Plant Genetic Resources Research Institute (CSIR-PGRRI) Genebank Review 2020	
Genebank reviewed	CSIR-Plant Genetic Resources Research Institute of Ghana
Site visit dates	October 3 - 8, 2019
Review report date	28 April 2020
Institution and Crop Trust responses	
Place	Bunso, Ghana
Genebank manager	Lawrence Aboagye
Review panel	Paula Bramel Simon Linington Bonny Ntare Milko Škofič
Crop Trust staff	Nora Castañeda

Nr.	Reviewers recommendation	Timeframe	Responses
1	Given the importance of crop genetic resource conservation to CSIR, CSIR-PGRRI, and the Crop Trust, we recommend that CSIR modify their performance contract with CSIR-PGRRI to adopt strict performance indicators that align with those in use by the Crop Trust to strengthen the value given for long-term conservation and use of the collection.	2020 - 2021	CSIR-PGRRI: Agreed but not entirely. In the CSIR the elements of the performance contract include publications, attraction of funding and administrative experience, which are linked to promotion. Going forward, core staff engaged for genebank activities will be placed in the Technologist category with different promotion and assessment criteria that reflect what is used by the Crop Trust. To facilitate this process, the CSIR-PGRRI is requesting a copy of the performance indicators used by Crop Trust for its attention. Crop Trust: The Crop Trust agrees with this recommendation and understands that CSIR-PGRRI uses a set of indicators to assess staff performance. It is of critical importance that CSIR-PGRRI's performance, as an institution, considers indicators that adequately reflect the role of the genebank in the long-term conservation and sustainable use of plant genetic resources. The genebank performance indicators used by the Crop Trust will be shared to prepare CSIR-PGRRI's workplan.
2	We recommend that the CSIR-PGRRI asset management be audited for compliance and internal controls. In the meantime,	2020 - 2024	CSIR-PGRRI: Agreed. An assets register is in place at the institute. Inventory is carried out on all assets at the end of every year. In

	clear terms need to be specified in the Seeds for Resilience (S4R) project contract on management of assets procured, maintained, or repaired by project.		the case of the Crop Trust, equipment procured, maintained or repaired by the project will be labeled accordingly and entered together with maintenance records, in an asset register to be created for the project, for easy reference as much as possible. Crop Trust: The Crop Trust agrees with this recommendation and the response.
3	We recommend that CSIR urgently addresses the need to allocate funds to fully cover the cost of electricity for the key conservation facilities used within CSIR-PGRRI, either through a government waiver or subsidy, in recognition of the national importance of conserving these genetic resources for the long-term.	2020	CSIR-PGRRI: Agreed. Some strategic laboratories, including three at the CSIR-PGRRI, have been identified within the entire CSIR for consideration for a government electricity tariff waiver and discussions on this are far advanced at the Ministerial level. Crop Trust: The Crop Trust agrees with this recommendation and the urgency to address it. It is not clear from your response whether the genebank is included for consideration for the waiver. If Crop Trust can assist in this process please inform us. Otherwise we look forward to updates on the status of the government electricity tariff waiver and its final approval at the Ministerial level.
4	We recommend that a long-term strategic business plan be developed by CSIR for the sustainable operation of CSIR-PGRRI and if the upgrade is funded and completed, a costing study of routine operations be done to help secure adequate annual funds for the conservation and use of the collections.	Q1 2023	CSIR-PGRRI: Agreed. A strategic plan and a business plan were developed in the past and these will be reviewed and PGR activities costed. Crop Trust: The Crop Trust agrees with this recommendation. To reach a steady state of operation, it will be important to have well-established processes and to clear all backlogs.
5	We recommend that CSIR-PGRRI invest in enhancing staff capacity for the long term through: ● On site capacity building by experts to train staff and upgrade key processes ● Exchange visits with ICRISAT, IITA, ILRI, etc. to build capacity for specific processes ● Staff succession planning to address the potential loss of key long-term staff with key knowledge of the collection or seedbank management.	2020 - 2023	CSIR-PGRRI: Agreed. Continuous staff development is key in running the institute. Capacity building will be agreed in collaboration with development partners and the CGIAR centers. This will also be a key objective in every proposal submitted for funding by the institute. Training will be undertaken either locally or elsewhere through higher degree and short tailor-made courses in plant genetic resources management in some cases, seasoned PGR experts within the CSIR will be engaged to mentor young and early-career scientists. Crop Trust: The Crop Trust supports this recommendation. Training on specific technical aspects of germplasm collection

			management is needed to upgrade the operations of CSIR-PGRRI. Given restricted resources, the project would prioritize on site capacity building with experts and exchange stays at international genebanks, over training programs that require longer time, such as high degree courses. A mentoring program may contribute to strengthen the existing technical capacity of the genebank. High-level support from CSIR and CSIR-PGRRI management will be required to encourage staff participation and to enable potential changes in processes and institutional culture. Working in a QMS framework will provide support to CSIR-PGRRI on staff succession planning.
6	CSIR-PGRRI should update the accession inventory to accurately reflect the current composition of the collection; indicate active or historical status and MLS status of all accession; and add all available passport and characterization data. This updated accession level information should be shared with users using the CSIR website and Genesys.	2020 - 2021	CSIR-PGRRI: Agreed. Action will be taken on the recommendation. Passport and some characterization data on accessions have been digitized. Data will be updated as and when received and data will be shared with stakeholders. Crop Trust: The Crop Trust agrees with this recommendation. We encourage CSIR-PGRRI to maintain an accurate inventory of its collection as a basis for effective management, collaboration and making accessions available. This inventory should distinguish existing material from historical material (e.g. collected in the past, but no longer available, for whatever reason). The inventory should thereafter be kept up to date, as well as relevant information published on Genesys. The Crop Trust encourages CSIR-PGRRI to update the notification letter of material available in the MLS and submit it to the ITPGRFA Secretariat.
7	We recommend that a study be done to formally determine redundancy with other national and international collections held by national and international institutes that were involved in joint collecting with CSIR-PGRRI or that serve as host sites for duplicates. This in-depth analysis of the uniqueness of the accessions should lead to opportunities for rationalization. It would also give CSIR-PGRRI an opportunity to recover accessions that have been lost and are no longer found in their original collection sites. The results of the study would allow for CSIR-PGRRI to prioritize crops and accessions for long term conservation.	Q4 2020	CSIR-PGRRI: Agreed. Kew, ICRISAT, IITA, National Institute for Agro-Biological Resources (NIAR), Japan will be contacted and engaged for the available data. A questionnaire will be developed to that effect. Crop Trust: The Crop Trust supports this recommendation. In the context of a global, rational system of PGRFA, it is critical to understand what unique accessions in national collections may be priorities for regeneration and safety-backup. Based on this study, we encourage CSIR-PGRRI to select unique accessions of specific

			crops, which will be used to assess genebank management performance under the Seeds for Resilience project.
8	To address the lack of secure safety back-up for the seed accessions, we recommend that CSIR-PGRRI prioritize unique accessions by crop and urgently arrange for safety duplication of those accessions not already duplicated with institutions outside Ghana to serve as a primary black box. CSIR-PGRRI should also dispatch high quality seed of priority unique accessions to Svalbard Global Seed Vault as the secondary site.	2020 - 2023	CSIR-PGRRI: Agreed. The international centers will be used for the duplication of crop accessions; Maize-CIMMYT, Rice-IRRI/African Rice; Legumes-ICRISAT, IITA, ICARDA; Cassava –CIAT, Vegetables - World Vegetable Centre; Crop wild relatives-Millennium Seed Bank/Global Seed Vault, Svalbard Crop Trust: The Crop Trust supports this recommendation. We encourage CSIR-PGRRI to prepare a plan for all unique accessions to be safely duplicated in Svalbard. The process of duplication at the first level should follow a strategic approach - many Centres may already conserve representations of the same diversity or even accessions (e.g. maize and cassava at IITA, rice at AfricaRice), in which case physical shipment of accessions may not be necessary. The emphasis here is on identifying as well as possible truly unrepresented accessions that are unique and unlikely to be found anywhere else.
9	We recommend that CSIR-PGRRI adopt a quality management system (QMS), including the development and regular updating of standard operating procedures (SOPs) for routine operations, as well as any new processes.	2020 - 2023	CSIR-PGRRI: Agreed. A proper and complete documentation of all genebank procedures (SOPs) will be developed to cover all basic elements of the genebank's operations. A consultant may be needed to work towards the establishment of a quality management system for all its routine activities. The Trust can advise on the way forward, e.g. distribution, regeneration, characterization, acquisition, documentation, seed health testing, conservation, collecting, *in-vitro* conservation etc. Crop Trust: The Crop Trust agrees with this recommendation. The Crop Trust will continue to provide technical support to CSIR-PGRRI on this, working towards the adoption of a minimal QMS by the end of 2023. It is important that the adoption of a minimal QMS is supported and encouraged by CSIR and CSIR-PGRRI management.
10	The Bunso site is not an appropriate environment for the secure long-term conservation and regeneration/multiplication/characterization of most of the seed crops. Minimally, we recommend that CSIR-PGRRI collaborates	Q2 2020	CSIR-PGRRI: Recommendation for collaboration with SARI agreed. Attempts were made in the past to have a station at the CSIR-SARI. In view of the current recommendation, the process

	with SARI through CSIR to shift all field and post-harvest seed processing activities for the seed crops to the SARI site as described for Model 1 in Table 4. Optimally, we recommend adoption of Model 3 or 4 for the long-term future. The procurement recommended in Table 6 will depend upon the model of operations (Table 4) adopted for the seed crops but should be implemented with careful consideration of each item by CSIR-PGRRI and SARI staff and with the guidance of the discussion in the relevant subsection of this report for any upgrade of the seedbank in the S4R project.		will be re-initiated. The Institute will however prefer either Model 2 or Model 3 with some modifications (See Annex 1 below). Crop Trust: The Crop Trust agrees with this recommendation and appreciates the commitment of CSIR-PGRRI in resuming a collaboration with CSIR-SARI. Based on the review report, we understand that the environmental conditions in Bunso are detrimental for a significant proportion of the seed collection, and that there is a need to identify an alternative location to conduct several routine genebank operations, including (but not restricted to) regeneration, seed drying and seed viability testing. During the on-site visit to Ghana, the reviewers were only able to visit CSIR-PGRRI facilities in Bunso, and therefore there has not been an on-site assessment of the available facilities at CSIR-SARI (This has been pointed out by the reviewers also). Further details about an alternative location and the model of operations will need to be worked out in collaboration with CSIR-PGRRI and CSIR management. An on-site visit and mini-review to identify the needs of such an alternative location is warranted. Specific actions should be described in the project workplan.
11	We recommend that CSIR-PGRRI address the backlog of seed viability monitoring as well as conduct initial viability tests. The rate of annual viability testing should relate to the needs of the collection but capacity should be built to conduct viability tests of at least 600 accessions per year to address the backlog in 5 years.	2020 - 2023	CSIR-PGRRI: Agreed. Staff will be allocated for the exercise on commodity basis (cereals, legumes and vegetables) with agreed performance targets. Crop Trust: The Crop Trust supports this recommendation. Further details about the viability testing plan should be described in the project workplan.
12	We recommend the establishment of a process for documenting and monitoring the quantity of seed conserved against acceptable thresholds using 100/1000 seed weight for each accession to determine the number of seeds per accession for the purposes of monitoring.	2020 - 2023	CSIR-PGRRI: Agreed, this would be carried out. Crop Trust: The Crop Trust supports this recommendation and CSIR-PGRRI's response. We encourage CSIR-PGRRI to record information on seed numbers directly in the genebank database and use it, together with viability test results, to decide when regeneration is needed.
13	We recommend that the seedbank adopt clear, transparent protocols to meet distribution requests by both national and international users for seed and vegetatively propagated	2020 - 2023	CSIR-PGRRI: Agreed. Requests for seeds will be in the following order: Application and approval of request, signing of a material transfer agreement (MTA) and dispatch of seeds. In addition,

	accessions. To address the inadequacy in feedback on the use of accessions, the reviewers recommend that CSIR-PGRRI uses a routine formal process for soliciting and using feedback from recipients to improve the use of the collection and seedbank operations with actions such as to: ● Conduct routine user surveys on the use of the collections, delivery timelines, quality of seed received and other useful information. ● Fully implement DOIs to better link to information generated on the accessions. ● CSIR and CSIR-PGRRI implement a policy that would ensure that data generated on the accessions by all institutes of CSIR, divisions in CSIR-PGRRI, or in collaborative studies with universities, be shared with the seedbank to enhance the knowledge of the accessions conserved for all future users.		feedback will be expected on the utilization of the materials including data on characterization information and publications emanating from the seeds sent. Similarly, the genebank QMS to be developed by the institute will have feedback/complaints procedures that will monitor and evaluate utilization and user satisfaction of its seeds and other propagating materials. With regards to transparency, the SOPs that will be developed and adopted by the institute, will document the protocol for the distribution of germplasm. Strict adherence to this will result in clear and transparent national and international germplasm distribution. Crop Trust: The Crop Trust supports this recommendation. We encourage CSIR-PGRRI to request DOIs for all existing accessions. It is important that CSIR-PGRRI develops a procedure to recover evaluation and characterization information of distributed germplasm, particularly from sister institutes within CSIR.
14	CSIR-PGRRI should develop and implement a realistic 5-year plan to securely regenerate at least 800 accessions per year, giving priority to accessions with poor viability or low seed number, utilizing appropriate sites and improved standard operating procedures to produce high quality seed. Formal arrangements may also need to be established with other CSIR institutes for use of their sites for regeneration, multiplication, and conservation of seed crops.	2020 - 2023	CSIR-PGRRI: Agreed. There is collaboration between all CSIR institutes of which, CSIR-PGRRI is one. These CSIR institutes have stations in all the major agro-ecological zones that would be conducive for the aforementioned crops and would be used for regeneration, multiplication and conservation of seeds. Crop Trust: The Crop Trust agrees with the recommendation. It is important that the regeneration plan gives precedence to unique, threatened accessions of selected crops that fall below seed quantity and viability thresholds. Further details about the regeneration plan should be described in the project workplan. We support CSIR-PGRRI collaborating with other institutions in regenerating seed material.
15	The reviewers recommend that CSIR and CSIR-PGRRI urgently renew the lease of the critical research field sites where the field collection is located before any further investment can be made into the upgrade of the Bunso site in the S4R project. The reviewers also recommend that prior to any upgrade, a long-term plan needs to be made to securely conserve	Q4 2020	CSIR-PGRRI: Agreed. The Government of Ghana has been involved in the process to renew the lease of the land at Bunso**,** since 2014, including the payment of rent charges by the Government of Ghana. The duplication of vegetatively propagated and tree crops will be done at out-stations of sister CSIR institutes in the forest and semi-deciduous agro-ecologies of Ghana. The

	vegetatively propagated and tree crops. Significant support should be solicited from IITA to provide technical guidance for the long-term planning and the action needed to secure these accessions in the field for the long-term. The planned actions should include an assessment of the risk of conserving these crops at the Bunso site and implementation actions to be taken to mitigate these risks such as: ● Building a secure, appropriate yam barn to store the yams after harvest until they are replanted to the fields. ● Development of improved protocols to manage the plant health of the accessions in the field to reduce the impact of disease and virus infection ● Urgent virus indexing for cassava where the best option initially could be to outsource to the CSIR-CRI at Kumasi, which has a state-of-the-art *in vitro* laboratory. ● Development and implementation of a five-year plan to transfer 40-50 accessions per year into *in vitro* culture with the focus on priority unique accessions. In addition, the plan needs to identify and implement a safety backup for the *in vitro* cultures.		CSIR-PGRRI has an on-station yam barn at Bunso and an out-station barn at the CSIR-CRI station at Ejura, this could be rehabilitated and used for yam storage. The institute has recruited a virologist, additionally, there are two plant mycologists at post to help manage virus infection and other plant diseases. Crop accessions not currently in culture will be introduced into *in-vitro* culture. The tissue culture laboratory at the CSIR-CRI can be used as a site for duplication. Crop Trust: The Crop Trust agrees with this recommendation. We encourage CSIR-PGRRI to finalize the process of renewing the lease of the site in Bunso as soon as possible. We look forward to updated information on this vital issue. We encourage CSIR-PGRRI to identify unique accessions of vegetative crops in coordination with IITA or other CGIAR Centres. It is important in a long term plan that cleaning, conserving, and safety duplicating such accessions is discussed with partners as well.
16	We recommend that all efforts are made by CSIR-PGRRI to enhance internet connectivity to the server to allow for the full implementation of seedbank information systems such as GRIN-Global.	2020 - 2021	CSIR-PGRRI: Agreed, to be worked on. Crop Trust: The Crop Trust agrees with both the recommendation and CSIR-PGRRI's response.
17	We recommend that CSIR-PGRRI and CSIR lead the development of a national strategy for *ex-situ* crop genetic resource conservation and use. This strategy development should be used to initiate joint actions of CSIR-PGRRI with other collection holders to better secure *ex-situ* conservation and use of key crop diversity in Ghana. These activities could include better coordination of conservation, greater sharing of accession level information, annual updates on the conservation status of accessions in the various collections, and increased safety duplication.	2020 - 2024	CSIR-PGRRI. Agreed. A number of documents, including the Genebank Review of 1997 and the National PGR Strategic Plan, developed modalities for this. In view of the recommendation, these strategies will be reviewed and implemented. Crop Trust: The Crop Trust supports this recommendation. As the national genebank of Ghana, it is important that CSIR-PGRRI coordinates activities related to germplasm use and conservation with other stakeholders in the country, particularly those conserving PGRFA in public institutions. A user group with representatives from other seed collections will provide CSIR-PGRRI the opportunity to meet and coordinate with national stakeholders.

18	We recommend that CSIR-PGRRI organize facilitated meetings at agro-ecological zone level (2-3) with representatives of farmers' organizations, NGOs, local government agencies, local research institutions/universities, and local seed producers (max. 40 participants per zone). We also recommend that CSIR-PGRRI constitute a technical working group of breeders/researchers at other national research centers, universities, and the private sector for characterization, evaluation and use of collections in crop improvement. In order to elevate the profile of the national seedbank and enhance awareness of the importance of supporting it, we strongly recommend that CSIR and CSIR-PGRRI hold at least two facilitated high-level meetings with key policy makers during the implementation of the project.	2020 - 2024	CSIR-PGRRI: Agreed. A PGR working group that will meet annually to discuss characterization and evaluation plans, acquisition of new genetic resources and other PGR related issues will be formed. Awareness creation events such as farmer's days, field days, open days, exhibitions, plant biodiversity conservation and utilization workshops with relevant farmer-based organizations (FBOs), NGOs, policy makers and users of PGR will be held on a scheduled basis. Crop Trust: The Crop Trust supports this recommendation. It is important that a structured communications plan is first developed, as this can guide CSIR-PGRRI's efforts to enhance its communications with all stakeholders, including genebank users. The Crop Trust will support CSIR-PGRRI in designing and implementing a communications plan aiming to enhance the genebank's visibility.
19	To address the limited use of national collections to enhance crop diversity to mitigate the effects of climate change, we recommend that CSIR and CSIR-PGRRI provide technical support in the evaluation, characterization, and multiplication of accessions of underutilized and climate-smart crops for direct use in the cropping system by the following actions: ● Together with the Technical Working Group of breeders/scientists, identify a core collection of underutilized and climate smart crops (e.g. Bambara, cowpeas, sorghum, pearl millet, popular vegetable land races, and some crop wild relatives) for use in crop improvement ● Multiply/bulk seed of selected accessions for distribution. ● Together with breeders/researchers, conduct phenotypic/genotypic characterization for climate smart traits. ● With user groups, provide technical support in the evaluation of characterized accessions for climate-smart traits with researchers, farmers' organizations, private	2020 - 2024	CSIR-PGRRI: Agreed. The institute has been working on neglected and underutilized species (NUS), climate smart (CS) crops and crop wild relatives. Some of these have been characterized and selections made in a participatory manner. The sustained implementation of this on a regular basis would promote their acceptance and use by key stakeholders. A Technical Committee to undertake joint screening and training of professionals/enthusiasts in NUS and CS PGR management will be formed. The committee will also partner with scientists/institutions with crop breeding programs in a bottom-up approach to promote eventual acceptance and utilization of developed NUS/CS populations and varieties. Crop Trust: The Crop Trust supports this recommendation. Given restricted resources we would prioritize: ● The identification of promising landrace material through participatory field evaluation trials. ● Multiplication and distribution of promising landraces displaying climate-smart traits. ● Registration and multiplication of selected accessions.

	seed companies, and NGOs that can then facilitate access to seed and knowledge to farmers. ● With researchers, undertake introgression and genetic enhancement with selected accessions to develop diversified populations. ● Conduct participatory selection with farmers to identify preferred resilient varieties (medium-term). ● Seek registration and seed multiplication of selected varieties ● With support from farmers' organizations, the private sector, and NGOs facilitate access to seed and knowledge to farmers (long-term).		● Preparation of core collections based on passport and characterization data. It is important that CSIR-PGRRI selects the most promising crop(s) for climate-change affected regions of Ghana, for which CSIR-PGRRI conserves a substantial diversity of accessions. Collaboration with relevant researchers and breeders is key and Crop Trust would support outsourcing some of these activities to specialized NGOs or other institutions based in Ghana.
20	We recommend that a detailed risk management matrix (such as Table 8) is agreed upon and used as the basis for monitoring risk for the seedbank on an annual basis with updates provided as needed by CSIR-PGRR Ito the Crop Trust.	2020 - 2024	CSIR-PGRRI: Agreed. A risk management matrix modeled on the one in Table 8 will be developed in consultation with expert advice from the Crop Trust. Crop Trust: The Crop Trust supports this recommendation and agrees with CSIR-PGRRI's response. Work on QMS will provide support to CSIR-PGRRI to strengthen its risk management.

Annex 1. Modifications proposed by the CSIR-PGRRI to models of operation recommended by the Crop Trust for seed conservation at the CSIR-PGRRI and SARI

Processes	**Model 2 with proposed modification in green font**	**Model 3 with proposed modification in green font**
Regeneration/multiplication/characterization	SARI	SARI
Thresh/clean seed in Crop Work Area	SARI	SARI
Drying with moisture testing	SARI	SARI
Germination/Seed count/packet weight	SARI	SARI
Packaging	SARI	SARI

Medium- and long-term storage	Bunso/SARI	SARI/Bunso
Distribution	Bunso	SARI /Bunso
Documentation	Bunso	Bunso
Germination monitoring	Bunso/SARI	SARI/Bunso
Plant/Seed health	Bunso	Bunso

Plant Genetic Resources Research Institute of Ghana – Bunso, Ghana

External Review Report

May 1, 2020

Review Team:

- **Paula Bramel**
- **Simon Linington**
- **Bonny Ntare**
- **Milko Škofič**

Executive Summary

The “National Seeds Collections for Climate-Resilient Agriculture in Africa – Seeds4Resilience” Project aims to safeguard selected national seedbanks in Africa and empower them as entry points for developing new, climate-resilient crop varieties. As the first step in the implementation of this project, an external review was commissioned to review the current institutional capacity, technical capacity, adequacy of facilities, and adequacy of operational procedures to meet the challenges of long-term conservation and use of key global collections held by national seedbanks. The external reviewers utilized a baseline survey, intensive site visits, and consultative discussion to assess the short-term and long-term upgrade needs for the Plant Genetic Resources Research Institute (PGRRI) to meet international seedbank standards in order to better secure conservation and enhance use for the future.

PGRRI is one of the 13 institutes of Ghana’s Council for Scientific and Industrial Research (CSIR). It was established in 1964 as a section within the Crop Research Institute (CRI), to carry out plant introduction and exploration. The section started with a field collection at Bunso for recalcitrant fruit crops but with time it expanded to include a seedbank for orthodox seeds as well. It was upgraded to the Plant Genetic Resources Centre within the CSIR and its mandate expanded in 1994. There was a concerted effort to collect grain and cereal crops under two World Bank projects. In 2005, PGRRI was again upgraded as one of the institutes of CSIR with its current focus to collect and conserve the plant genetic resources of Ghana as well as to coordinate plant genetic resource activities in the country.

In the baseline survey, the total number of accessions conserved at PGRRI is 4,213. They also have 48 accessions of citrus as well as 32 other medicinal and spice plants. The crops from Annex I account for about 65% of the accessions. They indicated that 3,855 accessions were landraces collected by the institute and 70 crop wild relatives (CWR) of finger millet, rice, cowpea, eggplants and sorghum. In a number of the documents they shared, they indicated that the collection had collected and conserved was over 10,000 accessions. The documentation unit indicated that they had digitized information on 9,979 accessions while 6,143 accessions had passport data that were cleaned and published on the Global Biodiversity Information Database (GBIF). Thus, there seem to be a significant number of historical accessions over time that indicate that almost 60% of the accession have been lost. The greatest loss was a 79% reduction for root and tuber crop genera with a 25% reduction for vegetable genera.

The Crop Trust utilizes a set of indicators to monitor various aspects of a seedbank’s performance. The baseline performance of PGRRI for this set of indicators was reviewed. There were significant gaps identified for: seed viability monitoring; seed health testing; regeneration; safety backup at sites outside Ghana; documentation and sharing of accession level information; and the use of a quality management system (QMS) with written, accurate standard operating procedures (SOP) for the key routine operations. Key recommendations were made to address these gaps. Many of these gaps were due to shortfalls in the current operational procedures, equipment, and facilities.

Each of the steps in the flow of seed through the seedbank operations was reviewed as well as the adequacy of the workspaces, laboratories, drying unit, seed storage freezers, and field sites to meet the needs for secure, cost-effective, sustained conservation for the long-term. The various risks associated with their current processes were identified and upgrade recommendations made to mitigate these risks and to improve the flow of the operations as well as reduce the loss of accessions.

A comprehensive risk assessment was done by the reviewers with the identification of key actions required to mitigate these risks. Generally, the reviewers found that PGRRI conserves an important national collection in the global system that could conserve unique accessions of key crops. There are some significant environmental and institutional constraints that need to be urgently addressed. Not least of these is the opinion of the

reviewers that Bunso is an unsuitable location for the production of quality seed and that processing and storage of the seed is made significantly more difficult by working in such a humid environment. The reviewers recommend that PGRRI should consider moving its seed collection operations to the drier SARI site. This should be done as soon as possible though it is accepted that negotiations, establishment of new facilities and the move may take some time. In the meantime, PGRRI should prepare for such a move by, for instance, checking the amount and, if possible, the germination of the seeds stored, and improving data handling. It was noted that PGRRI lacks some of the essential facilities, equipment, expertise, and operational processes required for secure long-term conservation. Investment for improved seed facilities should take place at the SARI site though purchase of easily moved equipment required for this work could proceed immediately. A set of key recommendations have been made by the reviewers to upgrade the seedbank operations to meet the future challenges for sustained, secure, cost-effective conservation and enhanced use. They all need to be considered in the light of the suggested move of seed operations to the SARI site.

The reviewers also considered the degree and effectiveness of the current use of the collection. They assessed the interaction with users through distribution of accessions nationally and internationally. The engagement with users was reviewed in relation to the effectiveness of feedback from users to improve seedbank operations as well as to enhance accession level information for future users. The level of engagement of PGRRI with stakeholders and users to enhance the use of accessions in the collection, especially to mitigate the impact of climate change, was assessed. Finally, the level of the current engagement of PGRRI within the global conservation system was reviewed. A key set of recommendations were made for action to be taken to enhance the use of the accessions and the engagement with stakeholders for the longer-term.

List of Recommendations

Recommendation 1: Given the importance of crop genetic resource conservation to CSIR, PGRRI, and the Crop Trust, the reviewers recommend that CSIR modify their performance contract with PGRRI to adopt strict performance indicators that align with those in use by the Crop Trust to strengthen the value given for long-term conservation and use of the collection.

Recommendation 2: The reviewers recommend that the PGRRI asset management be audited for compliance and internal controls. In the meantime, clear terms need to be specified in the Seeds for Resilience (S4R) project contract on management of assets procured, maintained, or repaired by project.

Recommendation 3: The reviewers recommend that CSIR urgently addresses the need to allocate funds to fully cover the cost of electricity for the key conservation facilities used within PGRRI, either through a government waiver or subsidy, in recognition of the national importance of conserving these genetic resources for the long-term.

Recommendation 4: The reviewers recommend that a long-term strategic and business plan be developed by CSIR for the sustainable operation of PGRRI and if the upgrade is funded and completed, a costing study of routine operations be done to help secure adequate annual funds for the conservation and use of the collections.

Recommendation 5: Generally, the reviewers recommend that PGRRI invest in enhancing staff capacity for the long term through:

- On site capacity building by experts to train staff and upgrade key processes
- Exchange visits with ICRISAT, IITA, ILRI, etc. to build capacity for specific processes
- Staff succession planning to address the potential loss of key long-term staff with key knowledge of the collection or seedbank management.

Recommendation 6: PGRRI should update the accession inventory to accurately reflect the current composition of the collection; indicate active or historical status and MLS status of all accession; and add all available passport and characterization data. This updated accession level information should be shared with users using the CSIR website and Genesys.

Recommendation 7: The reviewers recommend that a study be done to formally determine redundancy with other national and international collections held by national and international institutes that were involved in joint collecting with PGRRI or that serve as host sites for duplicates. This in-depth analysis of the uniqueness of the accessions should lead to opportunities for rationalization. It would also give PGRRI an opportunity to recover accessions that have been lost and are no longer found in their original collection sites. The results of the study would allow for PGRRI to prioritize crops and accessions for long term conservation.

Recommendation 8: To address the lack of secure safety back-up for the seed accessions, the reviewers recommend that PGRRI prioritize unique accessions by crop and urgently arrange for safety duplication of those accessions that have not already been duplicated with institutions outside Ghana to serve as a primary black box. PGRRI should also dispatch high quality seed of priority unique accessions to Svalbard Global Seed Vault as the secondary site.

Recommendation 9: The reviewers recommend that PGRRI adopt a quality management system (QMS), including the development and regular updating of improved standard operating procedures (SOPs) for current processes for their routine operations, as well as any new processes.

Recommendation 10: The Bunso site is not an appropriate environment for the secure long-term conservation and regeneration/multiplication/characterization of most of the seed crops. Minimally, the reviewers recommend that PGRRI collaborates with SARI through CSIR to shift all field and post-harvest seed processing activities for the seed crops to the SARI site as described for Model 1 in Table 4. Optimally, the reviewers recommend adoption of Model 3 or 4 for the long-term future. The procurement recommended in Table 6 will depend upon the model of operations (Table 4) adopted for the seed crops but should be implemented with careful consideration of each item by PGRRI and SARI staff and with the guidance of the discussion in the relevant subsection of this report for any upgrade of the seedbank in the S4R project.

Recommendation 11: The reviewers recommend that PGRRI address the backlog of seed viability monitoring as well as conduct initial viability tests. The rate of annual viability testing should relate to the needs of the collection, but capacity should be built to conduct viability tests of at least 600 accessions per year to address the backlog in 5 years.

Recommendation 12: The reviewers recommend the establishment of a process for documenting and monitoring the quantity of seed conserved against acceptable thresholds using 100/1000 seed weight for each accession to determine the number of seeds per accession for the purposes of monitoring.

Recommendation 13: The reviewers recommend that the seedbank adopt clear, transparent protocols to meet distribution requests by both national and international users for seed and vegetatively-propagated accessions. To address the inadequacy in feedback on the use of accessions, the reviewers recommend that PGRRI uses a routine formal process for soliciting and using feedback from recipients to improve the use of the collection and seedbank operations with actions such as to:

- Conduct routine user surveys on the use of the collections, delivery timelines, quality of seed received and other useful information.
- Fully implement DOIs to better link to information generated on the accessions.
- CSIR and PGRRI implement a policy that would ensure that data generated on the accessions by all institutes of CSIR, divisions in PGRRI, or in collaborative studies

with universities be shared with the seedbank to enhance the knowledge of the accessions conserved for all future users.

Recommendation 14: PGRRI should develop and implement a realistic 5-year plan to securely regenerate at least 800 accessions per year, giving priority to accessions with poor viability or low seed number, utilizing appropriate sites and improved standard operating procedures to produce high quality seed. Formal arrangements may also need to be established with other CSIR institutes for use of their sites for regeneration, multiplication, and conservation of seed crops.

Recommendation 15: The reviewers recommend that CSIR and PGRRI urgently renew the lease of the critical research field sites where the field collection is located before any further investment can be made into the upgrade of the Bunso site in the S4R project. The reviewers also recommend that prior to any upgrade, a long-term plan needs to be made to securely conserve vegetatively propagated and tree crops. Significant support should be solicited from IITA to provide technical guidance for the long-term planning and the action needed to secure these accessions in the field for the long-term. The planned actions should include an assessment of the risk of conserving these crops at the Bunso site and implementation actions to be taken to mitigate these risks such as:

- Building a secure, appropriate yam barn to store the yams after harvest until they are replanted to the fields.
- Development of improved protocols to manage the plant health of the accessions in the field to reduce the impact of disease and virus infection.
- Urgent virus indexing for cassava where the best option initially could be to outsource to the CSIR-CRI at Kumasi, which has a state-of-the-art *in vitro* laboratory.
- Development and implementation of a five-year plan to transfer 40-50 accessions per year into *in vitro* culture with the focus on priority unique accessions. In addition, the plan needs to identify and implement a safety backup for the *in vitro* cultures.

Recommendation 16: The reviewers recommend that all efforts are made by PGRRI to enhance internet connectivity to the server to allow for the full implementation of seedbank information systems such as GRIN-Global.

Recommendation 17: The reviewers recommend that PGRRI and CSIR lead the development of a national strategy for ex situ crop genetic resource conservation and use. This strategy development should be used to initiate joint actions of PGRRI with other collection holders to better secure ex situ conservation and use of key crop diversity in Ghana. These activities could include better coordination of conservation, greater sharing of accession level information, annual updates on the conservation status of accessions in the various collections, and increased safety duplication.

Recommendation 18. The reviewers recommend that PGRRI organize facilitated meetings at agro-ecological zone level (2-3) with representatives of farmers' organizations, NGOs, local government agencies, local research institutions/universities, and local seed producers (max. 40 participants per zone). The reviewers also recommend that PGRRI constitute a technical working group of breeders/researchers at other national research centers, universities, and the private sector for characterization, evaluation and use of collections in crop improvement. In order to elevate the profile of the national seedbank and enhance awareness of the importance of supporting it, the reviewers strongly recommend that CSIR and PGRRI hold at least two facilitated high-level meetings with key policy makers during the implementation of the project.

Recommendation 19: To address the limited use of national collections to enhance crop diversity to mitigate the effects of climate change, the reviewers recommend that CSIR and PGRRI provide technical support in the evaluation, characterization, and multiplication of accessions of underutilized and climate-smart crops for direct use in the cropping system by the following actions:

- Together with the Technical Working Group of breeders/scientists, identify a core collection of underutilized and climate smart crops (e.g. Bambara, cowpeas, sorghum, pearl millet, popular vegetable land races, and some crop wild relatives) for use in crop improvement.
- Multiply/bulk seed of selected accessions for distribution.
- Together with breeders/researchers, conduct phenotypic/genotypic characterization for climate smart traits.
- With user groups, provide technical support in the evaluation of characterized accessions for climate-smart traits with researchers, farmers' organizations, private seed companies, and NGOs that can then facilitate access to seed and knowledge to farmers.
- With researchers, undertake introgression and genetic enhancement with selected accessions to develop diversified populations.
- Conduct participatory selection with farmers to identify preferred resilient varieties (medium-term).
- Seek registration and seed multiplication of selected varieties.
- With support from farmers' organizations, the private sector, and NGOs, facilitate access to seed and knowledge to farmers (long-term).

Recommendation 20. The reviewers recommend that a detailed risk management matrix (such as Table 8) is agreed upon and used as the basis for monitoring risk for the seedbank on an annual basis with updates provided as needed by PGRRI to the Crop Trust.

Introduction to the external review

The Crop Trust has organized and facilitated a number of reviews to assess and monitor performance and identify improvements required to allow seedbanks to operate to internationally agreed management standards. This national seedbank review is an activity of the "National Seeds Collection for Climate-Resilience Agriculture in Africa-Seeds4Resilience" project that is funded by the Federal Republic of Germany.

A review team was engaged to conduct a review of each of the five seedbanks with the key expertise needed to cover the various aspects of the review. The review team were:

- Paula Bramel: Chair of the review panel with experience in conducting seedbank reviews with expertise in institutional analysis, diversity assessment, and seedbank management
- Bonny Ruhemurana Ntare: Operations and use expert, to support the chair in the areas of general seedbank management and links with users
- Simon Linington: Equipment and facilities expert, who assessed in detail equipment status and needs
- Milko Skofic: Information systems expert, who assessed seedbank management data flows and software and hardware needs

The review was to take into consideration various aspects that affect the overall functioning of the seedbank, including technical, financial, organizational, regulatory, social, and environmental aspects. The exact terms of reference for the review are given in Annex 1.

For the Seeds4Resilience Project, the Crop Trust staff and the reviewers prepared a baseline questionnaire on institutional, financial and technical topics and circulated it to all five pre-selected national seedbanks. The review team did a background review that included this baseline survey. Paula Bramel, Bonny Ntare, and the project manager visited the PGRRI seedbank from 4-7 October 2019. Simon Linington and Milko Škofič were not able to travel but extensive teleconferences were arranged for them during the visit. The agendas of each visit are available in Annex 2.

The reviewers have prepared this report with their recommendations for upgrades at PGRRI and submitted it to the Crop Trust. The Crop Trust will prepare a recommendations matrix where the reviewed seedbank comments their agreement or an alternative to each of the specific recommendations of the review, which is then further discussed with the seedbank and eventually agreed by the Crop Trust. Based on this matrix, a recommendation action plan will be developed which will be used to design project agreements between the Crop Trust and the seedbank. The Crop Trust have used this approach with all international seedbanks, and it has proven to be an effective tool in the preparation of multi-year upgrading projects.

History and current mandate

The Plant Genetic Resources Research Institute (PGRRI) is one of the 13 institutes of Ghana's Council for Scientific and Industrial Research (CSIR). It was established in 1964 as a section within the Crops Research Institute (CRI), to carry out plant introduction and exploration. The section started with a field collection at Bunso for recalcitrant fruit crops but with time it started to collect and store orthodox seeds as well. It was upgraded to the Plant Genetic Resources Centre within the CSIR and its mandate expanded in 1994. There was a concerted effort to collect grain and cereal crops under two World Bank projects.

In 2005, PGRRI was again upgraded to one of the institutes of CSIR with its current mandate to "collect and conserve the plant genetic resources of Ghana to save them from extinction" as well as to coordinate plant genetic resource activities in the country. PGRRI also conserves accessions that were held by the CRI and the Savanna Agricultural Research Institute (SARI). CRI and SARI are also institutes of CSIR, and conserve germplasm collected from farmers' fields but mainly in short-term storage for use in their research and crop improvement programs. The activities described by the Director of PGRRI during the review visit were focused on routine conservation as well as research on effective conservation and use of plant genetic resources. However, that was not reflected in the objectives given in the baseline, among which securing long-term conservation is not given only "To develop technologies for the efficient conservation". The objectives of PGRRI given in the baseline assessment were:

- To develop technologies for the efficient conservation and utilization of orthodox and recalcitrant plant genetic resource materials.
- To strengthen human resource capacity and capability.
- To identify, establish and strengthen inter-institutional collaboration and linkages.
- To identify and access external donor funding and commercialize research results.
- To gather, process and disseminate information relevant to plant genetic resources management in Ghana.

The reviewers recommend that CSIR and PGRRI review the current objectives for the institute to more accurately and transparently include their role in the long-term conservation of genetic resources in Ghana as stated in the mandate.

Institutional Capacity

CSIR was formally established with the CSIR Act 521 of 1996. It consists of the head office and 13 semi-autonomous institutes. Each institute operates with a director and a management board. The institutes have specific research mandates while the head office in Accra coordinates the research and development activities across institutes. A description of CSIR management, its specific role, and how it operates can be found at https://www.csir.org.gh/index.php/about-csir/structure-organisation. Generally, CSIR provides oversight for the performance of its institutes and projects and also has a role in reporting and representing the institutes in the Ministry and Parliament. CSIR has a Governing Council with a chair and 21 members. The composition of the Council is specified in the CSIR Act. CSIR has a Director General who is also the CEO. The Deputy Director General has a focus on research and development activities. CSIR is managed by an

Executive Committee. When issues cannot be resolved in the Executive Committee, they go up to the Council. The institute directors report to the Director General of CSIR. CSIR's Research and Development Directorate has two divisions: Quality Management, and Monitoring & Evaluation, the latter dealing with monitoring of research activities and performance assessments, that are reported to a Council sub-committee. CSIR does not currently have an impact monitoring system.

PGRRI has five divisions, with three focused on the seedbank. The Plant Genetic Diversity Division is responsible for characterization and diversity assessment. The Plant Genetic Conservation Division is responsible for conservation. The Plant Protection Division is responsible for plant and seed health. Currently, the Deputy Director is an entomologist so is part of the Plant Protection Division. The institute has a Management Board appointed by Government to supervise the institute's activities. The Director manages the day-to-day activities of the institute and reports to the Director General of CSIR.

According to responses received in the baseline and the visits, individual staff then Heads of Divisions and then the Director sign performance contracts with the Director General annually. They assess staff performance as well as key performance indicators for the institute. These are compiled and compared across institutes. Performance indicators include the proportion of annual funds obtained from donor funded projects and commercial activities. Targets are set for each institute annually to ensure adequate funding since the annual funding allocation to CSIR from the Ministry and Parliament has been declining. There are also indicators for CSIR and PGRRI staff relating to research outputs that include both the number of peer-reviewed journal articles and the journals' impact factors. There are no institute specific indicators used such as number of accessions securely conserved or the number of accession available for use or number of accessions distributed for use.

The performance indicators are used internally within PGRRI and reported to the Council but not shared externally. The DG of CSIR shared the 2018 performance indicators for PGRRI in comparison to the other institutes in a presentation given during the review visit. There is no performance management information system, although the Director General of CSIR stated that they do compile, compare, and report on institute-level performance targets. The current indicators do not give any value to this key mandate for PGRRI for the long-term. If CSIR priorities and funding allocations are tied to these current indicators, it could also result in a further reduction in the resources to conservation for the long-term. This could significantly impact on PGRRI ability to meet the Crop Trust requirement for any long-term grant. This should be seen as a prerequisite for any commitment for longer term funding.

Recommendation 1: Given the importance of crop genetic resource conservation to CSIR, PGRRI, and the Crop Trust, the reviewers recommend that CSIR modify their performance contract with PGRRI to adopt strict performance indicators that align with those in use by the Crop Trust to strengthen the value given for long-term conservation and use of the collection.

Finances and accounting

The Financial Administration Regulation 2004 (LI1802) deals with issues related to financial irregularities, terrorism, money laundering, corruption and similar. PGRRI has an internal auditor who advises management. Each CSIR institute is assigned by the Auditor General, an external auditor who reviews all accounts (project and government) and processes. A report is sent to the DG and the minister as well as the Auditor General. It is not clear if these are publicly available since none of these reports were shared with the reviewers by either CSIR or PGRRI. Any infringements are reported to the Public Account Committee of Parliament. The Public Financial Management Act requires that an audit committee must include two members who are chartered accountants or members of the Institute of Auditors. This same act listed all the institutes in CSIR, and nothing can be changed without a new act of Parliament, not even the name for the institute.

A policy, guidelines and systems are in place for preventing, reporting, and dealing with matters of discrimination, sexual harassment, sexual exploitation, sexual abuse and gender-based violence. Each institute has to have a mechanism to deal with complaints and there are various committees to deal with social issues. There is also a review board at institute level for approval to do research with animal or human subjects. There is an anti-corruption committee. No documents related to these guidelines, mechanisms, or committees were shared with the reviewers.

Assets management is based on a register, which is the responsibility of an administrative officer. When an asset is acquired, it is registered with the accounts section. To dispose of an asset, PGRRI must send a letter to the DG of CSIR for permission, an Asset Disposal Board is assigned and sent to inspect the item. On approval by Parliament, an auctioneer is assigned, and the asset duly disposed of. During the site visits, PGRRI described an asset management process that included a review of the inventory, making sure the asset was labelled, in the proper location, and with a proper documentation of its condition. If an asset is to be assigned to another unit, it has to be done with a request to the Director. During the visit, a request was made to physically locate an asset to test their asset management system, but it was not located during the visit.

Recommendation 2: The reviewers recommend that the PGRRI asset management be audited for compliance and internal controls. In the meantime, clear terms need to be specified in the Seeds for Resilience (S4R) project contract on management of assets procured, maintained, or repaired by project.

According to the baseline questionnaire, the finance office holds the expenditure records and supporting documentation. PGRRI can open a separate account for a project. The budgeting system allows projects to obtain monthly up-to-date expenditure reports. The Ghana Cedi (GHS) is the working currency, but they can also accept and operate in USD for international purchases. PGRRI does not have a procedure for annual cost recovery. They have an overhead policy of 15% on project costs as institutional support to cater for utilities charges.

We received audited financial statements for 2015/16 and part of the draft statement for 2017/18. The statement for 2017/18 shows negative reserves and less than USD 36,000 cash in hand. There is an increase in income of approximately 10% which is in line with increased personnel cost. We were not able to assess the current financial position, cash flow and the view of the external auditors. It is not clear if or how PGRRI meet their current liabilities.

Annual routine operational funds

Based on information provided in Table 1 in the baseline survey, the annual budget has been slowly increasing each year since 2015, at an annual rate of about 14%. It is understood that the total budget mainly caters for staff renumeration salaries with limited funds available for operations. In the baseline, PGRRI were also asked about the cost of routine seedbank operations. The estimated annual cost of routine operations provided in the baseline survey was only about 540,000 Ghana Cedis. This is only about 10% of the annual budget, and this included an allocation for purchase of new equipment. They indicated that the funds came about equally from the Government, projects and revenue generated. Thus, it was not clear how the annual budget was allocated across PGRRI, especially to routine conservation operations. The reviewers were told that a few years ago, that the institute was required to fully cover the cost of electricity with no allocation of a government subsidy. According to the Director, this has significantly raised their operating costs.

Table 1 PGRRI annual budget in Ghana Cedis and based on survey responses.

2015	2016	2017	2018	2019
4,004,923	4,176,285	4,377,480	4,862,525	5,778,005

One of the CSIR performance indicators for the PGRRI is the proportion of funds derived from projects. The current target is 30% of the annual budget but we were told that in 2018, there was only 8% of the budget from projects. Most of the projects have funded characterization of accessions. The International Network of Edible Aroids project focused on working with smallholder farmers to access disease resistant taro. The policy of CSIR to measure the performance of each institute's ability to generate income supplementing the government funding of operations will put pressure on the institute to give lower priority to the conservation of accessions. This policy and the need to fully cover the cost of the electricity without a government subsidy has had significant impacts on the annual budget. This needs to be urgently addressed given the vital role electricity has for many of the routine seedbank operations.

Recommendation 3: The reviewers recommend that CSIR urgently addresses the need to allocate funds to fully cover the cost of electricity for the key conservation facilities used within PGRRI, either through a government waiver or subsidy, in recognition of the national importance of conserving these genetic resources for the long-term.

Funds from government are not regular and if available, they are disbursed late. It is not clear if there are alternative sources of income for routine seedbank operations, other than the sale of seedling of fruit trees, medicinal/spice plants and ornamental plants. More strategic approaches must be made to ensure adequate resources to the seedbank for long-term conservation and enhanced use. Insecure annual funds result in inadequate operations and the reappearance of gaps to be filled. This risks loss of accessions and their genetic integrity.

With the upgrade, it will be necessary to assess the cost of routine operations to better secure the collections. There needs to be awareness raising at CSIR, the Ministry, and the Parliament on the urgent needs to secure consistent annual funds for routine operations for conservation. There is a need to invest in a long-term strategic plan and a business plan to secure annual funds for routine operations.

Recommendation 4: The reviewers recommend that a long-term strategic and business plan be developed by CSIR for the sustainable operations of PGRRI and if the upgrade is funded and completed, a costing study of routine operations be done to help secure adequate annual funds for the conservation and use of the collections.

Staff capacity for both long-term conservation and active use

The institute has a total staff strength of 128 out of which 64 are dedicated to seedbank operations and activities. The total number of staff is 128, comprising 30 senior members, 44 senior staff and 54 junior staff. In the baseline survey, PGRRI indicated that there had been no staff turnover in the last 5 years but the staff discussed how difficult it was to keep morale up due to low remuneration and inactivity if there are no project funds to conduct their research activities. Also, due to limited operational funds allocated to the seedbank most of the staff spend more time on other donor-funded projects that tend to distract them from the core routine activities of the seedbank. Further, staff are not evaluated on seedbank performance indicators but on the number of publications they generate, funded research proposals and outreach (extension) activities. This does not ensure priority is given to routine conservation. Inadequate number of staff, and capabilities, will result in risk to genetic integrity of the accessions and reduce the use of accessions. The proposed move of seed operations to the SARI site will have implications to the staff and how they are organized. The reviewers recommend that CSIR ensure staff allocations, operational support, and staff performance measures at PGRRI give high priority for secure, efficient and sustainable routine operations of the seedbank.

In the baseline survey, the details on staff qualifications, years of service, and if they had received additional training were given for 27 professional staff. Of these, 21 have doctorate

and master's degrees. More than half of these staff have more than 10 years' experience in their field of specialization and all but one has received some additional training. The staff mix is adequate to ensure long-term conservation but given the issues related to staff retention, it will be important for PGRRI to plan for staff succession.

Recommendation 5: Generally, the reviewers recommend that PGRRI invest in enhancing staff capacity for the long term through:

- **On site capacity building by experts to train staff and upgrade key processes**
- **Exchange visits with ICRISAT, IITA, ILRI, etc. to build capacity for specific processes**
- **Staff succession planning to address the potential loss of key long-term staff with key knowledge of the collection or seedbank management.**

Composition of the collection in relation to the uniqueness of the accessions

In the baseline survey, the total number of accessions conserved at PGRRI was 3,925 but they also gave a table for the composition of the crops conserved where the number of accessions conserved as seed or in the field totaled 4,213 accessions. This inventory is summarized in Table 2 by *Genera*. They also have 48 accessions of citrus as well as 32 other medicinal and spice plants that were given in a separate list during the visit. The crops from Annex I account for about 65% of the accessions. They indicated that 3,855 accessions were landraces collected by the institute and 70 crop wild relatives (CWR) of finger millet, rice, cowpea, eggplants and sorghum.

Table 2. The total number of accessions, number of seed accessions, number of field accessions, number of accessions according to GBIF (2018)[1], and number of accessions from Ghana held by other seedbanks according to Genesys[2]

Genera	Total in baseline inventory	Conserved as Seed	Conserved in the Field	GBIF(2018)	Genesys
	Number of accessions				
Manihot	201		201	407	258
Dioscorea	99		99	1030	226
Xanthosoma	39		39	72	
Ipomea	20		20	173	
Colocasia	39		39	214	
Solonestimon	55		55		
Zea	545	545		622	
Oryza	564	564		558	463
Sorghum	65	65		93	331
Pennisetum	5	5		84	435
Vigna	813	813		735	547
Phaseolus	30	30		150	60
Canavalia	20	20		23	
Kestigiella	16	16		26	
Arachis	171	171		155	
Sphenostylis	30	30			
Cajanus	17	17		34	
Mucuna	11	11		23	
Lycopersicon	286	286		512	
Abelmoschus	498	498		554	
Capiscum	379	379		545	
Solanum	310	310		350	66
Glysine				13	
Amaranthus					43

[1] www.gbif.org
[2] www.genesys-pgr.org

Other					320
Total	4213	3760	453	6373	2884

In a number of the documents they shared, they indicated that the collection conserved over 10,000 accessions and the documentation unit indicated that they had digitized information on 9,979 accessions while 6,143 accessions had passport data that were published on GBIF. The GBIF database was shared with the reviewers and a summary is given in Table 2 by *Genera*. When the inventory of accessions that have been uploaded to GBIF is compared with the accessions list given in the baseline, the greatest difference was a 79% reduction for the roots and tuber crop genera with a 25% reduction for vegetable genera. There were crops where no accessions are currently given in the baseline inventory or in the GBIF database.

Over time they seem to have lost almost 60% of the accessions. Many seedbanks would categorize these missing accession as ‘historical accessions”. It is important to maintain an up-to-date inventory that reflects the current composition of the collection. There is a need to do a careful inventory of accessions and identify gaps either for recollection of those lost or acquisition of accessions held by others, such as CSIR Crops Research Centers, the universities, or CGIAR Centers, if the long-term conservation can be secured.

Recommendation 6: PGRRI should update the accession inventory to accurately reflect the current composition of the collection; indicate active or historical status and MLS status of all accession; and add all available passport and characterization data. This updated accession level information should be shared with users using the CSIR website and Genesys.

In the selection of PGRRI as a key national collection for support by the Crop Trust, the Engels and Thormann study concluded that PGRRI potentially held unique accessions for Annex 1 crop such as aroids, banana, cassava, yams, cowpeas, rice, maize, pearl millet, and sorghum. To further assess the potential uniqueness of the accession currently conserved in Ghana, we compared the number of accessions held at PGRRI against other national and international seedbanks with Ghanaian holdings. There are 10 institutions that hold 905 of these accessions and 8 of these are international collections, such as IITA, ICRISAT, IRRI, AfricaRice, and others. When the number of accessions conserved is compared with those held by PGRRI, there are still a larger number of accessions held by PGRRI than held outside Ghana, except for *Manihot, Dioscorea*, *Sorghum*, *Pennisetum*, and *Phaseolus*. They seem to have unique accession globally for aroids, maize, and key vegetable crops. The discrepancies in the total number of accessions held, coupled with the loss of 6,000 accessions are alarming signals as to the number and quality of the remaining accessions. Given the diversity of agroecosystems in Ghana, the loss of such a high proportion of their accessions is very worrisome. The roots and tuber crops are viewed as a valuable collection held by PGRRI so the loss of nearly 80% accessions reported in the GBIF database would have an impact on the value of the current composition of the collection. Across crops, they have done joint collecting with JICA, IITA, ICRISAT, and CABI in the past. It seems that in most of these missions, the samples collected were shared and conserved in both institutes. A comparison needs to be made between the current collection and those held in other global seedbanks.

Recommendation 7: The reviewers recommend that a study be done to formally determine redundancy with other national and international collections held by national and international institutes that were involved in joint collecting with PGRRI or that serve as host sites for duplicates. This in-depth analysis of the uniqueness of the accessions should lead to opportunities for rationalization. It would also give PGRRI an opportunity to recover accessions that have been lost and are no longer found in their original collection sites. The results of the study would allow for PGRRI to prioritize crops and accessions for long term conservation.

Kiambi (2011)[3] pointed out that there has been a long history of cross-border movement of crop germplasm in this region, both of farmers' as well as improved varieties. Thus, much of the crop diversity is more unique for the region rather than for individual countries. Therefore, the germplasm held by PGRRI in the global system could be similar to the diversity held by the NACGRAB (Nigeria) seedbank that is also being considered for support by S4R and for the long-term by the Crop Trust. It is difficult to assess the uniqueness of these two seedbanks when considered separately. For the longer term, the reviewers recommend that the degree of diversity within locally collected germplasm of aroids, yams, cassava, *Musa*, and sweet potato from Nigeria, Ghana, and regionally, be determined to identify redundancies and significant gaps for all collections. This will likely need to be done with genotypic estimates of diversity but given the long-term cost of conservation for these crops, it will likely result in cost savings from rationalization across all collections in the region.

Baseline Performance Targets

The Crop Trust utilizes a set of indicators to monitor various aspects of a genebank performance. Table 3 gives the current status of PGRRI performance for these indicators. PGRRI indicated that they currently conserve 4,213 accessions as seed in the seedbank, in the field, and as *in vitro* cultures. Nearly 85% of the accession are conserved as seed.

Table 3. Baseline information on performance indicators

Baseline criteria	Number of accessions	% of total accessions
Composition of collections		
Number of accessions in total	4213	
Number of seed accessions	3760	84.0%
Number of accessions conserved in vitro	249	5.6%
Number of field bank accessions	453	10.1%
Availability		
Viable tested	944	21.1%
Viability above 85%	35	0.8%
Health tested	128	2.9%
Adequate seed number	not reported	
Included in MLS	2747	61.4%
Regenerated or multiplied in last 5 years	1172	26.2%
Security		
Number of LTS	3760	84.0%
Safety duplicated outside country	185	4.1%
Safety duplicated at Svalbard or other site outside country	0	0.0%
Field collection maintained in two site at least	0	0.0%
Distribution		
Total distributed nationally in last 5 years	792	
Total distributed internationally in last five years	20	
Number of countries distributed	2	
Information		
Minimum passport data (online)	4208	94.1%
Minimum characterization data (online)	2014	45.0%
Passport completeness index	not reported	
QMS		
Elements of QMS in place	0	
SOP written reviewed and approved	0	
Overall satisfaction of seedbank users	not reported	

About 65% of the accessions conserved are from Annex 1 crops. All accessions are fully owned by the CSIR- Plant Genetic Resources Research Institute (CSIR-PGRRI), the only

[3] Kiambi, Dan. 2011. Economic study on the contribution of local germplasm of yams, pearl millet, sorghum, and cowpeas to the agriculture of Ghana, Mali, and Nigeria.

ones responsible for management decisions concerning the collections and access. The accessions are available for use to all requesters within and outside the country. Germplasm exchange is governed by a Material Transfer Agreement (MTA) internally and a Standard MTA (SMTA) externally. There is no written documentation on the protocol for distribution. It should be made clear to the requester of the genetic resources what comprises the ABS terms and conditions. This would require a more formal process for communicating with requesters about the protocol. Lack of transparency as to terms and conditions for ABS will limit use as well as limit support for conservation.

Given the mandate of PGRRI in Ghana to secure the conservation of plant genetic resources, the average annual loss of more than 100 accessions (Table 2) is an indication of significant issues with the management of the conservation of unique diversity for long-term use. Only 70 accessions of CWR of *Solanum*, *Eleusine*, *Pennisetum*, *Oryza* and *Vigna* are kept at MSB, Kew, UK as black box/active safety duplicates. Seventy-nine accessions of yam are duplicated at IITA, Nigeria. Only 10 accessions of cowpea and 26 *Eleusine* are kept at ICRISAT, India. There are plans to duplicate within the country such as with the Savanna Research Institute (SARI) in northern Ghana for cereals and legumes, and at Crops Research Institute in Kumasi for some root and tuber crops. The focus for any upgrade project will need to be to reduce the loss with more secure conservation. To ensure no further loss, there is also a need to safety duplicate the collections at an additional site as soon as possible.

Recommendation 8: To address the lack of secure safety back-up for the seed accessions, the reviewers recommend that PGRRI prioritize unique accessions by crop and urgently arrange for safety duplication with institutions outside of Ghana to serve as a primary black box. They should dispatch high quality seed of priority unique accessions to the primary site as well as Svalbard as the secondary site.

CSIR has plans to implement a QMS (ISO 9005) across the institutes. For PGRRI, the baseline stated that established protocols in seedbank operations are followed, but no reference was made to any manual. There are no written procedures for the seedbank. Insecure and inefficient management of collections risks the further loss of genetic diversity among and within accessions as well as limit their availability to users.

Recommendation 9: The reviewers recommend that PGRRI adopt a quality management system (QMS), including the development and regular updating of improved standard operating procedures (SOPs) for current processes for their routine operations, as well as any new processes.

Seedbank operations for long-term and active use of the collections

This nationally important seedbank facility is in urgent need of investment through safety duplication as well as upgrades to meet internationally accepted standards of conservation to address the risk of loss of accessions. For example, nearly all the seed crops conserved are not adapted to such a wet, tropical environment as Bunso and this could be a main contributor to the significant loss of accessions in the case of crops such as sorghum and pearl millet. Eshan et al (2008)[4] indicated in the guide to regeneration that “Germplasm accessions should be regenerated when possible in the same ecological region where they originated. Alternatively, select a location that minimizes selection pressures on genotypes or populations. If no suitable sites are found, collaborate with other institutions that can provide suitable sites or facilities for regeneration.”

The reviewers understand that in the past there were collaborative plans made to shift multiplication/regeneration and conservation for these crops to the SARI site in Nyankpala.

[4] Dulloo M.E., Hanson J., Jorge M.A., and Thormann I. 2008. Regeneration guidelines: general guiding principles. In: Dulloo M.E., Thormann I., Jorge M.A. and Hanson J., editors. Crop specific regeneration guidelines [CD-ROM]. CGIAR System-wide Genetic Resource Programme (SGRP), Rome, Italy. 6 pp

Office space had been allocated but no formal agreement has been made to access fields, laboratories, or cold room space. Generally, no action had been taken due to a lack of funds. PGRRI needs to urgently reconsider the site for regeneration as well as conservation for the seed crops that make up 85% of their collection. In the international genebank standards, FAO (2014)[5] describes the key decision as "Regeneration should be undertaken with the least possible change to the genetic integrity of the accession in question. This means that, in addition to sampling considerations of the accession in question, due attention should be paid to the environment in which the activity will be undertaken, to avoid any severe selection pressure on the accession." As will be discussed in relation to all the genebank operations for PGRRI, the adverse impact of the Bunso site is not confined to regeneration but also the quality, efficiency, cost effectiveness, and security for the post-harvest seed handling processes, seed drying, and long-term seed storage

Prior to any upgrade, PGRRI will need to address the operational and management challenges of shifting the seed conservation processes to SARI. The various processes in seed conservation are generally described in Table 4 and four models for the future operations are compared for PGRRI in relation to the site for each operation.

- In Model 1, only the regeneration/multiplication/characterization and dirty post-harvest seed work is to be shifted to SARI. The cleaned seed will then be transported to Bunso for all the other processes and storage. In this model, it is assumed that PGRRI will have dedicated staff to manage the field operations and the cleaning.
- In Model 2, the routine operations conducted at SARI increase to include drying, moisture testing, germination, seed count/weight, and packaging. The seed is then sent to Bunso for long term storage in the freezers and for distribution.
- Model 3 also includes storage and distribution as well as monitoring for the seed crops in SARI.
- Model 4 is a complete shift of the seed conservation unit to SARI with no activities done in Bunso.

Table 4. Four models of operations for seed conservation processes at the SARI site, Bunso, or both.

Processes	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Regeneration/multiplication/characterization	SARI	SARI	SARI	SARI
Thresh/clean seed in Crop Work Area	SARI	SARI	SARI	SARI
Drying with moisture testing	Bunso	SARI	SARI	SARI
Germination/Seed count/packet weight	Bunso	SARI	SARI	SARI
Packaging	Bunso	SARI	SARI	SARI
Medium- and long-term storage	Bunso	Bunso	SARI	SARI
Distribution	Bunso	Bunso	SARI	SARI
Documentation	Bunso	Bunso	Bunso	SARI
Germination monitoring	Bunso	Bunso	SARI	SARI
Plant/Seed health	Bunso	Bunso	Bunso	SARI

All of these models are feasible but will require a differing degree of investment into infrastructure, staffing, equipment, and management for the upgrade and in the long term. Model 3 would reduce the need to have a separate documentation and plant/seed health unit at each site, since it is assumed that the field collections and in vitro facility will stay in Bunso. Model 4 will be more of a management challenge for PGRRI but could offer the more secure long-term conservation for the seed collections.

So while this shift for the conservation of the seed crops to SARI will reduce the risk of loss of an accessions genetic integrity during storage due to poor seed storability, it could introduce new risk such as:

- low quality seed from poorly supervised regeneration/multiplication;

[5] FAO. 2014. *Genebank Standards for Plant Genetic Resources for Food and Agriculture*. Rev. ed. Rome

- potential loss of seed viability and accession identity during transfer of seed between the SARI site and Bunso;
- poor short-term storage, drying and packaging from inadequate supervision at SARI;
- loss of accession identity during the various routine operations without links to newly established documentation systems.

All these risks need to be considered as PGRRI, SARI, and CSIR consider the operations that will be shifted. PGRRI will also need to address the implications of moving the staff involved in seed operations to the SARI site in terms of the operational model. The reviewers would recommend the adoption of model 3 and 4 as the most secure for the long term but ultimately this will be a decision for CSIR to take with the PGRRI and SARI institutes. The reviewers have considered this shift further in our recommendation for procurement and improving processes.

During the site visit, the reviewers focused on understanding the current flow of routine operations from receiving seed or plant material into the seedbank through to storage of seed or establishment of accessions in the field. Similarly, they focused on the flow from sending material to the field for regeneration/multiplication and characterization through to its receipt in the seedbank again for processing. The various facilities in the building or fields were assessed for their adequacy for the current operation as well as for the increased workflow expected from the upgrade. The essential equipment was reviewed based on baseline information requested prior to the visit and obtained during the visit to the PGRRI. Table 5 lists the flow of seed or plant material through the various steps at locations in the seedbank as given in Figure 1.

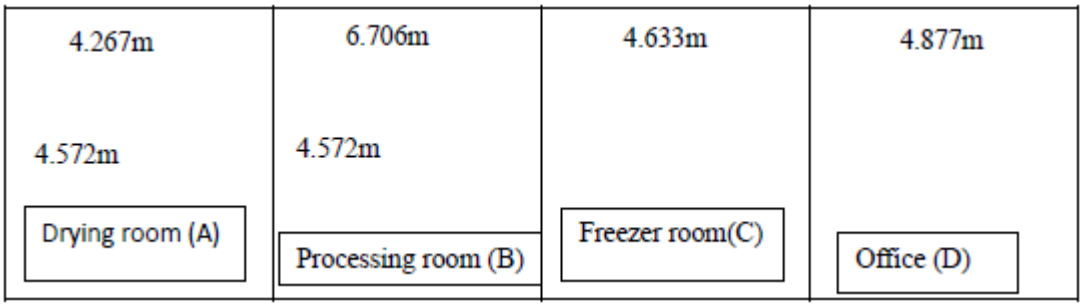
Recommendation 10: The Bunso site is not an appropriate environment for the secure long-term conservation and regeneration/multiplication/characterization of most of the seed crops. Minimally, the reviewers recommend that PGRRI collaborates with SARI through CSIR to shift all field and post-harvest seed processing activities for the seed crops to the SARI site as described for Model 1 in Table 4. Optimally, the reviewers recommend adoption of Model 3 or 4 for the long-term future. The procurement recommended in Table 6 will depend upon the model of operations (Table 4) adopted for the seed crops but should be implemented with careful consideration of each item by PGRRI and SARI staff and with the guidance of the discussion in the relevant subsection of this report for any upgrade of the seedbank in the S4R project**.**

Table 5. Flow of routine operations for seed and vegetatively propagated crops in PGRRI in Bunso

Steps	**Description of activity**	**Location**
	Seed Crops	
1	Seed or plant material received from multiplication of regeneration field is labeled with accession number and sent to dryer room	Drying Room
2	Harvested plant material or seed is placed in sun/shade or desiccator to dry	Outside or inside Processing Room
3	Seed threshed or extracted from fruits	Outside Processing Room
4	Seed cleaned by winnowing, sieving, and hand picking	Outside or inside Processing Room
5	Seed lot put in cloth bags with handwritten label	Processing Room
6	Seed received from a collection has a collection number that is registered in logbook and accession number assigned in logbook and sample is relabeled	Processing Room
7a	If needed, seed lot is fumigated in small containers or in hermetically sealed bags	Seed Health Laboratory
7b	If needed, seed is dried further in sun/shade outside seed processing room or put in desiccators for very small seed lots	Outside or inside Processing Room
8	Seed placed in the drying room	Drying Room

9	Initial non-destructive moisture test for large-seeded accessions and oven test for small-seeded accessions	Processing Room
10	Seed kept in drying room until 5-7% moisture obtained then taken back to the seed processing room for packaging	Drying Room
11	Small sample for germination testing and characterization packaged then bulk sample is separated into two aluminum packs, one for long-term storage and one for active collection	Processing Room
12	Packets sealed and put into large plastic bags with other accessions in freezer where crops are assigned	Processing Room
13	The long-term pack is placed in the freezers near the new cold store and the active collection sent to the freezers in the room next to the seed processing room.	Freezer Room
14	Seed germination percentage is determined, and data recorded on data sheets kept by the seed processing unit.	Processing Room and Office
15	If the initial viability is low or the seed quantity is inadequate, the accession is scheduled for multiplication/regeneration	Office
16	When seed quantity in the active collection pack falls below the minimum after a number of distributions, then the accession is scheduled for multiplication	Processing Room and Office
17	When funds are available or there is a research project, accessions are put into field trials for characterization	Processing Room, Office, and research Fields
18	Accessions from new collections and accessions that need multiplication are put together into a field list if funds are available	Processing Room and Office
19	If funds available, a list of accession that need to be characterized or have gaps in the current characterization dataset is put together and organized into replicated field trials by the Plant Genetic Diversity Division	Plant Genetic Diversity Division and Research Fields
20	Field layouts are planned, plots are planted, plots are labeled for multiplication or regeneration	Processing Room and Research Fields
21	Seed or plant material is harvested to be sent to seed store in step 1 or sent to Plant Genetic Diversity Division for further characterization	Processing Room and Plant Genetic Diversity Division
	Vegetatively-propagated crops	
1	Field plots are established and labeled	Research Fields
2	Tubers, vines, stems, etc. from collection or previous planting are replanted	Research Fields
3	Field plots are managed with weeding	Research Fields
4	Field plots are monitored for pests and diseases and treated when needed	Research Fields and Plant Health Laboratory
5	Tubers, etc are harvested and stored for replanting in following year	Research Fields and field storage equipment building
6	Stems, vines, etc. are taken for replant in Step 1	Research Fields
7	To initiate in vitro cultures, Samples are taken from plants grown in pots in the small greenhouse, washed under running tap water, and then surface sterilized	Preparation and transfer room in Biotechnology Building
8	Nodal cutting and trimmed shoots are inoculated in media and incubated at 16:8-hour day/night at 24 +/- 2 C	Transfer rooms in Biotechnology Building
9	Shoots sprouted from initiated cultures without contamination are sub-cultured on fresh media into 8 tubes per accession in transfer room and placed in culture room	Transfer rooms and culture rooms in Biotechnology Building
10	Growth and health of cultures in tubes is regularly monitored and recorded in logbook	Culture room in Biotechnology Building
11	Transferred to new tubes when needed (1-2 times per year depend upon crop)	Transfer Rooms in Biotechnology Building
12	Plants in the tubes are transferred to pots for hardening to check identity with accession in field but only for sweet potato so far	Screen houses

Figure 1. Current seedbank layout (as provided by PGRRI)



Short-term storage

There is no temporary holding space for collections arriving at the seedbank (see Seed Cleaning, below).

Seed cleaning

The current rate of processing is very low and there are a number of constraints to being able to increase this and address their significant backlogs in regeneration. PGRRI currently only process about 200 accessions per year. Once seed and fruits samples arrive from a collection mission, they are sun-dried on the lawn in front of a multipurpose operational room; threshing and cleaning are all done manually. They are also fumigated in small plastic bins or in hermetically sealed bags that they have obtained from GrainPro at one time and reuse. These are then transferred to the multipurpose and uninsulated drying room in which the dehumidifier and temperature monitors are not working. Consequently, there is no space for drying or to act as a temporary holding space.

The Bunso location is a very wet and humid environment for almost the entire year. As is reported already in the previous section, producing high quality seed for most of the crops they are conserving will always be very difficult due to the wet local environment, even with any upgrade in facilities for handling and processing seed after harvest. A significant constraint to post-harvest seed quality relates to the lack of a suitable separate dirty and clean crop work area, including provision for temporary storage for seed directly from the field. In the shift of post-harvest handling processes to SARI, there is a need to ensure access to a covered crop work area for the threshing, and initial seed cleaning. The lack of an appropriate crop work area and short-term storage room poses a high risk to loss of viability and long-term seed quality of freshly collected seed, especially given the humid conditions.

The following items for procurement could be used in any site. *No seed aspirator/blower at present so one has been included in the Table 6 (item 12). Good quality sieves are available though they are probably insufficient if throughput is increased. Budget for a further set is included in the Table 6 (item 13).* There was uncertainty over the effectiveness of the face masks currently used by PGRRI against dust inhalation that can lead to serious lung complaints. *It is recommended that mask with adequate known specification for protection against such dust are purchased (see Table 6 – item 25).*

Drying and moisture content determination

Seed moisture content is a key determinant of seed longevity and thus central to any seedbank operation. Within limits, a logarithmic decrease in moisture content leads to a logarithmic increase in seed longevity (straight-line relationship). For any given species, moisture content is determined by relative humidity and temperature. Having control of these two parameters is essential in the seed drying process. PGRRI's current drying room is not functional and has uninsulated walls, flooring and ceiling. When working, humidity is reduced using domestic dehumidifiers.

The current drying room in Bunso is not satisfactory and is currently being used mainly for storage. The room (4.3 x 4.6m) is not insulated, has three windows and a very high ceiling. PGRRI has installed wooden (untreated wood) shelves which clearly absorb and hold moisture. Seeds are spread out in plastic tubs to dry. The room does have an air conditioner and a dehumidifier though neither currently work. They also have a temperature and RH monitor in the room that does not work either. A domestic dehumidifier is insufficient when it is working to get the moisture content down to the required level (5-7%) for storage and extra drying either beforehand in the sun or, subsequently for small seed-lots, in a desiccator (within the Processing Room in Figure 1) often has to be used. Sun-drying is uncontrolled and under high, humid conditions exposes wet seeds to both very high temperatures and molds leading to seed deterioration even before storage. The peak period is over the two months of June and July when the drying room is used for drying uncleaned collections.

As stated in Recommendation 10, the best option for the conservation of the current seed crops is to transfer all the planned infrastructure, equipment, and processing upgrades to the SARI site if needed there. If the Bunso site were to continue to be used for drying, seed processing, packaging, and storage as in Model 1 in Table 4, the current drying room would either need to be upgraded to a standard drying room or the room should be repurposed for seed cleaning and short-term storage. It is currently not an appropriate closed space for drying. The reviewers consider the best option would be to utilize models 2, 3 or 4 (as described in Table 4) and to install a new drying facility at the SARI site to be used this for receiving cleaned seed lots as well as for final drying. Finding a suitable area for installing a new drying room might be more difficult than finding one for cleaning so PGRRI need to decide where the drying room should be installed. The new drying facility must consider energy efficiency in the design and procurement since the cost of energy and its availability is a major constraint to the conservation activities. Shifting the drying of seed to SARI will also improve the efficiency of drying since it is a less humid environment so there will be fewer issues with icing up or condensation.

The reviewers recommend that a refrigeration and air-conditioning consultant provides written advice on the design and cost of a new drying room and cold rooms (see Table 6 – item 2). This may require a visit by them to the SARI site. In particular they will need to:

- Provide an estimate for the installation of a drying room (not less than 15m^2 and preferably significantly larger if space permits), as directed by PGRRI at the SARI site, to include: walls and ceiling constructed of interlocking high quality insulated panels; an insulated floor; insulated doors with vision panels; paired Munters dryers feeding into the room via ductwork and a chilling system; an external control panel linking to ‘outside of condition alarms and sounders; fluorescent lighting and electrical sockets. There is considered insufficient space for an air lock. The required servicing of the equipment and the stock of spare parts that should be held. The room needs to be capable of maintaining 15% (± 5%) relative humidity and 15°C (± 3°C). See also comment regarding cold room(s) below.
- Provide an estimate for the installation of two new cold rooms (one for medium-term storage at about +5°C and one for long-term storage at -20°C). These cold rooms should be accessed directly from the new drying room. PGRRI and the Crop Trust will need to advise on the size of each cold room based on predicted needs over the next 20 years and also on the conditions required for the medium-term store. The cold rooms to include: walls and ceiling constructed of interlocking high quality insulated panels (not less than 100mm thick, and preferably thicker to reduce energy costs); an insulated non-slip floor; insulated doors with vision panels; paired refrigeration systems for each room; de-icing drains; pressure-equalization valves; an external control panel linking to ‘outside of condition alarms and sounders; and low temperature lighting.

- Creation of a new drying room / cold room facility needs either to be housed in an existing building (if available at the SARI site) or in a new purpose-built structure with an external plant room.

Please note, that this item of the budget has been costed independently of consultancies for the other four S4R facilities. By combining the visit (e.g., with the one to Nigeria) significant savings may be possible although the reviewers accept that there may be timing issues due to any delays in moving to the SARI site. Provision of air-conditioning potentially could be done by a local consultant or company. *The budget shown in the Table 6 includes a very notional cost for importation of components, and their construction (items 4-7), the cost of stackable fruit crates and trolleys (items 18 & 19) for the Drying Room, an RH / temperature logger (item 17) and shelving (preferably a simple mobile type to reduce floor area and hence reduce running costs) for the Cold Rooms (included in item 5). Additionally, the building of a small out-house for the plant for this facility has been included in the Table 6 (item 26). As an interim measure, a figure has been included for the purchase of some silica gel (item 9) for use in desiccators*.

Moisture content determination is carried out in the Processing Room. A moisture meter for large seeds is available. It determines moisture content non-destructively*. A further meter for rice and vegetable seeds is also required (see Table 6 – item 16).*

Seed viability monitoring

The seedbank appears to have limited capacity to monitor seed viability with the current low operational capacity and lack of adequate facilities for viability testing. Overall, just 25% of the accessions of orthodox seeds have been viability tested indicating a significant backlog in viability tests. More worrying is that PGRRI report only 35 accessions of rice to have more than 85% germination. This would indicate that they have a significant issue with the production of high-quality seed in multiplication or regenerations. This will be discussed later but will need to be addressed urgently as well as obtaining at least one initial germination test on all the accessions (and then subsequent retesting). Without information on seed viability, there is a high risk of loss of accessions in storage or a loss of genetic integrity on regeneration.

Recommendation 11: The reviewers recommend that PGRRI address the backlog of seed viability monitoring as well as conduct initial viability tests. The rate of annual viability testing should relate to the needs of the collection, but capacity should be built to conduct viability tests of at least 600 accessions per year to address the backlog in 5 years.

In Bunso, germination tests are carried out on the benches of the Processing Room with limited equipment and capacity, creating a backlog in viability tests. This room is used for nearly all seed processing operations. There is no functioning incubator. There is no air conditioning operating in the room so there is no temperature control. The reviewers understanding is that there is space in the plant pathology laboratory at SARI that could be used by PGRRI for germination and clean seed processing. It is unclear what equipment and infrastructure upgrade will be needed in any laboratory space at SARI but the conversion of part of the any seed processing room to establish a germination room is anticipated for the SARI site with the adoption of Models 2, 3 or 4 (Table 4). *Within the Table 6 potential building costs are covered (item 1) and the installation of air-conditioning (items 2, 4 & 8).*

No water purification unit is currently available for the supply of water for the preparation of germination media (e.g., agar or filter papers) or for tissue culture. *Because this equipment is central to these operations, a unit is included in the Table 6 (item 10). Additionally, a stereomicroscope is recommended for checking germinated material and cultures, one is also included in the Table 6 (item 11). Germination consumables are assumed to be covered by PGRRI's annual running costs.*

Packaging and quantity determination

There is no information being taken currently on the number of available seeds. This is a significant backlog that needs to be addressed. Lack of monitoring of the number of seeds available risks the loss of an accessions when the sample size falls below the number required to securely regenerate an accession. PGRRI needs to determine seed weight per 100/1000 seeds before sealing packets and digitize both 100/1000 seed weight and total packet weights to facilitate monitoring of seed quantity for distribution and multiplication. This database will be used to establish a monitoring system that alerts when multiplication or regeneration are required as discussed in the later section on documentation.

Recommendation 12: The reviewers recommend the establishment of a process for documenting and monitoring the quantity of seed conserved against acceptable thresholds using 100/1000 seed weight for each accession to determine the number of seeds per accession for the purposes of monitoring.

Once the seeds have been dried, it is essential that they remain that way during packaging and once sealed in the container. Dried seeds will readily imbibe moisture along a water potential gradient if the seal is ineffective and the storage environment is more humid. The current packaging system does not facilitate efficient inventory management of accessions under storage. This needs to be modified in an improved inventory system. All packaging is carried out in the Processing Room. Unknown seed quantities and weight are packaged in aluminum foil packets (1 for long-term, and 2-4 for active storage). Bags are labelled on the outside with permanent marker and label is placed inside the bag. At the same time, a seed sample is also set aside for viability testing. No estimates are made for 100/1000 seed weight.

Although there are balances of unknown age or standard on site, the seedbank needs a three-decimal place balance and a seed counter in order to determine quantities and 100/1000 seed weights (see Table 6 – items 14 and 15).

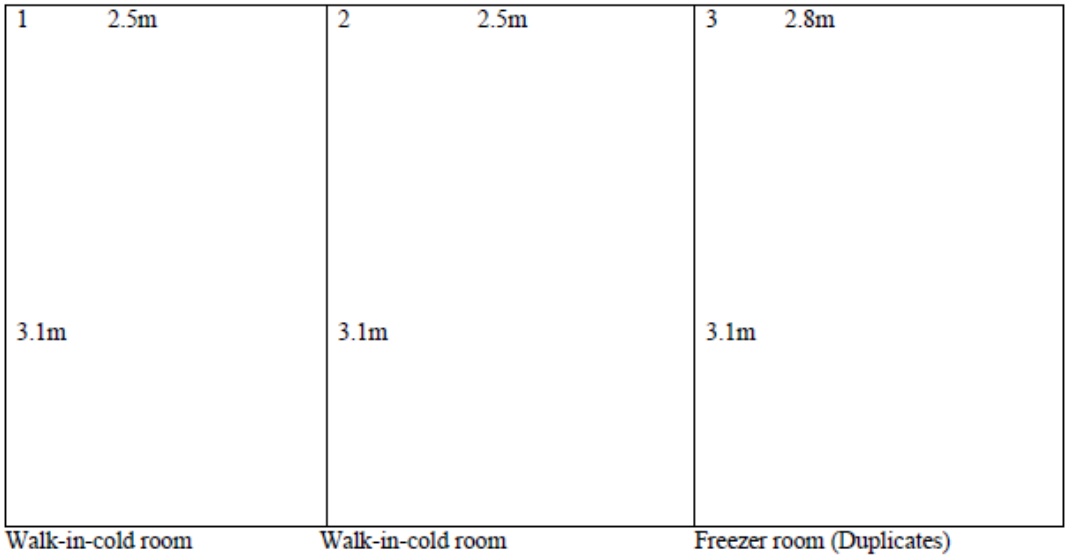
Seed packets are put together in large plastic bags for storage in a labelled freezer dedicated for a crop. However, there needs to be better organization of samples within each freezer such that storage of accessions in number sequence order is possible; this will facilitate retrieval. This can easily be modified if a cold room is used in SARI instead of freezers (Model 3 or 4 in Table 4).

PGRRI currently obtains their foil bags from Impact, USA. The specification of these bags is 5.25 x 8.0 inches. *Consequently, a notional sum for 4,000 high quality bags is included (see Table 6 – item 20).* The bag sealers currently used are designed for plastic rather than foil bags. *A rugged foil bag sealer is therefore included in the Table 6 (item 21).* PGRRI reported that they knew how to test that the seals were effective.

Seed storage

A cold store facility (Figure 2) with two cold storage rooms each of 3.1 x 2.5 m externally was built in 2007 with funds from the World Bank Project. It was designed as a long-term storage room, but it does not meet the standards. It has never been put into use. The room has concrete walls and no windows. Each walk-in cold room has a large door that is slotted into a door frame for insulation. They are both powered by a single compressor that is on the ceiling of cold room 2. On a positive note, the room has some very good aluminum mobile shelving.

Figure 2. Cold store facility in building adjacent to the Biotechnology Building



PGRRI have 11 chest deep freezers (two Whirlpool ones purchased in 2019; the rest are of various makes and purchased in 2011) for holding sealed seed packets. The active collections are located in a room that can hold a maximum of six freezers. The base collections are held in a room next to the walk-in cold rooms with four freezers (Figure 2). The freezers are not working at the desired temperature due to chronic electricity outages lasting up to 24 hours. There are no air conditioners in the rooms housing the freezers with the risk that there is an accumulation of warm air in the rooms that reduces their efficiency of operation. There is no external monitor for high temperature for the freezers and the only monitoring is done by staff checking to see if the lights are on to indicate they are working. There are no internal thermometers in the freezers to verify temperature. There is a need to install internal and external high temperature monitors on the existing freezers with an automatic notification system for the head of the seed unit and security. It is assumed that a new facility at the SARI site would have new cold rooms (Model 3 or 4 in Table 4). While there is a benefit of storing in deep freezer units in that the effect of any breakdown will be more limited than would be the case with one or two Cold Rooms, this may not be the most energy-efficient way to proceed. The energy use implication of the two options of freezers or cold rooms should be discussed with the refrigeration & air-conditioning and energy consultants. Assuming that cold rooms will be installed at the SARI site, the freezers could also be maintained in Bunso to hold duplicate samples securely at an additional site. This needs to be considered in the planning for the shift.

With the majority of freezers more than eight years old, a phased program of freezer replacement is required, assuming back-up seed storage continues at this site or the decision is taken to use freezers at the SARI site. Because chest deep-freezers make an inefficient use of the available floor area, *it is recommended that the S4R project replaces one of the old chest freezers with two upright ones (Table 6- item 22); ideally these should be compatible with a solar-power supply. This will create a small amount of extra storage capacity. Additionally, the two freezer rooms should have air-conditioning installed (see Table 6 – items 2, 4 & 8).*

At the SARI site, the reviewers understand that there is a cold room that has had the refrigerant system upgraded recently. However, it only acts as a medium-term store and is described as “old” meaning that its insulation may be ineffective thereby wasting electricity. It is described as of medium size and there would be space to accommodate PGRRI’s collections now. We also understand that it is in a separate building. However, this would mean that collections currently stored in deep freezers would now be subject to refrigerator temperatures instead which is far from ideal. Therefore, the reviewers recommend a cold room/drying facility built together in a building. If this is not possible in the current building,

then a new building may need to be built. This may require complimentary funds from CSIR or from other donors.

Plant health testing

The handout given for the visit indicated that 410 accessions from cold storage had been assessed for seed health. The baseline indicated that 128 accessions (28 pepper and 100 eggplant) have known health status but it was not clear how this was assessed or documented. The prevalence of both pathogenic and seed-borne diseases was reported to be moderate for the seed. It is important that standard operating procedures and a manual for detection and elimination of seed-borne pests, that are known to impact seed viability or are pathogenic diseases in regeneration is developed. This is especially important given seeds and field plants produced in this very high rainfall location. Poor seed health is a high risk for reduced viability, accelerated seed aging, loss of plants during regeneration, and spreading harmful pathogens through distributed seed and planting materials.

The reviewers recommend that a Seed Health Specialist consultancy be done to provide technical support on seed and plant health (Table 6- item 49) with the term of reference that includes: to establish generic (applicable to all crops) and specific (crop/pathogen) seed health testing protocols: develop a handbook for the identification of key pathogens and pests of the crops in the collections: establish appropriate protocols for seed phytosanitary to reduce pests and pathogens and provide capacity building with follow-up technical support on-site to institutionalize these processes. Ultimately, they will need to initiate the screening of the plants in the field and seed for key viruses.

Lack of proper seed health monitoring and functioning equipment for carrying it out risks non-detection of seed-borne pathogens or their misidentification leading to the spread of seed-borne pathogens in areas where they do not currently exist. There is thus a risk to crop productivity and food security. Users also lose confidence in the collection.

The plant pathology laboratory does not have an ultraviolet (UV) light in the incubation chamber. The only stereoscopic binocular microscope is not in good condition and the lab lacks equipment to undertake polymerase reaction (PCR) -based seed detection assays. Other challenges include no capacity to produce distilled water; a malfunctioning autoclave; and problems with microscopes and fridges.

On arrival, collections are treated by the Entomology Section (either removal of oxygen or by use of phosphine). In the latter case, collections are then well aerated; the security and safety of the site for fumigation and aeration is essential.

PGRRI need to establish a list of the minimum laboratory equipment needed to verify the seed health status of accessions in Bunso and at the new SARI site (Model 4 in Table 4). *At the very least, the compound microscope (for better identification of the pathogens) and the nonfunctioning UV light system need to be replaced (see Table 5 – items 27 & 28).* It also needs to enhance the monitoring of diseases incidences at field collection and regeneration sites.

Distribution

In the last 5 years, an average of 530 accessions were distributed annually within the institute and 158 within the country (Table 7). No distributions were made outside the country until 2018. The bulk of recipients were breeders/scientists. There was only direct distribution to farmers/farmer groups and NGOs of taro as part of a project. This limited use of accessions by farmers indicates that the seedbank is not meeting its key objectives in terms of contribution to agricultural development and food security, as well as global use.

Table 7 Number of accessions distributed to users from 2014-2019

Recipients	2014	2015	2016	2017	2018	TOTAL
Within the institute	31	343	1032	539	703	2648
Within the country (excluding your institute)	7	245	111	332	97	792

Outside the country	Nil	Nil	Nil	Nil	20	20

Accession distribution by user type includes 3558 accessions to scientists, 3 to others within the country and only 20 outside the country. These were all seed samples. It would seem that seedbank staff have limited experience with distribution of vegetatively-propagated crops. They also have limited experience with the distribution to international users. International distributions will be a challenge due to the need for additional packaging, phytosanitary permits, and shipping cost. No distribution internationally indicates limited contribution to the global system of conservation and use.

There are no formal mechanisms in place to solicit feedback on performance and use of the distributed germplasm. They do get informal feedback from recipients when there are issues, such as poor germination. Limitations in seedbank operations could lead to distribution of poor-quality seed with limited knowledge about the growing or use of the collections. Accessions requested by breeders are mainly for their other donor funded projects or students' projects and hardly any feedback is given to the seedbank.

Recommendation 13: The reviewers recommend that the seedbank adopt clear, transparent protocols to meet distribution requests by both national and international users for seed and vegetatively-propagated accessions. To address the inadequacy in feedback on the use of accessions, the reviewers recommend that PGRRI uses a routine formal process for soliciting and using feedback from recipients to improve the use of the collection and seedbank operations with actions such as to:

- **Conduct routine user surveys on the use of the collections, delivery timelines, quality of seed received and other useful information.**
- **Fully implement DOIs to better link to information generated on the accessions.**
- **CSIR and PGRRI implement a policy that would ensure that data generated on the accessions by all institutes of CSIR, divisions in PGRRI, or in collaborative studies with universities be shared with the seedbank to enhance the knowledge of the accessions conserved for all future users.**

There were no priority needs for equipment for distribution.

Regeneration, multiplication, and characterization of seed crops

Bunso is located in the tropical rainforest and is the only site currently being used for regeneration, multiplication and characterization of accessions. Most crop species, especially cereals and legumes, are better adapted to semi-arid environments than the humid conditions (with high rainfall, high relative humidity and prevalence of plant diseases) at Bunso. It is difficult to produce quality seed for crops such as sorghum, pearl millet, maize, cowpea, and eggplant at this site. FAO (2014) in the international genebank standards describe this issue for seed banks as "So there should really be a compromise between generalized, favourable conditions and those special signals (whether photoperiodic, nutritional or climatic) that are specific to local adaptation of individual accessions. This is part of the art of curation. If the genebank site does not provide favourable conditions locally, a curator should explore means to have the collection regenerated in a favourable environment; replication of the collection environment should not necessarily be the curator's goal."

In the last 5 years, they have regenerated about 160 accessions per year. At this rate, it will take about 18 years to fully regenerate the accession in the seedbank once. There is a need for a 4-fold increase in their current rate to address this backlog and address any increase in the collection to replace the accessions which have been lost. Currently, multiplication, characterization and regeneration are often combined for a limited number of accessions under project funds. This increased rate will be a significant challenge to their current approach to regeneration and multiplication. PGRRI needs to urgently shift the regeneration/multiplication/characterization to the SARI site (Recommendation 10). It may

also be necessary to utilize land and expertise of some of the other crop institutes of CSIR or the Universities to address the backlog.

They conserve a number of key legumes and vegetables that are insect cross pollinated. The reviewers strongly suggest that they use insect proof netting on mobile screen houses to control cross pollination for crops where needed.

Recommendation 14: PGRRI should develop and implement a realistic 5-year plan to securely regenerate at least 800 accessions per year, giving priority to accessions with poor viability or low seed number, utilizing appropriate sites and improved standard operating procedures to produce high quality seed. Formal arrangements may also need to be established with other CSIR institutes for use of their sites for regeneration, multiplication, and conservation of seed crops.

Handling species that are best conserved in the field or in vitro

A total of 453 accessions of vegetatively-propagated crops, such as cassava, yam, cocoyam, sweet potato, taro and frafra potato, are under field conservation. The frafra potato is a new collection. For the other crops, there has been a loss of more than 80% of the accessions over time. For the reviewers, there seemed to be significant challenges in field maintenance that need to be addressed for all crops conserved.

The lease for the land at the research field site at Bunso expired in 2004. This needs to be urgently renewed given the ongoing rate of development around the site that could result in a reallocate of this land if there is no lease in effect. This will still be required for the field collections. They have already lost the lease on the land where most of the medicinal, spice, and fruit trees were being conserved. They have been able to make arrangements to secure their conservation with the new tenants, who have set up the site as an eco-park, but this does not ensure their long-term conservation.

The field site is not secured so they have issues with trespassing and unauthorized harvesting. It is located next to a creek that is used for gold mining and the miners drag the dredging equipment through the field collections plots. This has resulted in a loss of cassava accessions in the past. There is a need to work with the adjacent communities to raise awareness on the value of the accessions conserved to reduce illegal harvesting. There is a need to fence off fields to secure field plots from trespass and unauthorized harvesting. Fencing for regeneration field plots is included in the Table 6 (item 34).

Yams seem to be more difficult to conserve at this site due to a high prevalence of Anthracnose observed in the field collection during the visit and the lack of a proper yam barn to store the roots after harvest. It was also clear that many of the cassava accessions were being affected by a virus. These will be lost if efforts are not made to clean them through an *in vitro* system or find a new supply of cuttings.

The field equipment is old and non-functional. Because of equipment breakdown, a lot of the work is carried out using 4x4 vehicles which is very inconvenient. Replacement of the Massey Ferguson tractor is the highest priority for field operations. Purchases of replacement field equipment in Bunso may be unwarranted when the seed crops conservation is shifted to another site.

Given the significant loss of accessions in the past and the significant constraints in the field seedbank, there is a need to have a secure *in vitro* laboratory to back-up all field accessions. They currently only have one room to use as a growth room. They have plans to build another room that was planned initially with World Bank funds, but they have not had the funds. The rooms that were built for seed storage could work very well as *in vitro* slow growth rooms.

The *in vitro* laboratory is not fully operational, and it faces challenges, such as contamination of tissue culture material. It also lacks capacity for virus indexing. Some equipment such as the autoclave and UV lighting are not operating optimally. Air conditioning is inadequate. In

addition, PGRRI Tissue Culture Section needs an autoclave; a water distillation unit; magnetic stirrer; pneumatic dispenser; servicing and repair of the laminar flow cabinet; purchase of one more laminar flow cabinet; and a microwave oven. *Table 6 (items 29-30) includes provision for an autoclave, magnetic stirrer, pneumatic dispenser, laminar flow cabinet and microwave oven. These is also need for procurement of consumables.*

Of those in the field, 249 (55.5%) accessions are backed-up in *in vitro* conservation. Only taro is fully backed-up. Only 10 accessions of sweet potatoes have had a field grow out to verify identity. The cassava accessions have been in culture for more than 10 years. The priority for culturing needs to be applied to yams but PGRRI can only focus on this when they have project funds. They have a small screen house for growing plants to put into culture and to harden when they grow out to take back to the field.

The lack of safety duplication for the field seedbanks is a very high risk that has already resulted in a significant loss of accessions. Lack of capacity for virus indexing means the quality of the conserved material cannot be guaranteed. Vegetatively-propagated crops suffer from significant virus and other disease issues that are difficult to manage for the long-term conservation of the accessions in the field collections. The low capacity of backing- up accessions from the field in the *in vitro* facility is increasing the risk of loss of accessions arising from diseases such as anthracnose in yam. Inadequate equipment to carry out *in vitro* conservation is of concern.

Recommendation 15: The reviewers recommend that CSIR and PGRRI urgently renew the lease of the critical research field sites where the field collection is located before any further investment can be made into the upgrade of the Bunso site in the S4R project. The reviewers also recommend that prior to any upgrade, a long-term plan needs to be made to securely conserve vegetatively propagated and tree crops. Significant support should be solicited from IITA to provide technical guidance for the long-term planning and the action needed to secure these accessions in the field for the long-term. The planned actions should include an assessment of the risk of conserving these crops at the Bunso site and implementation actions to be taken to mitigate these risks such as:

- **Building a secure, appropriate yam barn to store the yams after harvest until they are replanted to the fields.**
- **Development of improved protocols to manage the plant health of the accessions in the field to reduce the impact of disease and virus infection.**
- **Urgent virus indexing for cassava where the best option initially could be to outsource to the CSIR-CRI at Kumasi, which has a state-of-the-art *in vitro* laboratory.**
- **Development and implementation of a five-year plan to transfer 40-50 accessions per year into *in vitro* culture with the focus on priority unique accessions. In addition, the plan needs to identify and implement a safety backup for the *in vitro* cultures.**

Documentation

All of the accessions have passport data reported to GBIF but none of this is Multi-Crop Passport Descriptor (MCPD) compliant so cannot be shared with Genesys. About 50% of the accessions have been characterized with key morphological descriptors but none of this is available in a searchable database, although it has been digitized. Further it was reported that 195 accessions (113 for cowpea and 82 for taro) were genotyped using molecular markers. Characterization data is maintained on individual scientists' computers, the Director's computer, reports, brochures and pamphlets.

The first priority is to harmonize standards to MCPD, without losing information and to add, if necessary, significant missing MCPD descriptors from the original collection sheets. This will allow publishing on Genesys to share accession level information globally and will also a

secure back-up the database. They will need to indicate in the database if an accession is available, or an historical record.

They need to strengthen phenotypic and molecular characterization and evaluation and documentation to facilitate use. Lack of available characterization data being used in management risks the loss of genetic integrity and identity for accessions during regeneration. The users have limited knowledge available to enhance utilization of accessions and that risks future productivity and supply for key crops.

In PGRRI, all data is entered by each unit on paper forms. Some of this data is entered in Excel spreadsheets, but it is not clear which data is entered on which computer and who uses it. The only information handled by the documentation unit appears to be passport data, which covers all the accessions, which is uploaded to and published by GBIF. Unfortunately, the format of the data is not fully compatible with the MCPD standard, thus, as such, it cannot be published on Genesys.

While passport information is available with the documentation officer, all other accession level data is scattered on paper forms, in uncertain condition due to the humid climate, at the institute. About half of the accessions have been characterized with key morphological descriptors and, although the data has been digitized, this information is maintained on individual scientists' computers and on the Director's computer. In the baseline survey, they indicated that 195 accessions (113 for cowpea and 82 for taro) have been genotyped using molecule markers but it not clear where this data is stored. The accession level information from the research institute is still largely inaccessible and there is no mechanism for sharing knowledge about the accessions within the collections between divisions and staff. The unavailability of accession level information to users internally, nationally, and internationally limits knowledge and use of the germplasm.

The fragmented nature of the different units and the organization of the activities make it difficult to implement an integrated documentation system in the short run, so the first step is to implement a working documentation system using paper, Excel sheets and eventually Access databases. Then, in a future phase, it might be possible to migrate the current documentation system into a dedicated information system such as GRIN-Global. This strategy would allow the documentation unit to be responsive, while procedures and activities are revised and rationalized, without the constraint of having to conform to the rules of the management system. This approach will also raise the awareness of the staff on good and effective information management, preparing them to the time for when a system such as GRIN-Global could be adopted and implemented.

Given the number of accessions that have been lost, it seems that neither seedbank procedures nor documentation system operate in a manner that secures the accessions. External support is needed to guide the staff in implementing a sound workflow and develop an accession level information system that allows for monitoring and effectively supporting decision making. This could be provided by an expert that would revise, along with the staff, all steps necessary to safely and efficiently conserve germplasm, identifying, in the process, all the necessary information elements that must be recorded. This expert should be familiar with seedbank operations and expert in documentation systems and data management.

The reviewers recommend that an expert in seedbank operations and GRIN-Global visit the seedbank and analyze with the staff the current workflow and documentation practices to migrate the current activities under GRIN-Global. The role of the expert would be essentially to guide current staff in rationalizing the activities, to correct or add eventual missing steps and to translate this into a workflow that integrates with the features of GRIN-Global. The expert's experience in implementing that system should be tapped, so that the correct modules are covered in the right order, while the staff are trained on the tool using the actual data in the actual environment. Thus, the reviewers recommend a GRIN-Global Specialist consultancy with an expert who is also familiar both with seedbank operations and GRIN-Global to work directly with PGRRI (Table 6- item 50) with the following term of reference to:

- Rationalize the responsibilities of the various units to create a working environment that matches the features and organization of GRIN-Global
- Facilitate the full implementation of GRIN-Global.

Hard copy data sheets and logbooks are not securely stored or duplicated. Besides the issue of storing information on paper, digital information is stored in electronic sheets that cannot be shared and used efficiently. The fragmented nature of the different sections and work will make it difficult to implement an integrated documentation system. A local area network needs to be established connecting all workstations and the server together, to allow sharing accession level information among units and to enable multiple staff members to manage information at the same time. The server should host a common area where Excel sheets are stored and available to be updated by the relevant staff and read or copied by all staff, so that this information is available to the whole institute. The reviewers recommend that all computers operating in the seedbank should be connected to the same network, as well as to the server that should act as the shared data repository. The reviewers recommend that additional temporary staff be hired to digitize as much information as possible, to reduce the amount of information stored on paper and ease the migration to an information system such as GRIN-Global. The local area network is also required for this.

A Wi-Fi router (Table 6, item 40) could establish a LAN that covers a wide area, providing flexibility and options in the placement of the computers. A server and four workstations (Table 6, item 35-39) can establish a set of data entry stations and a common data repository. All of the important data should be centralized on the server and eventually copied to the workstations. This would allow aggregation of datasets which currently are distributed among the scientists' computers. A couple of rugged portable hard drives (Table 6, item 41) could perform full back-ups of the server, to provide the option of a full server restore in case of problems. Such a management system would also allow automatic publication of passport and characterization data on Genesys if the server was connected to the internet, thereby increasing awareness and requests for accessions.

Recommendation 16: The reviewers recommend that all efforts are made by PGRRI to enhance internet connectivity to the server to allow for the full implementation of seedbank information systems such as GRIN-Global.

When a dedicated seedbank management system has been installed, the barcoding system (Table 6, item 44-47) could be integrated, to better manage automation and accession identity. *The use of electronic tablets in the field and in the labs could be integrated in the documentation system to considerably reduce the reliance on paper when capturing information (Table 6, item 42-43). There is also a need for a camera dedicated to capturing images to be shared on accessions as well (Table 6, item 48).* For the long-term strengthening of the seedbank information systems, the best option would be to partner with IITA or Africa Rice, to receive assistance in implementing an integrated documentation system linked with barcoding and field electronic notebooks. This would take the form of expert advice and organizing placements of staff at IITA or Africa Rice for training. The reviewers recommend that PGRRI strengthen their past collaborative framework with IITA and AfricaRice to include all documentation areas. GRIN-Global, barcoding and the use of electronic tablets are areas that will benefit from that collaboration.

Buildings including safety, security and services

The institute has operations spread between three or four different building complexes. The administration building also seems to include the documentation group. The tissue culture facility (not finished completely) is in the biotechnology building. The plant diversity group has rooms in a separate building that used to also house the server and documentation specialist. The seed unit has a few rooms in an old building that includes another organization. The freezers for seed storage are located in two separate buildings. The plant health unit has a very old set of rooms adjacent to a very full warehouse of old farm equipment. If the seed conservation activities are not completely shifted to SARI, there will

be a need to reconsider the placement of activities and units to improve flow-through for the seed conservation section and the tissue culture facility.

The institute is in a compound where it hosts a number of other organizations. Most have new purpose-built facilities. The complex of buildings is not secured with fencing or with secure gates. Although PGRRI felt that the buildings relating to the seedbank operation were secure, the review feels that the institute needs to increase the security of the site and that of the various room used e.g., those used for the long-term freezers as well and the *in vitro* rooms.

There was also mention made of a leak in a roof and PGRRI need to confirm that it has been repaired.

The smoke alarms alert the night security guard and are tested. There is only one fire extinguisher of a powder type. Although CO_2 type extinguishers were mentioned there is uncertainty about their availability. Further fire extinguishers need to be purchased (see Table 6 – *item 24*).

There would appear to be no audible alarms on the freezers and what happens in the event of a freezer or *in vitro* equipment breakdown out-of-hours is uncertain. Other risks were explored including a nearby water tank which, although near the building, is not considered to be an impact risk. Impact from vehicles is considered unlikely and flooding was not thought to be a risk with no history of previous floods on site.

PGRRI need to carry out a full analysis of the risks both to staff and the collection carefully considering the likelihood of events occurring (and pairs of events) and the potential severity of their effects. They then need to put measures in place to mitigate against these risks.

Apart from the unsuitable conditions for seed work at the Bunso site, perhaps the biggest issues for the seedbank are the erratic supply and high cost for electricity and fuel. There are a number of generators for the complex of buildings. The newest is a generator obtained in 2014 for the cold room they built then. All of these are regularly maintained by a company based in Accra. All the generators have to be switched on manually when electricity goes off. Night security is trained how to do this though lack of an automatic switch is a risk. However, there would appear to be both problems with paying for electricity (government expects institute to fund it) and purchase of fuel for the generator.

CSIR has initiated a process to increase the use of alternative energy and to install the recommended system when funds available. The seed store has 24 panels (2015) installed on the roof with inverters and batteries installed in the seed processing room. It is not working due to a repair required to one of the inverters. It was initially intended for the tissue culture facility but was installed in the wrong place over a weekend. The system is set up to power the complex of rooms that include the drying room and freezers, but its capacity was not designed for that. If solar power is to be used to secure the freezers (as a back-up collection), then an investment must be made to establish a system that generates and stores enough power for new solar compatible freezers. *The use of solar energy for much of the seedbank energy needs to be investigated by means of an energy assessment that will include the design of an appropriate system (see Table 6 – item 3) for Bunso and the new SARI site.* Other project funds for purchase and installation would then need to be sought. Subsequent purchases of new equipment would then need to be energy efficient and solar-power compatible or even directly solar-powered.

Table 6. List of recommended infrastructure, equipment, supplies, and services to procure in upgrade. (Table excludes most consumables.)

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
1	Germination Room	Room conversion	(a) Local	2,000	-	-	2,000	Including benches and LED lighting
2	Refrigeration and air-conditioning consultancy		(a) Club Refrigeration, RSA	9,400	-	-	9,400	Assume return scheduled SAA flight RSA to Ghana = GB£ 1,487 = Euro 1,651; travel in-country = Euro 100; per diems x 4 nights = Euro 150 x 4 = 600; consultancy charges = Euro 1,000 per day x 7 days = 7,000. Total = Euro 9,351 say 9,400. Could visit other banks as well – one contract (more cost-effective)
			(b) Various potential RSA					

[6] Exchange rate assumptions: Euro 1 = US$ 1.11; Euro 1 = GB£ 0.86; Euro 1 = CDN$ 1.45

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
			Refrigeration companies online					
3	Solar-energy consultancy		(a) ?	5,000	-	-	5,000	Notional
4	Installation costs of following 4 items		(a) Club Refrigeration	100,000	-	-	100,000	Notional sum including shipment of items. Considerable error margin
			(a) Various potential RSA Refrigeration companies online					
5	Insulated structure & refrigeration	Insulated Cold and Drying Rooms including refrigeration, floors, door and vision panel. Air Lock. Shelving for the Cold Rooms.	(b) Club Refrigeration, RSA	200,000	1	-	200,000	Depends on advice received. Potentially fundable outside project. Notional sum – considerable error margin
			(c) Various potential RSA Refrigeration companies online					
6	Munters unit	Model tbc	(a) Club Refrigeration, RSA	5,000	2	-	10,000	Depends on advice received. Notional sum
			(b) Munters RSA					

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
7	Control panel	Model tbc	(a) Club Refrigeration, RSA (b) Munters RSA	1,000	1	-	1,000	Depends on advice received. Notional sum
8	Air-conditioning	Model tbc	(a) Club Refrigeration, RSA (a) Local supplier	1,500	3	-/Local	4,500	Depends on advice received. Local purchase
9	Silica gel	Indicating	(a) Baltimore Chemicals, UK (b) tbc	500	-	100	500	Depends. May be unnecessary if Drying Room improved.
10	Water purification unit	E.g., SLS Lab Pro 20T3 PurA-Q3 Reverse Osmosis + 35l storage	(b) SLS, UK (c) Try VWR / Avantor (but for different model)	4,000	1	1,000	5,000	Requires given water flow and pipe fittings. Also electricity supply.
11	Stereomicroscope	Nikon SMZ445	(a) Nikon Instruments Europe BV, NL (b) Try VWR / Avantor	1,000	1	250	1,250	May require light source within stand
12	Aspirator	Agriculex CB1	(a) Agriculex, Canada	3,500	1	1,000	4,500	Export to Africa? Do they require the CB-3 for larger seeds? Hoffman machine is

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
								cheaper at US$1,950
		Oregon Seed Blower	(b) Hoffman, USA					
13	Sieves	Endecott	(a) SLS, UK	100	10	1,000	2,000	Sieve dimensions / pore size to be advised
			(b) Endecotts, UK (RSA distributor)					
14	Balance (3 decimal place)	E.g., Ohaus Scout STX123 (max 120g)	(a) Fischer Scientific, UK	600	1	100	700	Institute needs to confirm exact requirements
			(b) Try VWR / Avantor					
15	Seed counter	Contador	(a) Pfeuffer, Germany	8,000	1	250	8,250	16kg but Check seed sizes required
			(c) (b) Hoffman, USA					
16	Moisture meter	E.g., Burrows DMC-750 or Gemini Tiny Tag View 2 TV-4500 plus probe	(a) Seedburo	250	1	50	250	Notional. Can't find Burrows machine on Seedburo website. Used by CIAT. Perhaps instead purchase modified Gemini data logger (extra to that below), probe and Wheaton Vial
			(b) Gemini Data Loggers, UK					

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
17	RH / Temperature logger	Gemini Tiny Tag View 2 TV-4500	(a) Gemini Data Loggers, UK (RSA distributor) (b) TBC	200	1	50	250	
18	Stackable crates	E.g., 600x400x154 ventilated HDPE	(a) Schoeller Allibert, NL (b) Local	15	50	200	950	Depends on above. Freight may be prohibitively expensive and >>Euro 200 given quantity
19	Trollies for crates	600x400	(a) Schoeller Allibert, NL (b) Local	45	5	150	375	Similar comments to above
20	Foil bags	Type 321/04 (Moore & Buckle)	(a) Moore & Buckle, UK (b) ?	3,000	-	250	3,500	Notional
21	Foil bag sealer	HM305CTD	(a) Hulme Martin, UK (b) ?	1,250	1	250	1,500	Do they export? 10.7kg DHL cost (up to 12kg) £139
22	Upright deep-freezers	Bosch – Model tbc Whirlpool	(a) Bosch (b) tbc	1,000	2	Local?	2,000	Notional
23	Cold room clothing	tbc	(a) tbc (b) tbc	500	-	100	600	Depends on functioning cold room
24	Fire extinguishers	TBC	(a) Local or regional supplier	100	4	Local	400	
25	Face masks	tbc	(a) 3M, UK	30	20	200	800	

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
			(b) Local					Preferably re-usable half masks with replaceable filters
26	Building work at the Bunso site		(a) Local	1,000	-	Local	1,000	Notional
27	Compound microscope	tbc	(a) ?	1,000	1	250	1,250	Notional. Depends what is required for seed pathology work
28	UV light	tbc	(a) ?	500	1	100	600	Notional. Uncertain of requirements. For seed pathology work.
29	Autoclave	(>24 litre) e.g., Astell Classic 33 litre	(a) SLS, UK (b) Try VWR / Avantor	7,000	1	1,000	8,000	Institute needs to confirm exact requirements
30	Magnetic stirrer	E.g. Stuart US152 Hotplate	(a) SLS, UK (b) Try VWR / Avantor	350	1	50	400	Institute needs to confirm exact requirements. May need stirrer rods
31	Perimatic dispenser	E.g., Jencons	(a) VWR, UK	5,000	1	1,000	6,000	

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
			(b) Cambridge Scientific, UK					Notional sum only. Institute needs to confirm exact requirements. Would need to get quote from companies.
32	Laminar flow cabinet	TBC	(a) SLS, UK (b) Try VWR / Avantor	6,000	1	1,000	7,000	Institute needs to confirm exact requirements. Notional sum
33	Microwave oven	TBC	(a) Local	200	1	Local	200	Notional sum
34	Fencing for regeneration plots	-	(a) Local	1,000	-	Local	1,000	Notional sum
35	Server	Dell Precision 3630 Tower Intel Core i7-9700 8Cores/8Threads 4.7GHz 12MB Cache; 16 GB DDR4 2,666 MHz RAM; 512 GB SSD		1,500	1		1,500	Server workstation to host seedbank management software and common storage pool.
36	Workstation	Dell Vostro Desktop 3471; Intel Core i7-9700 8Cores/8Threads 4.7GHz 12MB Cache; 8 GB DDR4 2,666 MHz RAM; 1 TB 7200 U/min HD		620	2		1,240	Data entry and application hosting workstations (Excel, Access, and other office applications); also potential servers.

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
37	Workstation	Dell Vostro Desktop 3670 MT; Intel Core i5-9400 8Cores/8Threads 4.1GHz; 8 GB DDR4 2,666 MHz RAM; 1 TB 7200 U/min HD		500	2		1,000	Data entry and application hosting workstations (Excel, Access, and other office applications).
38	Monitor	Dell 24 Monitor		100	5		500	Monitors for workstations and server.
39	Uninterrupted power supply	Eaton Ellipse ECO 800 USB UPS AC 9230 V (500W)		150	5		750	To power server and workstations during electricity outages. Should handle at least 500W.
40	Router	Nighthawk X4S AC2600 WiFi VDSL/ADSL Modem Router		330	1		330	Local Area Network router. The important feature is that it has a long communication range. A cable-based LAN is also an option and might be necessary due to the

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
								whereabouts of buildings.
41	Backup Hard Drives	Silicon Power Armor A60 IPX4 Shockproof/Waterproof 2.5 USB 3.0 Military Grade Portable Hard Drive – 2TB.		120	2		240	What is important is that the model is rugged, it should be water and shock proof. At least 2TB of storage to be twice the size of the hard drive to back up.

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
42	Electronic tablet	Zebra TC75		1,500	2		3,000	For use as mobile data input devices. These devices could be used when the seedbank management system is operational, thus the model depends on the compatibility with the management software.
43	Electronic tablet	Zebra ET50		3,500	1		3,500	For use as mobile data input devices with more complex input forms.
44	Barcode reader	Zebra Symbol LS2208		100	5		500	To be used to read barcoded labels.
45	Barcode portable printer	Zebra Series ZQ500		600	2		1,200	Use direct thermal printing for short term usage indoors.

	Item	Proposed purchase	Potential supplier	Est. item cost[6] (Euro)	No. items	Est. shipping & import cost (Euro)	Total cost (Euro)	Comment
46	Barcode printer	Zebra Series ZT410		1,200	1		1,200	Use thermal transfer resin labels for long-term storage or field use.
47	Printer/Scanner	Brother DCP-L5500DN DCP A4 Mono		300	1		300	Multifunction monochrome laser printer. To print forms that will be filled, then transcribed on the computer, for scanning and archiving documents, for general printing necessities.
48	Camera	Nikon Coolpix W300; Digital Camera (16 MP, 5x Optical Zoom/7.6 cm (3 Inch) LCD Display, 4K UHD Video, Image Stabilization, GPS)		350	1		350	To use when collecting and characterizing, to add images to germplasm information.
49	Seed Health Specialist Consultancy				1		16500	
50	GRIN-Global Specialist Consultancy				1		16500	
Total							438,785	

Distribution, Communication, and Use of accessions and linkages with its users

There are weaknesses in the level of promotion of use of accessions to users. The information from the research institute is still largely in inaccessible form and there is no mechanism for sharing knowledge about the collections. Some key actions would be to publish on Genesys in order to increase access to accession level information to all users. Limited knowledge about the value of the collections risks the continued valuing of, and support for, the conservation of the collection.

The main approaches currently used to promote accessions is to invite potential users to observe grow-out/characterization plots or to attend open days and demonstrations; to provide users with printed booklets or pamphlets describing the types of germplasm held in the collection; or through policy briefs, participation in exhibitions, national events, attachment of students from universities, and Research and extension linkages committee (RELC) meetings. Other pathways include radio talk shows at regional and district levels. At international level, publications, presentations at regional and international meetings and social media are used.

For all users, the reviewers recommend that accession level information be published online and updated regularly in a searchable database on the CSIR website and Genesys as discussed in the section on the baseline indicators. In addition, the reviewers recommend greater efforts be made to increase national awareness of the seedbank and the accessions conserved through key actions such as:

- With support from the Crop Trust, prepare a standard presentation on all aspects of the national collection conservation and use to be presented at various fora.
- Develop awareness materials and communication pathways tailored to different user groups including farmers/NGOs, seed producers at agroecological level; breeders/ scientists; and policy makers.
- Share information on accessions in both print and electronic media that is tailored more to the users' needs.
- Compile a list of key journalists to be contacted to write stories about the seedbank services and diversity available, for publication in local media.
- Prepare a calendar of agriculture-related events where the national seedbank can be presented, and its services and seeds showcased.
- Develop a mobile phone app that recommends seed material to users (e.g. farmers, NGOs, breeders) according to local agroecological conditions and availability.
- Ensure an online presence via social media, such as Facebook, Twitter and Instagram.

Effective engagement with other conservers nationally and internationally

Nationally, there are a number of CSIR Institutes and Universities that conserve crop genetic resources. PGRRI has a mandate to serve as the National Genebank and coordinate plant genetic resource activities in Ghana but it has very limited engagement with the other conservers nationally. Although some accessions are duplicated at IITA, ICRISAT and Kew, there appear to be no strong links with these conservators in effective management of the accessions. There is missed opportunities for technical support and skills upgrade from international conservers that are often offered to national seedbanks. Limited international linkages and knowledge about the collections risk support and use of collections for future agricultural development.

NACGRAB in Nigeria has a similar challenge to PGRRI where at least 12 other organizations or institutes in Nigeria are involved in conservation and use of plant genetic resources. NACGRAB is planning to hold a stakeholder meeting in Abuja in 2020 to develop a national strategy for crop genetic resources conservation and use. This is an excellent opportunity to not only raise the visibility of the opportunities and challenges for genetic

resources in Nigeria, but it will also give NACGRAB an opportunity to facilitate greater collaboration amongst the many conservers nationally. CSIR and PGRRI should consider the need to also develop an initiative to bring together national and international conservers of genetic resources to plan for coordinates and secure long-term conservation and use.

Recommendation 17: The reviewers recommend that PGRRI and CSIR lead the development of a national strategy for ex situ crop genetic resource conservation and use. This strategy development should be used to initiate joint actions of PGRRI with other collection holders to better secure ex situ conservation and use of key crop diversity in Ghana. These activities could include better coordination of conservation, greater sharing of accession level information, annual updates on the conservation status of accessions in the various collections, and increased safety duplication.

Engagement with stakeholders at local, national, and international levels in an effective manner

The Director of PGRRI is the focal point for the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). PGRRI has been involved in a number of networks, such as the International Network for Edible Aroids, the Korea-Africa Food and Agriculture Cooperation Initiative-Improvement in Conservation (KAFACI) and the Genetic Resources Network for West and Central Africa (GRENEWACA).

PGRRI had one meeting with stakeholders in 1995 but they have not had funds to do it again. Farmers come to ask for information and to buy plant material. CSIR policy is that no material can be given to farmers directly unless it is a released variety. They have been involved in projects that multiplied accessions for farmers' trials. In the International Network for Edible Aroids Project, they worked with extension agents and farmers at the primary multiplication field sites to raise awareness for new resistant varieties.

They also have communication activities to raise awareness of accessions and plant material for sale, such as showcasing products and information at national events and on radio and television. They have an open day in October during which visitors are given tours of the laboratory and field site. PGRRI attends the research Extension Link Committee (RELC) meeting at the district and regional level. They have students on attachment for short-term training from various universities. The staff also attend regional, national and international conferences and short-term training when possible.

Annual events are the mechanisms for engaging with stakeholders through organizing open days and group visits to the seedbank facilities. During such events, usually organized at the institute level, engagements on seedbank issues are rarely discussed. Publications from the institute are also made available during such field days. At the international level, the institute staff attend workshops and meetings related to plant genetic resources where they are expected to network with other research organizations or users. A more effective engagement requires a robust mechanism to create a network of stakeholders around national collections. Limited engagement with stakeholders is a risk to support for long- term conservation and use of the collection.

To enhance the engagement of PGRRI with stakeholders at the national, international, and local levels, the reviewers recommend the development of a participatory and cost-effective communication strategy to facilitate dissemination of appropriate information suited to each users group. Key activities are:

- Enhance collaboration and engagement with national and international stakeholders, including the private sector and CGIAR centers that are operating in Ghana
- Participate in regional events/shows related to plant genetic resources and climate change.
- Active engagement with regional and international plant genetic resources networks/platforms.

The main users of the accessions are breeders/scientists within the CSIR institutes and within the country. There appears to be no mechanisms for effective engagement with these users to increase knowledge on the accession for future use. The seedbank seems to be considered a mere seed store. Lack of effective engagement with the users to share knowledge about genetic resources management and conservation results in limited support for sustainable conservation of the collections. There is also a missed opportunity on demonstrating the value of the accessions.

From the above assessment, we identified three distinct user-groups that can contribute to increasing the use and visibility of PGRRI, and ultimately contribute to a more climate-change resilient agriculture. These include: 1) Direct users group representing all stakeholders operating in different agroecological zones; 2) breeders/researchers' group which includes breeding companies and researchers from national agricultural research institutes and universities interested in using seed diversity to develop new varieties; and the 3) Policy-makers -user group comprising of decision-makers such as director generals of key institutions and representatives from the government and donors where possible, relevant to increasing general awareness of the value of national seedbanks. Implementation of a tailored communications strategy will facilitate effective linkages with the various user/stakeholder-groups.

Recommendation 18. The reviewers recommend that PGRRI organize facilitated meetings at agro-ecological zone level (2-3) with representatives of farmers' organizations, NGOs, local government agencies, local research institutions/universities, and local seed producers (max. 40 participants per zone). The reviewers also recommend that PGRRI constitute a technical working group of breeders/researchers at other national research centers, universities, and the private sector for characterization, evaluation and use of collections in crop improvement. In order to elevate the profile of the national seedbank and enhance awareness of the importance of supporting it, the reviewers strongly recommend that CSIR and PGRRI hold at least two facilitated high-level meetings with key policy makers during the implementation of the project.

The objectives of the first meeting at the agro-ecological zone could be to:

- increase awareness about national seedbank and activities (e.g. the seed material adapted to the agroecological zone and available for distribution; process to request and obtain seed samples);
- identify farmers' "repatriation" needs;
- identify crops and varieties of interest for multiplication;
- identify opportunities for collaboration among the stakeholders;
- identify mechanisms for registering farmers varieties;
- identify collecting gaps (e.g. unique seed material available in farmers' fields but not yet conserved in the seedbank);
- articulate the information needs and feedback mechanisms for each agroecological zone;
- agree on the *modus operandi* of each agroecological zone user group for information sharing and feedback.

Other key activities that should be considered include:

- Multiply/bulk seed of accessions of identified crop portfolios for distribution.
- Conduct participatory multi-location (2-3 sites in each zone) trials to identify farmer-preferred and climate smart accessions for direct use in the cropping system.
- With support from farmers' organizations and NGOs, organize field days to expose a larger number of farmers to diverse accessions.
- Provide technical support in the registration of selected accessions for large scale use.

- Provide technical support to development projects to enhance use of accessions and conservation services by smallholder farmers.
- Provide technical support to programs engaging farmers in participatory evaluation and multiplication of local landraces for direct use.
- Participate in any annual biodiversity fairs in each agroecological zone.
- Engage researchers at Research Institutes, Universities, or private companies in adjacent areas to review germplasm being regenerated at the stations.

As noted earlier, PGRRI needs to establish formal processes to obtain feedback on the use of the germplasm in the breeding programs and to increase collaboration with national agricultural research institutions and private seed companies in the country. It is also essential to institute a formal agreement with researchers to share results and data for inclusion in the database.

We propose at least one annual meeting of the Technical Working Group to convene around 10-15 key breeders/scientists from CSIR agricultural research institutes, universities and any other institution conducting plant breeding in the country. The objectives of this user-group should be to:

- obtain direct feedback on minimum traits that breeding users need to make decisions on seed material requests;
- identify data needs;
- identify candidate seed material of interest to breeders;
- identify opportunities to create core collections;
- collaboratively introgress new genes in crop improvement;
- coordinate participation in multi-location diversity and participatory plots;
- identify opportunities for joint germplasm evaluations;
- publish results from joint activities.

Contribution to climate change adaptation and resilient seed systems

There seem to be no concerted efforts tailored towards climate change adaptation through the use of accessions. Apart from participation in a project on adapting agriculture to climate change, where 132 accession of taro were evaluated for yield and disease tolerance, the seedbank has not been engaged in other programs focusing on climate change. This is partly because the climate change programs are under the Ministry of Environment. However, the seedbank provided technical support in data capture and engaging farmers in selecting taro accessions with preferred traits. A report on this project was not shared with the reviewers. The limited use of the collections reduced crop diversity, thus, renders cropping and seed systems less resilient to climate change. The low level of knowledge and use of the collection risk the long-term adaptation to the changes in climate.

Recommendation 19: To address the limited use of national collections to enhance crop diversity to mitigate the effects of climate change, the reviewers recommend that CSIR and PGRRI provide technical support in the evaluation, characterization, and multiplication of accessions of underutilized and climate-smart crops for direct use in the cropping system by the following actions:

- **Together with the Technical Working Group of breeders/scientists, identify a core collection of underutilized and climate smart crops (e.g. Bambara, cowpeas, sorghum, pearl millet, popular vegetable land races, and some crop wild relatives) for use in crop improvement.**
- **Multiply/bulk seed of selected accessions for distribution.**
- **Together with breeders/researchers, conduct phenotypic/genotypic characterization for climate smart traits.**
- **With user groups, provide technical support in the evaluation of characterized accessions for climate-smart traits with researchers, farmers' organizations,**

private seed companies, and NGOs that can then facilitate access to seed and knowledge to farmers.

- **With researchers, undertake introgression and genetic enhancement with selected accessions to develop diversified populations.**
- **Conduct participatory selection with farmers to identify preferred resilient varieties (medium-term).**
- **Seek registration and seed multiplication of selected varieties.**
- **With support from farmers' organizations, the private sector, and NGOs, facilitate access to seed and knowledge to farmers (long-term).**

Risk management

For CSIR, the internal audit department is responsible for risk management, which starts at the institute level. The audit by the Auditor General's office also considers risk management. CSIR utilizes a risk matrix that includes a risk register with pre- and post-mitigation risk levels, likelihood of occurrence, and state of preparedness. This risk matrix for CSIR was not shared and is not available publicly on their website. The Environmental Protection Agency is also involved with the disposal of pesticides.

At PGRRI, the Director is responsible for conducting the risk assessment. It is the responsibility of each head of function and their respective departmental heads to ensure risk assessment for the seedbank. The management team is responsible for the development of a risk management plan. The management team also reviews the risk assessment and management plan on an annual basis. They were not able to share any formal documentation or a risk management plan.

Some of the potential risks recognized and managed for the seedbank are:

- Intermittent supply of electricity.
- Unreliable water supply.
- Unreliable freezers and generators.
- Invasive alien species are recognized as a social risk.
- Disease and pest attack, especially in the field from e.g. *Phytophtora colocasia* and fall army worms.

It was noted that the seedbank facilities are also vulnerable to a range of threats such as freezer breakdown, unreliable power, fire, illegal harvesting, etc. A practical risk management plan for the conservation units such as the seedbank, field seedbank, and tissue culture facility to mitigate the primary risks, needs to be developed as an urgent action. This should be done as part of the implementation of QMS and might involve the setting up of a standing committee on risk management with clear terms of reference. A number of the recommended actions given in the previous discussions were based upon the reviewers' consideration of risk. The review team has identified significant risks in Table 7 with level of risk before and after mitigation, suggested mitigation actions, likelihood of successful mitigation, and who is responsible for the risk management. These risks fall into a few key categories that are given in the Table 8. These are: risks that are external to PGRRI and the seedbank; those that are internal to the institute such as issues related to finance, administration, and policy; and finally, those that are related to the facilities, routine operations of the seedbank and its links to users. The suggested mitigation actions have also been taken into account in the development of the upgrade recommendation by the reviewers.

Recommendation 20. The reviewers recommend that a detailed risk management matrix (such as Table 8) is agreed upon and used as the basis for monitoring risk for the seedbank on an annual basis with updates provided as needed by PGRRI to the Crop Trust.

Table 8. Risk Management Matrix

Source of risk	Level of risk	Mitigation actions	Level of risk after mitigation	Likelihood of successful mitigation	Responsibility for risk management
External to PGRRI					
Loss of crop diversity in farmers field and in the wild	High	Long-term plan for collection of crop diversity with identification of priority gaps	Low	Medium	CSIR and PGRRI
		Secure conservation of accessions ex situ			
		Rationalize current collection to manage redundancy with other conservers			
Increased incidents of drought	High	Access to irrigation in regeneration sites	Low	High	CSIR and PGRRI
		Enhance testing and use of accessions with drought tolerant traits by researchers and farmers			
Inadequate and expensive electricity supply	High	Designate PGRRI seedbank facilities to have government waiver for electricity payment	Medium	Medium	CSIR and PGRRI
		Greater investment into energy efficiency and alternative energy by CSIR and project			
		Safety duplication of unique accessions to seedbank outside Ghana			
High cost of fuel	High	Greater investment into energy efficiency and alternative energy by CSIR and project	Medium	Medium	CSIR and PGGRI
		Safety duplication of unique accessions to seedbank outside Ghana			
Insecurity and encroachment at Bunso	High	Secure building and cold rooms with strong locks and/or keypad access	Medium	High	CSIR, PGRRI, and Crop Trust
		Secure field sites with fences			
		Increased monitoring of regeneration sites			
		Safety duplication of unique accessions to seedbank outside Ghana			
Institutional administration, finance, and policy					
Inadequate and inconsistent annual government spending for the crop seedbank in CSIR	Medium	Ensure government funding obligation in the project agreement	Medium	Medium	Crop Trust, CSIR, and PGGRI
		Increase visibility for PGRRI seedbank, its value, and its needs by CSIR to Ministries and Parliament			

Source of risk	Level of risk	Mitigation actions	Level of risk after mitigation	Likelihood of successful mitigation	Responsibility for risk management
Unclear financial situation of PGRRI due to the absence of externally audited yearly Financial Statements	Medium	Establish and publicly share external audits of financial statements for both CSIR and PGRRI on a yearly basis.	Low	Medium	CSIR
Inadequate implementation and/or financial reporting	High	Quarterly technical and financial monitoring by Crop Trust	Low	High	Crop Trust
		Annual audit by Crop Trust			
		Annual review of implementation by Crop Trust on site			
		Clear terms and conditions in project agreement on disbursement of funds and replenishment			
Inadequate management of key assets of project	Medium	Clear terms in project contract on management of assets procured, maintained, or repaired by project	Low	High	Crop Trust and PGRRI
		Clear terms for donation of assets to seedbank in PGRRI at end of project			
		PGRRI asset management audited for compliance and internal controls			
		Regularly scheduled maintenance of equipment			
		Timely repair when needed			
Bureaucratic procurement process	High	Crop Trust to handle project procurement directly	Low	High	Crop Trust, CSIR, and PGRRI
		Project agreement specifies custom clearance process for procurement, especially the payment of duties			
		Procurement includes cost for shipping and custom clearance			
Inconsistent implementation and monitoring of compliance with	Medium	Risk management plan for seedbank with annual monitoring and updates	Low	Medium	CSIR and PGRRI

Source of risk	Level of risk	Mitigation actions	Level of risk after mitigation	Likelihood of successful mitigation	Responsibility for risk management
environmental, human safety, and social risk according to government policy		Clear documentation and implementation tools regarding compliance with operational (e.g., procurement, health and safety, etc) and ethical (e.g., anti-terrorism, sexual harassment, financial irregularities, etc.) requirements utilized at CSIR and PGRRI, including awareness raising among staff, defining ownership of reference documents, defining responsibilities, setting up processes to ensure compliance, defining ownership of these processes, and ensuring annual reporting and updating			
Links to users					
Inadequate engagement with stakeholder for long-term support for crop conservation and uses	Medium	Long-term plan (10-20 years) for crop seedbank with implementation monitored transparently by key users and stakeholders	Medium	High	CSIR and PGRRI
		Increased collaboration with CRI, SARI, Universities, NGOs, and private sector to link to smallholder farmers and communities			
Inadequate communication on the seedbank, its accessions and any impacts to users, policy makers, and other key stakeholders	Medium	Communication strategy with implementation plan and key performance indicators	Low	High	CSIR and PGRRI
		Greater use of social media to raise awareness of the collection to areas outside Bunso			
Inadequate feedback to and from user	Medium	Establish a formal process to solicit feedback from recipient of accessions	Low	High	PGRRI and CSIR
		Establish process to feedback on the value of accessions to both the donors and users of germplasm			
		Monitor and report on the impact of the use of conserved accessions			
		Greater engagement with users through stakeholder meeting or through advisory group for the seedbank			
Inadequate accession level information for users	Medium	Recovery of data generated by recipients of accessions	Low	Medium	CSIR and PGRRI

Source of risk	Level of risk	Mitigation actions	Level of risk after mitigation	Likelihood of successful mitigation	Responsibility for risk management
		Formal agreements with research recipients on sharing research results and data for inclusion in seedbank information system			
		Collaboration with universities and others to increase opportunities for student projects			
		Access to accession level information increased with Genesys and PGRRI own website			
PGRRI Facilities					
Insecure long-term access to appropriate land resources for regeneration, multiplication, and other field related activities for the seedbank	Medium	Renew lease for field sites in Bunso with corresponding traditional authority	Low	High	CSIR, PGRRI, and Crop Trust
		Ensure clear commitment by CSIR and other relevant governmental agencies to make available appropriate land resources for long-term use by PGRRI			
		Provide sufficient resources to CSIR research institutes, its stations, and PGRRI to maintain land resources and ensure seedbank access for the long-term			
Fire	High	Adequate firefighting equipment	Medium	High	CSIR, PGRRI, and Crop Trust
		Internal and external alarms and sounders			
		Adequate fire safety training			
Theft and vandalism targeting ICT equipment, laboratory, conservation facilities, and seed samples	Medium	Increased security of key rooms and buildings with external locks, alarms, and sounders	Low	High	CSIR, PGRRI, and Crop Trust
		Restricted access to the seed stores with key pad access			
Routine operations					
Increased backlogs in routine conservation operations with required on research projects and income generation	High	Priority given to secure, cost effective routine operations for conservation in PGRRI annual performance contracts with CSIR	Medium	Medium	CSIR, PGRRI, and Crop Trust
		Clear costing for routine operations after upgrade			
		Annual transparent monitoring for key performance indicators for routine operations by Crop Trust and CSIR			

Source of risk	Level of risk	Mitigation actions	Level of risk after mitigation	Likelihood of successful mitigation	Responsibility for risk management
Insecurity and encroachment at field seedbank site in Bunso	High	Secure field sites with fences	Medium	Medium	CSIR, PGRRI, and Crop Trust
		Increased use of regeneration sites outside Bunso			
		Increase dialogue with local communities			
		Safety duplication of accessions to IITA			
Continued loss of viability of accessions in seedbank	High	QMS implemented for conservation processes at seedbank	Medium	Medium	CSIR, PGRRI, and Crop Trust
		Secure accessions in field seedbanks			
		In vitro conservation with virus cleaning			
		Upgrade of conservation facilities, equipment, and processes			
		Shift seed crop conservation to SARI site			
		Regeneration shifted to CRI, SARI, or others			
Conservation and distribution of seed with unknown seed health, especially for seed-borne diseases or virus.	High	Upgrade facilities, equipment, and processes to monitor and document the plant and seed health status routinely	Low	Medium	CSIR, PGRRI, and Crop Trust
Inadequate monitoring of seed quantity	High	Upgrade facilities, equipment, and processes to document 100/1000 seed weight and packet weight	Low	High	
		Initiate processes to document any change in seed quantity with distribution			
Loss or change in genetic integrity for accessions with poorly established and managed regeneration sites.	High	Implement standard operating procedures for regeneration for a range of mating types	Medium	High	CSIR, PGRRI, and Crop Trust
		Develop 5 year plan to regenerate at least 600 accession per year securely			
		Establish formal collaboration with partners at field sites with the sharing of guidelines and training on secure regeneration/multiplication			
		Utilize isolation cages for insect pollinated accessions			
Inadequate safety duplication	High	Prioritize unique accessions by crop and arrange for safety duplication with institutions outside of Ghana to serve as a primary black box	Low	High	CSIR, PGRRI, and Crop Trust

Source of risk	Level of risk	Mitigation actions	Level of risk after mitigation	Likelihood of successful mitigation	Responsibility for risk management
		Dispatch seed to Svalbard			
Lack of management and monitoring of significant virus and disease issues of vegetatively propagated accessions	Medium	Initiate a long-term plan to utilize an in vitro conservation system to complement the field seedbank for the secure conservation	Low	High	CSIR, PGRRI, and Crop Trust
		Implement protocol to monitor and clean up accession for viruses in field collection			
Insecure and inefficient routine management of conservation of accessions	High	Upgrade facilities, equipment, documentation, and processes for key routine operations	Low	High	CSIR, PGRRI, and Crop Trust
Lack of a secure, dedicated seedbank information system to manage accession identity, facilitate secure and cost effective routine operations, and enhance access by users to accession level information	High	Upgrade facilities and equipment for documentation	Low	High	CSIR, PGRRI, and Crop Trust
		Install and fully utilize a seedbank information system such as GRIN-Global			
		Ensure secure back-up of documentation			
		Update data in Genesys and own website as required			

Annex 1

Terms of Reference

National seedbank review

The Global Crop Diversity Trust (Crop Trust) commissions the review of national and international genebanks as part of the process to assess their needs for upgrading and their eligibility to receive long-term support from its endowment fund. This review provides direct inputs to the development of subsequent seedbank upgrading workplans.

This initial national seedbank review is an activity of the "National Seeds Collections for Climate-Resilience Agriculture in Africa – Seeds for Resilience" project. "Seeds for Resilience" is funded by the Federal Republic of Germany, and its goal is to:

Empower national seed collections, by safeguarding them in perpetuity through an endowment fund, documenting and managing them appropriately for conservation and use, and promoting their use, to serve as a basis for climate change adaptation of vulnerable African cropping systems.

This review will take into consideration various aspects that affect the overall functioning of the seedbank, including technical, financial, organizational, regulatory, social and environmental aspects.

The objectives of the review are to:

- Determine the institutional arrangement and organizational capacity of the seedbank.
- Assess the basic organizational structure of the seedbank and its parent institute.
- Identify risks and constraints that prevent the seedbank from fulfilling its main objectives.
- Assess the seedbank's environmental, social, health and safety risks and procedures.
- Determine the main funding sources of the seedbank and the proportion dedicated to germplasm conservation activities.
- Determine the number of potentially viable, available and safety duplicated accessions, disaggregated by species and crops.
- Determine the uniqueness of the collection in the context of the global system for long-term conservation of plant genetic resources for food and agriculture.
- Review the adequacy of the facilities, equipment and field sites for both long-term conservation and active use of the collections.
- Assess the capacity of the seedbank staff to carry out activities for both long-term conservation and active use.
- Assess written and actual procedures as demonstrated by staff and determine if the level of operation is adequate for long-term and active use of the collections.
- Assess the level of use of each crop collection and existing linkages with its users.
- Provide the Crop Trust with key findings, actionable recommendations actions for priority and suggestions for mitigating risks of all of the above.

The review is to be conducted in five preselected national seedbanks, prioritized according to the importance and potential uniqueness of their collections, and for being part of the donor's "One world – no hunger" initiative.

Review implementation

A panel of external consultants, with relevant experience in the region and the aspects to be addressed in the review, will be appointed for the review. The project manager will facilitate the review providing background information from each seedbank, coordinating the development of the agenda, the execution of the overall review and assist the chair of the review panel in any aspects of the review and the completion of the final report. The Crop Trust will not take part directly in the formulation of the review report and recommendations.

The review comprises three phases:

I. General background and literature review

The reviewers will aid in the preparation of questionnaires to be sent to each national seedbank considered in the review. These questionnaires will aim to gather baseline information about the seedbank and its parent institute.

The reviewers will be provided with:

- The responses to the questionnaires.
- Genebank website and related materials.
- Relevant past reviews of the genebank commissioned by the Crop Trust.
- Any other materials provided by the genebank as background for the review.

All review panel members and the seedbank manager will be involved in the development of the agenda for the site visit. This is an important process during which specific issues and questions are identified for review and relevant stakeholders and users within and outside the Centre are identified for consultation.

At least two calls will take place in advance of the site visit, between the panel members and Crop Trust staff.

II. Site visits and seedbank review

The panel members will conduct a site visit of the seedbank following the agreed agenda. Usually the site visit involves interactions between the panel members and senior management, researchers and the full genebank staff. There will also be at least one visit to field stations. The panel members should determine the scale of these interactions in the development of the agenda.

Given that discussions during the review are usually intensive, panel members may wish to review together the findings at the end of each day. There may also be a need to make adjustments to the agenda in order to pursue certain issues in greater detail. The draft recommendations will be presented to the seedbank staff and management on the last day of the site visit.

III. Completing the report and presenting the recommendations

The review panel will follow the agreed review checklist and complete the report format, including a report of the evidence provided by the seedbank for each checklist item, compliance of the seedbank/host institute to standard policies and guidelines, and a statement to indicate how any recommendations should be closed. Any additional reporting should be limited and justified.

A response will be solicited from the seedbank by the Crop Trust. The Crop Trust will provide its own response to the recommendations. In the event of a lack of endorsement by the seedbank or the Crop Trust to a recommendation, further discussions may be necessary between the Crop Trust, panel members and the seedbank staff. If necessary, the other specialist bodies may be consulted

Content of the report

The chair of the review panel will lead the preparation of an individual report of no less than 4,000 words per seedbank. The report will include the analysis of the various objectives of the review and key findings will be highlighted. The review panel is expected to make recommendations for the future management of the seedbank and its collections that should be actionable by the management of the seedbank, the Crop Trust, and the project.

Use of the review report

The report will be submitted to the Crop Trust for initial review to ensure completeness and clarity. A response will be solicited from the seedbank's host institute. The Crop Trust will provide its own response to the statements and recommendations with the agreement of the host institute and reviewers.

The reports will be used specifically to inform the project with regards to the final selection of national seedbanks to continue with the upgrading phase and provide a basis for preparing

recommendation action plans, workplans and activities to be considered during the upgrading phase.

Annex 2

Seeds for Resilience

October 3 - 8, 2019

Bunso, Ghana

Agenda

Time	Session	Items to be addressed	Participants	Facilitators
DAY 1: October 3				
11:20 - 12:00	Arrival to Accra			
13:30 - 15:30	Meeting with CSIR senior management	Reviewers are provided a description of the overall research strategy and where the genebanks fits into ongoing or planned research. Reviewers will address various aspects related to the institutional and management arrangement of the institute.	CSIR senior management: Director General, Head of budgets/finances, Governance official, Director of research, head of genebank Review panel, Crop Trust project manager	Chair of review panel/Crop Trust project manager
15:30 - 19:30	Travel to Bunso			
DAY 2: October 4				
09:00 - 09:30	Brief presentation by the Review Panel Chair and Q&A to all genebank relevant staff.	Introduction to the review panel and to the objectives of the review.	Head of genebank, genebank staff, review panel, Crop Trust project manager	Chair of review panel/Crop Trust project manager
09:30 - 10:00	General introduction to the genebank	Introduction to the history of the genebank, current activities	Genebank staff, review panel, Crop Trust project manager	Head of genebank

10:00 - 15:00	Tour of the genebank facilities and its operations	Getting to know the genebank and the people who work there. Introduction to all genebank operations by the staff responsible and review of the basic operations and main activities of the past 5 years. Include (but not restricted to): - Acquisition unit - Storage unit - Viability testing unit - Seed health unit - Distribution unit - Field operations (greenhouse unit) - Data management unit - In vitro (if available) - Characterization unit	Genebank staff, review panel, Crop Trust project manager	Genebank staff
15:00 - 16:00		Call with Equipment and Facilities reviewer		
16:00 - 17:00	Risk management & quality management system	General discussion on risk measures, implementation of a quality management system		
DAY 3: October 7				
07:30 - 12:30	Visit to regeneration site		Head of genebank, review panel, Crop Trust project manager	Head of genebank
12:30 - 14:00	Lunch			
14:00 - 15:00	Genebank IT systems	Call with IT reviewer	Genebank staff, review panel, Crop Trust project manager	Genebank staff
15:00 - 17:30	Review of any outstanding issues with genebank staff		Genebank staff	Review panel
DAY 4: October 8				
09:00 - 10:30	Review panel wrap-up		Genebank staff, review panel, Crop Trust project manager	Chair of review panel
10:30 - 12:30	Review panel internal meeting	Prepare presentation of preliminary recommendations	Review panel	Review panel
12:30 - 13:30	Lunch			
13:30 - 15:30	Review panel wrap-up presentation	Presentation of preliminary recommendations and wrap-up	Senior Management staff, genebank staff, review panel, Crop Trust project manager	Chair of review panel/Crop Trust project manager
15:30 - 18:30	Travel to Accra			