PRO-GRACE

PROMOTING A PLANT GENETIC RESOURCE COMMUNITY FOR EUROPE

DELIVERABLE 5.5

Identification of the scientific services, stakeholders, promoters, and utilizers of the proposed RI (v2)

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Contents

List of acronyms

AEGIS: A European Genebank Integrated System
ABS: Access and Benefit Sharing
BGCI: Botanic Gardens Conservation International
CAP: Common Agricultural Policy
CGIAR: Consultative Group on International Agricultural Research
CPVO: Community Plant Variety Office
CBD: Convention on Biological Diversity
CSB: Community Seed Bank
CWR: Crop Wild Relatives
D: Deliverable
ECPGR: European Cooperative Programme for Plant Genetic Resources
eDNA: Environmental DNA
ENA: European Nucleotide Archive
EPSO: European Plant Science Organization
ESFRI: European Strategy Forum on Research Infrastructures
EU: European Union
EUCARPIA: European Association for Research on Plant Breeding
EUFGIS: European forest genetic resources information system
EUFORGEN: European Forest Genetic Resources Programme
EUNIS: European Nature Information System
EUPHRESCO: European Phytosanitary Research and Coordination network
EURISCO: European Search Catalogue for Plant Genetic Resources
EVA: European Variation Archive
FAIR: Findable, Accessible, Interoperable, Reusable data
FAO: The Food and Agriculture Organization of the United Nations
FGR: Forest Genetic Resources
GBIF: Global Biodiversity Information Facility
GRC: Genetic Resources Centre
GRACE: Plant Genetic Resources Community for Europe
ITPGRFA: The International Treaty on Plant Genetic Resources for Food and Agriculture
LR: Landraces (including obsolete varieties, neglected crops, locally adapted regional selections, etc.)
NGO: Non-Governmental Organization
OECM: Other Effective area-based Conservation Measures
PA: Protected Areas
PGR: Plant Genetic Resources
PRO-GRACE: Promoting a plant genetic resource community for Europe
QMS: Quality Management System
RI: Research Infrastructure
SME: Small and medium enterprise
SOP: Standard Operating Procedure
WFP: Wild Food Plants
WIP: Wild Plants
WP: Work package

1. Executive summary

Despite the high number of accessions stored in European genebanks, several issues continue to undermine the conservation and hinder the efficient use of plant genetic resources (PGR) in research and breeding at the European level. Serious gaps that are often encountered in the current European PGR scenario include lack of quality management systems for PGR conservation; insufficient conservation planning and poor implementation; inadequate integration of *in situ* (including on farm) and *ex situ* conservation strategies; limited characterization and evaluation data including application of advanced -omics technologies and services, and inconsistent accessibility and interoperability of data; difficulties in identifying and accessing germplasm and associated datasets and ability in formulating, interpreting and applying policies and legislations on PGR; and finally, difficulties, by small public and private breeders, in using state-of-the-art technologies for incorporating PGR into their breeding programs. The proposed research infrastructure primarily dedicated to PGR, GRACE-RI, will address these challenges, and, through enabling research activities on PGR and promoting their use, help prevent the loss of PGR diversity and ensure effective conservation. In turn, this will support the transition to a more sustainable and productive agriculture in a changing climate, as well as underpinning long-term European food security.

Building on deliverable D5.2 (Identification of the scientific services, stakeholders, promoters, and utilizers of the proposed RI (v1)), the objective of this deliverable was to refine and expand the mapping of services and stakeholders of GRACE-RI. In doing so we identified and described the main areas where GRACE-RI could provide much needed services (i.e. services for improved *ex situ* and *in situ* PGR conservation; data and information; multi-omics technologies for PGR description and use; services for improved access; and finally capacity building, outreach and advice to political decision makers) that can fill current gaps in PGR conservation, access and use. These services will be organized into five pillars and one horizontal activity, and will form the core service portfolio of the GRACE-RI, provided by dedicated working groups in the central hub as well as member organizations with the relevant expertise within the national nodes of the RI. Moreover, we also envisioned how the main stakeholder groups identified in the previous version can contribute to or benefit from these services, either as providers, users, collaborators or others, thereby laying the groundwork for a coordinated approach to safeguarding PGR diversity and supporting agricultural research and breeding in Europe.

The GRACE-RI will establish its portfolio of services during the preparation and implementation phases, building on the support of its member countries and organizations and, developing a resilient system supporting the PGR research community and increasing the interconnection and relevance of plant science in Europe.

2. Introduction

Despite being an invaluable resource to ensure food and nutrition security for humankind, plant genetic resources (PGR) across the globe are increasingly under threat of extinction and genetic erosion, due to changing climates, changes in land use and agricultural systems and lack of coordinated conservation actions. In Europe, the European Cooperative Programme for Plant Genetic Resources (ECPGR, www.ecpgr.org) has been active for 45 years to provide a network ensuring effective conservation and sustainable use of PGR; two analogous programmes, dedicated respectively to forest genetic resources, (EUFORGEN, www.euforgen.org) and to botanic gardens (EBGC, www.bgci.org/our-work/inspiring-and-leading-people/where-we-work/europe/) were established more recently.

Two complementary documents outline strategic recommendations for ensuring conservation of European genetic resources in the 21st century: the Genetic Resources Strategy for Europe (GenresBridge, 2021), dealing with Plant, Animal and Forest Genetic Resources in general and the Plant Genetic Resources Strategy for Europe (ECPGR, 2021) dealing with Plant Genetic Resources specifically. The two documents identified major gaps in PGR conservation across Europe and outlined a series of recommendations, including the establishment of a long-term European infrastructure that would support PGR conservation and sustainable use (Table 1). Further, although the EU and its Member States are signatories to several international agreements (ITPGRFA, CBD, Nagoya Protocol), to date the EU has not undertaken any work to achieve a minimum level of legal harmonisation in the implementation of these agreements.

Table 1. Recommendations to secure the conservation and sustainable use of European genetic resources in the 21st century from the Genetic Resources Strategy for Europe and the Plant Genetic Resources Strategy for Europe. Recommendations highlighted in yellow call for the development/strengthening of research infrastructures

Genetic Resources Strategy for Europe
Prepare, make publicly accessible, and regularly update European inventories of plant, animal and forest genetic resources conserved *in situ* and *ex situ.*
Prepare, update, and implement national strategies and action plans (NSAPs) for integrated and complementary in situ and ex situ conservation and sustainable use of plant, animal, and forest genetic resources, engaging all relevant public and private stakeholders in the process.
Establish European collections of plant, animal and forest genetic resources actively conserved *in situ* and *ex situ*, including the necessary conservation infrastructures.
Develop and implement quality management systems for long-term in situ and ex situ conservation of plant, animal, and forest genetic resources in all countries.
Provide facilitated access to genetic resources under the control of European countries and in the public domain, as well as associated non- confidential data, for research, breeding, and training.
Develop and implement policies to stimulate innovation, demand and use of a broader range of interspecific and intraspecific genetic diversity by farmers, breeders, forest owners and other stakeholders.
Integrate genetic resources conservation and use objectives into national and regional plans related to other relevant policies (e.g. biodiversity, agriculture, rural development, forestry, environment, and climate change adaptation).
Increase the proportion of inventoried genetic resources—especially in the European collections—that are characterized and evaluated using genomic and phenotypic techniques, as well as social, economic, and eco-geographical criteria
Collate, store, and where appropriate, facilitate open access to characterization and evaluation data in an integrated European and national genetic resources documentation infrastructure.
Further engage in the development and endorsement of internationally accepted indicators of genetic diversity (as appropriate) to monitor the status and trends in conservation and use of genetic resources and offer them for use in relevant international fora.
Develop and endorse internationally accepted standards for assessing the threat to genetic resource collections (*ex situ*) and populations (*in situ*) to monitor trends in genetic diversity conservation.
Undertake regular monitoring of *in situ* and *ex situ* conservation and sustainable use and carry out threat assessment using the developed standards and indicators.
Based on harmonized standards, further expand, develop, and maintain the national inventories of plant, animal, and forest genetic resources, which feed into the three European information management systems, EURISCO, EFABIS and EUFGIS, under a national mandate to deliver high quality documentation.

Further develop the three European information management systems to be compliant with the FAIR principles and to be recognized as trusted data repositories, including through appropriate networking activities aimed at sharing good practices and expertise.
Review the existing European policy and legislative landscape and instruments related or relevant to the conservation and sustainable use of genetic resources to identify gaps and needs.
Based on the review, as appropriate, establish a specific European policy and regulatory framework for the conservation and sustainable use of genetic resources, and if necessary, amend the existing policies, regulations, and programmes.
Establish a European coordination and information centre for conservation and sustainable use of agricultural genetic resources.
Create integrated European and national technical and research infrastructures, as appropriate, to provide a long-term foundation for the conservation, documentation, and sustainable use of genetic resources in Europe.
Strengthen the capacity of the three existing European genetic resources networks.
Establish European and national human capacity development programmes in genetic resources conservation and sustainable use, and as appropriate, integrate genetic resources aspects into existing programmes in colleges, universities, and industry.
Increase professional awareness of the different values of genetic resources, including the relative costs and benefits of their conservation and sustainable use by different stakeholders at national and European levels, as an impetus to strengthen national and regional policy commitments to genetic resources conservation and sustainable use.
Increase education and awareness among the public, including children, of the values of genetic resources to society, the inter-dependence of all countries on genetic resources, and the importance of maintaining genetic diversity to sustain the provision and use of daily commodities by all households.
Foster the participation of, and collaboration between actors and domains, to identify potential synergies and greater integration of public and private genetic resources actors, as well as firm linkages with other stakeholder communities.
Develop collaborative activities in support of information infrastructures to enable better findability, interoperability, and access to all relevant sources of data and knowledge, develop a common ethic on data sharing, enhance outreach with global initiatives on linked open data, increase expertise in data stewardship among the different actors, and build capacity to address future documentation needs.
Provide appropriate and long-term financial support for European and national genetic resources conservation and sustainable use activities and measures, targeting the various stakeholder groups involved, and ensuring the equitable participation of all European countries.
To strengthen the coordination of European activities, alongside national government funding, introduce a contribution from the European Commission to ensure appropriate and long-term funding of the three European genetic resources networks, ECPGR, ERFP and EUFORGEN.
Promote pan-European collaboration for the conservation and sustainable use of genetic resources facilitating the active participation of all European countries in the implementation of the Genetic Resources Strategy for Europe and domain- specific strategies.
Maintain and develop inter-regional partnerships for conservation and sustainable use of genetic resources with other regions, especially the Caucasus, Near East and North Africa.
Reinforce, or where lacking, establish coordination measures and processes between national and regional focal points and representatives for Europe in international fora dealing with conservation and sustainable use of genetic resources.
Plant Genetic Resources Strategy for Europe
A European coordination and information centre should be established to support the European Commission, European governments and cooperative programmes for conservation and sustainable use of agricultural genetic resources and national programmes in implementing the European and domain-specific genetic resources strategies.
Adequate and permanent co-funding of national programmes by the EU, introduced for sustained support of European collaborative measures in conservation and sustainable use of genetic resources needs to be established as part of an overarching investment plan.
A European infrastructure for *ex situ* and *in situ* PGR conservation and sustainable use should be established or further developed. This infrastructure should include, inter alia, the decentralized/virtual European genebank (building on the AEGIS experience and principles), routine screening facilities, and a European Network of managed and monitored priority *in situ* populations.
A European PGR documentation and information infrastructure should be developed to support conservation, monitoring, research, breeding, sustainable use, and human capacity building among the main PGR actors and provide information about potential financing sources to better manage PGR at national, EU and European regional levels.
A European human capacity-building scheme, including PGR education and training programmes in schools, undergraduate biology degrees and MSc programmes and vocational and professional training that involves modules in PGR conservation and use should be established, continuing professional development short courses, and opportunities to undertake research topics for doctoral studies.
The EU policy and legislative landscape related to PGR should be reviewed, and the implementation of all relevant programmes, measures and instruments coordinated for a sustained long-term conservation and more effective utilization of PGR.
A European legal framework that facilitates and promotes genetic resources conservation, documentation and sustainable use at both national and European levels should be established.
European countries should develop and implement national action plans for the conservation and sustainable use of PGR, supported by different instruments and regulations at the EU level.
Adequate and permanent co-funding of national programmes by the EU, introduced for sustained support of European collaborative measures in conservation and sustainable use of genetic resources needs to be established as part of an overarching investment plan.

Within the PRO-GRACE project, the concept for the GRACE Research Infrastructure dedicated to plant genetic resources is being developed. The exact perimeter of this infrastructure is still being defined. The two vision documents mentioned above cite genebanks, botanical gardens, arboreta (collectively referred to as genetic resources centres or GRC), as well as *in situ* reserves/genetic conservation units and on-farm conservation as being integral parts and important stakeholders of the PGR conservation efforts. The infrastructure will include not only conservation and documentation, but also translational aspects on the use of PGR, such as evaluation and applications to (pre)breeding. The project has developed standards, protocols and blueprints for data management, quality conservation of *ex situ* and *in situ* PGR collections, characterization methods for various omics technologies to be applied to PGR and phenotypic evaluation of genebank collections. These deliverables served as input for WP5, which developed the concept of the GRACE-RI through a gap analysis of the current European RI landscape (deliverable D5.1; Gap analysis of the present European RI ecosystem, including an analysis of the possible synergies with existing RIs), a proposed governance structure (deliverable D5.4; Governance structure of the proposed infrastructure) and financial plan (deliverable D5.3; A financial plan for the proposed infrastructure, covering the design and preparation phases) of the GRACE-RI as well as a survey on ethical and legal issues relevant to PGR in Europe (deliverable D5.6; An analysis of the ethical, social and regulatory aspects of the transition of the present PGR system to an integrated pan-European Research Infrastructure).
In this deliverable, the stakeholder and services inventory of deliverable D5.2 were further developed into a service portfolio that the GRACE-RI will develop and provide to its future users. The portfolio was designed to meet the diverse needs of genetic resources centers, breeders, researchers, policymakers and other stakeholders, while reflecting the inherently multidisciplinary nature of PGR conservation and utilization. It also maps the stakeholders by identifying providers of services within the RI, internal and external users and possible collaborators, also within the ESFRI landscape. This approach highlights where stakeholders can align, identifies potential synergies and supports more efficient coordination and resource use across Europe's diverse research ecosystem. Furthermore, the structure of the proposed service portfolio is matched to the governance structure in deliverable D5.4 and both documents were used as basis for the development of the financial plan of the GRACE-RI (deliverable D5.3).

3. Methodology

Deliverable D5.2 summarized an inventory of important stakeholders in the PGR sector and listed a suite of potential services that would facilitate research on PGR and could be provided centrally by a dedicated GRACE RI. These were grouped into four main categories of PGR activities (Conservation & Documentation, Use, Policy, Networking & Capacity) and the relevant stakeholders mapped on this structure.
While many PGR activities remain within the capacity of national programmes and local actors, the services included in the GRACE-RI portfolio will enable them to be implemented effectively through a centralized support system promoting PGR research. Through additional surveys, workshops and discussions the most suitable service portfolio of a future GRACE-RI was developed. During a Workshop at NordGen in Alnarp (April 2024), WP5 members started discussions on the final composition of the RI service portfolio. A survey on benefits, impacts, and pilot projects of the proposed RI (see Appendix I) was shared and responses collected from other PRO-GRACE partners (during April - June 2024). Based on this survey, the main services were defined at a meeting held during EUCARPIA general congress. Expert focus groups further developed these to describe the state of the art, propose services of the GRACE-RI, and identified the main providers and potential users for each. This portfolio of services was further discussed and developed during regular on-line monthly meetings of WP5. Feedback was provided at three-monthly meetings of all PRO-GRACE partners.

4. Proposal for a GRACE-RI service portfolio

This chapter presents a list of the possible services of the future GRACE-RI including a list of providers and users for each service, based on the stakeholder groups described in deliverable D5.2. It is important to highlight that

GRACE-RI will be the main provider of the services through its central hub and national nodes, and that the GRACE-RI service portfolio will be evolving, based on GRACE users' and stakeholders' demands, the evolution of technologies, in order to provide cost-effective, state-of-the-art, services tailored to specific research and societal needs.

The proposed **scientific services supporting the conservation, documentation and utilization of plant genetic resources** are structured into five foundational pillars and one horizontal activity (Figure 1). The pillars focus on distinct but interconnected aspects of the GRACE-RI, including services for *ex-situ* and *in situ* conservation and management, data management integration, services for characterization and (pre)breeding, and access, while the transversal activity includes capacity building and outreach. Together, they provide a comprehensive framework to enhance the conservation and effective use of PGR across Europe. Each service pillar is described in detail below.

The services described hereafter form the essential portfolio necessary for the successful operation of the infrastructure and will build in many instances on existing initiatives developed over the past decades by ECPGR and other international networks. Their scope and focus may and will expand over time based on the monitoring and evaluation of the infrastructure by internal bodies as well as recommendations from the Scientific Advisory Board. It is expected that the portfolio of services will be further developed and specified during the preparatory phase of GRACE-RI and revised at least with each update of the roadmaps of the large infrastructures.

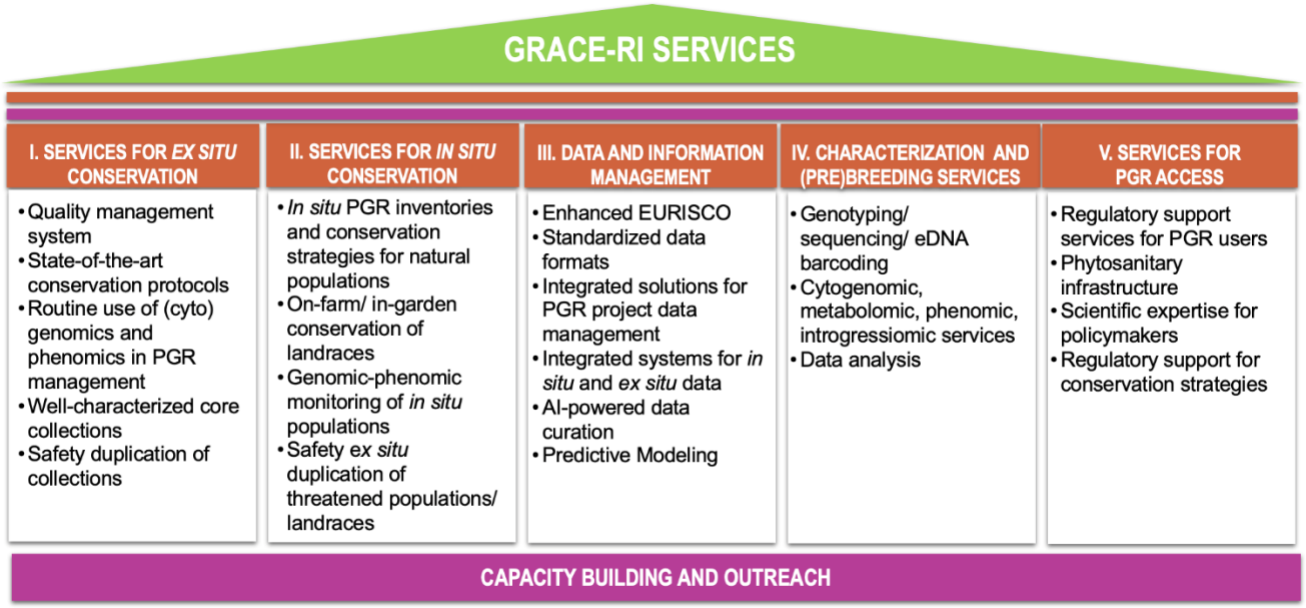

Figure 1. *Summary of proposed GRACE-RI Service pillars. The five main pillars "Services for ex situ conservation", "Services for in situ conservation" "Data and Information Management", "Characterization and (pre)breeding services" and "Services for PGR access" are the core services of the RI. The transversal activity "Capacity building and outreach" integrates with all main pillars, and together they form an interrelated structure of RI services.*

4.1. Pillar I. – Services for *ex situ* conservation

Current status

Currently, in Europe there are over 400 genebanks and collections listed in the EURISCO database, representing more than two million accessions, as well as around 900 botanic gardens. Despite these extensive resources, the management of the collections and availability of the accessions remain inconsistent. A strategic approach to GRC operations must prioritize long-term conservation, enhanced accessibility, and routine integration of state-of-the art technologies to support conservation and documentation. Enhanced research and development (R&D) activities will play a crucial role in transforming Genetic Resources Centres (GRCs) operations and will ensure that collections are well-characterized, evaluated, and readily available for innovation in agriculture and biodiversity conservation. Further, implementation of Quality Management Systems (QMS) and certification mechanisms are

necessary to ensure reliability, transparency, and adherence to best practices across all GRCs. The FAO Genebank Standards (FAO, 2014) and the AQUAS quality management system (https://www.ecpgr.org/aegis/aquas/overview) provide minimum benchmarks for genebank operations. AQUAS supports harmonized procedures and promotes AEGIS peer-review audits as well as the safety duplication of unique accessions under equivalent or better conditions at alternate locations, such as the Svalbard Global Seed Vault. BGCI's Manual on Planning, Developing and Managing Botanic Gardens (https://www.bgci.org/resources/bgci-tools-and-resources/bgcis-manual-on-planning-developing-and-managing-botanic-gardens/) provides similar benchmarks for botanic garden operations. Adherence to these benchmarks is voluntary, varies significantly across institutions, and national legislation and resources often influence their application.

Additional barriers include restricting policies regarding access to the germplasm, limited access to phytosanitary services, limited integration of molecular characterization data, lack of public databases and ordering systems, and insufficient characterization and evaluation data. Special collections of recalcitrant seeds, clonally propagated species conserved *in vitro*, in cryo or in the field have additional challenges that limit access and would benefit from research towards improving tools and protocols for conservation.

One of the main limitations in PGR use is the scarcity of well-characterized **core collections,** representative of the worldwide genetic and phenotypic diversity of a species (Van Hintum et al, 2000). Whenever these core collections are available, they come in high demand by users interested in screening for novel traits, thus establishing a win-win situation: for users, who direct their efforts on well characterized, representative materials; and for GRCs, that minimize the number of highly requested accessions and the consequent labour.

Finally, **safety duplication** of genebank accession ensures the long-term preservation of plant genetic resources by storing duplicate samples in geographically distinct locations. This strategy provides protection against genetic erosion, disasters, mismanagement, and political instability (FAO, 2014; Westengen et al., 2020).

Aims and objectives

The GRACE-RI will develop a framework for a European genebank certification system and support European genebanks in reaching the quality level required to obtain Genebank Certification. This will include:

1. A **GRC Quality Management and monitoring system**, featuring basic metrics for genebank evaluation (including all basic genebank operations and procedures), regularly updated and publicly accessible, to promote transparency and clear objectives. This will include dedicated auditing and certification mechanism to ensure compliance with SOPs and international standards across GRCs. The QM services will be gradually expanded to cover vegetatively propagated and recalcitrant species and live collections.
2. Continuous improvement of **protocols for conservation, testing of viability, seed regeneration** for diverse species.
3. Routine introduction of high-throughput, low cost **(cyto)genomic, metabolomic, and phenomic methods** in PGR management.
4. Establishment of **core collections** representative of the worldwide genetic and phenotypic diversity of a species.
5. Support for **safety duplication** of collections, emphasizing storage under secure conditions, like the Svalbard Global Seed Vault.

Proposed services

1. **A GRC Quality Management system, including monitoring, auditing and certification**: A Genetic Resource Center Monitoring System will be established, integrating a set of quantitative indicators tested in pilot projects. Metrics will include viability results, regeneration needs, and compliance with SOPs. The results will be published online to foster transparency and collaboration. Peer-review audits piloted will be expanded to a formal certification system managed by GRACE-RI, enabling harmonization of QMS

across European GRCs. A **helpdesk** will be established to support monitoring and certification requests, working with Pillar V on developing resources, linking existing tools and producing new training materials, including historical content digitization.

2. **State-of-the-art protocols** will be continuously elaborated and improved for seed and live plant long-term conservation, including in vitro, cryo- and pollen conservation. Methods for seed regeneration will be improvedto minimize selective pressure and maximize the transmission of genetic diversity during regeneration.
3. **Genomics, cytogenomics, and phenomics** will be routinely introduced in PGR management. Initially, medium density genotyping and cytogenomic methods will be used Europe-wide, in order to identify the extent of genetic diversity stored *ex situ*, identify genetic gaps and guide future collection expeditions to fill such gaps. As sequencing costs will decrease with time, the aim will be to progressively sequence and digitize all accessions stored in European GRCs, starting from the representative core collections described in point 4. Similarly, high throughput, low cost, portable device-based imaging methods will be introduced, in collaboration with the EMPHASIS and DISSCO RIs, for routine phenotyping and digitization of accessions in live collections or during seed regeneration (see Pillar IV for further details).
4. **Well characterized core collections,** representative of the world-wide genetic and phenotypic diversity and geographic distribution of important species and their CWR will be generated in collaboration with international GRC, based on phenomic/genomic data and publicly available plant pangenomes. The core collections will be sequenced and phenotyped using services from Pillar IV. These data will enable the services in Pillar III (predictive modeling) and IV (GWAS, genomic prediction). Their availability through multiple distribution points will greatly facilitate the work of both users and of GRCs, concentrating seed requests on a small number of accessions representative of the worldwide diversity .
5. **Safety duplication of accessions** emphasizing storage under secure conditions, like the Svalbard Global Seed Vault, provides protection against genetic erosion, disasters, mismanagement, and political instability. The use of genomics and phenomics will help prioritize duplication of high priority materials, such as core collections and rare/threatened genotypes/phenotypes.

Key performance indicators (KPIs)

- Number of GRCs included in the Quality Management System. Number of metrics (for individual genebanks) published.
- Number and adoption of novel, public protocols for PGR conservation/seed regeneration
- Number of accessions with genotyping and phenotyping (meta)data and images, collected according to standardized protocols
- Number of taxa with representative well-characterized core collections
- Number of safety duplicated accessions

Providers: Leading European GRCs and research institutes
Users: GRCs within and outside of the GRACE-RI; researchers and breeders.

4.2. Pillar II – Services for *in situ* conservation

Current status

Crop Wild Relatives (CWR), wild food plants (WFP), crop landraces (LR) and forest genetic resources (FGR) are vital for the enhancement of ecosystem services, agricultural resilience, crop diversification and food security, and the bioeconomy (FAO, 2010; Rajora & Mosseler, 2001; Maxted et al., 2006). They possess unique adaptive traits such as drought tolerance, disease resistance, and increased yield potential, or provide more diverse food choices. The Euro-Mediterranean region is a biodiversity hotspot for CWR, WP and LR

diversity related to cereals, legumes, industrial crops, and vegetables (Maxted et al., 2024). However, these critically important wild and cultivated resources face existential threats from, for example, habitat mismanagement, environmental instability, and unsustainable farming practices. An IUCN (International Union for Conservation of Nature) Red List Threat Assessment revealed that 11.5% of 572 European CWR were threatened with extinction (Bilz et al., 2011). Similar estimates are available for FGR (Ohlemueller at al., 2006). Anthropogenic threats, such as harmful agricultural practices, habitat loss, and climate change, further exacerbate the situation, leaving much of Europe's CWR, WP, FGR and LR diversity under-conserved, under-utilized and at risk of extinction. Despite their economic value and food security significance, the *in situ* conservation of PGR diversity remains inadequate, with only 53% of European priority CWR taxa represented in genebanks (Castañeda-Álvarez et al., 2016) and even fewer actively conserved *in situ* (Maxted et al., 2016). While efforts to *in situ* conserve PGR have been made at national levels, these initiatives often lack coordination and sufficient integration across Europe, limiting their effectiveness. There are currently no *in situ* CWR genetic reserves either in protected areas (PA) or other effective area-based conservation measures (OECM) sites, that fully meet the *in situ* standards defined by Iriondo et al. (2012) and Maxted et al. (2016). However, several countries have begun *in situ* CWR conservation management using the genetic reserve guidelines (Iriondo et al., 2021) with specific *ex situ* linkage for backup, characterization and user access, and putative national CWR *in situ* networks are being established.

Aims and objectives

GRACE-RI aims to mainstream *in situ* conservation implementation across Europe and establish a permanent multi-actor collaboration to conserve and utilize the full breadth of European CWR and LR diversity. It will leverage services developed in Pillars III-V and adapt them to specific needs of *in situ* conservation. By integrating *in situ* and *ex situ* conservation strategies, GRACE-RI will systematically secure the diversity of European PGR, ensuring its conservation and sustainable use for generations to come. The goals include:

- Provide tools and an evidence-base to support national programmes in their identification, conservation planning and management of *in* situ populations.
- Ensure systematic conservation, using *in situ* techniques, of priority populations and taxa across their geographic ranges and in diverse agroecological systems, and ensure the conserved resources are available for end-users.
- Monitor, characterize, evaluate and document conserved populations to identify their evolution over time as well as important adaptive traits.
- Provide safety *ex situ* conservation of threatened populations.
- Elaborate models and methods for the protection of *in situ* threatened populations from invasive species and pests.

Proposed services

1. Support development of national ***in situ*** **PGR inventories and conservation strategies for natural populations:** National PGR prioritized inventories and conservation networks will be provided with technical support, monitoring tools (including remote sensing) and conservation planning toolkits. The consistency and articulation of these national networks will be developed through a GRACE-RI working group. Collaborative efforts will include the identification of priority populations, development and implementation of site management plans, regular monitoring of conserved populations and *ex situ* backup to aid resource utilization. This will ensure conservation objectives are achieved and the range of genetic diversity available for use (assessed by establishing suitable Essential Biodiversity Variables - EBVs) is significantly enhanced, characterized and made easily available to users, including the relative genetic and phenomic information through the services in Pillar IV.
2. Support implementation of **on-farm/ in-garden conservation of LR** diverse sites: Establish and support on-farm and in-garden diversity management systems (in collaboration with Pillar I) consisting of networks of diverse stakeholders (including farmers, horticulturists, gardeners, breeders networks and small scale seed companies) that aid maintainers sustain and evaluate LR under different environmental

conditions and agronomic systems, provide tools and practical examples to foster sustainable use of LR diversity in general and broaden cultivation of crop and varietal genetic diversity in production systems.

3. **Genomic-phenomic monitoring of *in situ* populations.** The genetic diversity, population numerosity and health status of *in situ* conserved populations will be monitored through the application of a series of easy to apply, user-friendly genomic and phenomic technologies developed in Pillar IV, such as remote (satellite, drone) monitoring coupled with AI-driven individual count, eDNA metabarcoding, portable device phenotyping and periodical sampling of individuals, to monitor genetic diversity, presence of pathogens/invasive species, early warning of possible threats, and identification of individuals/populations carrying adaptive traits to biotic/abiotic stresses.
4. **Safety *ex situ* duplication of threatened populations/LR.** Based on the observations under service 3, populations/individuals that are threatened *in situ,* carry valuable adaptive traits, or fill genetic gaps in *ex situ* holdings, will be conserved and regenerated *ex situ* by specialized GRC personnel and, if possible, safety duplicated in a second *ex situ* location.

Key performance indicators (KPIs)

- Number of national PGR programmes actively managing WIP and LR conservation sites and *in situ* / on-farm conservation networks.
- Number of national inventories of CWR and LR published and approved by national authorities.
- Number of WIP and LR *in situ /*on farm populations actively conserved,
- Number of WIP and LR *in situ /*on farm populations actively conserved, genetically and phenotypically characterized and/or evaluated for adaptive traits.
- Number of WIP and LR *in situ* / on-farm populations with backup *ex situ* accessions.

Providers: National PGR and GRC programmes; public research centers and universities; International and national organizations and networks; Local communities and citizen scientists.
Users: Breeders and researchers, policy makers, allied EU agencies and projects, academic and researchers working on PGR (including ECPGR national *in situ* / on-farm focal points) and biodiversity, EURISCO***,*** GENESYS, EUNIS, GBIF, EUFGIS and other information systems, citizen scientists and the public***.***

4.3. Pillar III - Data and information management

Current status
Fragmented and inconsistent approaches to PGR data management hinder collaborative efforts across European agriculture and biodiversity sciences. Numerous information systems at institutional, national, and regional levels operate with varying data structures, standards, and practices, creating isolated and often incompatible data islands. Variations in taxonomic classifications, *ex situ* and *in situ* distinct passport descriptors, trait descriptors, and data recording methods further hinder integration and reuse of datasets (discussed in deliverable D1.4; Minimum Information About a Plant Genetic Resource standard).
At the European level, EURISCO (http://eurisco.ecpgr.org) serves as a central aggregator information system, consolidating *ex situ* passport data from over 400 institutions holding PGR in more than 40 countries, and has recently expanded to include *in situ* passport data for crop wild relatives (CWR) and some characterization data. Other European archives, such as EUFGIS (http://www.eufgis.org/) and PlantSearch (https://www.bgci.org/resources/bgci-databases/plantsearch/) provide information about forest genetic resources, and resources stored in botanical gardens, respectively. Additionally, the European Nucleotide Archive (ENA), the European Variation Archive (EVA), and MetaboLights, provide generic long-term storage and structured access to genomic and molecular phenotypic data (i.e., transcriptomic, proteomic and metabolomic data). Phenotypic data remain especially dispersed and difficult to integrate, often confined to isolated repositories or linked only to specific research publications, thus limiting broader accessibility and comprehensive analyses. These limitations underscore the urgent need for enhanced integration and/or

interfacing of multiple PGR-associated information systems (e.g. EURISCO, EUFGIS and PLANTSEARCH) and standardization of data types (e.g., *ex situ* and *in situ* passport, taxonomic, phenotypic, genotypic and metabolic data), improved interoperability between existing platforms, and systematic adoption of FAIR (Findable, Accessible, Interoperable, Reusable) principles for PGR data. Description and demonstration of data integration is also the aim of deliverable D4.4 (Interconnection of different phenotype databases with the central EURISCO information system).
Relying on the vision developed in deliverables D1.4 and D4.4 but also in former projects like GenRes Bridge (Adam-Blondon et al., 2021), GRACE-RI will address gaps in standardization, data completeness, and long-term accessibility by promoting shared guidelines, better streamlining FAIR PGR data produced or managed in Europe to global systems like Genesys, International Nucleotide Sequence Database collection (INSDC) repositories and other relevant repositories. Deliverable D1.5 (Inventory of PGR information not yet represented in EURISCO and unified strategy for the interfacing of different information systems with EURISCO) will further develop a strategy for data integration. These activities will enable the development of a federation of data on PGR, accessible from a central portal.

Aims and objectives

The general goal is to develop a central portal for accessing and integrating PGR data to support research on PGR and innovation in their multiple uses. Goals include:

- Establish a leading information system for the integration of PGR data.
- Develop or advance, and implement common data standards, including minimum information descriptors, to ensure consistency and quality.
- Promote the adoption of high-quality practices for PGR data curation and management, ensuring compliance with FAIR principles.
- Enhance integration and accessibility of *ex situ* and *in situ* data, providing comprehensive access to passport, phenotypic, and genomic datasets.
- Enhance integration with external information systems, linking with existing data providers and repositories.

Proposed services

1. **Enhanced EURISCO**: The functionality of EURISCO will be enhanced to strengthen its role as the primary and trusted repository/portal for PGR passport and phenotypic data as well as the linkage with genomic datasets. Federated access to external archives such as ENA and EVA for genomic and molecular data as well as main phenotypic databases will be implemented and link to CWR and LR inventory and *in situ* / on-farm population level data. Ultimately, this should become a “one-stop shop” for users to browse PGR accessions and order them from the holding institute directly via the portal.
2. **Standardized data formats**: A comprehensive data standardization framework will be established in collaboration with other repositories, such as EUFGIS and PLANTSEARCH, or research infrastructures such as ELIXIR, EMPHASIS, DiSSCO and GBIF. This framework will adopt and refine standards for data formats, taxonomies, and metadata protocols. Specific ontologies for *in situ* CWR reserves will be derived from EUFGIS data standards. Validation tools for automated checks on data completeness and consistency will be developed.
3. **Integrated solutions for PGR project data management:** This service will support PGR researchers and projects through providing data management guidelines, advice and support for data curation for a complete solution to manage relevant metadata in relation with the data sets that are produced (e.g. phenotypic and various -omics datasets) and streamline the data to the recommended dedicated repositories. This support will ensure that data sets are properly linked to each other through suitable PUID (e.g., DOI) and in particular with the corresponding PGR passport data in EURISCO.
4. **Integrated systems for *in situ* and *ex situ* data**: Tools for bidirectional data exchange between *in situ* and *ex situ* collections will be developed to enable seamless integration for comprehensive PGR data access.

5. **AI-powered data curation**: Employ AI to support data cleaning and integration, allowing users to better select the material they need in their research and breeding activities, but also supporting PGR curators in the identification of gaps or redundancies.
6. **Predictive Modeling**: Deploying a Virtual Research Environment (VRE) with tools for predicting natural population and crop performances and habitat suitability across Europe under future climate scenarios currently available (e.g. CHELSA/ WorldClim); tools for genome-wide predictions of field performances for all crop species; models for the future evolution of threats to the most vulnerable *in situ* conserved populations, including invasive species, pests, and abiotic stresses.

Key performance indicators (KPIs)

- Number of accession/population records integrated or updated in the enhanced EURISCO, including phenotypic and *in situ* data.
- Number of external archives interoperable with the enhanced EURISCO.
- Percentage of European collections and projects adopting the unified data standards and FAIR compliance.
- Increase in *ex situ* accessions/*in situ* populations with assigned DOIs.
- Establish and utilize a composite measure in enhanced EURISCO that consolidates inconsistencies, isolated datasets, incomplete metadata, and duplications into a single index. Data structure that allows easy reporting to FAO of the status of conservation and sustainable use of plant genetic resources for food and agriculture in Europe (FAO-Indicators GPA: https://www.fao.org/wiews/data/domains/monitoring-framework/en/).
- Number of crops/natural populations with experimentally verified performance models.

Providers: EURISCO, PLANTSEARCH and European regional and national *in situ* CWR and on-farm LR networks; Leading European genebanks and botanical gardens; Public research centers and universities; other Research infrastructures like ELIXIR, EMPHASIS, and GBIF; Genomic data repositories (e.g., ENA, EVA); Conservation networks (e.g., Natura 2000, Eurosite, EUFGIS).

Users: Genetic resource centers within and outside of the GRACE-RI; researchers' and breeders' community in/outside Europe through more informative catalog of resources.

4.3. Pillar IV - Services for characterization and pre-breeding

Current status

The value and significance of the accessions stored in in GRCs and *in situ* have increased in the light of climate change, which has heightened the need to develop plants that are both adapted to new environmental conditions and resilient to biotic and abiotic stresses. The holdings at major GRCs often include tens of thousands of accessions, and they only represent a minor fraction of the genetic diversity present in nature. Despite their importance, germplasm collections suffer from incomplete or even absent genetic and phenotypic characterization, rendering potentially valuable accessions "invisible" and leaving them underutilized in plant improvement programs. This lack of information is even more acute for natural/on farm conserved populations. In addition to the challenge of thorough characterization, another significant issue is the incomplete coverage by GRC collections of the phenotypic and genetic diversity found in nature. To address this, it is essential to expand collections to ensure as complete representation of genetic diversity as possible. This is vital not only for the potential use of these unrepresented accessions in crop improvement but also to safeguard these genotypes from the threats posed by human activities and changing environment. A further layer of complication is that much of the genebank historical data originate from periods prior to electronic data processing, resulting in loss of information during the transition from analog to digital formats or during exchanges between genebanks.

Therefore, genetic profiles for genebank accessions can both guide conservation decisions and complement incomplete passport data.

Current challenges include: a) Creating/restoring complete passport data for accessions and ensuring this information is publicly accessible and user-friendly; b) Conducting comprehensive and in-depth characterization of the genetic and phenotypic diversity of gene bank accessions and natural populations using advanced "omics" techniques; c) Applying whole-genome and pangenomic approaches to the *ex situ – in situ* continuum, assess the genetic diversity of individual species, identify gaps in germplasm collections and *in situ* populations, and inform future collection/conservation strategies; d) Integrating multi-omics data to identify and characterize duplicated accessions, adaptive traits, genes, and alleles essential for developing plants resilient to new environmental conditions and crops suitable for sustainable agriculture; e) applying association analyses and genomic prediction methods to identify accessions/populations carrying adaptive traits and mapping those traits; and f) introgressing the above genes and traits into vulnerable populations, or elite crop germplasm (Prohens et al., 2017).

These challenges can be addressed by adopting several technologies, including cytogenomics, high-throughput genotyping, (pan)genome and environmental DNA (eDNA) sequencing, metabolomics, phenotyping, association mapping, genomic prediction, interspecific crosses/embryo rescue and marker assisted selection. The rapid advancement of these technologies makes their large-scale application increasingly feasible. Their use holds the potential to revolutionize the characterization and utilization of plant genetic resources, identify gaps in germplasm collections, preserve valuable genetic material for future generations, and support the development of crop and non-crop populations with novel, beneficial traits. For instance, DNA barcoding of a sample with few thousands of Single Nucleotide Polymorphisms (SNPs) for a cost of a few €, in combination with passport/genebank phenotypic data, allows the identification of duplicated accessions, taxonomic misclassifications, the domestication history and migrations of a crop, genomic regions carrying important agronomic or adaptive traits, minimum population size to avoid inbreeding depression, and genomic prediction of the genetic potential of large, uncharacterized populations, utilizing as training populations representative subsamples for which both genotypes and phenotypes are available (Yu et al., 2016; Milner et al., 2019; Tripodi et al., 2021; Hoban et al., 2022; Omondi et al., 2025). Direct observations of genetic diversity by means of molecular markers can be characterized at multiple levels, including individual, population, and species levels, providing insights into the structure and dynamics of genetic diversity within and across populations, as well as in accessions conserved within and among GRCs. Additional parameters to consider for studying the genetic diversity include the nucleotide diversity, effective population size, and identity by state. The advent of long read sequencing provides a more comprehensive view of the genome, including difficult to sequence regions and large structural variants, facilitating the development of chromosome level (super)pangenomes at the species or genus level, and demonstrating the impact of structural variation/gene duplication on species evolution (Benoit et al., 2025). Such pangenomes, applied to the core collections constructed in Pillar I and fostered by pan-transcriptomes and pan-metabolomes, can assist in realizing this potential by more effectively linking sequence variation to phenotypes at the species or genus level and thereby facilitating the breeding of improved phenotypes. For monitoring of *in situ* populations, metabarcoding of soil eDNA has been found to closely mirror plant taxonomic diversity estimated from conventional surveys (Vasar et al., 2023). Additionally, eDNA methods could help to monitor the biodiversity in remote, difficult-to-access areas or subjected to strict management protocols and permitting requirements. Metabarcoding is a high-throughput method that, in combination with long read amplicons and primers for different taxa, can be used to monitor inter- and intra-species diversity of plants or invasive/pathogenic species (Lin et al., 2025)in a given natural area or agroecosystem, and monitor their evolution over time.

Cytogenomics provides crucial information for the characterization of PGRs by determining ploidy levels, genome size, and chromosome number, which are essential for ensuring taxonomic accuracy, detecting incorrectly classified accessions, and identifying potential breeding barriers (Christelova et al. 2017).

Metabolomics can play dual roles in PGR management: using mass imaging, metabolite spatial distribution can be used as a means for accession characterization (Li et al.,2022); or, using classical mass spectrometry methods,

for evaluating the content of health-promoting, antinutritious or pharmacological compounds in crops and WIP, supporting their safe utilization (Sreenivasulu et al., 2023).
High throughput, image based phenotyping combined with Artificial Intelligence (Das Choudhury et al., 2019) can bring phenotyping within reach of small GRC with limiting budgets, as well as Protected Areas managers. For monitoring Protected Areas and crop fields, both drone-based and satellite-based imaging can be used, alone or in combination, for monitoring plant populations and their health status (Yuan et al., 2025; Dash et al., 2018). Collaborations with the EMPHASIS RI will help establishing the most informative and cost-effective phenotyping methods suitable for GRCs and *in situ* reserves.
Pillar IV will be closely interacting with Pillar III to make the generated data available *via* the EURISCO information system and provide a framework for operations in Pillars I and II. The feasibility of proposed services was demonstrated in Pro-GRACE deliverables D3.2 (Demonstration of DNA barcoding, reduced representation sequencing/resequencing and cytogenomic methods and services for the assessment of the genetic variability, PAVs, assisting gap analysis, ploidy/aneuploidy determination and facilitation of interspecific crossing/introgression programs), D3.3 (Demonstration of metabolomic methods and services) and D3.5 (Demonstration of bioinformatic methods and services for kinship/population structure/pedigree determination, gap analyses, GWAS and QTL analyses).

Aims and objectives

- Standardize simple -omic (sampling, portable phenomics) methods suitable for use by small GRC and *in situ*/on farm maintainers. More specialized services (cytogenomic, metabolomic, resequencing/pangenome, eDNA-based, GWAS, genomic prediction, QTL analyses, introgressiomic, remote sensing/automated phenotyping) will be provided by specialized research centres. GRACE-RI will guarantee a sufficient Europe-wide coverage/redundancy of such centres and their coordination, for providing such services to small GRCs*, in situ*/on farm maintainers and SMEs.
- Develop workflows for various -omic approaches, including defining marker sets and analysis approaches (according to reproductive system, genetic materials, etc), and coordinating upstream and downstream activities.
- Develop services for rapid metabolic fingerprinting, as well as the identification of metabolites relevant to plant adaptation, performance and food/feed quality in PGR collections.
- Develop services for intra- and inter-specific introgression breeding.
- Contribute to the development and provision of tools and pipelines for data integration and analysis, in close collaboration with Pillar III.
- Provide training/capacity building for all public and private stakeholders in the above domains.

Proposed services

1. **Genotyping/sequencing/eDNA barcoding**: GRACE-RI will coordinate genotyping efforts across European GRCs, integrating public and private sector expertise to ensure consistent methodologies and cost efficiency. It will focus on developing and disseminating molecular passport data for accessions of important PGR species, establishing crop-specific standards (as described in deliverable D1.2; Standards for collecting and displaying genetic data), and facilitating effective genebank management, including the identification of duplicates and gaps, association analyses/genomic prediction. It will also provide valuable insights for breeding programs, as well as the basis for construction and pangenome sequencing of representative core collections for model and under-utilized species. Pangenomics will explore genetic diversity at the species and genus levels by analyzing both core and accessory genomes, and thus capturing the variability present in populations and across geographies. eDNA metabarcoding in Protected Areas will provide molecular monitoring of genetic diversity of conserved populations and invasive species.
2. **Cytogenomics:** Routine services will focus on genome size and ploidy and, on a case-by-case basis, aneuploidy and chromosome structural rearrangements. By linking cytogenomic data with genotyping

and pangenomic information, the service will enhance the identification of genetic markers associated with specific traits, supporting more precise breeding strategies, as well as biodiversity conservation and efficient use of PGR collections across European GRCs.

3. **Metabolomics**: Metabolomics services will emphasize metabolomic profiling to identify and evaluate metabolites relevant to plant adaptation, performance and food or feed quality within PGR collections. The introduction of simplified and, more importantly, standardised protocols for sample collection (as proposed by deliverable D3.1; Simplified sample collection protocols amenable to use by non-specialized personnel) and analysis will enable their use on the widest possible scale. Metabolomic profiling will directly support conservation and breeding by linking metabolomic data to taxa and desired agronomic traits and enhancing the utility of PGR collections.
4. **Phenomics.** In collaboration with EMPHASIS-RI, image/AI-based phenotyping and, for Protected Areas/farms, drone- and satellite-based monitoring services will be introduced and tailored to specific users' needs.
5. **Introgressiomics.** Already existing protocols for overcoming interspecific reproductive barriers will be compiled and expanded to novel taxa/genepools. Adopting a preemptive breeding approach, strategies will be developed to create crop populations introgressed with wild relatives or exotic germplasm. These strategies will be tailored to different species according to their reproductive biology, life cycle duration, and the availability of genomic resources and speed breeding protocols.
6. **Data analysis**: GRACE-RI will compile and further exploit or develop bioinformatics tools to enhance redundancy analysis, genetic gap identification, and trait mining. Collaborations with other RIs such as ELIXIR will be important in the development of bioinformatics pipelines for routine analyses, using well-established procedures available, such as Galaxy or nf-core. Standardized pipelines for kinship, core collections establishment, quantitative trait loci (QTLs) analysis, genome-wide association studies (GWAS), genomic prediction and pangenome construction will be developed, significantly enhancing breeding programs.

Key performance indicators (KPIs)

- Percentage of accessions with genotypic/resequencing/cytogenomic information across European GRCs.
- Percentage of accessions with phenotypic/metabolomic characterization data.
- Number of GRCs routinely using genotyping/cytogenomics/phenotyping/metabolic profiling in PGR management.
- Number of Protected Areas using phenotyping/remote sensing/genotyping/eDNA in population management.
- Number of taxa with pangenome, GWAS, genomic prediction information.
- Number of taxa with established introgressiomics protocols.

Providers: Public research centres and universities; Leading European GRCs.

Users: GRCs within and outside of the GRACE-RI; researchers' and breeders' community in/outside Europe; the Community Plant Variety Office (CPVO) and National Variety Offices.

4.4. Pillar V - Services for facilitated PGR access and use

Current status

Genebanks have historically provided access to PGR as a fundamental aspect of their mission. However, the regulatory landscape governing the access to and use of PGR has become increasingly complex, especially for the exchange of PGR across borders, shaped by ethical requirements, legal obligations, and phytosanitary safeguards. The Convention on Biological Diversity (CBD) and its Nagoya Protocol uphold national

sovereignty over genetic resources by mandating anyone seeking to use genetic materials to secure Prior Informed Consent (PIC) and adopt Mutually Agreed Terms (MAT) that guarantee fair and equitable benefit-sharing. In parallel, ITPGRFA facilitates access to certain crops (i.e., Annex 1 of the Plant Treaty) through a multilateral system, supporting collaborative research while retaining provisions for equitable returns to a Benefit-sharing Fund. Although the EU and most of its Member States are signatories to these international agreements (ITPGRFA, CBD, Nagoya Protocol), to date the EU has not undertaken any work to achieve a minimum level of legal harmonisation in the implementation of these legal texts. These issues are detrimentally impacting the effective conservation of PGR in Europe as well as the availability of PGR and related data for research and breeding activities (ECPGR, 2021). Superimposed on these legally binding access-and-benefit-sharing (ABS) commitments are the stringent phytosanitary measures imposed by countries to safeguard their nature from transboundary pests and diseases. Contracting parties to the Food and Agriculture Organization (FAO) - International Plant Protection Convention (IPPC) must adhere to International Standards for Phytosanitary Measures (ISPM), which are enforced through National Plant Protection Organizations (NPPO), to avert the transboundary spread of pests and diseases during the movement of germplasm and other plant products.

These concurrent obligations, each overseen by different authorities, can overwhelm stakeholders, both GRCs and potential PGR users, particularly when resources are limited or when national regulations impose additional documentation and monitoring requirements. Lengthy permit processes, incomplete understanding of legal duties, or insufficient guidance on phytosanitary inspections can delay projects, deter global collaborations, and inadvertently limit the availability and access of germplasm. Nonetheless, parties involved must contend with several procedural steps to comply with both ABS mandates and plant health regulations prior to the transfer and use of the germplasm. Recognizing these challenges, especially in light of increasing global demand for resilient crop varieties and emerging pest threats, GRACE-RI seeks to provide a range of services and resources that facilitate compliance with procedural requirements, offer context-specific guidance, and assist stakeholders in meeting the obligations set by these frameworks. This thereby ensures responsible, transparent, and timely access to PGR. Deliverable D5.6 (An analysis of the ethical, social and regulatory aspects of the transition of the present PGR system to an integrated pan-European Research Infrastructure) will provide more information on ethical and legal aspects that the GRACE RI can help to address through a centralized service.

Aims and objectives

The primary goal of this pillar is to facilitate efficient, transparent, and responsibly governed access to PGR, whether conserved *in situ, ex situ* or on-farm, ensuring that stakeholders can identify, obtain, and utilize germplasm in full compliance with regulatory and phytosanitary requirements. This includes:

- Scientific expertise and support to policymakers to guide policy and regulatory efforts towards harmonization of regulations, identification and removal of barriers and increasing accessibility of PGR in Europe.
- Providing a comprehensive resource for assisting PGR providers and users in ensuring compliance with the legal, regulatory, and administrative requirements governing the access and use of PGR, synthesizing international legal instruments, such as the Nagoya Protocol and the ITPGRFA, within the specific regulatory mandates of participating nations.
- Support to comply with international phytosanitary regulations, maintain the integrity of collections, and facilitate safer germplasm exchanges, closely collaborating with national and regional plant protection organizations.

Proposed services

1. **Regulatory support services for PGR users**: This service will guide users (GRCs, private and public researchers, breeders, farmers) through the complexities of PGR-related international and national

regulations. An online interface will facilitate the determination of the requisite permits and documentation by assessing criteria such as the material's provenance, taxonomic classification, and intended use. Standardized document templates, including Material Transfer Agreements, will be provided to streamline routine transactions, while an expert support helpdesk will address cases requiring further clarification. Regular updates will be carried out to ensure that the service reflects current legislative developments (e.g., emerging issues related to digital sequence information).

2. **Phytosanitary infrastructure**: A pan-European network to support GRCs in meeting phytosanitary requirements will be established, connecting with EUPHRESCO. This will include developing diagnostic protocols, offering pest surveillance services, ensuring compliance with international standards, as well as a centralized, high level phytosanitary/quarantine center for the processing of PGRs entering the EU. By centralizing resources, phytosanitary services will be more accessible and efficient for smaller GRCs and other stakeholders.
3. **Scientific expertise for policymakers**: GRACE-RI will also (in collaboration with CGIAR) provide advice and backstopping to policymakers to harmonize regulations and policies, promote the adoption of consistent and user-friendly legal frameworks, and address emerging challenges.
4. **Regulatory support for conservation strategies:** GRACE-RI will ensure linkage and better integration with other biodiversity and conservation fora (botanical gardens, Natura2000, CAP, environmental ministries) at national levels (link with pillars I and V).

Key performance indicators (KPIs)

- Number of the regulatory support requests answered.
- Number of policy recommendations adopted at the national and European levels.
- Number of GRCs with access to centralized phytosanitary services.

Providers: Central legal service; Public research centers and universities; Leading European genebanks (e.g., IPK, CGN, NordGen); public research centers and universities; EUPHRESCO.
Users: GRCs within and outside of the GRACE-RI; researchers' and breeders' community in/outside Europe; policy makers

4.6. Horizontal activity - Capacity building and outreach

Current status

Capacity building and outreach are essential for fostering collaboration and knowledge exchange among stakeholders in PGR conservation and GRACE-RI will provide centrally coordinated training and development for all its pillars. As outlined in deliverable D2.4 (A blueprint for a capacity building programme for genebanks and in situ/on farm conservation networks), the capacity building program will cover different aspects of technical or management expertise and develop enhanced professional training programs that address knowledge gaps in genebank management, data curation, and breeding applications, among others.
Notably, gaps in higher education courses specifically focused on PGR conservation and use have been identified in D2.4. Collaborative opportunities could be explored with existing M.Sc. programs, such as those in Plant & Crop Sciences that include PGR components, to develop specialized training modules. Initiatives like the M.Sc. in Plant Science at Wageningen University & Research and other relevant programs across Europe can serve as potential partners for integrating advanced PGR-specific curricula and capacity-building activities. Other Research infrastructures like ELIXIR, EMPHASIS, and BBMRI-ERIC offer resources and training focusing on data management, phenotyping, and biobanking practices, which could also serve the PGR community and be expanded to address PGR-specific capacity-building needs. National nodes will adapt training modules to be used in national context at local level and in local languages and professional exchange programmes will be developed to foster knowledge exchange. Collaboration among networks like ECPGR and global partners such as CGIAR or the Crop Trust can drive effective dissemination and skill development, ensuring the long-term conservation and utilization of plant genetic resources.

Outreach initiatives must target diverse audiences, from policymakers to farmers and the general public, raising awareness of PGR's critical role in food security and climate resilience. GRACE-RI will leverage its large network of stakeholders to foster collaboration, raise funds to support specific initiatives and actively engage with its national nodes and observers to implement the service pillars across Europe. As part of its dissemination activities, GRACE-RI will publish a dedicated peer-reviewed journal to provide a platform for PGR stakeholders to share their research results, protocols and other relevant information.

Aims and objectives

The overarching aim of this activity is to establish GRACE-RI as a leading platform for education, training, and dissemination in the field of PGR conservation and use. By establishing a robust framework for education and dissemination, GRACE-RI will cultivate a new generation of PGR professionals and foster a culture of appreciation and support for genetic resources. Specific aims include:

- Development of partnerships with universities and higher education schools to enhance curricula of existing educational programs and establish novel ones.
- Expand training and capacity building opportunities for PGR professionals to bridge knowledge gaps in PGR conservation and use.
- Provide comprehensive capacity-building tools and materials, including videos, manuals, templates, and SOP examples, workshops, staff exchanges, and peer reviews, designed to support GRCs.
- Develop and provide training on GRACE-RI services to users to enhance the impact of the RI and collect feedback to further improve its services.
- Development of public outreach and communication activities. Raise public awareness and engagement in the valuation and active conservation of CWR, WIP and LR diversity as a means of promoting sustainable maintenance of crop and natural biodiversity for the benefit of humankind.
- Provide scientific advice to policymakers at national and EU level

Proposed services

1. **Educational modules**: In collaboration with universities, GRACE-RI will develop new courses or adapt existing ones to train students in various aspects relevant to PGR conservation and use with the aim of addressing the diverse needs of students as emerging PGR professionals.
2. **Comprehensive training programs**: Modular training courses will be designed for students, professionals, and stakeholders at various levels of expertise. These programs will integrate online and offline learning, providing accessible and flexible professional development opportunities across Europe along with reusable training materials. Developed training modules will cover all aspects of PGR conservation and use, e.g. taxonomy, conservation planning and management, applied genetics or policy (details are described in deliverable D2.4). Training programs will highlight GRACE's services, as they incorporate modules from other GRACE-RI pillars, e.g. data curation, management and analysis, genotyping, metabolomics, phytosanitary issues, and integrated *in situ*/*ex situ* conservation methods.
3. **Training for data curation and management**: Capacity building and training programs will be introduced to include the development of training modules focused on data curation, management, and FAIR compliance. These programs will feature workshops, webinars, and hands-on sessions to equip data managers and curators with the necessary skills. An online hub will provide access to training resources, including videos, guidelines, and forums
4. **Support networks**: Forums will be established for all stakeholders to engage in discussion and skill sharing. A dedicated Stakeholder Forum is envisioned in the GRACE-RI governance to provide input and feedback to its strategy.
5. **Communication and Awareness campaigns**: Targeted campaigns will be implemented to engage diverse audiences, including farmers, policymakers, and the public. Interactive tools, citizen science projects, lectures, and storytelling approaches will be employed to highlight the relevance of PGR conservation in

addressing global challenges. The public engagement efforts will also draw on the participatory approaches outlined in other pillars to maximize inclusivity and impact.

6. **Outreach activities**: Outreach activities will improve linkages and enhance integration with other biodiversity and conservation fora (e.g. Natura2000, European on-farm conservation network "Let's liberate diversity", CAP, environmental ministries).
7. **Promotion of public engagement and citizen science initiatives**: To foster broader participation, GRACE-RI will develop programs that engage citizen scientists and local communities in CWR and LR conservation and monitoring. Training materials, identification aids and other digital tools, and collaborative platforms will be created to facilitate involvement and enhance awareness of CWR's and LR's importance

Key performance indicators (KPIs)

- Number of education modules developed and implemented in collaboration with GRACE-RI.
- Number of training courses developed and their attendance
- Increase in the number of trained professionals managing *in situ* and *ex situ* PGR resources.
- Outreach initiatives conducted targeting policymakers and the public.
- Research publications supported by GRACE-RI in open-access format.

Providers: GRACE-RI will work with education and communication professionals as well as universities and public research centers and other relevant actors to develop the capacity building and training courses. National nodes will coordinate capacity building at local level and in local languages to increase impact.

Users: students, researchers, genebank managers, citizen, and policy makers.

5. Mapping of stakeholders as users and providers of the GRACE-RI services

Pro-GRACE deliverable D5.2 identified relevant stakeholders of a future GRACE-RI and grouped them based on their involvement in the four main categories of PGR activities (Figure 2).

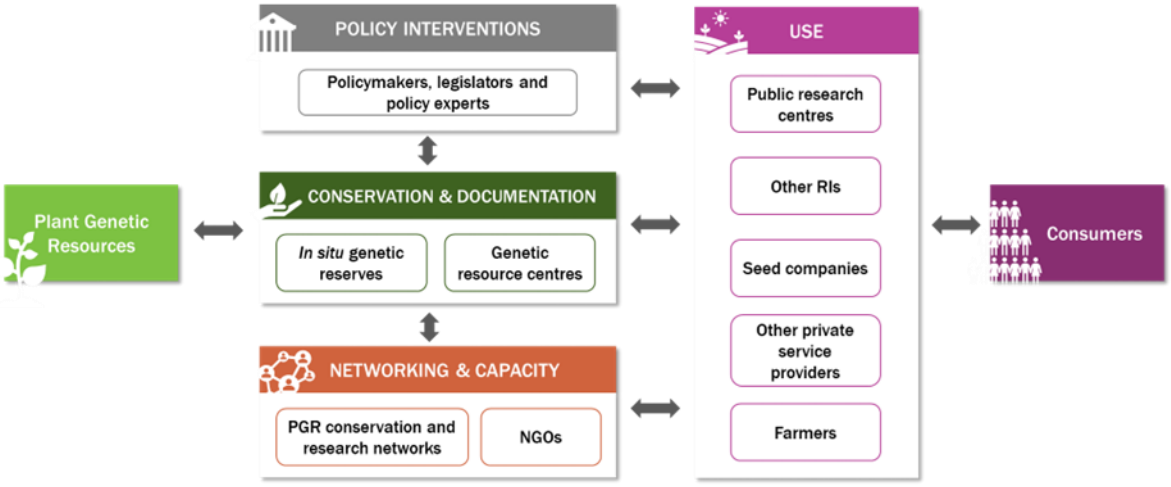

Figure 2. *Map of the four main categories of activities (Conservation & Documentation, Use, Policy, Networking & Capacity) adapted from deliverable D5.2.*

When implementing the GRACE-RI as an ESFRI project and future ERIC, these stakeholders should be grouped into possible providers and users of the services offered by the GRACE-RI. Services of an ESFRI must be centrally accessible to users and a clear access policy must be available.
According to the proposed governance structure of the GRACE-RI (deliverable D5.4), the future RI will be distributed across national nodes with a central hub coordinating common services and the overall functioning of the RI. In line with the gap and synergy analysis in deliverable D5.1, areas of collaboration with existing ESFRIs and ERICs will be developed to eliminate redundancies and create productive synergies.
Below we describe the main actors involved in implementing the GRACE-RI and its services. Some previously identified groups will not be actively involved in the GRACE-RI but remain as important stakeholders and potential users and strategic advisors. By emphasizing the functional connections between stakeholders and GRACE-RI, the document aims to provide a clearer understanding of how these groups contribute to and benefit from the infrastructure's activities, ensuring a systematic and effective approach to PGR conservation and utilization.

5.1 Providers of GRACE-RI services

Based on the content of the Service portfolio as described in Section 4 above and in line with surveys and discussions, the majority of scientific services envisaged under GRACE RI would be provided by GRCs or public research institutes/universities, who have the relevant expertise and infrastructure to effectively implement these services.
For example, the GRACE-RI service "PGR Conservation and Quality Management Implementation" will develop the standards, monitoring tools, capacity-building programs and certification processes that genetic resources centres will be able to implement to improve their operations, ensure and enhance access to PGR. These services will build on existing knowledge and involve further R&D by both genebanks and research institutes within the GRACE-RI. Capacity building and training as well as certification measures will also leverage the expertise of partners within relevant institutions, who themselves will be trained to provide these services to users.

GRACE-RI Central Hub
As in other distributed Research Infrastructures, the GRACE-RI Central Hub will play a critical role in coordinating the provision of services and thus the activities of the below mentioned service providers. Specialized teams for the individual service pillars with expertise in the relevant areas (including PGR conservation, data science, informatics, biology, communication, education, legal services, administration and management, among others) will manage the broad portfolio of the GRACE-RI, leading R&D efforts to develop and improve the services and engaging with other providers within the national nodes to ensure effective service delivery.

Genetic Resources Centres
Genetic Resources Centres (GRCs, including genebanks, botanical gardens or other PGR collection holders) are core service providers in GRACE-RI. They support the implementation of Pillar I (Services for *ex situ* conservation) through adherence to standardized procedures and certifications and also provide the PGR materials to research users. GRCs will also contribute to Pillar IV (Services for characterization and pre-breeding) by providing accessions for genotyping and metabolomic profiling, enhancing the integration of these data into EURISCO as part of Pillar III (Data and information management). GRCs are responsible for *ex situ* conservation of genetic resources and making germplasm accessible to users, which represents the ultimate goal of the GRACE-RI.

Public Research Centres - Universities
Public research centres and universities provide critical research and technical services across all pillars and may also function as genetic resource centres themselves. They should lead activities in Pillar IV by advancing -omics technologies and applying them to PGR characterization efforts. Public research centres and especially

universities will also play a key role in the Horizontal Activity (Capacity Building and Outreach) by creating educational modules and training programs for students and emerging PGR professionals.

Protected Areas – Natura 2000 sites
Protected Areas – Natura 2000 sites will support the implementation of Pillar II (Services for *in situ* conservation), including management of the sites and non-specialistic monitoring of natural populations.

Non-governmental Organizations (NGOs)
NGOs, such as those representing on-farm conservation networks will be potential providers of services for different horticultural and agricultural systems, e.g. as sites where applied science, field trials, etc. can take place. They will promote on-farm conservation and participatory plant breeding programs under the horizontal activity. They will also be involved in outreach initiatives, raising awareness about the importance of PGR conservation and utilization. Their role extends to capacity building, especially for local communities and citizen scientists. Finally, they may complement GRCs in PGR distribution to non-professional users.

Roles and responsibilities of National Nodes
Depending on the PGR conservation and research landscape in member countries, national nodes will include varying numbers of the above-mentioned stakeholders, under the umbrella of National PGR Programmes. Nominated organizations within a national node will be eligible to provide and use services by GRACE-RI. National nodes will be coordinated at the national level by a lead institute which is expected to develop close links with the central hub of GRACE-RI.

5.2 Utilizers of GRACE-RI services

The main users of the services offered by GRACE-RI will again be GRCs and public research institutes/universities. The private sector will also find these services beneficial, particularly for accessing novel genetic resources and associated data to support advanced breeding efforts and other research-driven innovations. Trainings and outreach programs should be targeted to researchers at varying levels, but also to the public and policymakers to raise awareness for PGR. The main group of users of the GRACE-RI infrastructure will be researchers and plant breeders, who will benefit from the enhanced access to PGRs and corresponding information through services provided by the RI. A portion of these users can be identified within existing networks of research and breeding organizations as well as PGR diversity managing networks (NGOs, CSB, SME seed companies, etc.). The European Plant Science Organisation (EPSO) gathers more than 200 research institutes and university departments from 31 countries, suggesting that the number of plant scientists who may potentially become users of GRACE-RI is thousands or more likely tens of thousands, in the order of magnitude. Similarly, the European Association for Research on Plant Breeding (EUCARPIA) has 59 corporate members, including breeding companies and research organizations, along with 194 individual members, amounting to a total of 894 members across 44 countries. This suggests a substantial user base of plant breeders and research professionals who would utilize GRACE-RI's resources. While there is likely to be some overlap in memberships across these organizations, the scale of these networks (and the assumption that many other organisations are not engaged in them) highlights the broad reach and potential interest of the research and breeding communities in GRACE-RI services. All users will benefit from the ethical and legal guidance provided by the services in GRACE-RI pillar V. Last but not least, entities authorising new varieties, like CPVO and National Variety Offices, will benefit from genotyping standards developed in Pillar IV.

Genetic resources centres
Genetic resources centres that are not part of the GRACE-RI consortium will benefit from its services, including quality management standards, certifications, and capacity building. They will also utilize centralized data

platforms developed under Pillar III to improve their management practices and data accessibility. Finally, they will be able to utilize advancing -omics services developed by Pillar IV for characterization of their collections.

Public Research Centres - Universities
As the primary users of GRACE-RI services, researchers will benefit from enhanced and simplified access to genebank materials. They will utilize them together with available genomic, phenotypic, and metabolomic data to advance fundamental and applied studies on plant biology and genetic diversity.

Protected Areas – Natura 2000 sites
They will be utilizing specialistic services provided by other stakeholders, especially those developed in Pillar IV (eDNA analysis/metabarcoding, drone-based phenotyping, satellite-based monitoring) and Pillar II (safety ex situ duplication).

Breeders
Plant breeders, both from the public and private sectors, will be important users of GRACE-RI services. They rely on genebank accessions, genomic data, and phenotypic evaluations to select useful germplasm for their breeding programmes. Enhanced characterization of collections will accelerate the development of resilient and high-performing crop varieties.

Seed Companies
Seed companies will utilize services and capacity building provided under all pillars and the horizontal activity.

Non-governmental Organizations (NGOs)
NGOs will be potential users of training and informational services provided under the horizontal activity.

5.3. Collaborators

Private Service Providers
Private service providers, including genotyping and research companies, will likely be involved as third-party contractors but might also be involved in developing and delivering technical expertise under Pillar IV. They will mainly support the provision of cost-effective genotyping/genomic services.

Seed Companies
Seed companies will act as collaborators of the future GRACE-RI, contributing to the adoption of cost-effective, high throughput phenotyping and genotyping services under Pillar III. Their involvement ensures the development of breeding programs utilizing genebank materials and the effective integration of public-private partnerships.

Other Research Infrastructures
Research infrastructures will be important collaborators as the GRACE-RI develops its complementary service portfolio. Some GRACE-RI services address aspects that are also covered by existing ESFRIs or national research infrastructures and relevant synergies should be leveraged to avoid duplication of efforts and promote integration of tools and methods. Data and information management (Pillar III) should explore synergies with DISSCO, ELIXIR, EURISCO, GENESYS and work with organizations who have developed project-specific solutions for data management and analysis. These partnerships will ensure interoperability of data platforms and alignment with FAIR principles, improving accessibility and usability of PGR data and enhance resource efficiency across communities. EMPHASIS is working on plant phenotyping and collaborations should be established for the systematic and standardized phenotypic evaluation of PGR collections. BBMRI-ERIC has built a large body of

expertise on biobanking, quality management, certification and data management and would be an ideal partner for related services in Pillar I and III of GRACE-RI.

PGR Conservation and Research Networks, organizations, scientific societies

Collaboration with European and international organizations, networks and scientific societies representing the interests of different stakeholders in PGR (e.g. EPSO, BGCI, EUROSEEDS, EUCARPIA, EUPHRESCO,) will be crucial to secure the strategic alignment and support of everyone involved. As such they may be represented in the GRACE-RI advisory board but may also provide technical expertise and support for any of the GRACE-RI service pillars. These organizations will also be involved in outreach and education activities, and where possible contribute to facilitating coordination of European and global conservation efforts.

Global Initiatives

Global organizations like FAO, CGIAR and the Crop Trust can provide feedback and valuable input on all Pillars, sharing best practices and aligning GRACE-RI with international conservation goals to ensure the global availability of PGR materials. Collaborating with them, the GRACE-RI would leverage their expertise and provide the linkage of the European region with their global efforts, which are mainly dedicated to the global south, ensuring that Europe maintains a global leadership role also in PGR conservation and research.

ECPGR

ECPGR has built a trusted network of national PGR conservation programmes in its >40 years of operations and has developed products which form the basis of services in the proposed GRACE-RI portfolio, such as EURISCO, AEGIS and the European Evaluation Network EVA. Nevertheless, the PGR landscape in Europe is still unequal in terms of capacity and available funding. As outlined in its PGR Strategy for Europe (ECPGR, 2021) the establishment of a permanent infrastructure with secure and sustainable funding should strengthen national and regional programmes. In this scenario, ECPGR will continue to play an important role to strengthen collaboration and cooperation between multiple stakeholders and can contribute to the coordination of the GRACE-RI as well as to its service portfolio and outreach activities.

5.4. Other stakeholders

Policymakers, Legislators, and Policy Experts

Policymakers are working on the regulatory alignment and creating a supportive framework for PGR conservation and use. Under Pillar V, the GRACE-RI will provide the necessary scientific and technical input to help them harmonizing PGR-related legislation across Europe. Policymakers will also promote legislative initiatives for sustainable PGR management and *in situ* conservation, based on recommendations developed by the GRACE-RI.

Funders

The development and operation of the GRACE-RI will rely on financial support from various sources. Funding opportunities and funders are categorized into two main levels:

- Support for the Central Coordination: The central hub, which oversees the integration and functionality of the infrastructure, will receive basic funding through membership contributions from participating member countries. Additional funding for strategic activities implemented by the central hub may come from the European Union's research and innovation programs, such as Horizon Europe, and from partnerships with international organizations, charitable foundations, and private sector stakeholders who benefit from enhanced access to PGR and data.
- Support for National nodes: Each participating GRACE-RI member state will establish and maintain national nodes, which will serve as localized centers for the infrastructure's operations at national level. To support the added functions provided as part of a GRACE-RI, organizations within the national nodes should source dedicated funding from national governments, leveraging their commitments to agri-food and biodiversity

goals. Collaborative projects between countries may access co-funding opportunities through EU structural funds and transnational initiatives to enhance resource sharing and integration.

Both levels of funding will play a critical role in ensuring the long-term sustainability and effectiveness of the infrastructure by aligning their contributions with shared goals of conservation, research, and innovation. A more detailed financial plan is being developed under deliverable D5.3.

Promoters

Relevant stakeholders, across the groups defined in deliverable D5.2, will contribute to promoting the infrastructure. Promoters will increase awareness about the importance of GRACE-RI's initiatives, foster connections among public and private entities, and support collaborative efforts across sectors. In close collaboration with the communications and outreach office of the GRACE-RI, these entities can host events, publish reports, and engage in advocacy to highlight GRACE-RI's value in addressing food security and biodiversity challenges. By leveraging their networks and influence, promoters play a crucial role in securing long-term support and visibility for the infrastructure, ensuring its successful integration into European research and policy frameworks. Besides stakeholders listed in D5.2, trade and farmers associations, educational institutions, and media organizations will also be involved. Pillar VI will focus on identifying and developing collaboration with GRACE-RI promoters to amplify its outreach.

Farmers

Farmers will indirectly benefit from GRACE-RI services, gaining access to resilient and nutritious crop varieties and germplasm, as well as relevant training and capacity building. Under the horizontal activity Capacity building and outreach, they will play a critical role in on-farm conservation efforts and will be engaged through participatory projects.

6. Conclusions

The establishment of the GRACE-RI will represent a significant advancement in the conservation, accessibility, and utilization of plant genetic resources (PGR) for research and innovation across Europe. By addressing existing gaps in conservation and quality management, data completeness and integration, and *in situ* and *ex situ* conservation strategies, the research infrastructure aims to ensure long-term sustainability of PGR conservation and access and their vital contribution to global food security and climate resilience.

It is acknowledged that current PGR conservation and use is hindered by the lack of an efficient and effective infrastructure and sound research base. GRACE-RI will build on the existing but resource limited networking efforts of ECPGR to build an evidence-based RI fit for the 21st century that can meet the challenges of climate change, sustainable agricultural intensification and provide long-term food security for Europe. Through collaborative efforts involving partners such as genetic resources centers, organizations involved in the conservation of PGR and researchers, GRACE-RI will facilitate the development of innovative solutions to current challenges in PGR conservation and use. The integration of practical and advanced technologies, such as *in situ* genetic reserves and on-farm conservation, multi-omics characterization and AI-driven data curation, will enhance the utility of PGR collections and provide valuable improvements to services supporting research on plants, crop improvement and agricultural sustainability.

Furthermore, GRACE-RI's focus on capacity building, education, and stakeholder engagement will foster a culture of collaboration and knowledge sharing, empowering a new generation of PGR professionals. By guiding through regulatory frameworks and promoting public awareness, GRACE-RI will establish itself as a hub for coordinated efforts to safeguard Europe's genetic diversity and strengthen the continent's role as a global leader in PGR conservation.

In conclusion, GRACE-RI is poised to not only preserve Europe's rich plant genetic heritage but also to leverage it in addressing pressing global challenges, ensuring that plant genetic resources remain a foundation of sustainable agriculture and biodiversity for generations to come.

7. References

- Adam-Blondon, A.-F., Tixier-Boichard, M., Bozzano, M. et al. (2021). D4.4/D19 Strategy and priorities for delivering information services to end users (2021-07-28). Zenodo. https://doi.org/10.5281/zenodo.5141212
- Benoit, M., Jenike, K.M., Satterlee, J.W. et al. (2025). Solanum pan-genetics reveals paralogues as contingencies in crop engineering. Nature, 640, 135-145. https://doi.org/10.1038/s41586-025-08619-6
- Bilz, M., Kell, S.P., Maxted, N. and Lansdown, R.V. (2011). European Red List of Vascular Plants. Luxembourg: Publications Office of the European Union. ISBN 978-92-79-20199-8.
- Castañeda-Álvarez, N.P., Khoury, C.K., Achicanoy, H.A. et al. (2016). Global conservation priorities for crop wild relatives. Nature Plants, 2, 16022, https://doi.org/10.1038/nplants.2016.22
- Christelova, P., De Langhe, E., Hřibová, E. et al. (2017). Molecular and cytological characterization of the global Musa germplasm collection provides insights into the treasure of banana diversity. Biodivers Conserv 26, 801–824, https://doi.org/10.1007/s10531-016-1273-9
- Das Choudhury, S., Samal, A., and Awada, T. (2019) Leveraging Image Analysis for High-Throughput Plant Phenotyping. Front Plant Sci, 10, 508. https://doi.org/10.3389/fpls.2019.00508
- Dash, J.P., Pearse, G.D., and Watt, M.S. (2018). UAV Multispectral Imagery Can Complement Satellite Data for Monitoring Forest Health. Remote Sensing, 10, 1216. https://doi.org/10.3390/rs10081216
- ECPGR (2021). Plant Genetic Resources Strategy for Europe. Rome, Italy: European Cooperative Programme for Plant Genetic Resources. Available at https://ecpgr.org/pgrstrategy21
- Engels, J.M.M., & Visser, L. (2003). Genebank Management for Sustainable Crop Improvement. CABI.
- FAO (2010). Second report on the State of the World's Plant Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at http://www.fao.org/agriculture/seed/sow2/en/
- FAO (2014). Gene bank Standards for Plant Genetic Resources for Food and Agriculture. Rev. Ed. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at http://www.fao.org/3/a-i3704e.pdf
- GenRes Bridge Project Consortium, ECPGR, ERFP and EUFORGEN. 2021. Genetic Resources Strategy for Europe. European Forest Institute. Available at https://www.genresbridge.eu/fileadmin/templates/Genres/Uploads/Documents/Publications/GenRes_GRSE_publication_2022_web.pdf
- Hoban, S., Archer, F.I., Bertola, L.D. et al. (2022). Global genetic diversity status and trends: towards a suite of Essential Biodiversity Variables (EBVs) for genetic composition. Biol Rev Camb Philos Soc, 97, 1511-1538. https://doi.org/10.1111/brv.12852
- Iriondo, J.M., Maxted, N., Kell, S.P. et al. (2012). Quality standards for genetic reserve conservation of crop wild relatives. In: Maxted, N., Dulloo, M.E., Ford-Lloyd, B.V., Frese, L., Iriondo, J.M. and Pinheiro de Carvalho, M.A.A. (eds.) Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces. Pp. 72-77. CAB International, Wallingford.
- Iriondo, J.M., Magos Brehm, J., Dulloo, M.E. and Maxted, N. (eds.) (2021). Crop Wild Relative Population Management Guidelines. Farmer's Pride: Networking, partnerships and tools to enhance in situ conservation of European plant genetic resources. ECPGR, Rome, Italy. Available at University of Birmingham, Birmingham, UK. https://more.bham.ac.uk/farmerspride/key-documents/crop-wild-relatives/

- Li, X., Hu, H., Yin, R. et al. (2022). High-Throughput Nano-DESI Mass Spectrometry Imaging of Biological Tissues Using an Integrated Microfluidic Probe. Analytical Chemistry, 94, 9690-9696. https://doi.org/10.1021/acs.analchem.2c01093
- Lin, C., Liu, C., Chen, L. et al. (2025). Data on insect biodiversity in a Chinese potato agroecosystem from DNA metabarcoding. Sci Data, 12, 131. https://doi.org/10.1038/s41597-025-04452-8
- Maxted, N., Ford-Lloyd, B.V., Jury, S.L., Kell, S.P., Scholten, M.A., (2006). Towards a definition of a crop wild relative. Biodiversity and Conservation, 15: 2673-2685. https://doi.org/10.1007/s10531-005-5409-6
- Maxted, N., Amri, A., Castañeda-Álvarez, N.P. et al. (2016). Joining up the dots: a systematic perspective of crop wild relative conservation and use. In: Maxted, N., Ehsan Dulloo, M. & Ford-Lloyd, B.V. (eds.), Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement. Pp. 87-124. CAB International, Wallingford, UK.
- Maxted, N., Magos Brehm, J., Abulaila, K. et al. (2024). Review of crop wild relative conservation and use in West Asia and North Africa. Plants, 13, 1343. https://doi.org/10.3390/plants13101343
- Milner, S.G., Jost, M., Taketa, S. et al. (2019). Genebank genomics highlights the diversity of a global barley collection. Nat Genet 51, 319-326, https://doi.org/10.1038/s41588-018-0266-x
- Ohlemueller, R., Gritti, E. S., Sykes, M. T., and Thomas, C. D. (2006). Quantifying components of risk for European woody species under climate change. Global Change Biology, 12, 1788-1799. https://doi.org/10.1111/j.1365-2486.2006.01231.x
- Omondi, E., Barchi, L., Gaccione, L. et al. (2025). Association analyses reveal both anthropic and environmental selective events during eggplant domestication. The Plant Journal, 121, e17229. https://doi.org/10.1111/tpj.17229
- Prohens, J., Gramazio, P., Plazas, M. et al. (2017). Introgressiomics: a new approach for using crop wild relatives in breeding for adaptation to climate change. Euphytica, 213, 1-19. https://doi.org/10.1007/s10681-017-1938-9
- Rajora, O.P., and Mosseler, A. (2001). Challenges and opportunities for conservation of forest genetic resources. Euphytica, 118, 197–212. https://doi.org/10.1023/A:1004150525384
- Sreenivasulu, N., Alseekh, S., Tiozon, R.H. et al. (2023). Metabolic Signatures from Genebank Collections: An Underexploited Resource for Human Health? Annu Rev Food Sci Technol, 14, 183-202. https://doi.org/10.1146/annurev-food-060822-113022
- Tripodi, P., Rabanus-Wallace, M.T., Barchi, L. et al. (2021). Global range expansion history of pepper (Capsicum spp.) revealed by over 10,000 genebank accessions, Proc Natl Acad Sci USA, 118, e2104315118. https://doi.org/10.1073/pnas.2104315118
- Van Hintum, T. J., Brown, A. H. D., and Spillane, C. (2000). Core collections of plant genetic resources (No. 3). Bioversity International.
- Vasar, M., Davison, J., Moora,M. et al. (2023). Metabarcoding of soil environmental DNA to estimate plant diversity globally. Front Plant Sci, 14, 1106617. https://doi.org/10.3389/fpls.2023.1106617
- Westengen, O.T., Lusty, C., Yazbek, M. et al. (2020). Safeguarding a global seed heritage from Syria to Svalbard. Nat. Plants, 6, 1311–1317. https://doi.org/10.1038/s41477-020-00802-z
- Yu, X., Li, X., Guo, T. et al. (2016). Genomic prediction contributing to a promising global strategy to turbocharge gene banks. Nature Plants, 2, 16150. https://doi.org/10.1038/nplants.2016.150
- Yuan, L., Yu, Q., Xiang, L. et al. (2025). Integrating UAV and high-resolution satellite remote sensing for multi-scale rice disease monitoring. Computers and Electronics in Agriculture, 234, 110287. https://doi.org/10.1016/j.compag.2025.110287.

Appendix I

Report of the PRO-GRACE survey on benefits, impacts, and pilot projects of the proposed research infrastructure.

Prepared by Filippo Guzzon (ECPGR)

The aim of this survey was to understand the perceived benefits and impacts of establishing GRACE-RI, for partners' institutes and the community in general. Moreover, ideas for pilot projects that could be implemented by the GRACE consortium were collected. This document provides a summary and analysis of the received responses.

I. Respondents to the survey.

The survey received 25 responses. The 25 respondents are affiliated to 23 different European institutions, based in 16 different countries, all of them project partners in Pro-GRACE. See below a map (Fig.1) highlighting the countries where the respondents are based. Italy was the most represented country in terms of participants to this survey (n=8).

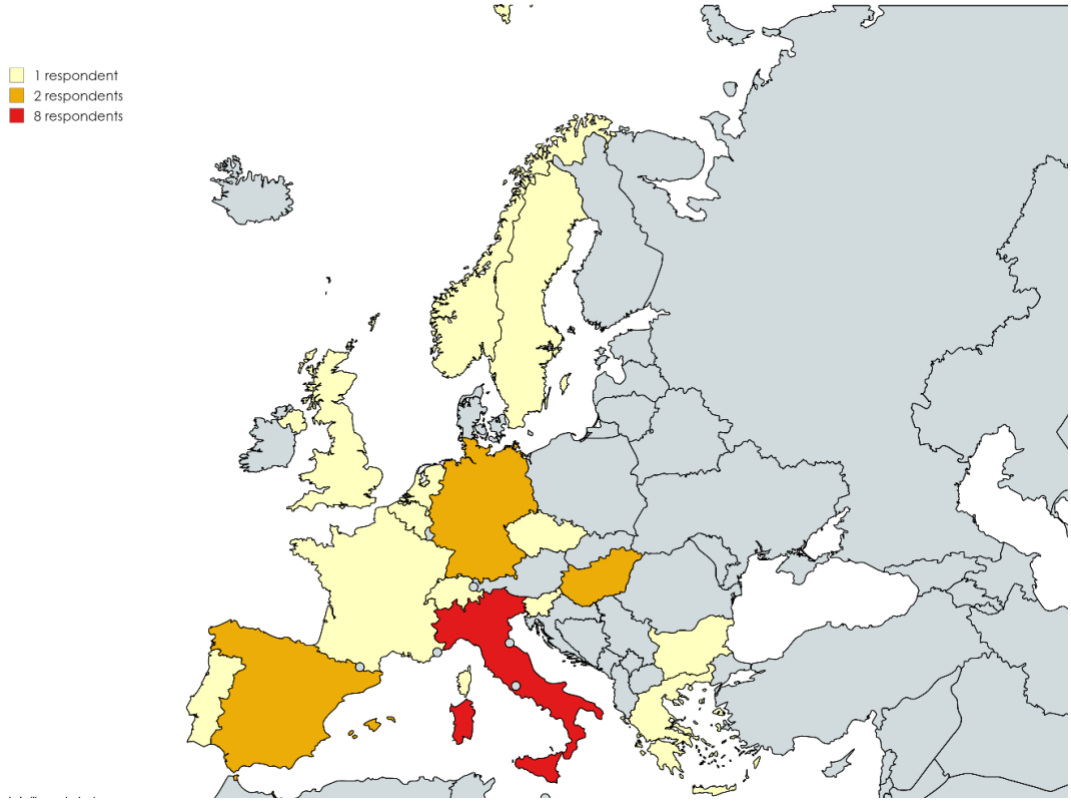

Figure 1: Countries where the respondents of the survey are based, yellow: one respondent, orange: two respondents, red: eight respondents.

The respondents were categorized in the stakeholders' groups proposed by PRO-GRACE deliverable D5.2.
In Fig. 2, it can be noticed that the most represented stakeholder's groups are genetic resources centres (n=10) and public research centres (n=9).

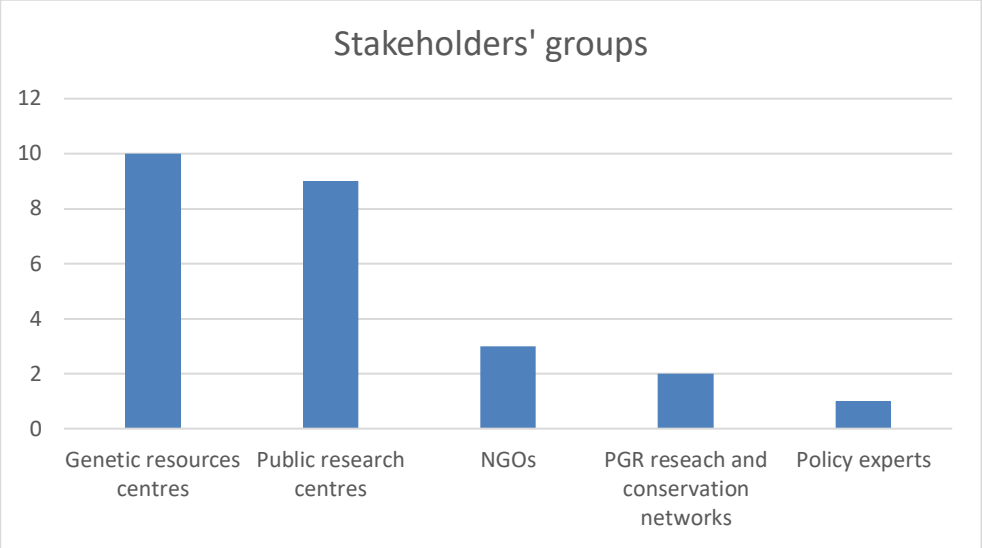

Figure 2: Participants organized in the stakeholders' groups proposed by PRO-GRACE deliverable 5.2, based on their affiliation.

II. Benefits for individual institutes

The first question of the survey was: "What benefit(s) do you think would establishing GRACE-RI bring for your institute?". The multiple questions received were organized in different categories and the results are presented in Figure 3.

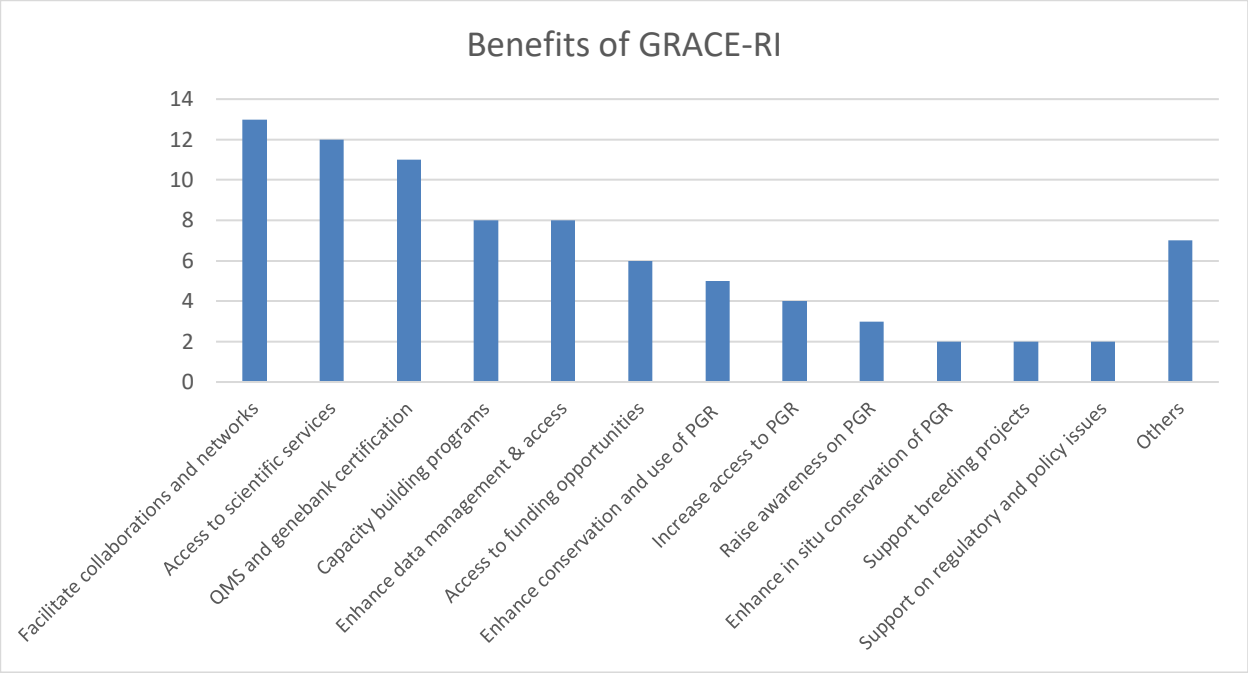

Figure 3: Main benefits of GRACE-RI expressed by the participant of the survey

The main benefits at institutional level identified by the respondents were: I) facilitate collaborations and networks on PGR (n=13); II) access (and contribute) to scientific and technical services (n=12); III) implement a quality management and certification systems of genebanks (n=11); capacity building and knowledge exchange programs on PGR (n=8) and enhance management, integrations and access of PGR data (n=8).

III. Impact on the PGR community and key-messages

Another question of the survey was: "Where do you see the main possible impact of GRACE-RI on the PGR community in general? What are the key messages to communicate to funders and policymakers?". The multiple questions received were organized in different categories and the results are presented in Figure 4.

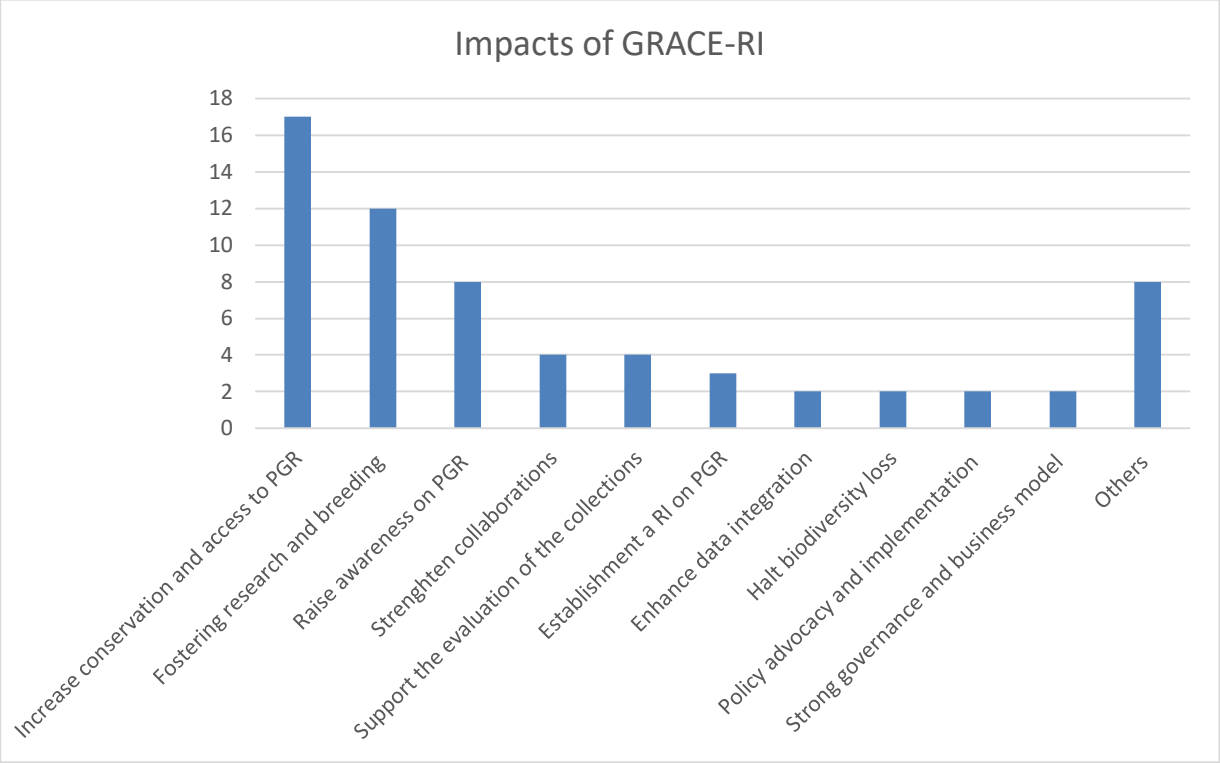

Figure 4: Impact of GRACE-RI expressed by the participant of the survey

The main foreseen impact of the future GRACE-RI on the European PGR sector in general is the improvement of PGR conservation standards as well as increased access to PGR (n=17), followed by the possibility of fostering research and breeding activities (n=12) and raising awareness on PGR, including encouraging community participations (n=8). The possibility of strengthening collaborations among different stakeholders (n=4) as well as strengthening the multi-omics evaluation of the conserved collections (n=4) were also mentioned by multiple responses.

Comparing the expected benefits of GRACE-RI at institutional level (see section above) with impacts of the infrastructure on the PGR community, it can be noticed that benefits at institutional levels are mostly related with specific scientific services as well as an increased collaboration among stakeholders. On the other hand, expected impact at PGR community level are expected more in terms of an increased access to PGR as well as enhancing research, awareness and collaborations on genetic resources.

Several interesting key messages for funders and policymakers were mentioned by the respondents, we reported some highlights in Appendix III. This could be useful when developing policy briefs and outreach materials.

IV. Pilot projects

Finally, it was asked to the participants: "What pilot projects would you propose for the next phase of GRACE-RI?". The multiple pilot projects (n=49) proposed by the participants to the survey were organized in the different services groups proposed by deliverable 5.2 The results are presented in Figure 5. Moreover, the most articulated pilot projects and activities proposed by the respondents are highlighted at the end of this report in Appendix II.

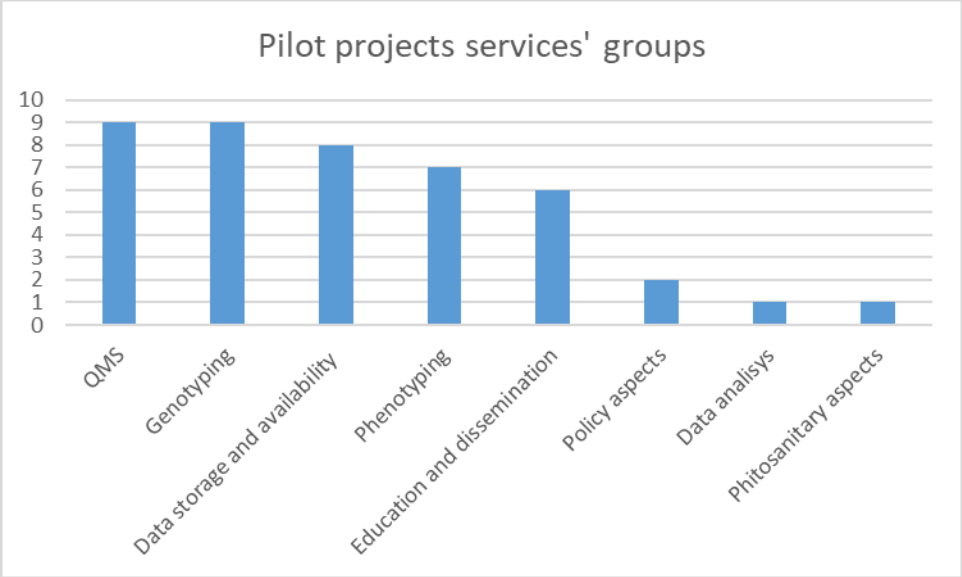

Figure 5: Pilot services organized in services' groups proposed by PRO-GRACE deliverable 5.2

Most of the pilot project ideas were related to establishing a quality management systems (QMS) for PGR conservation (n=9) and with genotyping and metabolomic profiling (n=9) as well as phenotyping (n=7), in several instances proposing a multi-omics approach to foster PGR conservation, evaluation and research. Several proposed pilot projects deal also with data storage, completeness and availability (n=8) as well as education and dissemination (n=6). It is also important to notice that a few of the pilot services proposed (see Appendix II) were not fully considered in the services' groups proposed by D5.2. These include: I) socio-economic and value chain assessments of PGR; II) pre-breeding initiatives (including participatory plant breeding, PPB); III) Development of an evaluation system for incentives for the subsidization of *in situ* conservation of PGR.; IV) Support cryopreservation of PGR at European level.

V. Conclusions

1) A strong focus on: I) **implementing a QMS system for PGR** conservation; II) **multi-omics research** on PGR collections; III) **increase data completeness, integration and access**; IV) **capacity building and training** and V) increased collaborations among stakeholders, emerged as the key benefits and desired services of the future GRACE-RI.

2) A wide list of interesting pilot project ideas was proposed by the respondents of the survey (see Appendix II). A consolidated list of these pilot projects will be shared with the PRO-GRACE partners for them to vote what would be the priority pilot projects to be implemented in the next stages of the Research Infrastructure. It will be important also to find colleagues/institutions that will lead the development of the pilot projects.

3) The main perceived impacts of establishing a GRACE-Ri will be an increase in the conservation standards and access to PGR, accelerating research and breeding efforts as well as raising awareness on PGR at European level.

4) The missions and potential outcomes of this research infrastructure are key to increase productivity as well as sustainability of European agriculture, contributing significantly to global food security and to the reduction of biodiversity losses.

Appendix II

A selection of pilot project ideas proposed by the respondents of the survey.

Services' groups	Proposed pilot project ideas
QMS	This pilot aims at **establishing an advanced certification system for PGR conservation** based on quality management standards. By developing and implementing a certification framework for conservation practices, the pilot might be implemented in genebanks participating in the RI. Collaborating with international standard-setting organizations and leveraging consortium expertise would also be essential. As part of the QMS system it will be important to provide capacity-building opportunities. To initiate this pilot project one strategy can be the selection of a limited number of genebanks (e.g. three) and support the process of implementation of a QMS. This will include I) document the steps and lessons, II) make templates of all documents available and IIII) create on-line content on this basis supporting other genebanks that would like to fully implement the QMS. In this framework, it can be useful to develop an online and open access European manual for PGR conservation. This will be an online tool that can provide guidance on different technical aspects of PGR conservation to enhance the knowledge sharing and capacity building among institutions. This tool will inform and guide the daily activities of current and future genebank / *in situ* reserves curators. This can include several technical aspects and can build on existing public databases and websites, updating these and making sure that all the information is available in a centralized and searchable source. This will be an important opportunity to extract relevant information from scientific publications that are relevant for genebank curators and have them readily available. Finally, a helpdesk can be created where curators can post their technical questions to the community. This QMS should also include support to develop an adaptive management system for *in situ* PGR conservation (including complementarity with *ex situ* conservation) as well as community seed banks (CSB). Finally, this pilot can also clarify the link between quality assurance and how this would contribute to greater use of PGRs.
Multi –omics characterization (Phenotyping, genotyping, resequencing, cytogenetics and metabolic profiling.)	The goal of this pilot could be **incorporating advanced -omics technologies** into routine genebank operations and PGR research activities to enhance PGR characterization and utilization. This will include a portal to access to a first set of transnational services including access to collections and *in situ* conservatoires for researcher and genetic resources managers as well as multi-omics characterization tools (polyploidy, genotyping, phenotyping). Potential activities (or pilot projects) could include:

	I) An assessment of genetic diversity in genebank collections by screening with SNP arrays. Customized arrays can be developed to assess the genetic diversity of a representative sample of the genebank collection. The project should assess genetic diversity within and between accessions in genebank collections, identify gaps and redundancies and provide useful results for improving the conservation PGR. II) Super-pan-metabolome studies on a couple of clades. III) Identification of abiotic stress-related tolerant loci by using Genome Wide Assocation Studies (GWAS) and QTL analysis and introgression of these loci into commercial cultivars. Characterization for abiotic stress tolerance can include drought, salinity, flooding stress as well as multiple stresses occurring simultaneously. IV) Characterization and exploitation of PGRs, specifically cultivars of fruit tree and vegetable crops, for longer postharvest life by decreasing the rate of either ripening or senescence through metabolic suppression and/or specific ripening-related developmental programmes such as softening. V) Evolutionary time frames of selection in different environments: based on a single population, what impact does growing and multiplying at different locations, with different environments (e.g. soil, exposure, altitude m.a.s.l., etc.) and with different farming methods have? What differences show up after how much time (generations?) What to expect from this question for the different plant species ? – This project could deliver answers for questions like: after how much time (generations) should we consider a separate line as a new accession? Does it make sense to mix up different lines of an accession? Does it make sense even to mix up different accessions of a variety? And vice versa does it make sense to keep several accessions of a variety separately; does it make sense to keep more than one (two, three, four…) accession(s) of the same variety? Would some of the processes even foster robustness of a population during time?
Data storage, completeness and availability; data analysis;	This pilot project aims at integrating, curating, and analyzing **PGR data from various genebanks** across Europe, enhancing the EURISCO database to be more comprehensive. Strategies to improve EURISCO can be: I) Multi-institutional proof of concept/ validation studies for data standards and protocols (developed within PRO-GRACE) II) Using machine learning, the system could help in harmonizing data, identifying gaps, predicting missing information, and providing insights. III) Facilitating access to data and PGR outputs from projects: many research projects funded by EU, bilaterally or nationally have generated data on PGR and created/developed new PGR materials. Both these data and plant materials are often scattered

	across databases, research publications, and laboratory storage spaces. GRACE-RI could provide a service to projects to facilitate accessible and centralized public repository for both data and plant materials. Standards in data management (WP1) could be implemented, also within a database extension of EURISCO for these types of data specifically, to enable cross-compatibility (see EVA, AGENT, INCREASE). Similarly, GRACE member institutions could facilitate medium- or long-term storage and access to relevant project-derived plant genetic resources materials, in line with exploitation expectations (now an important aspect of EU projects). Funding could be through participation in new projects, for legacy data and materials one could come up with a project proposal to get this started. In the long term, it could be implemented as a service, financed either via membership fees or service agreements with external users. IV) Integrating PGR and climate data platforms
Education and dissemination	**Capacity building activities** will be likely included in several services. In this pilot project, practice-oriented workshops can be organized on relevant topics e.g.: - phenotyping - phytosanitary issues - seed germination - *in vitro* tissue culture - cryopreservation- QMS and certification - policy issues It could be useful if the participants can get together at one of European genetic resources center and study the above practices with the help of experts. The knowledge obtained should be transferred and adopted into daily routine activities of all participants. Moreover, there will be the opportunity to set up pilots to **increase public awareness and involvement** in PGR conservation through citizen science initiatives. By developing mobile apps and online platforms, the project may enable citizens to participate in data collection and conservation activities.
Others/ **Cryopreservation**	Implementation of a **cryopreservation strategy for clonal crops in Europe**, with the aim to set up a network of cryo-hubs, devoted to providing expertise for development of methodologies, moving research results into operational protocols, organizing capacity building initiatives, providing services for operational cryopreservation and putting in cryo entire European collections under a multilateral system arrangement. This network would rely on existing expertise and infrastructure and adopt a specific quality management system, connected to the overall genebank QMS. The pilot project could start with a few crops (such as garlic, potato, apple). It should also be possible to set up a financial plan defining cost elements of this initiative.

Others/ **Pre-breeding**	This pilot is connected with the multi –omics pilot projects and aims at strengthening public-private **pre-breeding** consortia, including participatory pre-breeding initiatives (PPB). A focus on neglected crops and abiotic stress tolerance was suggested. A specific pilot/activity can clarify these questions: how could quality assurance, improved conservation, improved characterization, and improved documentation of non-commercial PGRs contribute to greater utilization of PGRs in breeding programmes?
Policy aspects	Activities and pilot projects on **policy aspects** can focus on: I) Vegetatively propagated PGR and virus-related sanitary status including germplasm health research as well as a work with the policy makers on sanitary policies II) PGR digital sequence information and ABS: scientific, ethical and legal issues.
Others/ ***in situ* on-farm conservation / community seed banks**	Pilot services to enhance in situ/on-farm conservation by: I) Providing a governance structure to take forward the *in situ* conservation network concept developed in Farmer's Pride and extended in Pro GRACE D1.3 and D2.3. II) Developing an evaluation system for incentives that can be adapted to national circumstances for the subsidization of on-farm and *in situ* management of landraces and crop wild relatives. The landrace threat assessment methodology suggested by Nigel Maxted could be a basis for this. III) Involving farmers and farmers organizations in the GRACE-RI, identify their involvement and role. IV) For the CSB systems research would give some background information to define complementarities between *ex situ* and on-farm conservation and PGR management systems linked with their sustainable use . e.g. how big seed samples of interesting varieties with interesting traits should be for a quickly bringing them to farmers and on the market? Which specific information would be needed to foster the transfer of interesting varieties - PGR from the breeding or conservation stations to farmers and to the market? In future do we need more independent breeding activities – adapted to local and regional conditions to enhance the diversity of PGR on-farm or are the present large scale structures able to fulfil these needs? Could decentralized well managed and monitored CSB-systems fill in this gap? Research and scientific support would be needed to enable CSB-structures and people. V) Self-compatibility vs. in-breeding threat – deriving management strategies for different conservation systems: This should be regarded for a) every species b) different time frames/number of generations c) different available resources (space, number of

	plants per propagation, respectively), and solutions should be found for 1) different conservation systems 2) different contexts as for a line, an accession, a variety or a species 3) different time frames
Others/**socio economic aspects**	Additional pilot projects can deal with: I) PGR value chain development. II) Socio-economic impact assessment of PGR conservation and utilization.

Appendix III

A selection of key-messages for funders and policymakers proposed by the respondents of the survey.

Respondent	**Key-messages**
Respondent 1	-GRACE-RI will provide a robust, integrated system that improves the conservation standards of genebanks and facilitates easier access to PGR for researchers, breeders, and farmers. This will help preserve genetic diversity essential for future agricultural resilience and food security. -By integrating advanced technologies such as genomics and bioinformatics into PGR management, GRACE-RI will accelerate research and breeding programs. This will lead to the development of new crop varieties with improved traits, supporting sustainable agriculture and climate adaptation. -Improved PGR management and utilization will have significant economic benefits, including increased agricultural productivity and sustainability. It will also contribute to societal goals such as job creation in the agricultural and biotechnology sectors, and enhanced food security. -GRACE-RI will work towards harmonizing policies and regulations across Europe, facilitating smoother international collaboration and exchange of PGR. This will ensure compliance with international agreements and support the equitable sharing of benefits arising from PGR use. -GRACE-RI will provide training and capacity-building programs for genebank managers, researchers, and farmers, enhancing their skills and knowledge in modern PGR management practices. This will ensure the long-term sustainability and effectiveness of PGR conservation efforts. -By involving the public and stakeholders in PGR conservation through citizen science and educational initiatives, GRACE-RI will raise awareness about the importance of plant genetic diversity and encourage community participation in conservation efforts.
Respondent 2	GRACE will serve national, European and global ambitions by fostering research and development on agroecological solutions including varietal diversity to meet the current and future challenges of agriculture through: - access to high quality and well characterized genetic resources and other harmonized, sustainable and high-quality transnational services for the public and private research and development;

	- securing these resources and services through a governance and business model adapted to the needs of all stakeholders and allowing to sustain both new services development and *ex situ* and *in situ* conservation; - improving the quality of its services and developing new ones to meet the evolution of R&D needs in collaboration with other ESFRIs.
Respondent 3	The GRACE infrastructure will provide a multidisciplinary services network for the PGR sector. The support of this infrastructure creates great future value: the involvement of seed companies and the private sector ensures that scientific discoveries are rapidly translated into practical solutions, while the involvement of academic institutions ensures innovative research at a high level.
Respondent 4	The GRACE-RI should facilitate, accelerate, increase the efficiency of exploitation of PGRs for breeding purposes to face climate change, to increase the sustainability of agricultural production and to increase the dissemination efficiency of these research approaches.
Respondent 5	GRACE-RI will facilitate pan-European, and, ultimately, global collaboration and data sharing, dismantling silos and enabling the broader PGR community to work together more effectively. Through streamlined data integration, and improved access to genetic resources, research tools and services, GRACE-RI will prevent duplication of efforts, enhance research capabilities, and improve operational efficiency, ensuring optimal returns on research investments. Investing in GRACE-RI is a strategic step towards ensuring global food security. By enhancing our ability to safeguard and utilize PGR, this initiative will support the development of crop varieties resilient enough to ensure stable food production amidst the complexities of evolving global agroecological systems. GRACE-RI's commitment to evidence-based research and data-driven insights will empower stakeholders at every level, from scientists and policymakers to farmers and local communities across Europe. This collaborative approach will bridge the gap between PGR conservation and utilization, strengthen sustainable agricultural practices, boost biodiversity conservation efforts, and align with SDG targets related to zero hunger, climate action, and life on land.
Respondent 6	To ensure food security, we need genetic diversity at all levels, and farmers can be a central driver in maintaining and increasing this diversity with on farm and in situ PGR management. Strengthening local networks and communities that collaborate with research institutes, national gene banks, farmers, and local value chain actors can greatly contribute to building diversity-based, resilient food systems.
Respondent 7	We have kept a big PGR treasure from previous generations, but it is threatened as few and fewer people work and live with the PGR, leaving the PGR only in the hand of our few organisations of genebanks, breeders and community seed banks (CSBs). o For the value we have in our hands we know dangerously few about most of the PGR we're trying to maintain. o For the future challenges it is important to maintain and enlarge this PGR treasure, and to unlock it's potential by breeding and using it in different agricultural systems o In the future we will need decentralized, independent and locally adapted structures that are able to cope with a bigger diversity of PGR on the field and in marketing systems. CSB could help here but need scientfic support and methods/infrastructure and resources for knowledge transfer.
Respondent 8	Plant genetic resources are the raw material for breeding new crop varieties that are adapted to changes in the environment, including climate change, are resistant to biotic and abiotic stress and meet the consumers 'requests. To be efficiently used in the plant breeding

	process they need to be well characterized and the associated knowledge shared. Because of the importance of PGR there is a firm need to properly conserve them for future generations and make them accessible for the current one. For sustainable operation of GRACE-RI in the long term a firm political commitment is needed and sustainable funding available.
Respondent 9	1. A GRACE-RI would help to overcome the deep divide that separates (legally, bureaucratically), on one hand, conservation and basic research uses of PGR, and on the other hand breeding activities. 2. A GRACE-RI will contribute to the adoption/ dissemination of better standards of performance and quality regarding *ex situ* conservation. 3. A GRACE-RI, in cooperation with EU authorities, will help to generate better possibilities for access and conservation of *in situ* EU PGR resources."
Respondent 10	Genetic diversity in crops is fundamental to food security. It provides the raw material for developing new varieties that can withstand pests, diseases, and changing climate conditions. Genetic diversity allows plants to adapt to changing climatic conditions. Breeding programs that utilize diverse genetic resources can develop crops that are more tolerant to drought, heat, and other climate-related stresses. Conservation and sustainable use of plant genetic resources are aligned with the United Nations Sustainable Development Goals (SDGs), particularly those related to zero hunger (SDG 2), life on land (SDG 15), and climate action (SDG 13). For all these reasons an RI on PGR is essential for Europe.
Respondent 11	Biodiversity loss is a big keyword in European policy at the moment, large sums of money are being spent on nature conservation and agricultural policy. GRACE-RI would be an important initiative to position the PGR community within this context, establishing solid grounds to halt biodiversity loss at the same time enabling research to tackle the big problems of our time, enhancing diversity and making use of our natural resources. Establishing the GRACE-RI will provide the necessary impetus to guarantee long-term conservation and facilitated access to PGR conserved in >400 genebanks for a European collaborative research and breeding targeted to the public good, also building capacity of those involved in PGR management and research. It can also create visibility of the diversity within our genebanks and their potentialities among diverse communities of stakeholders as well as the general public.
Respondent 12	Sufficient funds are spent on PGR conservation - however the effectiveness of these funds is very low. But investing a little, in time we can save a lot, in terms of funds but more importantly, in terms of reliability of conservation and access to PGR. This will facilitate and stimulate European crop science and plant breeding and thus European agriculture.
Respondent 13	We need to identify, preserve and maximise the potential of PGRs in Europe for the environment, food and agriculture.
Respondent 14	We need to diversify our farming systems in a time of climate change and we need to start from seeds, varieties and PGRFA. At this regard we have to overcome the old vision: ex situ materials as raw materials for breeding for conventional agriculture and on farm as a museum of times past. The new vision should include new actors in breeding and breed for diversity and not uniformity. It means release varieties that are less uniform, e.g. populations, heterogeneous materials.