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System Level Review of Genebank Costs and Operations September 2020

Paper 3: Germplasm Health Units

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1. Background – current status

It is well-known that plants and seeds can harbor various pests (pathogens, insects, nematodes, and all other harmful biotic agents) that can spread along with germplasm (propagation material) into new territories. The importance of this threat at global level led to the International Plant Protection Convention (IPPC) enforced since 1953. IPPC is a multilateral treaty of 183 countries overseen by the FAO to secure coordinated action to prevent and to control the introduction and spread of pests of plants and plant products, along with the international movement. Countries have quarantine/biosecurity legislation based on IPPC International Standards for Phytosanitary Measures (ISPMs), enforced by the national plant protection organization (NPPO or quarantine agency) to regulate pest spread with international transfers of germplasm into their territories.

Inadvertent spread of pests with germplasm distributions are also a concern for the CGIAR centers, that to a major extent supply to developing countries and biodiversity hotspots lacking sufficient NPPO capacity to prevent pest entry or respond to pest outbreaks. The safe transfer of germplasm is crucial for the Center international programs and public goods delivery. The Centers (CIAT, CIMMYT, CIP,

ICRISAT, ICARDA, IITA, and IRRI) have implemented phytosanitary protection measures since the 1970s to ensure the distribution of pest-free germplasm. In the 1990s, as per the recommendations of Sixth International Plant Protection Congress (August 1993, Montreal), CGIAR centers have established Germplasm Health Units (GHUs) with objectives to (i) avert the spread of quarantine pests with the CGIAR germplasm transfers, (ii) prevent pest outbreaks, (iii) safeguard biodiversity, and (iv) strengthen phytosanitary capacity development. The functions of GHUs are listed in Annex-1.

The GHUs are located as independent units in the headquarters of the 11 centers, which are also the locations of genebanks and the main breeding programs (Fig 1.1). They are referred differently as, Germplasm Health Unit (AfricaRice, CIAT, ICRAF, IITA, ILRI), Seed Health Unit (CIMMYT, ICARDA, IRRI), Health Quarantine Unit (CIP) and Plant Quarantine Unit (ICRISAT). In the case of Bioversity, GHU functions are outsourced to the University of Liège (Belgium). AfricaRice and ICRAF created their own GHU's in 2017 as previous arrangement with the Pathology Unit (AfricaRice), and ICRAF outsourcing to Kenya Forestry Research Institute (KEFRI) was insufficient to address the genebank needs. Administratively, GHUs are independent units (CIMMYT, CIP, ICARDA, ICRISAT, IITA, and IRRI) or managed by Genebank (AfricaRice, Bioversity, CIAT, ICRAF, and ILRI). Regardless of the administrative positioning, the GHU in each Center operates as an autonomous program with a separate budget and program management structure making go/no-go decisions on germplasm transfers based on phytosanitary status and maintenance of multidisciplinary capacities required to test and treat germplasm.

Fig 1.1. Location of GHUs

In 2017, GHUs were aligned to the "Conservation Module" of the Genebank Platform, to improve the GHUs capacity necessary to alleviate phytosanitary bottlenecks to genebank targets. Before this alignment, the GHUs within Centers had minimal interaction with GHUs in other centers. This alignment plan provided a unique opportunity for collaboration among 11 GHUs and to develop an uplifting plan to meet genebank targets. This collaboration has triggered strong synergies and led to the evolution of the "One GHU program," catalyzing harmonized strategy, procedures, and cross-center research initiative to address common phytosanitary challenges. The Platform's funding contributed to GHU strengthening in many ways, which are summarized in this Working Paper, along with status, advantages, needs and future scenarios.

1.1 Individual GHU capacity and status

The modalities, procedures, staffing, and facilities of individual GHUs vary across CGIAR centers. Four main factors contribute to this diversity: (i) the administrative alignment of each GHU within the center's program, (ii) crop species and the complexity of phytosanitary issues, (iii) frequency of germplasm exchanges, and (iv) funding. The overall capacity of key areas (staff, facilities, procedures, and funding) based on self-assessment on a 1 to 10 rating scale, with 1 as the least and 10 as optimum capacity, is summarized in Figure 1.1.1, and the Center-specific summaries are presented in Annex 2.

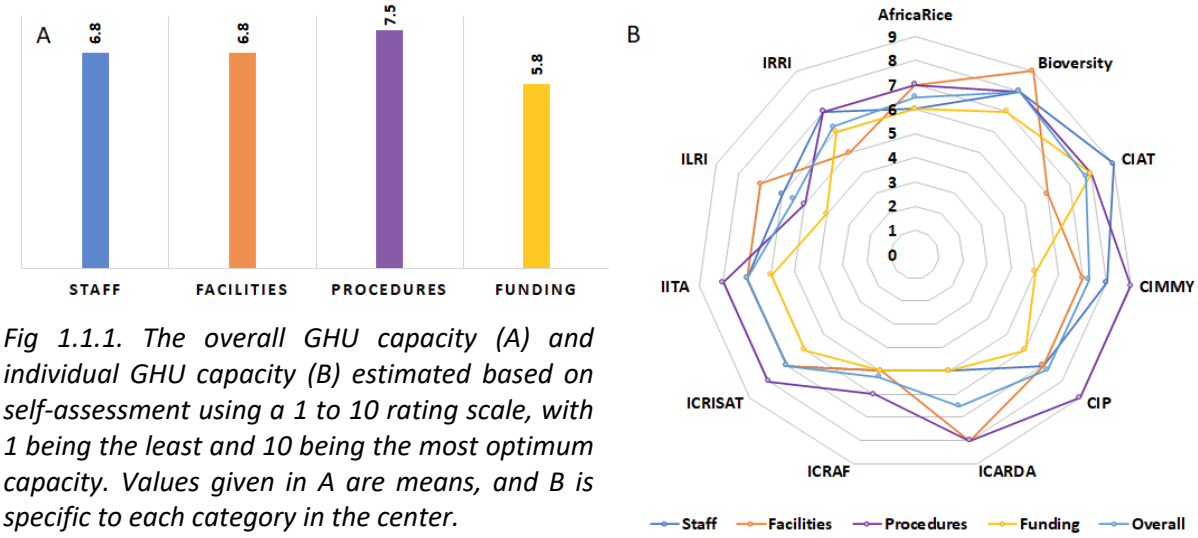


Fig 1.1.1. The overall GHU capacity (A) and individual GHU capacity (B) estimated based on self-assessment using a 1 to 10 rating scale, with 1 being the least and 10 being the most optimum capacity. Values given in A are means, and B is specific to each category in the center.

Procedures (7.5/10): Most GHUs have adequate procedures for testing a wide range of pests (at least 309 species and strains of bacteria, fungi, insects, nematodes, phytoplasma, viruses and viroids) and phytosanitation of a range of crop species (about 30 species of frequently exchanged species and underutilized species belonging to over 150 genera). However, procedures for underutilized/locally valuable germplasm, including trees and forages, are insufficient due to limited knowledge on pests and general lack of technologies due to limited global research. GHUs regularly adopt new technologies for improved sensitivity and throughput and meet up with the changing phytosanitary threats. Putting emphasis on harmonization of procedures and services across the centers. GHUs are establishing a common Quality Management System (QMS). Some GHUs are already accredited under the ISO (CIMMYT, and CIP) and the ISTA (IRRI). Significant efforts are needed to install automated systems for data collection and develop GHU phytosanitary databases for harmonization of data collection and open sharing, with interoperable features to interact with other databases.

Facilities (6.8/10): Limited infrastructure and equipment are significant bottlenecks to increasing throughput and a main cause for longer processing time. With the support of the Genebank Platform funding significant upgrades were made to replace ageing equipment and infrastructure. Further investments are necessary to enhance GHU facilities at AfricaRice, which has recently shifted to M'be (Cote d'Ivoire), and at CIAT, ICRAF, and ILRI, which are in the process of developing new GHU facilities.

Staff (6.8/10): Each GHU has 1 IRS serving as a Unit Head, which often is a shared position with other projects, and a few nationally recruited staff, whose number varies between 2 to 11 per unit. At least 50% of the staff working in GHUs have more than eight years of experience and broad skills to perform multiple tasks. GHUs often hire temporary workers during peak seasons to meet the shortfall. Staff retention has been a challenge due to uncertain funding and short-term contracts. Stable financing is essential for long-term recruitment, experience building, and succession planning. The value of experienced staff with multitasking skills was demonstrated during the COVID-19 lockdown when only limited number of staffs were able to work due to restrictions.

Funding (5.8/10): GHUs are funded through pooled contributions from the Genebank platform, CRP W1 and W2 allocations by the centers, W3 projects, and service costs recovery in some centers, which vary from full cost recovery (CIMMYT, CIP, and IRRI) to partial cost recovery (ICRISAT and IITA). In some centers, GHUs are mostly financed by the Genebank Platform funding (AfricaRice, Bioversity, ICRAF, CIAT, and ILRI). Insufficient and unpredictable funding is a significant challenge. GHUs that depend on cost recovery face more formidable challenges of maintaining essential operations when cash flows drop below the requirement. Funding from the Genebank Platform has boosted most essential

upgrades and cross-center collaboration, development of QMS, fostered new partnerships, and GHU Community of Practice (CoP). Funding also supported the convening of annual GHU team meetings since 2017 to share progress, exchange ideas, work planning, advocacy, and awareness raising. GHUs did not have the funds or organizational capacity to hold such meetings in the past. It is always a challenge to raise funds for GHU work, often perceived as routine tasks despite significant efforts to generate innovations to stay ahead of the phytosanitary threat curve to CGIAR mandate crops. A costing study is essential for determining the optimum and a sustainable funding model for GHUs.

1.2 Working for genebanks and for breeding programs

Offers comprehensive support: Since GHUs are designated to serve as the single entry and exit point for the exchange of all the regulated bioresources, the users from genebanks and breeding programs approach GHUs services through an established process. GHUs enable (i) plant germplasm exchanged by genebanks, breeding (and crop improvement) programs, and seed system initiatives; (ii) non-plant taxa (fungi, bacteria, insects, viruses) exchanged by other types of R&D programs; (iii) plant material (DNA, RNA, plant extracts) requiring regulatory clearances; and (iv) GMOs and gene-edited (CRISPR) products, and GMO-free declarations. The GHUs of CIMMYT and IRRI coordinates the SMTA process involved in the exchange of germplasm from genebank and breeding programs. Magnitude and range of GHU activities depend on the center's activities and differ across the centers (Table 1.2.1).

Table 1.2.1. GHUs involvement in centres bioresource exchange activities

	Genebank	Breeding/Crop improvement	GMO exchange	GMO-free declaration	Non-plant taxa	Plant material*
AfricaRice	✓✓✓	✓✓✓	–	✓	–	✓
Bioversity	✓✓✓	✓	–	–	–	✓
CIAT	✓✓✓	✓	–	✓	–	✓
CIMMYT	✓✓✓	✓✓✓	–	✓	✓	✓
CIP	✓✓✓	✓✓✓	✓	✓	✓	✓
ICARDA	✓✓✓	✓✓✓	–	–	✓	✓
ICRAF	✓✓✓	✓	–	–	–	–
ICRISAT	✓✓✓	✓✓✓	–	✓	✓	✓
IITA	✓✓✓	✓✓✓	✓	✓	✓	✓
ILRI	✓✓✓	✓	–	✓	–	–
IRRI	✓✓✓	✓✓✓	✓	✓	✓	✓

Level of engagement: ✓✓✓ = High; ✓✓ = Moderate; ✓ = Low; – = None; *DNA, RNA, plant extracts

Offers system-wide coverage: GHU needs of both genebanks and breeding programs predominately originate from the countries of genebank location, usually headquarters, with the exception of ICARDA, which has genebanks in both Morocco and Lebanon (headquarters). Some crop breeding programs are decentralized, i.e., located in more than one country (e.g., bean, cassava, chickpea, groundnut, lentil, maize, potato, sorghum, sweetpotato, rice, and wheat). Special arrangements have been made to address the phytosanitary needs of such programs using GHUs located in the countries or third-party organizations (e.g., KEPHIS in Kenya used by CIP and IITA to address clonal crop phytosanitary needs in the East Africa sub-region). The GHUs establish protocols based on the diverse species conserved in the genebanks.

Uses common standards: GHUs apply similar procedures for genebanks or breeding programs, including the documentation needs stipulating the requirements for quarantine agencies to issue import or export permits. Genebanks materials are more diverse and sometimes involve wild species which may demand complex/time-consuming procedures owning to species biology and pest risks. Based on the years of experience, GHUs have established routine protocols for conducting active

growth stage inspections of regeneration fields together with NPPO, and assessing the status of pest-free sites where applicable (e.g., Karnal bunt field sites in Mexico).

Germplasm testing and germplasm transfers: The GHUs operations are demand-driven as per the needs of the genebanks and breeding programs. For instance, in 2018 and 2019, GHUs facilitated 1,300 and 2,600 international germplasm transfers from genebanks and breeding programs, respectively, reaching >100 countries each year. In the same period, GHUs have tested 335,928 genebanks samples and eliminated 7% pest affected samples. Similarly, 118,044 samples were tested and eliminated 3% of contaminated samples from breeding programs. In the two years, a total of 453,972 samples were analyzed, 74% from genebanks and 26% from breeding (Fig 1.2.1). Majority of samples analyzed for genebanks are for regeneration, clean-up and conservation. Collectively, GHUs have employed 2.47 million diagnostic reactions, which at an average cost of US$10 amounts to US$ 24.7 million or about US$12 million per annum investment on the generation of clean germplasm and preventive diagnostic testing to control the transboundary spread of pests by the CGIAR programs.

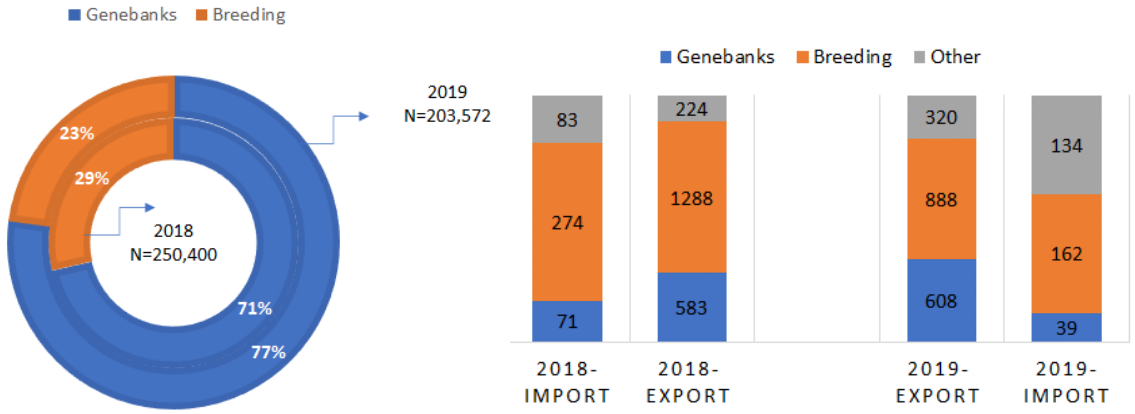


Fig 1.2.1. Percentage of samples processed by GHUs for genebanks (blue) and breeding (orange) in 2018 and 2019 (left); and GHU facilitation of import and exports events in 2018-19 (right)

The annual germplasm exchange account for about 40% for genebanks and 60% for breeding programs. In 2018 and 2019, a total of 4674 international transfer events were facilitated by GHUs, 28% of which from genebanks, 56% from breeding and 16% other biological materials to over 100 countries (Figs. 1.2.1) and it varies by year and center (Table 1.2.2). Genebanks were never involved in exchange for GMOs or gene-edited products. Although rare, GHUs of IRRI (rice), IITA (cassava), and CIP (potato and sweetpotato) have been involved in exchange of GMO events for their centers respective crop improvement programs. The CIMMYT GHU is anticipating the exchange of gene-edited maize products in the near future.

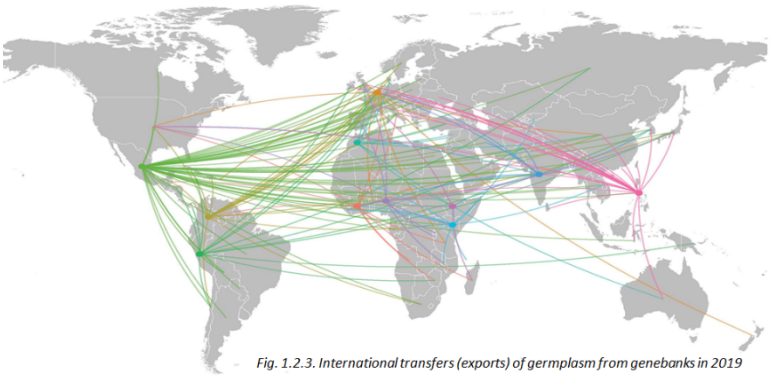


Fig. 1.2.3. International transfers (exports) of germplasm from genebanks in 2019

Responds to user feedback: Most often, GHUs receives positive feedback from the users. However, a frequent feedback across most centers pertains to slow turnaround time or not delivering on the demanded date. Multiple factors contribute to this situation, including a short notice from the requestor. Some accessions require multiple cycles of testing/phytosanitation to generate clean

germplasm, conditions set by the importing quarantines demands additional time and a long waiting time as GHUs are engaged in other activities. These are not easy challenges to overcome, but efforts are being made to improve throughput by using time-saving procedures, and developing activity calendars to capture annual needs in advance for appropriate planning. There is a plan to establish "GHU helpline" for troubleshooting and advisory service to be run in a coordinated way with the existing "CGIAR GR Policy Helpdesk" supported by the Genebank Platform.

Table 1.2.2. Summary of import and export events facilitated by GHUs in 2019

	Genebank		Breeding/CI		Other		
	Import	Export	Import	Export	Import	Export	Total
CIMMYT	4	284	53	274	10	24	649
IRRI	2	92	53	300	49	131	627
ICARDA	8	28	40	151	0	3	230
IITA	8	20	9	74	11	17	139
CIP	-	62	-	50	-	10	122
ICRISAT	7	17	3	22	-	16	65
CIAT	-	37	-	17	-	-	54
ICRAF	3	8	3	-	13	23	50
Bioversity	3	33	-	-	-	-	36
AfricaRice	4	25	1	-	-	-	30
ILRI	-	2	-	-	-	-	2
Total	39	608	162	888	83	224	2004

1.3 Working as a system under the Genebank Platform

One GHU: Before alignment to the Platform, each of the GHUs worked in isolation with minimal interaction with other centers. Working as part of the platform contributed to the integration of 11 GHUs as "one GHU program" and harmonizing operations, procedures, reporting, and developing cross-center collaborations to address common challenges and innovate new approaches.

Established a harmonized GHU QMS: Helped to develop minimum QMS, with the support of Crop Trust QMS specialist, as a harmonized approach for quality assurance and quality control in GHU operations. GHUs have learned from the Genebank QMS, CIMMYT and CIP GHUs using ISO system and QMS used at the University of Liège. A training workshop was organized to develop QMS systems and prepare standard operation procedures (SOPs) to implement "GHU QMS" from 2021.

GHU Community building: The annual GHU working group meetings since 2016 provided a unique opportunity for learning and for improving operations, including brainstorming on GHU service delivery and phytosanitary challenges cutting across centers. Such interactions inspired GHUs to improve performance and centers such as AfricaRice, ICRAF, and ILRI to establish dedicated GHUs to address phytosanitary needs, which were long overdue. The learning visits to the center GHUs and genebanks were exposed to facilities and procedures used to handle germplasm. The working team members established bridges for interactions, troubleshooting, and harmonization of procedures.

Advocacy for GHU mission: Over the course of the last two years, CGIAR GHU progress and challenges were presented to delegates attending the 8th Governing Body of the ITPGRFA (Oct 2019), the Secretariat of IPPC, ISF, the Secretariats of regional agricultural research organizations and NPPO of a

number of countries. The objectives of these engagements was to raise awareness about the importance of plant health, and the efforts across CGIAR to ensure we were not contributing to the international movement of diseases, and to build support for the concept of CGIAR GreenPass protocol to facilitated international movements of PGRFA from CGIAR Centers. (as discussed more below). These reports showcased how GHUs mitigate the introduction of dangerous pests and prevent potential new outbreaks. It also gave opportunities to present GHU viewpoints to Platform Management and benefitted from the Management Team advocacy for improvement and increased support to GHUs.

Improved capacity: Funding from the platform came at a very crucial time point. The accumulation of several years of decreasing institutional support due to dwindling core funding had resulted in underinvestment and aging of facilities. The platform funding helped to invest in the renovation of old infrastructure, upgrade equipment and protocols, train staff in new skills, and hire staff for critical positions that could not be filled due to institutional budget limitations. For some centers (e.g., AfricaRice, ICRAF, and ILRI), funding from the Platform is the main source for GHU operations. Investments in capacity have made visible improvements to throughput and service delivery in all the centers and improved visibility to GHU mission within the centers and externally. GHUs are also leveraging strategic presence in all continents to position as the global network on invasive pest diagnosis, germplasm phytosanitation, and contribute to the worldwide pest surveillance system.

Established germplasm health CoP: For better exploration of collective strength, a GHU Community of Practice (GHU-CoP) was formed. It is improving with continual feedback to enhance the international profile and strengthen partnerships with global regulatory agencies, such as IPPC. Training workshops were organized to internal and NARES and the 'annual phytosanitary awareness' events were held to raise GHU profile. Joined the international consortium on "UN International Year of Plant Health 2020 (IYPH 2020)" to organize awareness raising events and capacity development activities.

2. Challenges and opportunities

2.1 Different needs, different standards, different costs

GHUs work on different crops, different pests, and in various countries. Therefore, variation in needs arises from the different phytosanitary status of the crops in each geography, technologies for diagnosis, and phytosanitation, and standards adopted by NPPO in the country of operation. In general, standards for germplasm distribution from genebanks are least developed. NPPOs adopt ISPMs designed for commercial consignments of plants and plant products with specific modifications of their own for dealing with small sample sizes distributed from genebanks. Due to better knowledge on pest risks, standards for some crops (e.g., banana, beans, cassava, cowpea, chickpea, groundnut, maize, potato, rice, wheat and other) are relatively well defined. However, due to the vast taxonomic and geographic diversity and limited knowledge on pest risks of crop wild relatives, tree, and forages, poses a significant challenge for implementing appropriate testing standards for pest detection.

GHUs have established SOPs according to crop specific requirements in a country. Some centers (CIAT, CIMMYT, and CIP) have adopted the ISO17025 quality assurance system according to the NPPO demands. In contrast, others adopted a generic QMS based on ISPMs and ISTA procedures. Since alignment to the Platform, GHUs began developing harmonized QMS, termed as the GHU-QMS, to achieve uniform standards (Fig 2.1.1). As of 2019, 139 SOPs were established, at least seven to a maximum of 30, depending on the center and country. The varied experiences across centers help find the right balance between optimum technology, cost, and quality assurance. However, achieving a more homogenous standard across the GHUs will be challenging due to the significant difference in pest risks and country-specific variables. On the other hand, these differences prove to be an asset as a broad range of experiences and approaches (fit-for-purpose) across the centers. The centers are also

working to establish a GreenPass protocol as a quality assurance system that demonstrates the use of best procedures for germplasm production and health assurance, while maintaining transparency in risk assessment and mitigation strategies used across the centers.

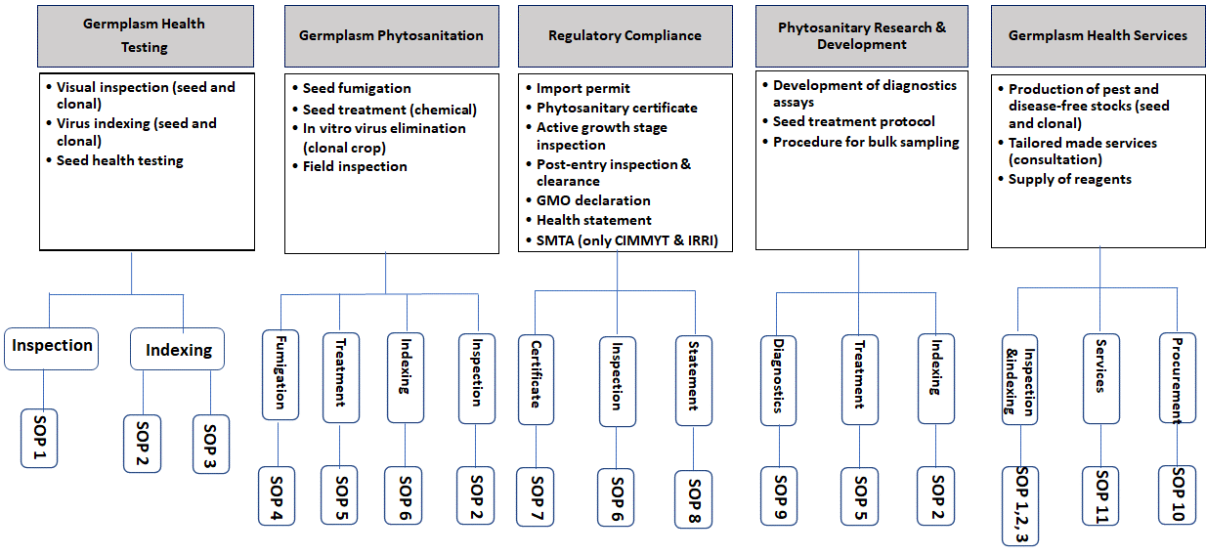


Fig 2.1.1. Harmonized GHU operational map and SOPs to some essential activities

As shown in Figure 2.1.2, at least ten variables, depending on the type of pest, crop, and country of operation, influence the needs, standards, and costs of phytosanitary procedures. The same crop species' requirements vary depending on the country, sample size, or phytosanitary status. Health testing of clonal crops is generally much more demanding per unit than seed crops that can be treated in big bulks. Typically, testing demands are high for newly acquired collections due to unknown pest risks, prompting comprehensive testing for both known and unknown threats.

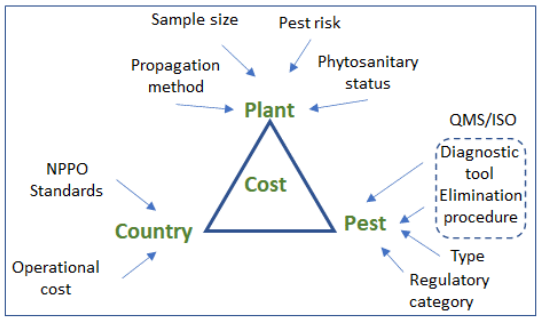


Fig 2.1.2. Influence of various factors on germplasm phytosanitation and health certification costs

2.2 Trends in phytosanitary risks and technologies

Pest risks: Changes in the dynamics of pests occurring significantly impact germplasm transfers from the Centers. Several economically import pest outbreaks in the last decade were attributed to introduced pests: fall armyworm (FAW), desert locusts in Asia and Africa; maize lethal necrosis (MLN) in East Africa; wheat blast in Bangladesh, cassava mosaic in Southeast Asia, and banana fusarium wilt TR4 spread to Colombia; banana bunchy top virus (BBTV) in West and Southern Arica; and cassava brown streak in Eastern and Southern Africa; tar spot complex spread in Latin America and USA; tomato leafminer into Europe, Africa and Asia; potato zebra chip into South America. The pest risk perception is also influenced by severe destruction caused by unrelated pest outbreaks. For instance, olive decline by introduced *Xylella fastidiosa* in Italy; citrus greening in the USA; and several other examples, including Covid-19 pandemic, have a significant influence on the regulatory procedures and decision making on germplasm transfers. In addition, the discovery of new virus species using novel technologies (e.g., NGS-based methods) is adding to the known pest risk burden.

Over the years, GHUs have adjusted to changing pest dynamics and have taken adaptive measures to sustain the operations. More often, GHUs play a crucial role in early diagnosis and implementation of

preventive measures to control emerging pest outbreaks of its mandate crops in the countries of operation and sustain germplasm transfers amidst the epidemics and pandemics. Following the MLN outbreak in East Africa, the CIMMYT GHU team established sampling and treatment procedures to sustain maize germplasm transfers. Similarly, IITA-CIAT established cassava virus elimination protocols to maintain germplasm transfers between continents while benefitting from other initiatives on epidemiological studies. Recently, ICRAF GHU documented invasive pests of native African tree germplasm conserved as a resource for updating pests' lists. IITA GHU made the first record of FAW in Africa (first record outside the Americas). These examples highlight GHUs advantage to centers as a key player in international efforts to mitigate transboundary spared of pests. This area needs strengthening in One CGIAR, to avert the potential damage transboundary pest can inflict on achieving One CGIAR goals in an ever more globalized world and changing climate.

Adaptive changes take a longer time in the lack of sufficient knowledge on pests, efficient protocols, and insufficient funding. It is a challenge particularly for forage (CIAT and ILRI) and tree germplasm (ICRAF) as fewer institutions are undertaking trees and forage germplasm health research. Such limitations are opportunities for GHUs, which can generate new knowledge and procedures provided there is an investment. An increase in international trade and research material exchanges are likely to exacerbate the risk of new pest outbreaks. It is safe to assume that the drivers responsible for transboundary pest outbreaks are difficult to contain and high levels of vigilance will be required to monitor pest dynamics to sustain the CGIAR operations.

Technologies: GHUs uses a broad range of technologies for pest diagnosis and germplasm phytosanitation. New technologies are evolving all the time for phytosanitation and more accurate and rapid detection of pests. GHUs need to maintain a balance in adopting the best technologies that offer cost and time efficiency, meet regulatory requirements, and comply with ISO/QMS systems. It is vital for GHUs remain up to date to stay relevant. As an example, next-generation sequencing-based diagnostic methods, already in use by several diagnostic lab from NPPOs around the world, are progressively adopted as a universal screening tool for viruses in clonally propagated crops by Bioversity, CIAT, CIP, and IITA. GHUs have identified a need to intensify efforts towards developing nucleic acid-based detection protocols for the pests that are difficult to detect through routinely used conventional tests such as blotter technique. Efforts are also required to standardize protocols for non-invasive techniques for the detection of seed-borne pests (e.g., Videometer for the detection of fungal pathogens, soft X-ray analysis to detect hidden seed infestation by pests). Similarly, new and safe crop protection solution and, seed treatments, are needed as some treatments are banned or restricted for use on specific crops and countries.

Phytosanitary polices: The NPPO regulations based on IPPC ISPMs govern phytosanitary requirements for germplasm exchange. However, ISPMs developed in view of the requirements of commercial trade and large volume samples are inadequate for the purpose of international transfer of germplasm from research programs which often involve diverse samples in small size. Therefore, the NPPOs either develop and follow their own norms or follow those prescribed through ISPMs dealing with commercial seed, which are not appropriate for germplasm exchange from genebanks and breeding programs, and introduces differential requirements from country to country making germplasm transfers a challenging endeavour. The existence of conflicting regulatory frameworks in the different countries due to outdated regulations or absence of them, not aligned with IPPC or the RPPOs, restricts the exchange of seed and other plant materials. Outdated pest lists are often restrictive to obtain permits for distribution or import. Unforeseen changes to policies are not uncommon in the countries of operations. Most often, policy changes are triggered by (i) new pest outbreaks, (ii) risk perception on invasive pest spread into their territories, (iii) introduction of new/amended procedures, and (iv) changes in administrative and implementation protocols. GHUs have adopted to

make necessary adjustments to align with policy requirements in countries of operations to enable germplasm distributions.

In some cases, policies do not match with biological complexities and restrict germplasm distribution. For instance, genomes of some viruses are integrated in the host genome (e.g. the Banana streak virus (BSV) genome integrated in the B-genome of banana and plantain (*Musa* sp.); the genome of Dioscorea badna viruses (DBV) are integrated in yam (*Dioscorea* sps.,) genome). In essence, integrated viral genomes inseparable part of the host. The existing regulations do not consider these complexities, consequently all the germplasm with integrated viruses were stopped from international transfers, which amounts to over 50% of *Musa* collection. In 2015, GHUs of IITA-Bioversity together with the *Musa* Working Group on Genetic Resources has developed a new approach to transfer germplasm with integrated viral sequences, which was approved by the global stakeholders, thereby liberating significant proportion of germplasm from the non-distribution list.

Similarly, the current phytosanitary polices are insufficient to address the germplasm "safety duplication" (also referred as black box conservation) efforts in Svalbard Global Seed Vault or in other third-party countries. The safety duplication involves transfers of both health certified and untested accessions to another country (third-party) exclusively for conservation and repatriation to the 'country of origin' when required (Fig 2.2.1). The NPPO requirements however are difficult to fulfil, as the procedures stipulates mandatory health declarations and entry prohibition of untested germplasm. However, ad hoc bilateral arrangements have been established between source of origin countries and third-party countries to facilitate safety duplication as an interim arrangement. Although, this system is working but not always smoothly due to ambiguities arising from differential understanding among NPPOs. GHUs are working with regulatory agencies to establish a standard policy to streamline procedure for this important activity of genebanks.

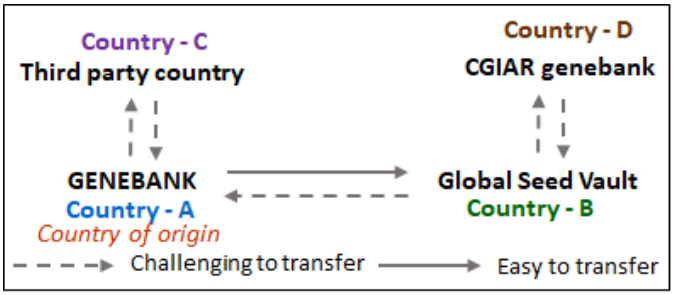


Fig 2.2.1. Germplasm transfers for safety duplication

Recently, GHUs have initiated the development of "CGIAR GreenPass Phytosanitary Protocol (GreenPass)" as a comprehensive phytosanitary compliance assurance procedure that will demonstrate best procedures in use for germplasm production and health assurance, while maintaining transparency in risk assessment and mitigation strategies to get NPPO accreditation as trusted to fast track germplasm distribution. The IPPC endorsement of this initiative is expected to eliminate redundant checks by cutting some steps or reducing processing time for material from GreenPass-accredited facilities. A consultation workshops were held in 2018-19 with FAO, Crop Trust, International Seed Federation (ISF), APPAARI (Asia-Pasic Association of Agricultural Research Institutions), IPPC, RPPOs, and NPPOs. Approval of GreenPass protocol is expected to soften a number of bottlenecks for germplasm transfers from the CGIAR.

Maintaining GHU advantage: GHUs have right expertise in surveillance, early diagnosis, and mitigation of endemic and transboundary pests. Years of experience indicates that GHUs adaptability is a vital requirement for sustaining operations in era of constant changes (pests, policies and procedures). Updating the capacity to adapt will always require investments, which is becoming more and more uncertain for preventive approaches. On the other hand, due to high-level capacity, experience, track record, and global distribution in the developing world, the GHU have an opportunity to play an important role not just in the safe transfer of germplasm but also as centers of excellence in support of national or regional pest and disease surveillance and rapid response. A strong case exists

for positioning GHUs as part of a global network of diagnostic hubs to manage emerging and invasive pests as part of the One CGIAR. The COVID-19 epidemic has highlighted the importance of early detection and epidemic preparedness plans and raising awareness that this is just as applicable and important to plant health is an opportunity for GHUs to explore under One CGIAR.

3. Future scenarios for CGIAR GHUs

3.1 What happens if there is not enough investment?

A few scenarios of consequences of reduced funding are presented.

Slowing down of germplasm exchange and increase in non-compliance to procedures

Insufficient budget to operations and upgrades will lead to a very high risk of failure to comply with regulations. Inadequate funding will restrict health testing capacity to a few accessions and dramatically slow down the conservation and distribution of healthy germplasm, jeopardize the timely exchange of materials and result in missed seasons. It will also risk the distribution of unhealthy germplasm within and across borders with significant implications for the spread of pests to new areas and a potential damage to CGIAR image and sanctions on germplasm transfers. Reduced investment would force the GHUs to charge cost recovery for performing routine analyses required by genebanks and breeding programs. Depending on the type of mechanism (full or partial), GHUs may have to charge a premium price considering the downtimes and upgrades. The recovered fund may still fall short of the need, and eventually, GHUs become under resourced and weak.

Depletion of world-class transdisciplinary plant health capacity

Responsibilities of GHUs often go beyond testing of germplasm; they support seed system initiatives, diagnostics, phenotyping needs of breeding programs, NPPO programs needing sophisticated diagnostics, and surveillance of emerging pest threats. Decreased funding will reduce the number of skilled staff and permanent loss of the broad-based plant health protection capacity. Traditional plant health programs in the centers maintain issue-based capacity, often limited to a few pests of interest, not broadly resourced as GHUs. Such programs often put heavy demands on GHUs for resourcing. Centers also lose vital connections with national and international regulatory agencies. The SOPs, QMS, and partnerships with NPPO, authorization to centers for in-house testing, institutional culture, and institutional knowledge on the safe handling of germplasm will erode beyond recovery. Special initiatives such as the GreenPass protocol and shared GHU service hubs may fail to materialize.

Outsourcing options are limited

What may appear as a routine, GHU activities involve a complex stage-gate process for various streams of activities established based on years of experience of processing CGIAR crops, knowledge on pest risks, and working experience with the internal users and NPPOs. GHUs gain understanding and maintain flexibility to act based on the users' needs and changing pest landscape. There is no alternative to this system within CGIAR or elsewhere that can deliver services as efficiently and at a low cost. Without the necessary funding for phytosanitary activities in-house, outsourcing will represent higher costs at a higher risk. If GHUs do not operate, genebank and breeding programs would need to contract multiple third-party organizations for such evaluations. Creating a new alternative requires new investments to build staff capacity, facilities, procedures, and other elements, that may have no added benefit.

Loss of innovation and ability to control emerging diseases of rare species

Lack of sufficient funds would retard the update of technologies that facilitate, speed up, or include evaluation tests for novel diseases of quarantine interest. An increase in diseases and pests, especially of trees, forages, and underutilized crop germplasm calls for concerted efforts to address the threats. Failure to do this will endanger biodiversity held in the *in situ* collections. Besides, the spread of an

invasive pest or disease that may lead to the decimation of populations of an economically important tree and other perennial species will have setbacks on the livelihoods of concerned communities.

3.2 Two or three scenarios for CGIAR GHUs based on a One CGIAR world

The CGIAR requires a comprehensive arrangement to safeguard germplasm from endemic and emerging pests and prevent their spread with the international distribution of germplasm to its programs and partners worldwide. Such a system is even more crucial with the increasing demand for international germplasm transfers from genebanks and “Crops to End Hunger” initiative for enhancing nutritional security and resilience to climate change risks. Building on the “One GHU program” model in progress since 2017, GHUs proposes the "CGIAR Germplasm Health Program (CGHP)" as an integrated transdisciplinary initiative for research, identify and assess pest risks, provide knowledge, technologies, procedures, and partnerships to achieve the all-important goal of pest prevention in germplasm transfers, thereby secure the One CGIAR goal of food and nutrition security.

Scenario 1. GHUs transformation to CGHP with a well-formulated funding mechanism to support essential staff and services, as part of the Genebank platform or a similar new structure. This two-tier mechanism articulated the inter-center collaboration and coordination at a higher level, with the second level focused on crop-specific operations at the country level (Fig. 3.2.1). The 11 GHUs have thrived to establish a “One GHU program” and the progress stands as a testament to functioning as a one team. Moving forward, the GHUs anticipates increased coordination to strengthen its mission on ensuring Center’s compliance to phytosanitary regulations, and alignment with a global network of centers of excellence to support plant and animal health in agriculture, and climate change mitigation in line with the “One Health priority” of the One CGIAR mission. Together with national and regional plant protection organizations, GHU needs to strengthen its involvement in preventing the spread of invasive pests, biorisk management, and improving system resilience to cope with gradual or sudden changes in pest incidence due to climate change or other factors.

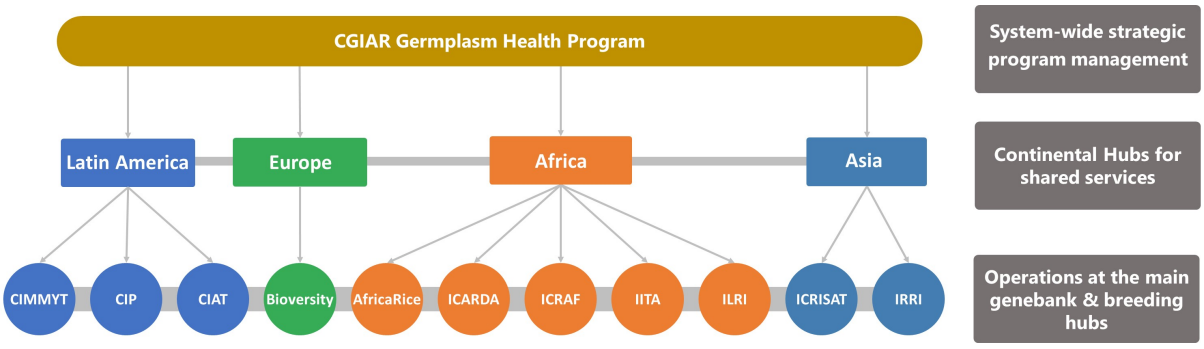


Fig 3.2.1. The One GHU operational model fostered by the Genebank Platform.

Scenario 2. The second possibility in case of discontinuation of the Genebank Platform is to formulate a unique "CGIAR Germplasm Health Program (CGHP)" for system-wide coordination with hub-level operations focused on crop-specific tasks at the country level, similar to the “One GHU” model in operation (Fig 3.2.1). Essentially it is similar to the model presented under Scenario 1, with an appropriate mechanism for independent implementation.

Scenario 3. A third possibility is devolving GHUs as independent units attached to the crop specific initiatives without a coordinated structure. However, will undo the benefits reaped from the ongoing collaboration and harmonization efforts and least desired.

All scenarios require a funding plan. Scenario 1 and 2 are likely to be the most economical because of shared administration and services across multiple entities. Presently, GHU operations are financed through multiple sources, including fixed annual contributions from the Genebank Platform for strategic improvements, ad hoc annual allocations from the CRP W1&W2 to support some essential maintenance and staff costs, full to partial service cost recovery, and GHU W3 projects on specific priorities. Fund allocations from these streams are variable, and revenues from cost recovery are unpredictable as they depend on the rate of service utility. Unreliable annual appropriations impose severe challenges to sustain the essential staff, services, QMS (ISO) maintenance, and undertake crucial upgrades. Therefore, a stable funding mechanism is vital for GHUs under One CGIAR. One option is to adopt a dual funding model, with a fixed allocation of operational funds and full to partial cost recovery for service delivery. The cost of operations for GHU services is influenced by several variables across the locations (see Fig 2.1.2). A costing study is necessary to help formulate an accurate budget plan for core operations of each GHU, assuming different scenarios of low, medium, and high levels of operations. It also helps to fix optimal service rates and set benchmarks for operational costs in comparison with services elsewhere. GHU services across centers may vary, but are likely to be most sustainable and economical compared to sourcing for equivalent services from the other sectors.

4. What do we have to do to get the optimal scenario?

4.1 The proposed way forward to agree on One GHU system and modus operandi

The GHUs propose transformation to CGIAR Germplasm Health Program (CGHP). Restructuring of R4D, genebank, and breeding operations under One CGIAR is expected to have an ultimate influence on future GHU operations. While it is early to predict future structure, the One CGIAR inclination towards “institutional integration and shared services” strikes a chord with the cross-center GHU collaboration initiated as part of the GHU program of the Genebank Platform. It served as a good model for the inter-center collaboration and coordination to tackle complex phytosanitary requirements of the CGIAR system, besides addressing emerging challenges from the invasive transboundary pests. Ideally, the ongoing program should be elevated as a CGHP linked to the Genebank Platform or a similar new alternative or implemented as an independent program. Besides continuity, it offers several advantages:

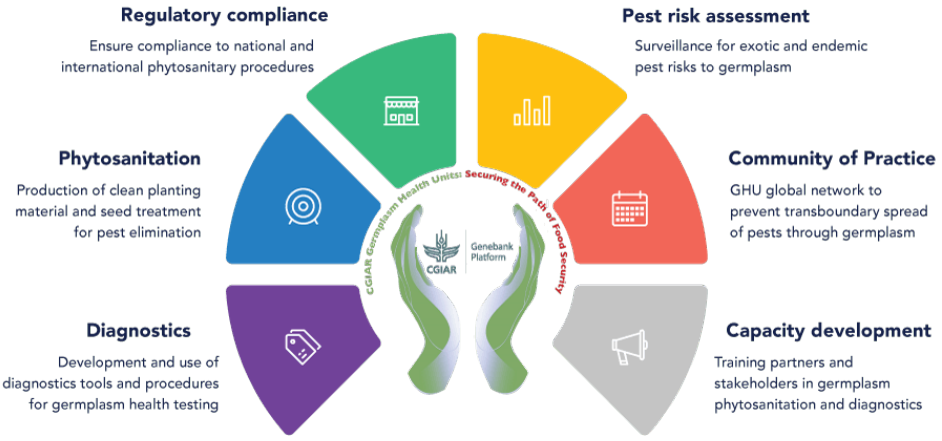
- The transformation from One GHU to CGHP is expected to be least disruptive in the retention of the Genebank Platform or a similar structure.
- It provides endless opportunity to build on the strong One GHU foundation and work as part of a common platform with shared objectives, operational standards following common SOPs and QMS, and common performance targets.
- It sustains strategic interactions and strengthen complementarities to address complex phytosanitary requirements and broaden traditional crop-based mandates to serve as country/regional hubs for the transfer of CGIAR crops germplasm. Such an interaction is deserved for a program concerned with preventing transboundary pest spread.
- It leverages the collective strengths to secure regulatory approval for the CGIAR GreenPass protocol, the success of which would lead to a paradigm shift in germplasm health management and germplasm distribution from CGIAR.
- It allows GHUs to harness transdisciplinary capacity and presence in various continents to serve as vital reference laboratories for rapid diagnosis of a wide range of pests, offer clean seed production and seed health testing services, and serve as a key component of the global surveillance and early warning programs on controlling the spread of transboundary pests.
- It enables GHUs to serve as training hubs for building phytosanitary capacity for strengthening national genebanks, phytosanitary risk management of crop improvement and seed system programs and foster globally coordinated phytosanitary networks in partnership with governments and intergovernmental plant health organizations.

Access and international mobilization of germplasm remain a fundamental requirement to achieve One CGIAR mission on ending hunger by 2030. GHUs are well poised to transform from the One GHU model to CGHP to make direct and indirect contributions to accomplish this mission.

4.2. Next steps

- Organize GHU working meeting in the first quarter of 2021 to prepare for One CGIAR transition.
- Plan GHUs costing study in 2021 to estimate operating costs, understand the financial requirements of each GHU and prepare budget plan for CGHP. Based on the costing study analysis, identify innovative income generation options to make the GHUs self-sustainable.
- Perform consultation to identity phytosanitary priorities of the Genebanks and Crops to End Hunger initiative in One CGIAR. Prepare renovation plans to improve services to enable >90% of the annual phytosanitary targets met on time, and timely distribution of germplasm to end users.
- Align processes among GHUs by crop, by type of pathogens, by type of method of diagnostics, etc., to standardize protocols and processes that could be homologized among Units and allow them to support each other.
- Develop training package to leverage expertise of GHUs and other stakeholders to develop phytosanitary capacity within CGIAR and among the NARES and NPPO partners
- Organize impact analysis to study the benefit of preventing the transboundary spread of pests and cost of containing epidemics caused by invasive pests (and subsequent need for aid with emergency funding vs. the cost of prevention through approaches used by GHUs).
- Streamline phytosanitary procedures across centers and implement the GreenPass protocol for phytosanitary risk assessment, risk management and distribution of germplasm.
- Develop novel methods for assessing seed transmission levels and their relevance to disease levels in crops in support of pest risk assessment.
- Use novel diagnostic tools, including NGS based diagnostics and non-invasive techniques for detecting seed-borne pests
- Develop an integrated database for all biological material related knowledge such as phytosanitary requirements and documentation, process flows, protocols for sampling, treatment, and testing and reporting.
- Develop risk prediction models on emerging crop pests and diseases for prioritizing germplasm health activities across the CGIAR
- Strengthen GHU CoP to promote information sharing and capacity development. Perform awareness-raising/media campaign highlighting the importance of GHU's agricultural health potential to contribute more extensively through a One CGIAR – One health approach.

Annex 1. Core functions of CGIAR GHUs



Securing the pathways of food security

Regulatory compliance

- Checks import and export requirements for each material meant for exchange, and provides consultation and advice to scientists on phytosanitary matters
- Arrangement and participation along with NPPO in active crop growth stage, pre- and post-entry inspections
- Arrangement of permits, health statement and NPPO authorization of germplasm transfers from CGIAR centres
- Maintain records of biological materials distributed for traceability

Phytosanitation to generate clean germplasm

- Development and application of therapy procedures to eliminate bacteria, fungi, virus, and pests
- Elimination of seed-borne and seed-transmitted pests in botanic seeds and vegetatively propagated crops, including salvaging contaminated germplasm, to meet the phytosanitary requirements of germplasm exchange and safe conservation

Diagnostics for monitoring and health certification

- Development, standardization, validation of diagnostics for quarantine and non-regulated pests of importance for conservation and health indexing of germplasm
- Conducts germplasm health testing and grow-out tests as a check for seed-transmitted pests

Pest risk assessment

- Updating knowledge on pest distribution relevant to mandate crops and geographies
- Conducts pest risk assessment of genebanks, research stations and seed production sites to mitigate biotic risks
- Ensuring the phytosanitary protection of germplasm conserved in vitro and ex situ collections of Genebanks, breeders' germplasm and breeding lines

Capacity development

- Ensuring the availability of adequate facilities and skills for handling germplasm exchanges
- Periodic updates of GHU procedures to stay in line with the changing phytosanitary policies and pest risks, and develops standard operating procedures
- Development of training package to leverage expertise of GHUs and partners for internal and partner capacity strengthening

Community of Practice

- Formation of CGIAR GHU network for better collaboration, cooperation and communication
- Organization of phytosanitary awareness weeks to Inform, Update, Inspire and Engage partners and stakeholders on phytosanitary matters
- Organization of training workshops to transfer know-how and knowledge to the partners

Annex 2. GHU needs

AfricaRice

The GHU functions are coordinated by the Genebank with the involvement of a senior pathologist responsible for overall strategic planning, implementation, and management, supported and the genebank manager. This genebank staff is specialized in seed health together with the pathology team of the center. The GHU operations were conducted in collaboration with the NPPO of Benin and Cote d'Ivoire, the two countries where main genebank activities are based. The seed health facility at M'be has been fully commissioned since the genebank was relocated in 2018. The GHU caters to both genebank and the breeding program distributions and importations of the Center.

Staff	*Facilities*	*Procedures*	*Funding*
6	7	7	6
Multidisciplinary staff from Genebank and Pathology Unit share responsibilities and relies on short-term staff to cover shortfall during the peak season. Risk of untrained people on the job without long term hiring.	Just adequate to carry essential work, however, not enough to increase throughput during peak periods. New facilities are being established at M'be.	Research required to establish robust seed treatment for eliminating seed-borne bacteria.	Operations and infrastructure funded through Genebank platform allocation, and staff are supported by CRPs (W1/W2) and W3 projects. Fluctuation risk.

Bioversity

The Genebank coordinates the GHU functions with the technical expertise from the Integrated and Urban Plant Pathology Laboratory, Gembloux Agro-Bio Tech, at the University of Liège, Gembloux (Belgium). A senior scientist is responsible for overall strategic planning, implementation, and management of phytosanitation and health indexing, supported by the genebank staff, specialized in performing germplasm virus indexing and in vitro virus elimination procedures. Genebank material requiring health tests and phytosanitary cleaning are sent from ITC Leuven (Belgium) to the University of Liège, and health tested material is sent to the ITC. A bilateral agreement between Bioversity and ITC guides the operations.

Staff	*Facilities*	*Procedures*	*Funding*
8	9	8	7
Staff of Genebank (ITC) and University of Liège share responsibilities and hire short-term staff to cover shortfall during peak season. Available staff are well trained to meet the demands.	Just adequate to carry essential work. Additional screenhouse and bioinformatics capacity required to increase throughput	Virus indexing procedures requires improvement to reduce duration of health certification. NGS-based indexing methods and testing corms are being explored	Operations and infrastructure funded through Genebank platform allocation for GHUs. Staff time (senior scientist) not paid, except for short-term staff hired on need basis. Bioversity provides a fee per sample to University of Liège for providing phytosanitary services.

CIAT

GHU is part of the genetic resources program located in Colombia. This lab is responsible for phytosanitary activities of the bean, cassava, and forage germplasm of genebank. It also supports some breeding material exchange. Work is in progress to make GHU as a single gateway for germplasm changes at CIAT. In 2019, the laboratory obtained the Colombian authority's endorsement, Instituto Colombiano Agropecuarias (ICA), as a registered laboratory for plant diagnostics and had a quality management system under ISO 17025. This laboratory conducts research to develop and implement more sensitive and effective methodologies for the diagnosis of plant pathogens. The Unit has a dedicated team and facilities, led by a senior manager.

Staff	*Facilities*	*Procedures*	*Funding*
9	6	8	8
Multidisciplinary expert team available for diagnosis and detection of pathogens in the fields of regeneration, and maintenance of the quality management system.	Currently the laboratory is small, with limited area for the work to be done, although it is well compartmentalized. Approximately, in a year the GHU will be shifted to purpose build facilities within the "Future Seeds building" (still under construction).	We count with standardized procedures, with methodologies continuously under critical revision and improvement according to emerging pathogens and/or diagnosis technologies. QMS similar to ISO 17025 system is implemented and the GHU is accredited by ICA (NPPO) as a national reference laboratory.	Funded through Genebank budget, including the GHU funding from the Genebank Platform. No funding from other programs or cost recovery model exist, which is a limitation to extend services to other programs.

CIMMYT

Since 1988, the Mexican Phytosanitary authorities SENASICA allowed CIMMYT to carry out in house seed health testing at CIMMYT Seed Health Laboratory (SHL) through a written agreement (Convenio). It is part of research support services units under the Director Genetic Resources Program. The laboratory is accredited with ISO/IEC 17025:2017 by the Mexican Accreditation Entity and according to ISO standards, with an operational quality management system with supporting process operational documentation. The unit supports the maize/wheat germplasm bank and breeding programs through post-entry handling of seed and plant materials in compliance with national and international germplasm exchange guidelines. The unit also works closely with other GHUs, the Mexican authorities, and regulatory organizations in countries where CIMMYT operates to ensure that operations at different experimental stations have necessary safeguards to avoid the unintended transfer of pathogens.

Staff	*Facilities*	*Procedures*	*Funding*
8	7	9	5
Adequate numbers and well trained to perform analysis. But occasionally get overwhelmed during peak testing	Sufficient facilities at the headquarters. Two satellite laboratories in Kenya and Zimbabwe that assist in MCMV and SCMV monitoring in maize breeding materials before	Adequate in the detection of fungi, bacteria, and viruses. New protocols are required to	About eighty percent of the SHU budget is from charge backs and about 15% from W1 and W2 funding.

season of international nurseries.	exchange. In future these units may need to be expanded and consolidated to operate directly under CIMMYT GHU. Adequate and compliant equipment but some may soon need replacement.	target emerging pathogens outside the three categories.	Reliance on chargebacks is a risk especially during low seasons or pandemics.

CIP

The GHU is an autonomous unit responsible for plant and seed health. It operates as part of the Research Support Unit (RSU), under CIP DDG-Research Office, providing authorization for the movement of plant material (germplasm, breeding lines, and botanical seed) in and off- CIP's stations (Peru) and its international distribution. The budget is mostly from cost recovery, including external clients using CIP facilities, bilateral projects, and CRP allocations (W1 and W2). The Unit has an ISO/IEC 17025:2017 accreditation of its testing services for the last 12 years and undertakes research to develop protocols and procedures to improve phytosanitary services.

Staff	*Facilities*	*Procedures*	*Funding*
7	7	9	6
Just adequate since during the last 3 years, key staff retired and succession has been hampered by staff turnover, currently temporarily replaced by a short-term staff. Risk of losing critical mass and operational capacity to achieve the goals without long term hiring staff.	Just adequate, aging facilities and breakdown risk without replacement. Last year and with funds provided by GB platform is helping to remodel 2 facilities out of several labs and greenhouses that are part of HQU.	The Unit has an ISO/IEC 17025:2017 accreditation since 2008 which mean a continuous effort to meet local and int'l regulations on phytosanitation as well as customer satisfaction	The budget is made up mostly from cost recovery (including externals), bilateral projects and institutional support. Fluctuant and partially subsidized by projects and institutional budget

ICARDA

The GHU belongs to the Seed Systems and International Nurseries (SSIN) group under the Biodiversity and Crop Improvement Program (BCIP). The GHU is responsible for monitoring, clearance, and documentation of safe germplasm movement of the center in Terbol (Lebanon) and Rabat (Morocco). All incoming and outgoing genetic resources and breeding germplasm must go through a strict quarantine monitoring system. ICARDA-SHL collaborates with the quarantine services of the host countries, where ICARDA has breeding and genetic resource conservation activities, to ensure safe movement of seeds and avoid any breaches of the host and receiving countries' quarantine protocols. ICARDA follows a regulatory and quarantine program that collaborates with competent institutions where ICARDA has platforms for crop breeding, germplasm multiplication and evaluation, and genetic resources. SHL budget is made up of International Nursery, CRPs, and GenBank platform funding.

Staff	*Facilities*	*Procedures*	*Funding*
5	8	8	5

Adequate and relies on low numbers of hired staff to implement multiple tasks	Just adequate, approximately, all facilities are new, calibrated and up to date	Adequate, using high technology to cope with any needs	Funding shortage usually affect the expected deliverables

ICRAF

The genebank has been relying on national tree research centers for the services on plant pathology testing. In Nairobi, seed Genebank has had a partnership with the Plant Pathology Department of Kenya Forestry Research Institute (KEFRI). Unfortunately, the Genebank has experienced many challenges in this arrangement that has led to the delay of health reports. Under the GHU project initiated in 2017, the Genebank collaborated with the KEFRI pathology department to optimize health testing protocols while ensuring that the desired efficiency under the GHU project has been a challenge as ICRAF had no control the Laboratory activities. In 2019, the Genebank decided to establish a germplasm health testing laboratory to directly bring the germplasm health testing responsibility under the Genebank and follow up with the implementation of a quality management system in its operation. Finalizing the laboratory set up has progressed well but has been delayed by the COVID-19 pandemic related closures. Hopefully, the lab will be fully operational in October 2020. Initially, this GH lab will be supported under W1 and W2 Genebank funding, but future funding will also target bilateral grants as it transforms into a research support unit that will extend services to other units and regions.

Staff	*Facilities*	*Procedures*	*Funding*
5	5	6	5
Currently, the established GH Lab is under the management of a Consultant Senior Researcher and one nationally recruited technician. Plans to regularise the senior researcher position are under way. Other staff will be hired on short term contacts as deemed necessary subject to funds availability.	Laboratory has just been set up. Adequacy of the current facility to fully support tree germplasm testing cannot be determined at this stage	Bacterial and fungal testing protocols have been developed and are now being optimised in the new GH lab. Virus related health tests will continue to be outsourced. Continuous efforts will be made to meet emerging needs	With Genebank Platform ending in 2021, future funding for the GH is uncertain. The GH Lab team will reach out to ICRAF Tree Theme bilateral proposals to incorporate GH aspect and to obtain some funding. As this will depend on proposals being successful, the funding approach is also uncertain.

ICRISAT

The GHU caters to the plant quarantine requirements of ICRISAT scientists for the safe exchange of germplasm and breeding material and ensures conservation of healthy germplasm in the Genebank. The unit works closely with the National Bureau of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research (ICAR), New Delhi, India, the designate plant quarantine authority responsible for ICRISAT's germplasm exchange. The GHU was recognized by the Government of India (GOI) as an Export Certification Laboratory to work under its close supervision. It also organizes

specialized training on the use of methyl bromide and aluminium phosphide fumigants and other plant quarantine activities in collaboration with the National Institute of Plant Health Management (NIPHM), Hyderabad, India.

Staff	*Facilities*	*Procedures*	*Funding*
7	7	8	6
PQU is working with bare minimum staff, who are well trained for the job needs.	Adequate facilities, but aging. High risk of breakdown of very old equipment/ facilities	Adequate, but continuous efforts required to update/revise the procedures and protocols as per requirements of the quarantine authorities.	Apart from the GHU funding from the Genebank platform, operational budget is raised through full-cost recovery (per sample charges). Under-recovery due to a smaller number of samples processed in a specific year is challenging.

IITA

GHU is a standalone unit within the Genetic Enhancement and Biotechnology program of the R4D Directorate in Ibadan, Nigeria. It serves as a gateway for the international transfers of germplasm from genebank and breeding programs and other bioresources requiring regulatory clearance [biocontrol agents (insects, microbes) and nucleic acids]. It collaborates with the NPPOs of the host countries and has authorization of the Nigerian Agricultural Quarantine Service (NAQS) to undertake phytosanitary activities of its mandate crops under NAQS oversight. GHU budget comprise bilateral projects, W1&W2 funding, W3 project and partial cost recovery from users. The unit adopted GHU QMS from 2017 and established partnerships with other GHUs for a system-wide coordinated action to improve phytosanitary research and service delivery. GHU develops protocols, procedures, and policies appropriate for safe exchange of germplasm within Africa. The Unit serves as a reference lab for pest diagnosis in samples from other countries under 'destructive testing' permit, which enabled GHU to play a crucial role in pest and disease surveillance and control of pest spread in sub-Saharan Africa.

Staff	*Facilities*	*Procedures*	*Funding*
7	7	8	6
Just adequate and relies on short term staff hired to cover shortfall during peak season. Short term funding is challenge to skill building, staff retention and succession planning.	Adequate facilities available for broad range of phytosanitary activities and pest diagnosis of both clonal and seed crops. Also conserves reference material and maintenance of isolates. However, infrastructure is aging, and requires large screenhouses and lab space for improving	Adequate and continuous efforts being made to develop protocols for emerging pest risks, non-invasive diagnosis, and other procedures to improve turnaround time, and exchange of planting material in the forms appropriate for use	From the Genebank Platform for essential upgrades and services; from CRPs (W1 and W2), which covers most of the support staff costs; a few W3 projects supporting development of new innovations; and limited cost recovery (about 20 to 30%) from service seekers .

	turnaround time. The Genebank fund helped to make some essential improvements which brough-up facilities to meet the demands. However, aging facilities and breakdown risk persists.	by the partners in the developing and under developed countries.	Funding fluctuation is a risk for maintaining staff, facilities, and operations.

ILRI

GHU was established in 2017 to support the regeneration, conservation, and distribution of healthy and clean germplasm from the genebank. A GHU scientist has been recruited to lead the GHU activities. GHU looks after the overall health aspects of germplasm (seeds, plants in greenhouse, and four field sites) and provides test results for decision before seed packing and/or distribution. GHU has benefited from Genebank Platform in many ways such as unified technology and networking and experience sharing opportunity among scientists across centers and funding support to upgrade lab facilities (biosafety cabinets, ELISA readers, PCR machines, pipettes, microscope with a digital camera, etc.) and procurement of consumables and supplies. However, improvement in health testing procedures, quality management, and capacity building are required to deliver quality test results to end-users and a level similar to other centers with a well-established GHU system.

Staff	*Facilities*	*Procedures*	*Funding*
6	7	5	4
The GHU scientist has recently resigned which created a gap in the coordination and communication of the overall GHU activities. Mr. Alemayehu Teressa took over the role of coordinating the overall GHU activity and there are only three technicians fully working on the fungi and virus testing with a capacity of up to 5000 samples per years. Additional funding is required to recruit new staff to speed up the seed testing activities.	There are facilities for fungi and virus testing. Additional facilities such as dedicated incubators are required once the routine testing of bacteria is started. Replacement of the clean benches is required to ensure seed health testing quality standard.	SOPs for Virus, fungi and phytoplasma testing have been established. Bacteria testing procedure is being developed. There is a lot of backlog testing to be done to achieve the 90% clean seed availability by 2021.	GHU per se has limited funding. Substantial support is provided by the Genebank. However, additional funding is needed to ensure continuity of the germplasm health testing. Capacity building in advanced high throughput disease diagnosis is required to improve staff procedures

IRRI

SHU is an autonomous unit within the Research & Regulatory Compliance cluster of the Integrative Research Support platform. It operates on full to partial cost-recovery basis serving genebank and the breeding programs. IRRI prioritizes germplasm safety, which is exchanged with partners and recipients

of the germplasm. To meet this objective, IRRI continues to collaborate and receive guidelines and compliance requirements from the Philippine Plant Quarantine Service. Bureau of Plant Industry (BPI) and IRRI established an on-site SHU with laboratory facilities. BPI has deputized IRRI to undertake major routine activities on rice seed health testing under its guidelines phytosanitary certification process. Unlike other GHUs, IRRI handles SMTA applications of all exchanges made by IRRI.

Staff	*Facilities*	*Procedures*	*Funding*
7	5	7	6
Just adequate and relies on interim staff hired to cover shortfall during the high demand season. Increased risk of untrained or not competent enough people responsible for the job without long term hiring and expertise development.	Aging equipment, risk of breakdown without replacement. Facility (i.e. NUV chamber) requires upgrade to accommodate high volume of requests during the high demand seasons. Inadequate equipment for new procedures, some activities need to be conducted outside SHU facilities.	Incomplete development. Require update and upgrade. Not all the processes are defined, and decision making is frequently relying on authorities' instructions. Continuous efforts are made to meet emerging needs.	Fluctuation risk often shortfall subsidized by other projects. Chargeback of supplies and services are often processed. Also updates and upgrades in protocols for compliance are not supported by regular funding.