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Organization of plant Biological Resource Centers for research in France: History, evolution and current status

Valérie Bergheaud [*,a], Jean-Marc Audergon [b], Arnaud Bellec [c], Anne Delaunay [a], Jérôme Duminil [d], Stéphane Dussert [d], Florence Esnault [e], Emmanuel Geoffriau [f], Brigitte Gouesnard [g], Cristophe Jenny [g,h], Alain Label [i], Philippe Lashermes [d], Najate Maghnaoui [g,h], Cécile Marchal [b], Françoise Nuissier [j], Nilda Paulo-de-la-Réberdiere [g,j], Aurélia Priet [k], Valérie Rieucau [g,h], Paule Térès [g,h] and Anne-Françoise Adam-Blondon [l]

[a] *Université Paris-Saclay, INRAE, BAP, F-78026 Versailles, France*
[b] *INRAE, PACA Center, UGAFL, F-84143 Montfavet, France*
[c] *INRAE, CNRGV French Plant Genomic Resource Center, F-31320 Castanet Tolosan, France*
[d] *DIADE, IRD, Université Montpellier, Cirad, F-34090 Montpellier, France*
[e] *INRAE, institut Agro, Université de Rennes, IGEPP, F-29260 Ploudaniel, France*
[f] *Institut Agro, Université d'Angers, INRAE, IRHS, SFR Quasav, F-49045 Angers, France*
[g] *UMR AGAP Institut, Université Montpellier, CIRAD, INRAE, Institut Agro, F-34090 Montpellier, France*
[h] *CIRAD, UMR AGAP institut, Cirad, Montpellier, France*
[i] *Diagonal, INRAE, F-29260 Ploudaniel, France*
[j] *INRAE, UR ASTRO, F-97170 Petit-Bourg, Guadeloupe, France*
[k] *INRAE, UR4 (UR P3F), Nouvelle-Aquitaine-Poitiers Center, F-86600 Lusignan, France*
[l] *Université Paris-Saclay, INRAE, URGI, F-78026 Versailles, France*

Abstract: Since their inception, the French academic organizations dedicated to agricultural research have developed plant collections in genebanks, often within a public–private framework, to support the study of plant traits and the development of new improved varieties. In addition, since the 2000s, a centre for genomic resources has also been established in France. Over the last 20 years, this decentralized system, consisting of the academic genebanks and the centre for genomic resources, has been supported by a national coordination structure. The objectives were to align the network activities with the framework proposed by the Organisation for Economic Co-operation and Development (OECD) for Biological Resource Centres and to foster collaboration with other national stakeholders involved in the conservation and characterization of plant genetic resources (PGR). In 2015, the network was named BRC4Plants and become part of the French National Research Infrastructure RARe (www.agrobrc-rare.org), supported by the French Ministry of Research. This paper describes BRC4Plants, its users, services and cross-cutting activities. We also highlight its relations with its national and international stakeholders involved in the conservation and characterization of PGRs. BRC4Plants aims to be a key player in addressing societal and research challenges regarding agroecology, climate change mitigation and healthy food systems.

Keywords: Plant genetic resources, genomic resources, BRC, Research Infrastructure, ECPGR, genebanks

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Origins of BRC4Plants, the French network of Plant Biological Resource Centers (BRC) for research

Since their inception, the French academic organizations for research in agriculture have built plant collections to support the study of plant traits and the development of new improved varieties. Among the oldest academic French collections, the grapevine collection began to be established in the late 19^{th} century by the College of Agriculture of Montpellier, to tackle the challenges of mildews and phylloxera that were devastating French viticulture (Pouget, 1990). Another emblematic example is the creation in the 1960s of the PRO-MAIS French non-governmental organization grouping all the French maize breeders to facilitate collaborations with the academic sector, in particular to collect and conserve maize genetic resources (Dallard *et al*, 2000). Today, the conservation of biodiversity – particularly cultivated biodiversity or agrobiodiversity – is more crucial than ever and is key for adaptation to the accelerating global changes impacting the planet, human health and nutrition (Pilling *et al*, 2020; ECPGR, 2021; Lefèvre *et al*, 2024).

The organization and evolution of the French activities dedicated to genetic resource conservation are described in Roux-Cuvelier *et al* (2021). Here, we summarize the main steps and provide additional insights.

In 1983, the French Ministry of Agriculture set up a coordination office for the conservation of genetic resources (plants and domestic animals) which operated until 2008 – the *Bureau de Ressources Génétiques* (BRG). The BRG was a *Groupement d'Intérêt Scientifique*, a French associative structure gathering under a memorandum of understanding the Ministries of Research, Agriculture and Environment and six French Research Institutes. It had three main mandates: the coordination of genetic resource management, the representation of France in international bodies, and the facilitation of genetic resource research. The BRG was in particular mandated to implement a decentralized system for PGR conservation and to facilitate the establishment of commodity-specific and multi-stakeholders networks – including academic institutions, non-governmental organizations, regional organizations and private companies – to carry out this conservation. After 2008, the French Government decided to merge BRG with a newly created foundation, the *Fondation pour la Recherche sur la Biodiversité*. In reality, coordination and facilitation – in particular for basic genetic resource conservation activities – have not been taken over by the *Fondation pour la Recherche sur la Biodiversité*, which has focused on supporting the development of biodiversity knowledge. To address this gap, the managers of the plant collections from the main French research institutes developed their own inter-institute networking and coordination activities. Since the end of the 1990s, the management of plant biological resources dedicated to research and development activities (R&D) has been professionalized using the concept of Biological Resource Center (BRC, OECD - Organisation for Economic Co-operation and Development, OECD (2001)) as a reference. In particular, academic BRC managers actively contributed to the development of a French quality management norm dedicated to BRCs, S96-900:2011. Later on, they contributed to the international norm dedicated to Biobanking ISO 20387:2018 and its technical specification (ISO/TS 23105:2021) in order to improve the quality of their services, which include, among others, the conservation, documentation and provision to users of plant biological resources. A still growing number of French BRCs dedicated to R&D are certified based on these norms and/or ISO9001. These developments were supported by a French inter-research institute organization, *Infrastructures en Biologie, Santé et Agronomie* (IBiSA, https://www.ibisa.net/) , aiming at labelling research facilities and funding their developments.

In 2015, the informal network of plant BRCs supported by French academic organizations joined four other BRC networks on domestic animals, microbes, forest trees and environmental samples to set up a national infrastructure of resources for research in agriculture, RARe (https://www.agrobrc-rare.org; Figure 1) (Tixier-Boichard *et al*, 2024). RARe is included in the French Ministry of Research's roadmap and will soon need to reapply for this label, which provides access to funding and recognition. The plant network was named BRC4Plants: it currently gathers 21 BRCs, including the French National Center of Genomic Resources (CNRGV, Table 1). The network spans the entire French territory, including overseas departments and regions, and conserves species cultivated in a wide range of climates (Figure 2).

The main missions of BRC4Plants's BRCs are to 1) ensure the proper maintenance of crop diversity in relation to the challenges faced by both biodiversity and agriculture (Lefèvre *et al*, 2024) and 2) provide access to high-quality biological resources and associated data to the scientific community of plant biologists and breeders. BRC4Plants coordination activities aim to effectively support these initiatives through strategic discussions and decisions, training and facilitation.

BRC4Plants has developed a formal governance structure that supports strategic decisions through a committee comprising representatives of the main funding institutes (INRAE, the National Research Institute for Agriculture, Food and Environment; CIRAD, the French agricultural research and cooperation organization working for the sustainable development of tropical and Mediterranean regions, and IRD, the French National Research Institute for Sustainable Development) and the coordinator of RARe who meet twice a year. In addition, coordinated cross-cutting activities are organized

*Corresponding author: Valérie Bergheaud (valerie.bergheaud@inrae.fr)

both at the plant network level and the RARe level. For instance, all BRCs are supported by such internal transversal activities for their compliance with access and benefit sharing (ABS) rules, the General Data Protection Regulation and for their capacity to become certified ISO9001. In 2020, RARe established its international scientific advisory board comprising experts of all domains, which has met annually since then, along with an annual thematic scientific workshop. These two new annual events foster scientific strategic discussions across domains. RARe facilitated the contribution of several networks to common projects such as the Coordination Support Action of the H2020 EC programme, 'GenRes Bridge' (grant agreement No 817580). The GenRes Bridge project partners developed a Genetic Resources Strategy for Europe (GenRes Bridge Project Consortium, ECPGR, ERFP and EUFORGEN, 2021) in collaboration with the three European networks for the conservation of genetic resources – the European Cooperative Programme for Plant Genetic Resources (ECPGR), the European Forest Genetic Resources Programme (EUFORGEN) and the Regional Focal Point for Animal Genetic Resources (ERFP). BRC4Plants coordinated a strategic document on data management (Adam-Blondon *et al*, 2021).

Finally, RARe has clarified the conditions necessary for a BRC to join or leave the infrastructure. As a result, within some of the RARe's networks such as BRC4Plants, BRCs are divided into two groups: full members of RARe and those in progress towards membership. BRC4Plants is currently composed of 18 RARe member BRCs and three in-progress BRCs (Table 1). The difference between these two statuses is not yet significant as the only benefits obtained by BRCs from RARe derive from low-cost networking activities and it is not in the global interest to restrict access. However, the criteria of differentiation (certification of the quality management and/or IBiSA label) might soon be important for getting access to some funding dedicated to BRCs. After almost ten years of operation, this framework has reached its full maturity and its renewal on the roadmap is planned for 2025.

BRC4Plants collections and services for the research community

Crop genetic and genomic resources have always been instrumental for research in plant genetics, plant biology and for fostering academic and socio-economic research and development partnerships. They have been intensively used to characterize genetic diversity, explore the evolutionary history of crops, develop advanced genomic tools, select panels of genetic resources for association studies, carry out pan-genome studies, develop prediction models and breeding strategies, screen for adaptive traits, and decipher molecular mechanisms with mutant collections (Jourdan *et al*, 2015; Allier *et al*, 2020; Leuenberger *et al*, 2024; Healey *et al*, 2024).

Most BRCs and their collections are managed or co-managed by INRAE, CIRAD and IRD in partnership with technical institutes and higher education institutions (Roux-Cuvelier *et al*, 2021).

As a whole, BRC4Plants maintains 214,918 accessions of a large range of model species, field crops, vegetables and fruit trees (Table 1). An accession is defined as an entry in the collection and the unit of conservation. A crop variety can be represented by several accessions. Different types of material (samples) can be conserved and distributed from a given accession: reproductive (e.g. seeds, in vitro plants, pollen, cuttings, etc.) or non-reproductive (e.g. leaf, DNA, etc.). The collections are usually very diverse, in terms of accessions' country of origin, phenotypes or genetic diversity (Salinier *et al*, 2022). They include varieties, landraces and wild relatives but also material derived from breeding or research programmes (Roux-Cuvelier *et al*, 2021; Salinier *et al*, 2022; Esnault *et al*, 2025).

Figure 1. Organization of the RARe National Research infrastructure (Tixier-Boichard *et al*, 2024), in five domain-specific networks of Biological Resource Centres (BRCs): CRB-Anim manages biological resources for domestic animals, BRC4Env manages biological resources and specimens in relation with various types of terrestrial environments (soils, lakes, pathogens, etc.), FBRC manages forest trees biological resources dedicated to research purposes, BRC4Microb manages microbial resources and BRC4Plants manages model and cultivated plant biological resources.

Table 1. List of the Biological Resource Centers that are members of BRC4Plants or with a status of candidate, their supporting institutes, the type of resources that they manage, the state of their contribution to national public–private networks dedicated to the conservation of genetic resources and to international working groups (2024).

Name	Main genera or species	Institute(s)	French public–private networks	International networks	Rare	Reference
French Plant Genomic Center (CNRGV)		INRAE			Member	Roux-Cuvelier *et al* (2021)
Versailles Arabidopsis Stock Center (VASC)	*Arabidopsis thaliana*	INRAE			Member	Ricou *et al* (2025)
BrACySol	*Brassica oleracea, Brassica napus, Allium cepa* Aggregatum group, *Allium sativum, Solanum tuberosum*	INRAE	Vegetable crucifers, Oilseed crucifers and potato networks	ECPGR *Allium*, *Brassica*, Potato	Member	Roux-Cuvelier *et al* (2021); Esnault *et al* (2025)
Coffea	*Coffea* spp.	IRD, CIRAD		ECPGR Cryopreservation	Member	Joët *et al* (2021)
Carrot and other vegetable Apiaceae (Carpia)	*Daucus* spp., *Chaerophyllum bulbosum*, other Apiaceae	Institut Agro	Carrot and other *Daucus* network (coordination)	ECPGR Umbellifer crops EVA ISHS Carrot and other Apiaceae	Member	Roux-Cuvelier *et al* (2021)
Small grain cereals (Cereales)	*Triticum* spp., *Hordeum* spp., *Secale* spp., *Triticosecale* spp., *Avena* spp.	INRAE	Small grain cereals network	ECPGR Wheat, *Avena*, Barley	Member	Debiton (2021)
Citrus	*Citrus* spp., *Poncirus* spp., *Fortunella* spp., *Clausena* spp.	INRAE, CIRAD			Member	Roux-Cuvelier *et al* (2021)
Forage and turf species (Prairies)	*Lolium* spp., *Festuca* spp., *Dactylis* spp., *Medicago* spp., *Trifolium* spp.	INRAE	Forage and turf network	ECPGR Forages	Member	Sampoux *et al* (2025)
Pip fruit and rose (RosePom)	*Malus* spp., *Pyrus* spp., *Cydonia* spp., *Rosa* spp.	INRAE	Pip fruits and Rose networks	ECPGR *Malus*/*Pyrus*	Member	Roux-Cuvelier *et al* (2021); Feugey *et al* (2025) submitted
Seeds adapted to Mediterranean and tropical conditions (GAMéT)	*Oryza* spp., *Sorghum* spp., *Digitaria* spp., *Gossypium* spp., *Arachis* spp., *Vigna unguiculata*, *Zea* spp., *Medicago* spp.	INRAE, CIRAD	Promais network	ECPGR Maize	Member	Maghnaoui and Prosperi (2017)

Continued on next page

Table 1 continued

Name	Main genera or species	Institute(s)	French public–private networks	International networks	Rare	Reference
Vegetable germplasm (Leg)	*Solanum melongena, Capsicum annuum, Solanum lycopersicum, Cucumis melo, Lactuca sativa*	INRAE	Solanaceae, *Lactuca* and melon networks	ECPGR Cucurbits, Solanaceae, Leafy Vegetable	Member	Salinier *et al* (2022)
French Maize Inbred Lines Genebank (Mais-Lig)	*Zea* spp.	INRAE	Promais network	ECPGR Maize	Candidate	Diaw *et al* (2017)
Olive trees (Olivier)	*Olea europaea*	Conservatoire Botanique National Méditerranéen (CBNMED), INRAE		International Olive Council	Candidate	Marchal *et al* (2017); Roux-Cuvelier *et al* (2021)
Perennial plants in Guyana (PPG)	*Coffea* spp., *Theobroma* spp., *Hevea* spp., *Dalbergia* spp.	CIRAD			Member	
Tropical plants (PlanTrop)	*Musa* spp., *Ananas* spp., *Saccharum* spp., *Mangiferea* spp., *Dioscorea* spp.	CIRAD, INRAE			Member	Roux-Cuvelier *et al* (2021)
Grain legumes (Protea)	*Vicia faba, Lupinus* spp., *Pisum* spp.	INRAE		ECPGR Grain Legumes	Member	Aubert *et al* (2023); Carrillo-Perdomo *et al* (1914)
Prunus-Juglans (Pru-Ju)	*Prunus armeniaca, Prunus dulcis, Prunus persica, Prunus cerasus, Prunus domestica, Juglans* spp.	INRAE	*Prunus* (in progress), Juglans	ECPGR *Prunus*	Member	Roux-Cuvelier *et al* (2021)
Sunflower and soy (Helia-Soja)	*Heliantus* spp., Glycine max	INRAE	*Helianthus* and Soya		Candidate	Terzić *et al* (2020)
Vanilla of Tahiti (Vanira)	*Vanilla* spp.	Etablissement Vanille de Tahiti			Member	Roux-Cuvelier *et al* (2021)
VATEL	*Vanilla* spp., tropical *Allium* spp., roots and tubers, neglected vegetables	CIRAD		Germination International Network	Member	Roux-Cuvelier *et al* (2021)
Grapevine Biological Resources Center (Vigne)	*Vitis* spp.	INRAE	*Vitis* network	ECPGR *Vitis*	Member	Roux-Cuvelier *et al* (2021)

In addition, CNRGV develops and maintains plant genomic resources with a catalogue of more than 300 bacterial artificial chromosome (BAC) libraries (around 35 million samples) from more than 60 different plant species. CNRGV provides the research community with a range of services to characterize genetic resources at the genomic level with cutting-edge technologies, in collaboration with other French national genomic facilities that together allow the production of high-quality reference genomes required for diversity analysis and association studies, and the detailed analysis of intraspecific diversity at loci carrying key genes.

In 2022, BRC4Plants provided around 13,000 genetic resources accessions, over 100 BAC clones or libraries and globally billed an important vol-ume of genomic services to a diversified panel of users: 49% to French public institutes, 37% to foreign public institutes, 13% to private companies or producers and 1% to schools, regional public structures, NGOs etc. The introduction and distribution activities follow national and international regulations concerning sanitary issues and ABS. The terms of access to BRC's services are available on the CNRGV website for genomic services (https://cnrgv.toulouse.inra.fr/fr/Services) and on the web portal of BRC4Plants for the other BRCs (e.g. https://florilege.arcad-project.org/fr/crb/bracysol/conditions-generales). The Standard Material Transfert Agreement (SMTA) of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) is used for species on Annex 1 of ITPGRFA. An INRAE standard material transfer agreement, compliant with the Convention on Biological Diversity (CBD) Nagoya Protocol is used for other species or for material developed by INRAE (e.g. segregating population, pre-breeding material, etc.). In case of scarcity of the material for distribution, the priority has been so far to support research, development and training.

BRC4Plants activities (of individual BRCs as well as those coordinated by the network) are supported by academic organizations, within the framework of their research priorities, with permanent positions dedicated to the BRC missions and a wide range of infrastructures, including robots, refrigerators, freezers (-20°C and -80°C), cryotanks, seed drying rooms, greenhouses, field plots for seed regeneration or plant conservation (vegetatively-propagated or perennial plants).

The network as a whole also provides an important volume of communication activities that contribute to raising awareness of genetic resources to a large audience (e.g. Pic *et al* (2017), New York Times (Poll, 2021), Le Monde (Rosier, 2021)). Finally, the network contributes to training and education on biodiversity conservation as well as on genomic approaches.

BRC4Plants R&D activities

BRC4Plants regularly updates its priorities in terms of R&D, which can be seen at two levels.

First, R&D activities that aim at improving the efficiency of conservation and distribution of accessions. Key areas include transversal issues such as management and legal compliance regarding phytosanitary and ABS issues (Tixier-Boichard *et al*, 2024), FAIR (data are findable, accessible, interoperable and reusable) data management and automated data workflows between local databases and central information systems, andimproved cryopreservation methods (Markovic *et al*, 2015). These activities also include local improvements of processes and equipment in BRCs and are mainly funded by French research organizations, the French National Research Agency or sometimes European Funds for Regional Development (FEDER).

The second level includes R&D activities aiming at improving services dedicated to research projects using genetic resources to achieve their goals: development of new services, such as the development of new populations and core collections (Esnault *et al*, 2017; Terzić *et al*, 2020; Salinier *et al*, 2022), new knowledge on biological resources, e.g. through their genomic or phenotypic characterization (Antoine *et al*, 2023; Martínez-Flores *et al*, 2020), and improved breeding strategies (Sanchez *et al*, 2023). These R&D activities are supported by a diverse set of national and European calls and the applications are frequently driven by public and/or private researchers who are not BRC members. Calls dedicated to infrastructures at the national or international level can be an opportunity to work with other infrastructures. For instance, BRC4Plants has actively liaised with the European infrastructures EMPHASIS (plant phenotyping) and ELIXIR (bioinformatics for life sciences) to contribute to the development of a suite of guidelines and resources supporting FAIR-compliant management of plant genotyping and phenotyping data. This work was supported by several EU programme Horizon 2020-funded projects: ELIXIR-Excelerate, grant agreement no. 676559 https://elixir-europe.org/about-us/how-funded/eu-projects/excelerate; AGENT, grant agreement no. 862613 https://www.agent-project.eu/ and ELIXIR-CONVERGE, grant agreement no. 871075 https://elixir-europe.org/about-us/how-funded/eu-projects/converge, and all the results can be accessed through the ELIXIR portal of resources for data management (https://rdmkit.elixir-europe.org/). Building on these resources, a national project currently gathers partners from three French national infrastructures, RARe, the French Institute of Bioinformatics (https://www.france-bioinformatique.fr/) and INRAE Genomics (https://inrae-genomics.hub.inrae.fr/) to develop a comprehensive service of genomic data management from data production to data submission to the European archives maintained by the European Bioinformatics Institute (EMBL-EBI). Projects including the characterization of PGR or the development of pre-breeding populations can be funded by national calls dedicated to public–private partnerships. They often build on the trust developed in the public-private networks in which many of the BRCs are involved (see below and Table 1).

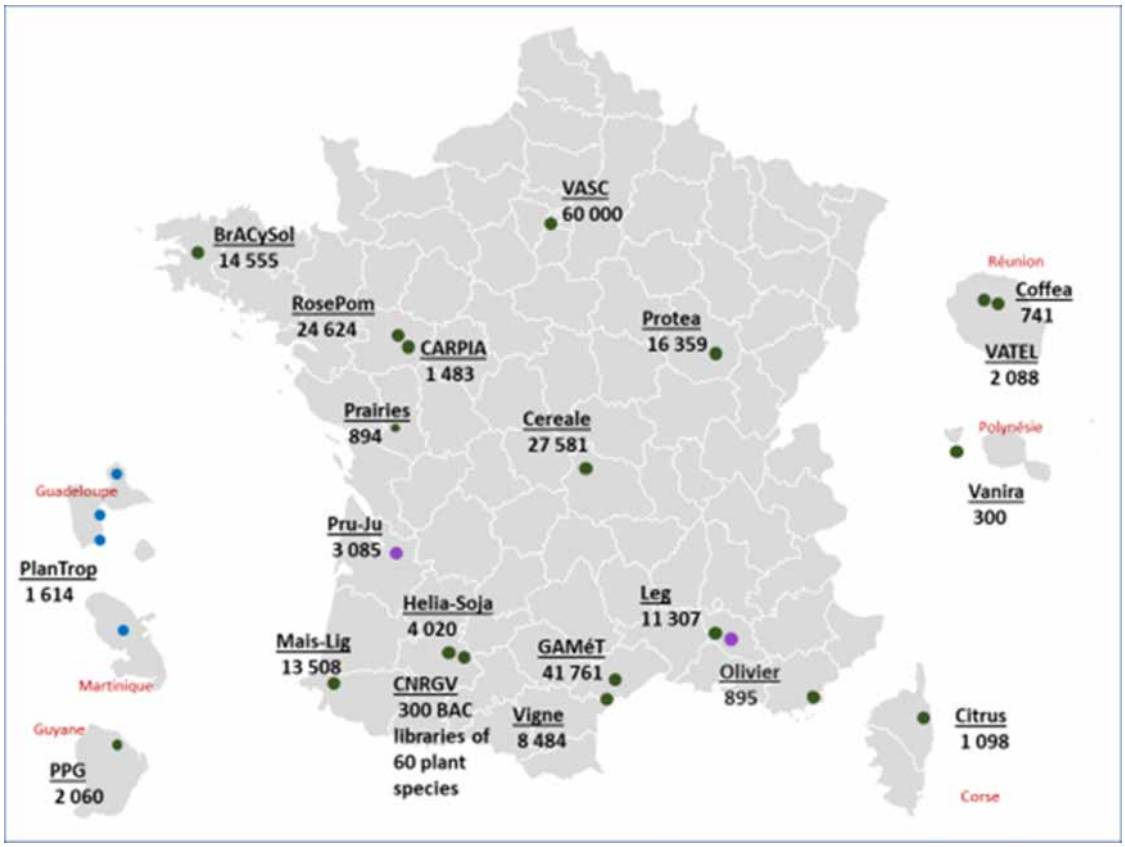

Figure 2. Localization of the 21 BRCs facilitated by BRC4Plants together with the number of accessions they manage. In general, they are single-located (green points) but two have several locations, Pru-Ju (purple points) and PlanTrop (blue points).

They can also be funded by the European Commission (e.g. H2020 G2P-Sol project, grant agreement no. 677379, http://www.g2p-sol.eu/).

BRC4Plants organizes training and dissemination activities to ensure that the outputs of the projects can be leveraged by all BRCs.

Public–private partnerships

Half of the BRCs collaborate with networks gathering different types of partners (seed companies, breeders, extension institutes, regional organizations for genetic resource conservation, NGOs; Table 1, Figure 3). These collaborative networks, established in the 1990s, aim to pool efforts to manage and study mostly traditional genetic resources of a species or a related group of species. A model charter for these 'genetic resources networks' was developed in 2018 and updated in 2021 by BRC4Plants, INRAE central services, the French Seed Association and the French Ministry of Agriculture to define the rules for material and data exchange within and out of the network. Some of these networks have formal organizations (e.g. Promaïs for maize, http://pro-maize-corn.com/, the *Federation Franc*
for the rose or a joint unit of INRAE with the *Institut Français de la Vigne et du Vin*, IFV, for grapevine).

The existence of such partnerships has made it possible to inventory and secure old French genetic material (e.g. Dallard *et al* (2000); Terzić *et al* (2020)). Additionally, the grapevine-dedicated joint unit has been instrumental in exchanging technical expertise. IFV and INRAE have also brought together all the other French regional extension services for viticulture and oenology to formally organize the development of grapevine varieties resistant to diseases and adapted to each French terroir (INRA, 2018). INRAE and IFV are promoting both traditional genetic resources (a renewal of interest for old varieties was observed in many places) and new resistant varieties under the brand ENTAV-INRA (www.entav-inra.fr). Similarly, a convention between INRAE and the four French potato breeders gathered within the association named ACVNPT (*Association des Créateurs de Variétés Nouvelles de Pomme de Terre*) was signed in 1995. ACVNPT provides financial support to INRAE for the conservation and characterization of potato genetic resources maintained within the BrACySol BRC, and in return gets free access to the pre-breeding material generated by INRAE within the framework of its research activities (Kerlan *et al*, 2017; Esnault *et al*, 2025). Since 1995, INRAE has proposed 994 pre-breeding clones, improved mainly for resistance to biotic stress. Forty-one potato varieties, originating from these pre-breeding clones, have been registered.

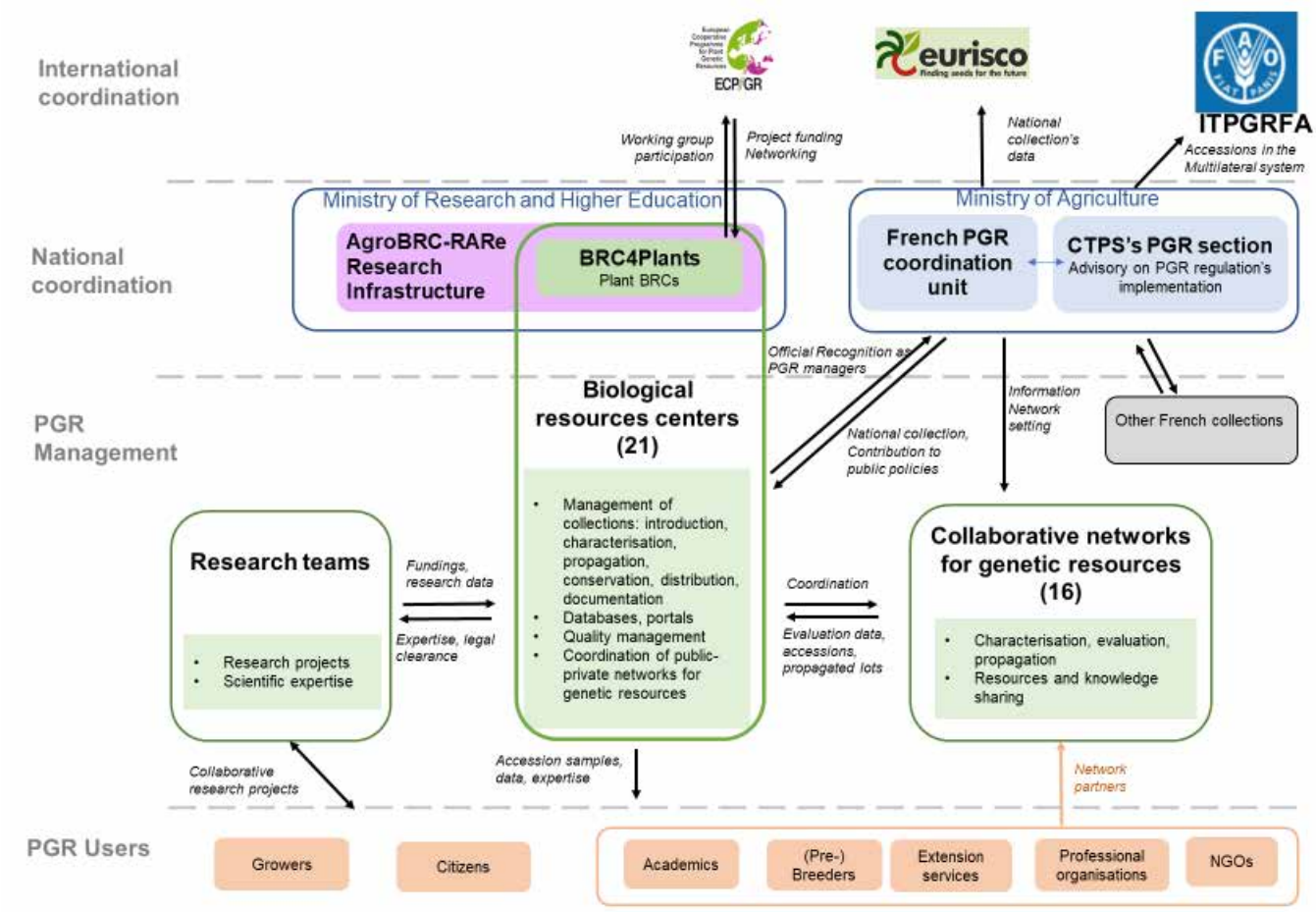

Figure 3. BRC4Plants in its 'ecosystem' of stakeholders at different levels. At the international level, BRC4Plants contributes to the activities of the European Cooperative Programme for Plant Genetic Resources (ECPGR), deposits data in the catalogue of ECPGR, EURISCO, and contributes to the deposition of collections of accessions in the multilateral system of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). At the national level, BRC4Plants: 1) is funded by the French Ministry of Research and follows its recommendations related to research infrastructures (enforced by BRC4Plants main funding institutes, INRAE, CIRAD and IRD) and 2) interacts with the French coordination on plant genetic resources conservation and contributes to the section of the technical committee for breeding (CTPS) dedicated to plant genetic resources that are both under the governance of the French Ministry of Agriculture. The daily management of BRC4Plants collection is made in collaboration on one side with research units that were often at the origin of the collections and often on the other side with national public–private networks of partners that may also represent important users of those collections. The interactions with BRC4Plants stakeholders are represented by arrows and their results or purposes are specified in italics.

BRC4Plants contribution to the French National Coordination for Plant Genetic Resources activities

BRC4Plants is a self-organized, research-driven network of BRCs. Many other organizations are contributing to the conservation of PGR in France (Duval *et al*, 2023): regional centres, NGOs, the Network of Botanical Conservatories, private companies, etc. The French Ministry of Agriculture is in charge of developing the French strategy for the conservation and use of PGR for food and agriculture. In particular, this strategy aims to contribute to FAO's global plans of action on genetic resources and to the ITPGRFA (Duval *et al*, 2023). To support this endeavour, the Ministry established the French National Coordination for PGR, which comprises a national support structure hosted within GEVES (Group for the Study and Control of Varieties and Seeds) and a section of the French multi-stakeholder organization CTPS (Permanent Technical Selection Committee). This coordination is responsible for implementing French policies on genetic resources (Duval *et al* (2023); Figure 3). BRC4Plants contributes to the CTPS plant genetic resources section and facilitates, in collaboration with its funding bodies, the official recognition of BRCs through ministerial acknowledgement. This recognition identifies them as managers of genetic resources and acknowledges their contribution to the French National Collection of Genetic Resources (Duval *et al*, 2023). So far, INRAE and

the *Etablissement Vanille de Tahiti* have been officially recognized as managers of genetic resources and INRAE is yearly increasing the official collection set under its responsibility in collaboration with its BRCs (MAA, 2022, 2024).

The French National Coordinator for Plant Genetic Resources is also the French National Coordinator for ECPGR (Duval *et al* (2023); Figure 3). BRC4Plants' coordination and its BRCs are actively contributing to ECPGR Working Groups (Table 1) dedicated to crops as well as to cross-cutting themes. In collaboration with the National Coordination, BRC4Plants deposits data in the European Search Catalogue for Plant Genetic Resources (EURISCO), managed by ECPGR, and contributes to the inclusion of accession collections in the ITPGRFA multilateral system. In 2019, ECPGR launched the European Evaluation Network (EVA) which leverages public–private partnerships at the pre-competitive stage, to jointly generate standardized characterization and evaluation data on crop accessions present in European genebanks. These accessions are often poorly characterized and, consequently, underutilized. ECPGR provides the EVA networks with standards and platforms for documentation and results sharing (Kumar *et al*, 2024). So far, four French BRCs are contributing to EVA networks: CRB GAMéT for maize (Balconi *et al*, 2024), CRB CARPIA for carrot (Goritschnig *et al*, 2023) and CRB-Leg for pepper and lettuce.

Conclusions and perspectives

The overarching goal of BRC4Plants is to facilitate the mobilization of its resources and services for research and innovation, with the aim of enhancing genetic diversity and beneficial interactions within agroecosystems. This supports the agroecological transition and the development of sustainable and healthy food systems. The network of BRCs plays an important role as a source of genetic diversity to be screened for new traits (e.g. plant-plant or plant-microbe favourable interactions). BRCs can also support the development of new plant materials for research on new breeding or cropping strategies. In this context, BRC4Plants faces several challenges that will need to be addressed through a mix of social, technical and scientific approaches:

- How should BRC4Plants be organized to address new needs regarding species, material development or introduction of accessions, while ensuring these efforts remain feasible within a realistic level of funding and support?
- How to increase *in situ* dynamic conservation activities and their integration with *ex situ* conservation?
- How to deal with the threats associated with climate change, including the spread of new diseases, in particular for the conservation of perennial plants in orchards?
- How to ensure that the variety of jobs necessary for the management and dissemination of genetic resources remains attractive and rewarding despite increasing legal and administrative complexity and responsibility?

Tackling these challenges requires the co-construction of strategies with BRC4Plants supporting research organizations, as well as with other stakeholders involved in the conservation and use of genetic resources, in particular with the National Coordination on PGR. The current lack of full alignment or integration between research, agriculture and environment-driven national governance on PGR conservation is reducing the efficiency of efforts to coordinate the different stakeholders. It should be noted that this lack of integration is also a challenge at the European level and was identified as a major issue in the Genetic Resources Strategy for Europe developed in the frame of the GenRes Bridge project (GenRes Bridge Project Consortium, ECPGR, ERFP and EUFORGEN, 2021).

Nevertheless, at the national level, RARe, as a national research infrastructure, is an effective platform for conveying messages through its participation in ministry-driven committees and initiatives, its governance committee, which includes representatives of its main supporting institutes, and its advisory committee, which includes members of the research community and other international infrastructures. RARe can develop and present coordinated perspectives on issues common to all genetic resources domains (e.g. implementation of the French law on ABS or phytosanitary risk management). In addition, BRC4Plants operates at the interface of a significant variety of stakeholders as illustrated in Figure 3. This position enables it to co-develop responses and solutions with research organizations, different types of genetic resources users, and policymakers, such as national decision support systems dedicated to ABS or diseases under regulation. Another important benefit of these multi-stakeholder approaches is a more realistic distribution of responsibilities among research organization central offices, official agencies and individual BRC managers.

The contribution of BRC4Plants BRCs to multi-stakeholder networks facilitates the development of species-specific collaborations aiming at characterizing and enhancing the use of PGR. However, a challenge now is to expand their diversity to include new players such as farmers, citizens, or industries, in order to develop integrated *in situ* and *ex situ* approaches for the management of genetic resources. This will also require an evolution in networking practices, including the structure of governing and advisory bodies (Louafi *et al*, 2021). Some BRCs are currently involved in projects aiming at developing a common understanding of different stakeholders and expectations, and co-developing common objectives in the context of the conservation and use of genetic resources.

The French choice to organize PGR conservation in a fully decentralized way has some disadvantages in terms of visibility and requires a layer of coordination to avoid redundancy and identify and support common devel-

opments and resources. However, it should be noted that nationally centralized genebanks in other countries primarily hold seed-propagated genetic resources and only a few vegetatively propagated species, whereas BRC4Plants manages many of the latter. Moreover, the French academic decentralized network has a historical origin: BRC collections were initially developed by individual researchers for their own breeding and research objectives, and were later centralized by crops by Research Institutes. Since then, they have remained closely linked to research units that contribute to their development, characterization, funding and reputation within their specific species communities of interest. Given the very low level of long-term funding for the basic operation and maintenance of collections, these tight links with research teams, various regional bodies and other stakeholders such as industry have been instrumental in raising funds for BRCs. The decentralized organization also offers significant flexibility for including new partners with additional collections or new expertise and tools. Additionally, it can provide backup solutions should any of the BRCs face problems due for example to climatic and environmental changes (perennials) or changes in the local scientific and technical teams (all types of BRCs).

Many of the challenges described above are also relevant in other countries (Smith *et al*, 2021). On the other hand, the international level can provide cooperation and solutions. At the European level, the conservation of genetic resources is organized in a decentralized model by ECPGR, which fosters cooperation under the ITPGRFA principles. BRC4Plants is already well involved in this framework. An ongoing project, PRO-GRACE (https://www.grace-ri.eu/pro-grace), funded by the EU programme Horizon Europe (grant agreement no. 101094738) aims at extending or completing this framework through the creation of a pan-European Research Infrastructure on PGR. BRC4Plants is keen to contribute to such an infrastructure, including through its links with other national (e.g. METABOHUB for metabolomics, PROFI for proteomics and France Genomics for genomics) and European infrastructures (EMPHASIS for phenotyping and ELIXIR for life science data) that could be leveraged in the context of the characterization and use of genetic resources. Such a Research Infrastructure would strengthen the links of BRCs with public and private researchers in to foster their contributions to addressing the current challenges of agriculture[1].

[1] See for instance the publications derived from three projects aiming at facilitating adaptation of different crops to climate change: SUNRISE for Sunflower, https://anr.hal.science/search/index/?q=*&anrProjectReference_s=ANR-11-BTBR-0005; the AMAIZING for maize, https://anr.hal.science/search/index/?q=*&rows=30&anrProjectReference_s=ANR-10-BTBR-0001 or BREEDWHEAT for wheat, https://anr.hal.science/search/index/?q=*&rows=30&anrProjectReference_s=ANR-10-BTBR-0003

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Authors contributions

VB and AFAB drafted the paper, JMA, AB, AD, JD, SD, FE, EG, BG, CJ, AL, PL, NM, CM, FN, NP de la R, AP, VR and PT revised it. AP and EG contributed to the design of the figures.

Conflict of interest statement

The authors declare that there are no conflicts of interest

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