donation, a certificate of no commercial value and an import permit.

✔ **Arrangements are made with competent authorities or agents (i.e. the country's National Plant Protection Organization) to inspect or test the material in order to ensure compliance with the regulations of the importing country and to issue the relevant phytosanitary certificate.**

✔ **The length of time between receipt of a request for seeds and the dispatch of the seeds is kept to a minimum.[50]**

✔ **Samples are labelled carefully and are not mixed during handling.**
Correctly labelled samples, preferably with computer-produced labels to reduce transcription errors, should be placed both outside and inside each seed packet to ensure that the material is properly identified.

✔ **The choice of packaging material and transport allows for safe and timely delivery.**
Ensure that the material reaches the destination genebank in good condition, bearing in mind the time needed for document processing, duration of shipment, transit time and transit conditions (high temperatures and/or humidity in tropical countries). The use of packing and shipping guidelines/recommendations similar to those utilized for acquisition is recommended (see acquisition section).

[49] Standard 4.8.4.

[50] Standard 4.8.3.

✔ **All required documentation is included inside the shipment (for the recipient) and attached to the outside of the container for the customs officials in order to guarantee smooth processing during transit and at the border of the destination country).**[51]

Consider scanning documents and sending them by e-mail, or sending hard copies by mail, prior to the dispatch of the germplasm. Items of documentation to consider include:

- data on accessions (including an itemized list with accession identification, seed lot/generation identification, number and/or weight of samples, and key passport data); and
- import permit, phytosanitary certificate or customs declaration, if appropriate.

✔ **The delivery of the germplasm and its condition on arrival at its destination is checked by following up with the recipient.**

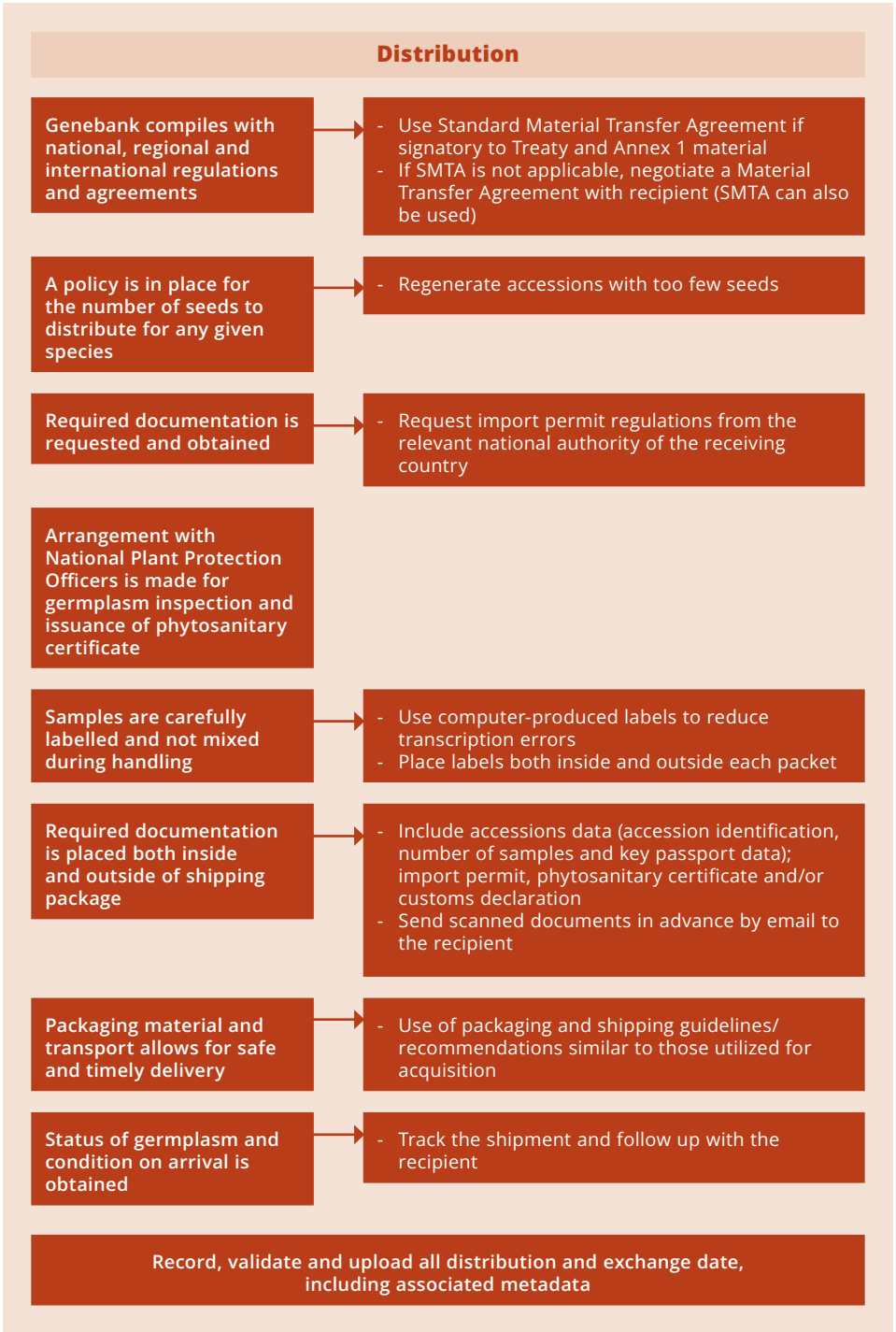
It is recommended to track the shipment and follow up with the recipient on the status and performance of the distributed germplasm.

✔ **All distribution data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**

Data to consider include: requester's name and address, purpose of request and request date; samples requested, samples sent, number of seeds per sample and/or weight; reference to phytosanitary certificate and SMTA or MTA; and shipping log and user feedback. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of bar-code labels and barcode readers facilitates accession management and minimizes human error.

[51] Standard 4.8.2.

Figure 10. Summary diagram of the workflow and activities for distribution of germplasm



10. Safety duplication

Svalbard Global Seed Vault, Norway

The genebank is recommended to have a documented policy and/or procedure, as applicable, for the safety duplication of germplasm, including the review process for checking for fulfilment of legal, phytosanitary and other regulations and requirements, and step-by step-instructions for consignment preparation, post-consignment follow-up and shipment schedules.[52]

- ✔ **A safety duplicate sample for every original accession is stored at a distant location, under appropriate conditions and utilizing best practices.**
  Safety duplicates are generally deposited in a base collection at a different location, usually in another country. Safety duplication can also involve the placement of accessions in a genebank where they are actively managed. The safety duplicate location is chosen so as to minimize possible risks and provide the best possible conditions, taking into account the need for adequate facilities, staff and financial resources. It should be in a sociopolitically and geophysically stable location. In addition, many genebanks send "black box" samples to the Svalbard Global Seed Vault or other institutes, as a safety backup. In such cases, the recipient only stores the materials in their long-term base storage facility and should not open the boxes or seed packages.

- ✔ **A legal agreement between the depositing and recipient genebanks that clearly specifies the terms and conditions under which material is maintained and managed is in place.**
  If the holding genebank does not already have an agreement with another genebank to safety duplicate the original accessions, consideration should be given to where best they could be duplicated.

[52] See Figure 11 at the end of this section for a summary diagram of the workflow and activities for safety duplication of germplasm.

✔ **The genebank complies with legal, phytosanitary and other regulations and requirements and each safety duplicate sample is accompanied by relevant associated information.**
Discussions should take place with the host genebank early in the planning process on the required documentation (both for the genebank and the host country) and the applicable customs and quarantine procedures. This will help ensure timely movement of the germplasm.

✔ **The safety duplicates are of high quality and have a sufficient quantity of seed.**
It is the depositor's responsibility to ensure that the deposited material is of high quality. Best practices to consider include:

- ensuring duplicated material is clean and healthy and has a high initial viability;
- ensuring that the safety-duplicated samples are large enough to allow at least three regenerations to be conducted (FAO, 2014);[53]
- including a subset of materials to be used for viability testing in the future; and
- using viability monitoring data for seeds from the same seed lot stored in the originating genebank's base collection to determine whether viability monitoring of the safety duplicate sample should commence (if samples are included for monitoring) or otherwise whether the safety duplicate sample should be replaced.

✔ **Samples are labelled carefully and are not mixed during handling.**
It is important to use seed packets that are durable and impervious to moisture in order to maintain viability and that samples are correctly labelled, preferably with computer-produced labels, to reduce transcription errors in names and numbers.

✔ **The choice of packaging material and transport allows for safe and timely delivery.**
Ensure that the material reaches the destination genebank in good condition, bearing in mind the time needed for document processing, duration of shipment, transit time and transit conditions (high temperatures and/or humidity in tropical countries).
Best practices include:

- packing all seed samples for safety duplication in clearly labelled, vacuum-sealed trilaminate aluminium foil packets seamed on all four sides with no gusset;
- including an outer and inner label for each packet to ensure that the material can be properly identified; and
- using packaging and shipping guidelines/recommendations similar to those used for distribution is recommended (see distribution section).

[53] If possible, a safety duplicate of an accession in a seed genebank should contain at least 500 viable seeds for cross-pollinating species and a minimum of 300 seeds for genetically uniform accessions (see Genebank Standards Section 4.9).

✔ **Each safety duplicate sample is accompanied by relevant associated information.**[54]
It is recommended that relevant information be sent with the shipment, including an itemized list with accession identification, key passport data, total quantity of seeds (by weight or number), type of container, and import permit, phytosanitary certificate or customs declaration, if appropriate.. Consider scanning documents and sending them by email, or sending hard copies by mail, prior to the dispatch of the germplasm.

✔ **All safety duplication data, including associated metadata, are recorded, validated and uploaded to the genebank information management system.**
Data to consider include: location of the safety-duplicated accessions; packing date, samples sent, seed number and/or per sample and packaging information; and shipping log and reference to legal agreement, phytosanitary certificate, etc. Consider the use of electronic devices to avoid transcription errors and for ease of uploading into the genebank information management system. Otherwise, the use of indelible ink (or pencil) and clear, legible writing is required when recording data. The use of barcode labels and barcode readers facilitates accession management and minimizes human error.

✔ **The genebank information management system is regularly reviewed to ensure that any new accessions not safety duplicated are identified and prepared for safety duplication, as appropriate.**

[54] Standard 4.9.2.

Figure 11. Flow diagram of the workflow and activities for safety duplication of germplasm

11. Personnel and security

©Shawn Landersz

Machine threshing safety, IITA

Personnel:

It is recommended that the genebank have a strategy in place for personnel, including a succession plan; a corresponding budget must be allocated and reviewed regularly.[55]

- ✔ **The genebank has a human-resources plan with appropriate annual budget allocation, and staff have the critical knowledge, skills, experience and qualifications needed to implement all genebank tasks effectively and efficiently.** Successful genebank management requires a minimum of well-trained staff with clearly defined responsibilities for accession management.[56] The following practices should be considered:
  - ensuring that the genebank manager and those staff carrying out specific tasks regularly review and update SOPs, as applicable;
  - ensuring that curators and technical support staff have knowledge and skills in agriculture, horticulture and taxonomy of cultivated plants and their wild relatives;
  - having access to disciplinary and technical specialists in a range of subject areas, such as taxonomy, physiology, phytopathology, breeding and population genetics;
  - holding regular on-the-job training sessions and, if possible, ensuring that staff can attend training opportunities at regular intervals to keep up to date with recent developments;
  - rotating tasks to make work as varied as possible and involving all staff (where possible) in meetings and discussions; and

[55] See Figure 12 at the end of this section for a summary diagram of the workflow and activities for personnel and security.

[56] Standard 4.10.3.

- retaining competent staff by providing recognition and rewards for excellent performance.

✔ **Risks associated with staffing are included in the risk identification, analysis and management.**
Secure conservation depends on accurate assessment and appropriate management of risks (see Annex). Therefore, all genebanks should establish and implement risk management strategies that address the physical and biological risks in the every-day environment to which the staff, collections and related information are exposed.

Security:

A genebank is recommended to have a documented risk management strategy in place that includes measures for dealing with power cuts, fire, flooding, earthquakes, war and civil strife.[57] This strategy and an accompanying action plan should be regularly reviewed and updated to take changing circumstances and new technologies into account.

✔ **A risk management strategy is in place.**
A risk management strategy has the following components (SGRP-CGIAR, 2010d):
- *Communication and consultation*: ensure that all those who will be involved in implementing a risk management system are oriented in the concepts, methodology, terminology, documentation requirements and decision-making processes of the system;
- *Establishing the context*: consider the objectives/activities/tasks of the genebank, the environment in which the activities operate, and the stakeholders;
- *Risk identification*: carry out an inventory of relevant risks to the genebank operations;
- *Risk analysis*: assess the potential impact (or consequence) of the identified risks and their likelihood (probability);
- *Risk evaluation*: determine the level of risk that is acceptable;
- *Risk treatment*: identify actions that need to be undertaken in order to deal with those risks for which the current total risk rating is considered unacceptable, giving top priority to the highest assessed residual risks; and
- *Monitoring and review*: analyse the risk management system and assess whether changes to the system are needed. Responsibilities for monitoring and review should be clearly defined and documented.

✔ **A staff member with responsibility for occupational safety and health (OSH) in the genebank is appointed and receives training in OSH.**
OSH deals with all aspects of health and safety in the workplace and has a strong focus on primary prevention of hazards.[58] Most countries will have an OSH policy.

[57] Standard 4.10.1.

[58] Standard 4.10.2.

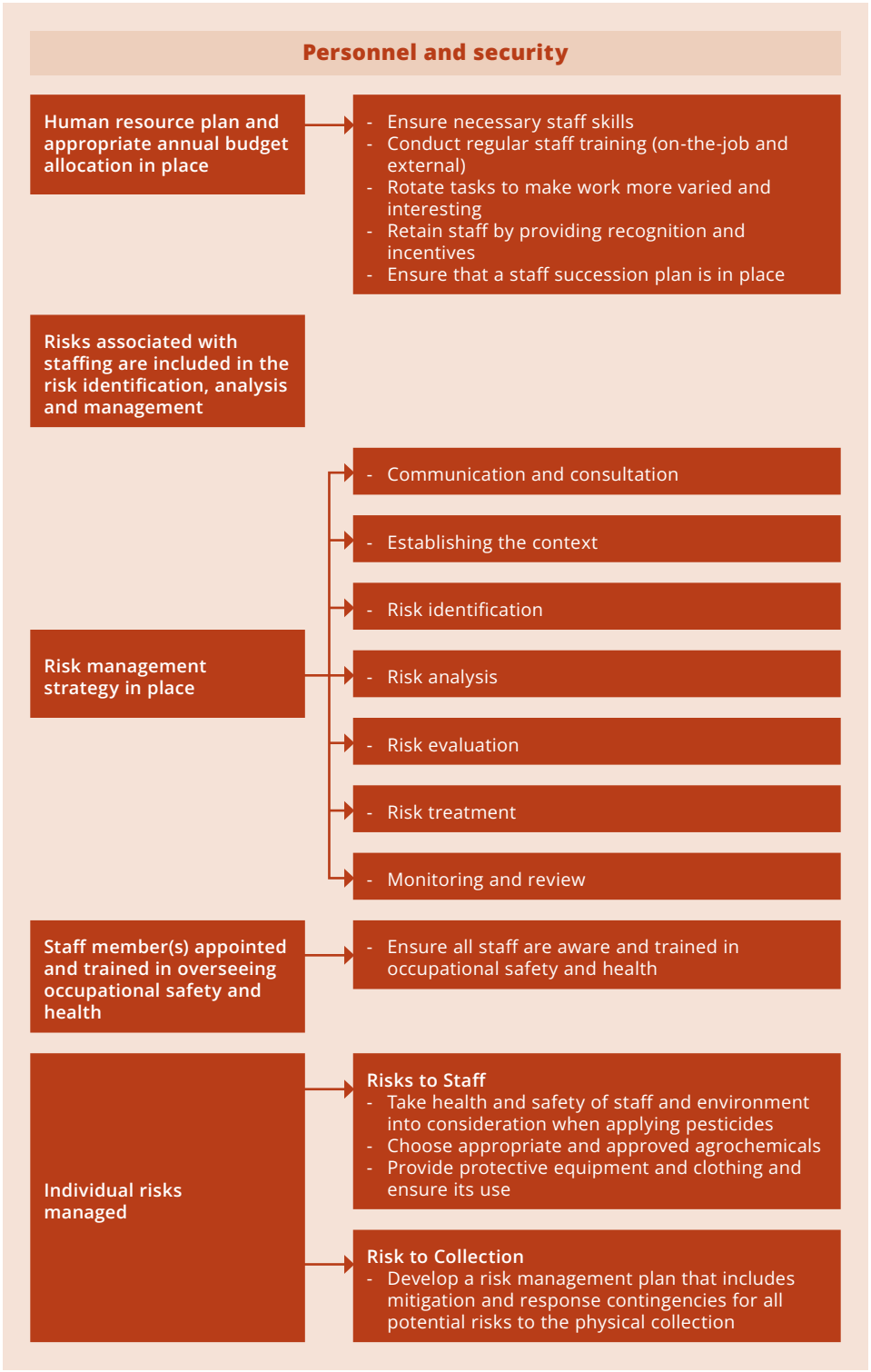
The International Labour Organization (ILO) provides country profiles on OSH (ILO, 2021).

✔ **All staff are aware of OSH requirements and are kept up to date regarding any changes.**

It is recommended that all genebank staff be made aware of the details of the risk management strategy and have a clear understanding of responsibilities for implementing and monitoring the strategy and action plan. Best practices to consider include:

- ensuring that OSH rules are visible in the more risk-prone areas of the genebank;
- instructing staff in the correct and safe use of equipment with regular training provided in health and safety in field, greenhouse and laboratory environments;
- choosing appropriate and nationally approved agrochemicals to reduce risk; and
- providing properly functioning protective equipment and clothing, as required by OSH, and ensuring that they are regularly checked and used as expected. The OSH officer is responsible for the upkeep of safety equipment.

Figure 12. Summary diagram of the workflow and activities for personnel and security



12. Infrastructure and equipment

Seed storage facilities, Indonesia National Genebank

This section considers the suggested infrastructure and equipment for a seed genebank (Table 2). The long-term storage of orthodox seeds is based on reduction in seed moisture content followed by hermetic storage at low temperature. The seed genebank infrastructure is therefore centred around seed drying and storage facilities, together with laboratory, glasshouse, field and office facilities for associated operations such as seed cleaning, viability testing, plant health testing, regeneration, characterization and evaluation, documentation and seed distribution (Table 2).

Factors to be considered when designing or modifying genebank facilities include: (a) the function of the facility (research, medium- and long-term storage); (b) the projected throughput and number, volume and weight of accessions for storage; (c) the expected distribution rates; (d) the local climate (of particular importance in the tropics because of potential contamination issues); and (e) the number of qualified staff.

A useful case study from India calculated the costs of establishing seed genebank facilities, and acquiring, processing, storing (medium- and long-term), monitoring and regenerating germplasm (Singh, Varaprasad and Venkateswaran, 2012). The Millennium Seed Bank's series of technical information sheets provides some helpful background information and specifications for key seed genebank activities and areas (RBG undated). It is important to note that costly facilities are not always required – high-quality, small-scale seed banking can be accomplished with simple desiccation drying techniques and domestic refrigerators/freezers.

Table 2. General infrastructure and equipment recommended for a seed genebank

Genebank operation/management area
General needs
Office space and supplies; computers, printers and accessories; climate data loggers; mobile devices for electronic data recording and barcode readers; access to scientific and technical literature; internet access.
Acquisition
Collecting equipment including cloth and/or paper bags, labels (ideally barcoded), hand lenses, scissors, secateurs, tarpaulins, packaging materials, herbarium presses, simple desiccation drier.
Collecting data sheets or mobile devices for electronic data recording, GPS or altimeter.
Drying and storage
Dry room and associated plant room and/or other appropriate drying facilities, digital humidity monitor or other means of measuring moisture status.
Hermetic containers or tri-laminate foil bags/bag sealer for long-term storage, airtight easily opened containers for medium-term storage, labels (ideally barcoded), balances, seed counter, data sheets or mobile devices for electronic data recording, barcode reader.
Cold room(s) including plant room for refrigeration equipment and shelving system and/or refrigerators, thermostat, low temperature alarm, personnel panic button.
Seed viability monitoring
Germination test facilities including media preparation area, test set-up/scoring area, dissection equipment, microscopes, controlled environment facility (plant growth room, germination chamber(s), incubator(s)), viability test sheets, data sheets or mobile devices for electronic data recording, barcode reader.

Table 2 *(Cont.)*

Genebank operation/management area
Regeneration
Access to field or greenhouse/screenhouse areas, as required.
Isolation tents; overwintering storage for biennial vegetables; fenced area for perennial nurseries.
Pollinator-rearing equipment/incubators as required.
Growth chambers if required for quarantine.
Field/greenhouse/screenhouse equipment and machinery, as necessary, according to species.
Plot stakes and labels (ideally barcode labels), labelled cloth bags or other appropriate containers.
Data sheets or mobile devices for electronic data recording, barcode reader.
Characterization and evaluation
Access to field, lab or glasshouse areas, as required.
Field/lab/greenhouse/screenhouse equipment and machinery, as necessary, according to the species and traits being recorded.
Plot stakes and labels (ideally barcode labels), labelled cloth bags or other appropriate containers.
Molecular analysis (RAPD, ISSR, SSR) equipment, if possible.
Data sheets or mobile devices for electronic data recording, barcode reader.
Documentation
Suitable designed database/genebank information management system aligned to FAO/Bioversity Multi-Crop Passport Descriptors and other data standards, e.g. GRIN-Global.
Database with built-in automated tools for checking seed-lot inventory and viability, and flagging accessions requiring regeneration.
Data backup/storage
Distribution and safety duplication
Balances, seed counter, tri-laminate foil bags, bag sealer, labels (preferably barcoded), packing materials.
Data sheets or mobile devices for electronic data recording, barcode reader.
Security and personnel
Generator(s), fire-extinguishing equipment, security cameras, alarm systems, security doors.
Protective clothing and protective gear such as dust masks, gloves and footwear.

13. References

Alercia, A., Diulgheroff, S. & Mackay, M. 2015. *FAO/Bioversity Multi-Crop Passport Descriptors V.2.1 [MCPD V.2.1]*. Rome, FAO and Bioversity International. 11 p. http://www.bioversityinternational.org/e-library/publications/detail/faobioversity-multi-crop-passport-descriptors-v21-mcpd-v21/

AOSA (Association of Official Seed Analysts). 2021. *Association of Official Seed Analysts*. Wichita, USA. Cited 29 October 2021. https://www.analyzeseeds.com

AVRDC (World Vegetable Center). 2012. *Material Transfer Agreement for Germplasm Accessions*. Shanhua, Taiwan Province of China. Cited 29 October 2021. https://avrdc.org/?wpfb_dl=524

AVRDC. 2021. *Vegetable Genetic Resources Information System*. Shanhua, Taiwan Province of China. Cited 29 October 2021. https://avrdc.org/our-work/managing-germplasm

Bioversity International. 2007. *Guidelines for the development of crop descriptor lists*. Bioversity Technical Bulletin Series. Rome. https://www.bioversityinternational.org/index.php?id=244&tx_news_pi1%5Bnews%5D=1053&cHash=39138c10e405dcf0f918c6670c877b4f

Bioversity International. 2018. *Descriptors*. Rome. Cited 29 October 2021. https://www.bioversityinternational.org/e-library/publications/categories/descriptors/?L=0&cHash=2a5afb80deee509d79ba1b4e1f13e003

CBD (Convention on Biological Diversity). 2018. *Frequently asked questions on access and benefit-sharing (ABS)*. Montreal, Canada. https://www.cbd.int/abs/doc/abs-factsheet-faq-en.pdf

CGIAR Genebank Platform. 2021. *Quality management*. Bonn, Germany. Cited 29 October 2021. https://www.genebanks.org/the-platform/quality-management

Crop Trust. 2021. *Genesys*. Bonn, Germany. Cited 29 October 2021. https://www.genesys-pgr.org

Diederichsen, A. & Raney, J.P. 2008. Pure lining of flax (*Linum usitatissimum* L.) genebank accessions for efficiently exploiting and assessing seed character diversity. *Euphytica*, 164: 255–273. https://doi.org/10.1007/s10681-008-9725-2

Ellis, R.H., Nasehzadeh, M., Hanson, J. & Woldemariam, Y. 2019. Medium-term seed storage of diverse genera of forage grasses, evidence-based genebank monitoring intervals, and regeneration standards. *Genet. Resour. Crop Evol.*, 66: 723–734. https://doi.org/10.1007/s10722-017-0558-5

Embrapa. 2021. *Alelo*. Brasilia. Cited 29 October 2021. http://alelo.cenargen.embrapa.br/alelo_en.html

FAO (Food and Agriculture Organization of the United Nations). 1995. *Annex I List of crops covered under the Multilateral System*. Rome. https://www.fao.org/3/bc084e/bc084e.pdf

FAO. 2014. *Genebank Standards for Plant Genetic Resources for Food and Agriculture*. Rome. http://www.fao.org/3/a-i3704e.pdf

FAO. 2021a. *Digital Object Identifiers (DOI).* Rome. Cited 29 October 2021. http://www.fao.org/plant-treaty/areas-of-work/global-information-system/doi/en

FAO. 2021b. *The Multilateral System*. Rome. Cited 29 October 2021. https://www.fao.org/plant-treaty/areas-of-work/the-multilateral-system/the-smta/en

FAO. 2021c. *Easy-SMTA Homepage*. Rome. Cited 29 October 2021. https://mls.planttreaty.org/itt

FAO. 2021d. *WIEWS - World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture*. Rome. Cited 29 October 2021. https://www.fao.org/wiews/en

FAO. 2021e. *WIEWS:* Ex Situ *(SDG 2.5.1) – Overview.* Rome. Cited 29 October 2021. https://www.fao.org/wiews/data/ex-situ-sdg-251/overvew/en

GBIS/I. 2021. *GBIS - The information system of the German Genebank. Gatersleben.* Cited 29 October 2021. https://www.denbi.de/services/349-gbis-the-information-system-of-the-german-genebank

GRIN-Global. 2021. *The GRIN-Global Project*. Fort Collins, USA. Cited 29 October 2021. https://www.grin-global.org

Guarino, L.G., Rao, L.R. & Reid, V., eds, 1995. *Collecting plant genetic diversity. Technical guidelines*. Wallingford, UK, CAB International. https://www.bioversityinternational.org/e-library/publications/detail/collecting-plant-genetic-diversity/

Hay, F.R. & Whitehouse, K.J. 2017. Rethinking the approach to viability monitoring in seed genebanks. *Conservation Physiology*, 5(1). https://doi.org/10.1093/conphys/cox009

IITA (International Institute of Tropical Agriculture). 2012. *Standard Operation Procedures (SOP) for IITA Seedbank*. Ibadan, Nigeria. https://www.iita.org/wp-content/uploads/2017/SOP_for_IITA_Seedbank.pdf

ILO (International Labour Organization). 2021. *Country profiles on occupational safety and health and labour inspection.* Geneva, Switzerland. Cited 29 October 2021. https://www.ilo.org/global/topics/safety-and-health-at-work/country-profiles/lang--en/index.htm

IPGRI (International Plant Genetic Resources Institute). 2001. *Design and analysis of evaluation trials of genetic resources collections. A guide for genebank managers*. IPGRI Technical Bulletin No. 4. Rome. https://cropgenebank.sgrp.cgiar.org/images/file/learning_space/technicalbulletin4.pdf

IPPC (International Plant Protection Convention). 2021. *List of NPPOs of IPPC Contracting parties* . Rome. Cited 29 October 2021. https://www.ippc.int/en/countries/nppos/list-countries

ISTA (International Seed Testing Association). 2021. *International Seed Testing Association – ISTA*. Wallisellen, Switzerland. Cited 29 October 2021. https://www.seedtest.org/en/home.html

Lehmann, C. & Mansfeld, R. 1957. Zur Technik der Sortimentserhaltung. *Die Kulturpflanze,* 5: 108–138. https://doi.org/10.1007/BF02095492

Nagel, M. & Börner, A. 2010. The longevity of crop seeds stored under ambient conditions. *Seed Science Research*, 20(1): 1–12. https://doi.org/10.1017/S0960258509990213

RBG (Royal Botanic Gardens). undated. *Resources*. Kew, UK. Cited 29 October 2021. https://brahmsonline.kew.org/msbp/Training/Resources

RBG. 2014. *Identifying desiccation sensitive seeds*. Kew, UK. Cited 29 October 2021. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/10-Desiccation-tolerance.pdf

RBG. 2015. *Germination testing: procedures and evaluation*. Technical Information Sheet_13a. Kew, UK. Cited 29 October 2021. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/13a-Germination-testing-procedures.pdf

RBG. 2018. *Seed Information Database (SID). Version 7.1*. Kew, UK. Cited 3 March 2018. http://data.kew.org/sid

Rao, N.K., Hanson, J., Dulloo, M.E., Ghosh, K., Nowell, D. & Larinde, M. 2006. *Handooks for Genebanks No. 8: Manual of seed handling in genebanks*. Rome, Biodiversity International. https://www.bioversityinternational.org/e-library/publications/detail/seed-handling-in-genebanks

SGRP-CGIAR (System-wide Genetic Resources Programme-CGIAR). 2010a. *Crop Genebank Knowledge Base - Seed Bank*. Rome. Cited 29 October 2021. https://cropgenebank.sgrp.cgiar.org/index.php/procedures-mainmenu-242/conservation-mainmenu-198/seed-bank-mainmenu-199

SGRP-CGIAR. 2010b. *Crop Genebank Knowledge Base - Guidelines for testing germination of the most common crop species*. Rome. Cited 29 October 2021. https://cropgenebank.sgrp.cgiar.org/images/file/procedures/guidelines%20for%20testing%20germination%20of%20the%20most%20common%20crop%20species.pdf

SGRP-CGIAR. 2010c. *Crop Genebank Knowledge Base - Regeneration*. Rome. Cited 29 October 2021. https://cropgenebank.sgrp.cgiar.org/index.php/procedures-mainmenu-242/regeneration-mainmenu-206

SGRP-CGIAR. 2010d. *Crop Genebank Knowledge Base - Risk management*. Rome. Cited 29 October 2021. https://cropgenebank.sgrp.cgiar.org/index.php/management-mainmenu-433/risk-management-mainmenu-236

SGRP-CGIAR. 2011. *Crop Genebank Knowledge Base - Collecting plant genetic diversity: Technical guidelines. 2011 update* online]. Rome. Cited 29 October 2021. https://cropgenebank.sgrp.cgiar.org/index.php?option=com_content&view=article&id=390&Itemid=557

Singh, A.K., Varaprasad, K.S. & Venkateswaran, K. 2012. Conservation costs of plant genetic resources for food and agriculture: seed genebanks. *Agricultural Research*, 1(3): 223–239. https://doi.org/10.1007/s40003-012-0029-3

United Nations. 2021. *SDG Indicators*. New York, USA. Cited 29 October 2021. https://unstats.un.org/sdgs/metadata?Text=&Goal=2&Target=2.5

UPOV (International Union for the Protection of New Varieties of Plants). 2011. *Descriptor lists*. Geneva, Switzerland. Cited 29 October 2021. https://www.upov.int/tools/en/gsearch.html?cx=016458537594905406506%3Asa0ovkspdxw&cof=FORID%3A11&q=descriptor

USDA-ARS (United States Department of Agriculture-Agricultural Research Service). 2021. *U.S. National Plant Germplasm System – Descriptors*. Fort Collins, USA. Cited 29 October 2021. https://npgsweb.ars-grin.gov/gringlobal/descriptors

Way, M. 2003. Collecting seed from non-domesticated plants for long-term conservation. *In* R.D. Smith, J.D. Dickie, S.H. Linington, H.W. Pritchard & R.J. Probert, eds. *Seed conservation: turning science into practice*, pp. 163–201. Kew, UK, Royal Botanic Gardens.

14. Further information/reading

The list of references below provides guidance and/or technical background on genebank operations and management. Additional references can be found in the *Genebank Standards for Plant Genetic Resources for Food and Agriculture* (FAO, 2014).

General

Ellis, R.H., Hong, T.D. & Roberts, E.H. 1985. *Handbook of seed technology for genebanks*. Rome, IBPGR. https://www.bioversityinternational.org/e-library/publications/detail/handbook-of-seed-technology-for-genebanks-1

Engels, J.M.M. & Visser, L., eds. 2003. *A guide to effective management of germplasm collections*. *IPGRI handbooks for genebanks No.* 6. Rome, IPGRI. 165 p. https://www.bioversityinternational.org/e-library/publications/detail/a-guide-to-effective-management-of-germplasm-collections

Greene, S.L., Williams, K.A., Khoury, C.K., Kantar, M.B. & Marek, L.F. 2018. *North American crop wild relatives, Volume 1*. Cham, Germany, Springer. https://doi.org/10.1007/978-3-319-95101-0

International Treaty on Plant Genetic Resources for Food and Agriculture. 2021. *International Treaty on Plant Genetic Resources for Food and Agriculture Organization of the United Nations*. Rome. Cited 2 November 2021. http://www.fao.org/plant-treaty/en

IPK (Leibniz Institute). undated. *Mansfeld's World Database of Agriculture and Horticultural Crops*. Gatersleben, Germany. Cited 2 November 2021. http://mansfeld.ipk-gatersleben.de/apex/f?p=185:3

Upadhyaya, H.D. & Gowda, C.L. 2009. *Managing and Enhancing the Use of Germplasm – Strategies and Methodologies*. Technical Manual No. 10. Patancheru, India, International Crops Research Institute for the Semi-Arid Tropics. 236 p.

Wiersema, J.H. & Schori, M. 1994. *Taxonomic information on cultivated plants in GRIN-Global*. https://npgsweb.ars-grin.gov/gringlobal/taxon/abouttaxonomy.aspx

Acquisition and distribution

Bioversity International. 2009. *Descriptors for farmers' knowledge of plants*. Rome. https://cgspace.cgiar.org/handle/10568/74492

ENSCONET. 2009. *Seed collecting manual for wild species*. http://www.plants2020.net/document/0183

Eymann, J., Degreef, J., HŠuser, C., Monje, J.C., Samyn, Y. & VandenSpiegel, D., eds. 2010. *Manual on field recording techniques and protocols for all taxa biodiversity inventories and monitoring*. *Abc Taxa*, 8: 331–653. http://www.abctaxa.be/volumes/volume-8-manual-atbi

Greiber, T., Peña Moreno, S., Ahrén, M., Nieto Carrasco, J., Kamau, E.C., Cabrera Medaglia, J., Oliva, M.J., & Perron-Welch, F. (in cooperation with Ali, N. & Williams, C.). 2012. *An Explanatory Guide to the Nagoya Protocol on Access and Benefit-sharing*. Gland, Switzerland. IUCN. xviii + 372 p. https://cmsdata.iucn.org/downloads/an_explanatory_guide_to_the_nagoya_protocol.pdf

Hay, F.R. & Probert, R.J. 2011. *Collecting and handling seeds in the field*. In: L, Guarino, V. Ramanatha Rao & E. Goldberg, eds. *Collecting plant genetic diversity: Technical guidelines* – 2011 update. Rome, Bioversity International. https://cropgenebank.sgrp.cgiar.org/index.php?option=com_content&view=article&id=655

Lopez, F. 2015. *Digital Object Identifiers (DOIs) in the context of the International Treaty*. http://www.fao.org/fileadmin/templates/agns/WGS/10_FAO_gs_activities_ITPGRFA_20151207.pdf

Mathur, S.B. & Kongsdal, O. 2003. *Common laboratory seed health testing methods for detecting fungi*. Bassersdorf, Switzerland, International Seed Testing Association.

Maya-Lastra, C.A. 2016. ColectoR, a digital field notebook for voucher specimen collection for smartphones. *Applications in Plant Sciences*, 4(7). https://doi.org/10.3732/apps.1600035

Moore, G. & Williams, K.A. 2011. Legal issues in plant germplasm collecting. In: L. Guarino, V. Ramanatha Rao & E. Goldberg, eds. *Collecting plant genetic diversity: Technical guidelines* – 2011 update. Rome, Bioversity International. https://cropgenebank.sgrp.cgiar.org/index.php?option=com_content&view=article&id=669

Ni, K.J. 2009. Legal aspects of prior informed consent on access to genetic resources: An analysis of global law-making and local implementation toward an optimal normative construction. *Vanderbilt Journal of Transnational Law*, 42: 227–278.

RBG (Royal Botanic Gardens). 2014. *Assessing a population for seed collection.* Millennium Seed Bank technical information sheet 02. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/02-Assessing-population.pdf

RBG. 2014. *Seed collecting techniques*. Millennium Seed Bank technical information sheet 03. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/03-Collecting-techniques.pdf

RBG. 2014. *Post harvest handling*. Millennium Seed Bank technical information sheet 04. Kew, UK. http://www.anayglorious.in/sites/default/files/04-Post%20harvest%20handling%20web_0.pdf

Smith, R.D., Dickie, J.B., Linington, S.H., Pritchard, H.W. & Probert, R.J., eds. 2003. *Seed conservation: turning science into practice*. Kew, UK, Royal Botanic Gardens

Sheppard, J.W. & Cockerell, V. 1996. *ISTA handbook of method validation for the detection of seedborne pathogens*. Basserdorf, Switzerland, International Seed Testing Association.

Way, M. 2011. *Collecting and recording data in the field: media for data recording*. In: L. Guarino, V. Ramanatha Rao & E. Goldberg, eds. *Collecting plant genetic diversity: technical guidelines – 2011 update*. Rome, Bioversity International. https://cropgenebank.sgrp.cgiar.org/index.php?option=com_content&view=article&id=659

Drying and storage

Ellis, R.H. 1991. The Longevity of Seeds. *HortScience*, 26: 1119–1125.

Ellis, R.H. & Hong, T.D. 2006. Temperature sensitivity of the low-moisture-content limit to negative seed longevity–moisture content relationships in hermetic storage. *Annals of Botany*, 97(5): 785–791. https://doi.org/10.1093/aob/mcl035

Ellis, R.H. & Hong, T.D. 2007. Quantitative response of the longevity of seed of twelve crops to temperature and moisture in hermetic storage. *Seed Science and Technology,* 35: 432–444. https://doi.org/10.15258/sst.2007.35.2.18

Ellis, R.H., Hong, T.D. & Roberts, E.H. 1985. Sequential germination test plans and summary of preferred germination test procedures. *Handbook of seed technology for genebanks*. *Vol I: Principles and methodology*. Chapter 15, pp. 179–206. Rome, International Board for Plant Genetic Resources. https://www.bioversityinternational.org/fileadmin/user_upload/online_library/publications/pdfs/52.pdf

Pérez-García, F., Gómez-Campo, C. & Ellis, R.H. 2009. Successful long-term ultra-dry storage of seed of 15 species of *Brassicaceae* in a genebank: variation in ability to germinate over 40 years and dormancy. *Seed Science and Technology*, 37(3): 640–649. https://doi.org/10.15258/sst.2009.37.3.12

RBG. 2014. *Selecting containers for long-term seed storage*. Millennium Seed Bank technical information sheet 06. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/06-Containers.pdf

RBG. 2014. *Low cost moisture monitors*. Millennium Seed Bank technical information sheet 07.Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/07-Low-cost-moisture-monitors.pdf

RBG. 2014. *Small-scale drying methods*. Millennium Seed Bank technical information sheet 08. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/08-Small-scale-drying-methods.pdf

Whitehouse, K.J., Hay, F.R. & Ellis, R.H. 2015. Increases in the longevity of desiccation-phase developing rice seeds: response to high-temperature drying depends on harvest moisture content. *Annals of Botany*, 116(2): 247–259. https://doi.org/10.1093/aob/mcv091

Viability monitoring

AOSA (Association of Official Seed Analysts). 2016. *AOSA Rules for Testing Seeds. Volume1 Principles and Procedures*. http://www.agriculture.ks.gov/docs/default-source/public-comment-on-proposed-regulations/docs-adopted-for-kar-4-2-8/volume-1---aosa-rules-for-testing-seeds.pdf?sfvrsn=4

AOSA & SCST (Society of Commercial Seed Technologists). undated. *Test Methods for Species without Rules*. https://www.analyzeseeds.com/test-methods-for-species-without-rules

Ellis, R.H., Nasehzadeh, M., Hanson, J. & Woldemariam, Y. 2017. Medium-term seed storage of 50 genera of forage legumes and evidence-based genebank monitoring intervals. *Genetic Resources and Crop Evolution*, 65: 607–623. https://doi.org/10.1007/s10722-017-0558-5

ENSCONET. 2009. *ENSCONET Curation Protocols and Recommendations*. http://ensconet.maich.gr/PDF/Curation_protocol_English.pdf

ENSCONET. 2009. *ENSCONET Germination Recommendations UPDATED*. http://ensconet.maich.gr/PDF/Germination_recommendations_English.pdf

Hay, F.R., Mead A., Manger, K. & Wilson F.J. 2003. One-step analysis of seed storage data and the longevity of *Arabidopsis thaliana* seeds. *Journal of Experimental Botany,* 54(384): 993–1011. https://doi.org/10.1093/jxb/erg103

Hay, F.R. & Probert, R.J. 2013. Advances in seed conservation of wild plant species: a review of recent research. *Conservation Physiology*, 1(1). https://doi.org/10.1093/conphys/cot030

Hay, F.R. & Whitehouse, K.J. 2017. Rethinking the approach to viability monitoring in seed genebanks. *Conservation Physiology*, 5(1). https://doi.org/10.1093/conphys/cox009

ISTA (International Seed Testing Association). 2018. *International Rules for Seed Testing 2018*. Basserdorf, Switzerland. https://www.seedtest.org/en/international-rules-_content---1--1083.html

Nagel, M., Rehman Arif, M.A., Rosenhauer, M. & Börner, A. 2010. *Longevity of seeds – intraspecific differences in the Gatersleben genebank collections*. Tagungsband der 60. Jahrestagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs 2009, pp. 179–181. http://www.ecpgr.cgiar.org/fileadmin/templates/ecpgr.org/upload/NW_and_WG_UPLOADS/Wheat_Misc/GUMP_NAGEL_2010.pdf

Mondoni, A., Probert, R.J., Rossi, G., Vegini, E. & Hay, F.R. 2011. Seeds of alpine plants are short lived: implications for long-term conservation. *Annals of Botany*, 107(1): 171–179. https://doi.org/10.1093/aob/mcq222

Probert, R.J., Daws, M.I. & Hay, F.R. 2009. Ecological correlates of *ex situ* seed longevity: a comparative study on 195 species. *Annals of Botany*, 104(1): 57–69. https://doi.org/10.1093/aob/mcp082

RBG. undated. *Seed Information Database: Seed Viability.* Kew, UK. Cited 4 November 2021. http://data.kew.org/sid/viability

Santos, L.G. 2017. *Sequential sampling for seed viability testing at CIAT's genebank*. Paper presented 23 May 2017, Addis Ababa. https://cgspace.cgiar.org/bitstream/handle/10568/89648/SEEDS_SEQUENTIAL_SAMPLING_ETHIOPIA_May-22-2017.pdf?sequence=1

Walters, C., Wheeler, L.M. & Grotenhuis, J.M. 2005. Longevity of seeds stored in a genebank: species characteristics. *Seed Science Research*, 15(1): 1–20. https://doi.org/10.1079/SSR2004195

Regeneration

Ahuja, M.R. & Jain, S.M. 2015. *Genetic diversity and erosion in plants: indicators and prevention*. New York, USA,. Springer. 327 p.

Breese, E.L. 1989. *Regeneration and multiplication of germplasm resources in seed genebanks: the scientific background*. Rome, International Board for Plant Genetic Resources. http://www.bioversityinternational.org/fileadmin/bioversity/publications/Web_version/209/begin.htm

Crossa, J. 1995. Sample size and effective population size in seed regeneration of monecious species. *In* J.M.M. Engels & R. Rao, eds. *Regeneration of seed crops and their wild relatives*, pp. 140–143. Proceedings of a consultation meeting, 4–7 December 1995. Hyderabad, India, ICRISAT, and Rome, IPGRI. https://cropgenebank.sgrp.cgiar.org/images/file/learning_space/regeneration_seed_crops.pdf

Crossa, J. & Vencovsky, R. 2011. Basic sampling strategies: theory and practice. In: L. Guarino, V. Ramanatha Rao & E. Goldberg, eds. *Collecting plant genetic diversity: technical* guidelines – 2011 *update*. Rome, Bioversity International. ISBN 978- 92-9043- 922- 926. https://cropgenebank.sgrp.cgiar.org/images/file/procedures/collecting2011/Chapter5-2011.pdf

Dulloo, M.E., Hanson, J., Jorge, M.A. & Thormann, I. 2008. *Regeneration guidelines: General guiding principles*. Rome, Bioversity International. https://cropgenebank.sgrp.cgiar.org/images/file/other_crops/Introduction_ENG.pdf

Engels, J.M.M. & Rao, R., eds. 1995. *Regeneration of seed crops and their wild relatives*, pp. 140–143. Proceedings of a consultation meeting, 4–7 December 1995. Hyderabad, India, ICRISAT, and Rome, IPGRI.

Jorge, M.A. 2009. *Introduction to guidelines on regeneration of accessions in genebanks*. Paper presented at International Course on Plant Genetic Resources and Genebank Management, 2009, Suwon, Korea. https://cropgenebank.sgrp.cgiar.org/images/file/learning_space/korea_workshop/lecture1and2/Lecture%202%20-%20regeneration%20guidelines.pdf

Sackville Hamilton, N.R & Chorlton, K.H. 1997. *Regeneration of accessions in seed collections: A decision guide*. Handbook for Genebanks No. 5. Rome, IPGRI. https://www.bioversityinternational.org/e-library/publications/detail/regeneration-of-accessions-in-seed-collections

Characterization and evaluation

Alercia, A. 2011. *Key characterization and evaluation descriptors: methodologies for the assessment of 22 crops*. Rome, Bioversity International. 602 p. https://cgspace.cgiar.org/handle/10568/744910

FAO. 2011. *Pre-breeding for effective use of plant genetic resources*. Rome. http://www.fao.org/elearning/#/elc/en/course/PB

Thormann, I., Parra-Quijano, M., Endresen, D.T.F., Rubio-Teso, M.L., Iriondo, M.J. & Maxted, N. 2014. *Predictive characterization of crop wild relatives and landraces Technical guidelines version 1.* Rome, Bioversity International. https://www.bioversityinternational.org/fileadmin/user_upload/online_library/publications/pdfs/Predictive_characterization_guidelines_1840.pdf

Thormann, I. 2015. *Predictive characterization: an introduction*. Paper presented at Regional Training Workshop, 13 April 2015, Pretoria, South Africa. http://www.cropwildrelatives.org/fileadmin/templates/cropwildrelatives.org/upload/sadc/project_meetings/Lectures_Predictive_characterization_pre-breeding/Introduction_Predictive_Characaterization_Thormann.pdf

Molecular characterization and evaluation

Arif, I.A., Bakir, M.A., Khan, H.A., Al Farhan, A.H., Al Homaidan, A.A., Bahkali, A.H., Sadoon, M.A. & Shobrak, M. 2010. A brief review of molecular techniques to assess plant diversity. *International Journal of Molecular Sciences*, 11(5): 2079–2096. https://doi.org/10.3390/ijms11052079

Ayad, W.G., Hodgkin, T., Jaradat, A. & Rao, V.R. 1997. *Molecular genetic techniques for plant genetic resources*. Report on an IPGRI workshop, 9–11 October 1995, Rome, IPGRI, 137 p. http://www.bioversityinternational.org/fileadmin/bioversity/publications/Web_version/675/begin.htm

Bretting, P.K. & Widrlechner, M.P. 1995. Genetic markers and plant genetic resource management. *Plant Breeding Reviews*, 13: 11–86. https://doi.org/10.1002/9780470650059.ch2

D'Agostino, N. & Tripodi, P. 2017. NGS-based genotyping, high-throughput phenotyping and genome-wide association studies laid the foundations for next-generation breeding in horticultural crops. *Diversity*, 9(3): 38. https://doi.org/10.3390/d9030038

de Vicente, M.C. & Fulton, T. 2004. *Using molecular marker technology in studies on plant genetic diversity*. Rome, IPGRI, and Ithaca, USA, Institute for Genetic Diversity. https://www.bioversityinternational.org/fileadmin/user_upload/online_library/publications/pdfs/Molecular_Markers_Volume_1_en.pdf

de Vicente, M.C., Metz, T. & Alercia, A. 2004. *Descriptors for genetic markers technologies*. https://www.bioversityinternational.org/e-library/publications/detail/descriptors-for-genetic-markers-technologies

Govindaraj, M., Vetriventhan, M. & Srinivasan, M. 2015. Importance of genetic diversity assessment in crop plants and its recent advances: an overview of its analytical perspectives. *Genetics Research International*. https://www.hindawi.com/journals/gri/2015/431487

Jia, J., Li, H., Zhang, X., Li, Z. & Qiu, L. 2017. Genomics-based plant germplasm research (GPGR). *The Crop Journal*, 5(2): 166–174. https://doi.org/10.1016/j.cj.2016.10.006

Jiang, G.-L. 2013. Molecular markers and marker-assisted breeding in plants. In: S.B. Andersen. *Plant breeding from laboratories to fields*. IntechOpen, Denmark. https://doi.org/10.5772/52583

Karp, A., Kresovich, S., Bhat, K.V., Ayad, W.G. & Hodgkin, T. 1997. *Molecular tools in plant genetic resources conservation: a guide to the technologies*. IPGRI Technical Bulletin No. 2. Rome, IPGRI.

Keilwagen, J., Kilian, B., Özkan, H., Babben, S., Perovic, D., Mayer, K.F.X., Walther, A. *et al.,* 2014. Separating the wheat from the chaff – a strategy to utilize plant genetic resources from *ex situ* genebanks. *Scientific Reports*, 4: 5231. https://doi.org/10.1038/srep05231

Kilian, B. & Graner, A. 2012. NGS technologies for analyzing germplasm diversity in genebanks. *Briefings in Functional Genomics*, 11(1): 38–50. https://doi.org/10.1093/bfgp/elr046

Laucou, V., Lacombe, T., Dechesne, F., Siret, R., Bruno, J.P., Dessup, M., Dessup, P. *et al.* 2011. High throughput analysis of grape genetic diversity as a tool for germplasm collection management. *Theoretical and Applied Genetics*, 122(6): 1233–1245. https://doi.org/10.1007/s00122-010-1527-y

Mishra, K.K., Fougat, R.S., Ballani, A., Thakur, V., Jha, Y. & Madhumati, B. 2014. Potential and application of molecular markers techniques for plant genome analysis. *International Journal of Pure & Applied Bioscience*, 2(1): 169–188. http://www.ijpab.com/form/2014%20Volume%202,%20issue%201/IJPAB-2014-2-1-169-188.pdf

van Treuren, R. & van Hintum, T. 2014. Next-generation genebanking: plant genetic resources management and utilization in the sequencing era. *Plant Genetic Resources*, 12(3): 298–307. https://doi.org/10.1017/S1479262114000082

Documentation

Ougham, H. & Thomas, I.D. 2013. Germplasm databases and informatics. In: M. Jackson, B., Ford-Lloyd & M. Parry, eds. *Plant genetic resources and climate change*, pp.151–165. Wallingford, UK, CAB International.

Painting, K.A, Perry, M.C, Denning, R.A. & Ayad, W.G. 1993. *Guidebook for genetic resources documentation*. Rome, IPGRI. https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Guidebook_for_genetic_resources_documentation_432.pdf

Safety duplication

Nordgen. 2008. *Agreement between (depositor) and the Royal Norwegian Ministry of Agriculture and Food concerning the deposit of seeds in the Svalbard Global Seed Vault.* The Svalbard Global Seed Vault. https://seedvault.nordgen.org/common/SGSV_Deposit_Agreement.pdf

Infrastructure and equipment

Bretting P.K. 2018. 2017 Frank Meyer Medal for Plant Genetic Resources Lecture: Stewards of Our Agricultural Future. *Crop Science,* 58(6): 2233–2240. https://doi.org/10.2135/cropsci2018.05.0334

Fu, Y.-B. 2017. The vulnerability of plant genetic resources conserved *ex situ*. *Crop Science*, 57(5): 2314. https://doi.org/10.2135/cropsci2017.01.0014

Linington, S.H. 2003. The design of seed banks. In: R.D. Smith, J.B. Dickie, S.H. Linington, H.W. Pritchard & R.J. Probert, eds. *Seed conservation: turning science into practice*. Kew, UK, Royal Botanic Gardens.

RBG.2014. *Post-harvest handling*. Millennium seed bank technical information sheet 04. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/04-Post-harvest-handling.pdf

RBG. 2014. *Measuring seed moisture status using a hygrometer*. Millennium seed bank technical information sheet 05. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/05-eRH-moisture-measurement.pdf

RBG. 2014. *Selecting containers for long-term seed storage*. Millennium seed bank technical information sheet 06. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/05-eRH-moisture-measurement.pdf

RBG. 2014. *Low-cost monitors of seed moisture status*. Millennium seed bank technical information sheet 07. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/07-Low-cost-moisture-monitors.pdf

RBG. 2014. *Small-scale seed drying methods*. Millennium seed bank technical information sheet 08. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/08-Small-scale-drying-methods.pdf

RBG. 2014. *Seed bank design: seed drying rooms*. Millennium seed bank technical information sheet 11. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/11-Seed-drying-room-design.pdf

RBG. 2014. *Seed bank design: cold rooms for seed storage*. Millennium seed bank technical information sheet 12. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/12-Cold-room-design.pdf

RBG. 2015. *Germination testing: procedures and evaluation*. Millennium seed bank technical information sheet_13a. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/13a-Germination-testing-procedures.pdf

RBG. 2015. *Germination testing: environmental factors and dormancy-breaking treatments*. Millennium seed bank technical information sheet_13b. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/13b-Germination-testing-dormancy.pdf

RBG. 2014. *Cleaning seed collections for long-term conservation*. Millennium seed bank technical information sheet 14. Kew, UK. http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/14-Seed-cleaning.pdf

Annex: Risks and associated mitigation

It is important that staff are properly trained and follow documented procedures at all stages of genebank operations. Specific risks to be considered during genebank operations are presented below.

Acquisition

Risk	Risk control/mitigation
Diversity of the source population is not adequately represented in the collected sample	Develop and follow an agreed collecting strategy and methodology that adequately follow genetic sampling guidelines
Taxonomic misidentification	■ Include a taxonomist in the collecting team and have genebank staff trained in taxonomy ■ Take herbarium vouchers and photos for verification by experts ■ Ensure that data-collection sheets include other descriptors to be recorded during the collecting mission
Mislabelling/loss of labels	■ Firmly attach one label to the outside of each collecting bag; place another label inside the collecting bag
Transcription errors	■ Consider the use of mobile devices, ensuring regular data backup and availability of sufficient charged batteries ■ Implement data validation
Loss of viability during collecting missions/transport leading to reduced seed longevity (and earlier regeneration)	■ Ensure timely transfer to controlled drying conditions ■ Ensure appropriate post-harvest handling according to the maturity of the seeds and the prevailing environmental conditions

Drying and storage

Risk	Risk control/mitigation
Reduced seed longevity due to moisture uptake during packing	■ Pack seeds in a controlled, dry environment
Reduced seed longevity and earlier regeneration due to container leakage	■ Leak-test every new batch of packaging material. ■ Ensure the sealing machine is working properly ■ Ensure screw caps are adequately tightened ■ Set up a monitoring system to periodically measure the moisture content of randomly selected samples from the genebank and of any accessions removed for testing or distribution
Mixing/mislabelling of samples	■ Pack carefully to avoid mixing ■ Place labels inside and outside of packets ■ Use computer-generated barcode labels to minimize errors
Stored samples fall below viability or quantity thresholds	■ Ensure that the documentation system includes automated tools for monitoring seed-lot viability and inventory and flag accessions requiring regeneration
Inadequate storage temperature due to power failure	■ Ensure backup generators and fuel are available

Seed viability monitoring

Risk	Risk control/mitigation
True viability of accessions is not reflected during germination testing	■ Optimize germination testing and dormancy breaking methods. ■ Use replicated testing procedures ■ Carry out cut tests to identify seeds that are still firm/fresh to estimate the viability of dormant accessions ■ Outsource germination testing if necessary
Inappropriate viability testing intervals result in depletion of seeds or significant fall in viability	■ Use all available viability-monitoring data (for example, germination rate, and number of abnormal seedlings) for the accession and collection to set appropriate monitoring intervals. ■ Consider shortening the monitoring intervals when seed lots are known/predicted to be approaching the viability threshold.

Regeneration

Risk	Risk control/mitigation
Loss of adaptive alleles due to selection pressures	■ Regenerate under controlled environmental conditions ■ Regenerate at a site with a similar climate to that of the collection site where the material originated ■ Outsource regeneration
Loss of purity due to cross-pollination from other accessions of the same species or from nearby crops	■ Follow recommended crop-specific isolation distances or use isolation cages, bagging or other pollination-control measures
Poor levels of pollination	■ Use pollination cages to enclose insect pollinators ■ Ensure adequate availability of insect pollinators ■ Hand pollinate as required/possible
Misidentification of samples	■ Check plot and bag labels prior to sowing and harvesting; use barcodes
Loss of purity due to contamination/mixing of seed samples during seed preparation, sowing, harvesting and post-harvest handling	■ Carefully inspect and clean all machinery between each processing step ■ Compare harvested material against reference material for the regenerated accessions

Characterization and evaluation

Risk	Risk control/mitigation
Poorly recorded, unreliable data	■ Train staff well ■ Use appropriate cultural practices ■ Use mobile devices to record field data ■ Ensure data validation by curator and/or documentation officer
Misidentification of samples	■ Check plot labels while collecting data ■ Check plot and bag labels prior to sowing and harvesting

Distribution

Risk	Risk control/mitigation
Mixing/mislabelling of samples	■ Pack carefully to avoid mixing ■ Use labels on the inside and the outside of seed packets ■ Use computer-generated barcode labels to minimize errors
Viability loss due to delayed or damaged shipments	■ Pack seeds in suitable packaging to minimize uptake of moisture. ■ Ensure seeds are dispatched promptly, and use the fastest and safest way of sending them.

Safety duplication

Risk	Risk control/mitigation
Mixing/mislabelling of samples	■ Packing carefully to avoid mixing ■ Use labels used on the inside and the outside of seed packets ■ Use computer-generated barcode labels to minimize errors
Viability loss due to delayed or damaged shipments	■ Ensure seeds are dispatched promptly and use the fastest and safest way of sending them. ■ Assess the likelihood of significant decline in viability based on a worst-case scenario of conditions during transport (in particular temperature if the seeds are in air-tight moisture-proof packets). ■ Include viability monitoring samples and agree on whether these will be tested by the recipient or returned to the sending institution

FAO has developed the *Practical guide for the application of the Genebank Standards for Plant Genetic Resources for Food and Agriculture: Conservation of orthodox seeds in seed genebanks* to be used as a companion volume to the *Genebank Standards for Plant Genetic Resources for Food and Agriculture*. The action steps of the genebank workflow are presented in a sequential manner and provide guidance on the complex steps and decisions required when operating a seed genebank. The accompanying summary charts for the respective action steps underscore the intended use of this practical guide as a handbook for routine genebank operations for the conservation of orthodox seeds. While this practical guide is particularly useful for genebank technicians for their day-to-day activities, it may also be used as a basis for the development of standard operating procedures and quality management systems. Genebank managers will also find it useful for conducting training exercises.

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