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Thematic Review

Microbial *ex situ* preservation supporting science and bioeconomy in Brazil

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Abstract: One of the texts in the "Biodiversity in the State of São Paulo" series, within the FAPESP-Biota Program, was dedicated to the Infrastructure for Biodiversity Conservation, with a focus on Biological Collections and Conservation Units. From the early 1960s, when FAPESP was established, to the present day, financial resources have been invested in the preservation of the biodiversity of the national genetic heritage, besides other fields. History of years of advances in scientific knowledge was built, which can be portrayed through the projects that resulted in high-quality data of national and international impact. Microbiological collections are centers that generate technology and specialized human resources, and act (among other things) as living repositories preserving reference material and as witnesses to the history of microbial biodiversity because they preserve what may no longer exist. They have enormous potential to promote the global bioeconomy and address problems that have resulted from the misuse of natural resources. This reading brings everyone the history, advances, and future perspectives of culture collections, within the efforts of 60-year scientific activities in Brazil.
Keywords: *Ecosystem services; microbial culture supply; research infrastructure; microbial taxonomic investigation; valorization of genetic resources.*

Preservação de microrganismos *ex situ* como suporte para a ciência e a bioeconomia no Brasil

Resumo: Um dos textos da série "Biodiversidade do Estado de São Paulo", dentro do Programa FAPESP-Biota, foi dedicado à Infraestrutura para Conservação da Biodiversidade, com foco nas coleções biológicas e nas unidades de conservação. Do início dos anos 60, quando a FAPESP foi criada, até os dias atuais muito foi investido em pesquisa nas mais diversas áreas, incluindo a preservação da biodiversidade do patrimônio genético nacional. Uma história de longos anos de avanços no conhecimento científico foi construída, a qual pode ser retratada através dos projetos que resultaram em dados de alta qualidade com impacto nacional e internacional. As coleções microbiológicas são centros geradores de tecnologia e recursos humanos especializados, que atuam (dentre outros) como repositórios vivos, preservando material de referência, e como testemunho da história da biodiversidade microbiana, preservando o que pode não mais existir. Possuem enorme potencial para alavancar a bioeconomia global e tratar de problemas que resultaram do mau uso dos recursos naturais. Essa leitura traz a todos o histórico, os avanços e as perspectivas futuras das coleções de microrganismos, dentro dos esforços de 60 anos de atividades científicas no Brasil.
Palavras-chave: *Serviços ecossistêmicos; fornecimento de culturas microbianas; infraestrutura de pesquisa; investigação taxonômica; valorização dos recursos genéticos.*

Introduction

Since 1890, when Prof. Frantisek Král established the first recorded culture collection at the German University of Prague (Czech Republic), the impact of microorganisms on human life has gone to another level in an irremediable way (Çaktü & Türkoğlu 2011). The importance of these microscopic beings of such diversity is undeniable, whose metabolisms lend themselves to the solution of so many challenges that we face in the areas of health, environment, agriculture and industry.

Linking the application of microorganisms to mankind, we have the culture collections, which are expected to provide microbiological material with assured compliance of present and future importance. These centers of preservation and knowledge truly work as a "key component of the scientific and technological infrastructure of the life sciences and biotechnology" (OECD 2001). This recognition justifies the worldwide presence of collections of microorganisms that emerged after Král´s, like the Mycothèque de l'Universitée Catholique de Louvain (MUCL) founded in 1894, in Belgium, and the Centraalbureau voor Schimmelcultures (CBS) in 1904, in the Netherlands, recently renamed the Westerdijk Fungal Biodiversity Institute (Uruburu 2003; Çaktü & Türkoğlu 2011). Later on, other resource centers were created outside Europe, for example, the American Type Culture Collection – ATCC (1925), in the USA, and the All-Russian Collection of Microorganisms – VKM (1958), in Moscow.

The last few decades have been marked by a rapid pace in the advancement of scientific discovery and technology. Bioinformatics, combinatorial chemistry, high throughput screening (HTS) techniques, Meta-Omics approaches and metabarcoding methods to investigate microbial diversity emerged, among others. Withal, both society and industry began to demand faster responses, and the pressure to achieve a better cost/benefit of products and services in less time was very much increased (Canhos & Manfio 2001). In addition, the dynamism of studies in microbial taxonomy has been generating a continuous accumulation of a wealth of data, important for the constant revision of classification and nomenclature schemes. Surveying the geographic distribution of microbial species, their substrates of origin, and their changes through geological time (biogeography) also plays a relevant role. When one brings all this information together, it is possible to more accurately determine the extent of microbial diversity, identify threatened taxa and reveal the ecological functions of the species in a given ecosystem (Canhos & Manfio 2001; OECD 2001). This also works as a guide to develop strategies that help to find microbial resources still unknown to science, and recognize possible hidden biodiversity hotspots.

It is quite understandable why there is a rush to build integrative and consolidated databases where all associated information about a microorganism can be found. There is no better place to store such data and the microbial culture itself than a Culture Collection. And so, over more than a century these depositories of genetic material and knowledge have been facing great challenges but also offering huge opportunities. If it is true that the Sustainable Development Goals (SDGs) cannot be achievable without microbiology, because microbes are key players interconnecting with each of the 17 SDGs (Fagunwa & Olanbiwoninu 2020; Oliveira et al. 2022), culture collections are definitely in the center of this scenery (Figure 1).

In the State of São Paulo, Brazil, the Biota Program invested in Infrastructure for Biodiversity Conservation, focusing on Biological Collections and Conservation Units through the call FAPESP 16/2009. At that time, the fundamental importance of biological collections for the productive sector interested in the development of molecules and natural products was understood. It was requested that the information should be properly incorporated and referenced in databases. Next, some contributions of the research groups on Culture Collections supported by FAPESP are presented. Their titles and grant numbers are mentioned for reference.

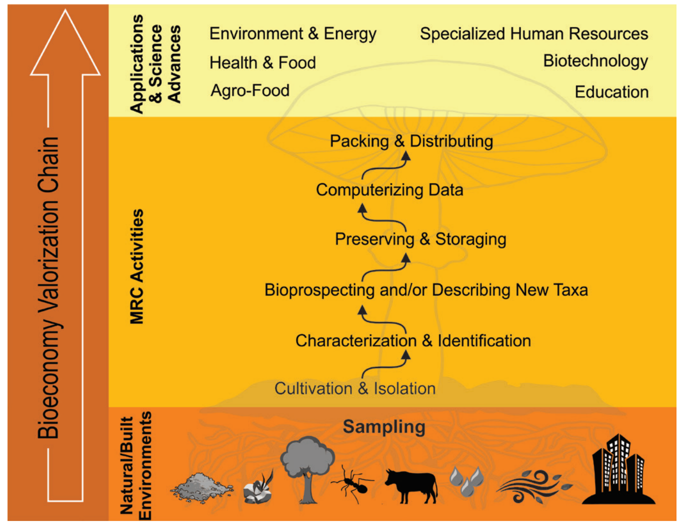

Figure 1. Bioeconomy valorization chain, highlighting the central position of Microbiological Resource Centers.

History

For many years, the soil was considered a highly complex environment with multiple abiotic and biotic components, and where one should search for microbial biodiversity. With the advancement of research, especially on environmental samples, it became clear that many other niches could be as diverse as the soil depending on the isolation technique applied. The availability of metagenomics methods and DNA/protein sequence-based classification (Oliveira et al. 2022) revealed a micro world that was not supposed to exist.

Marine microorganisms called the attention of researchers looking for strains and enzymes with unique properties. This results from a metabolism able to deal with high-salt concentration, large range of temperature and pH, organic solvents, surfactants, metal ions, and high incidence of light and pressure (Birolli et al. 2019). Currently, the bloom of blue biotechnology is highly dependent on those microorganisms.

Thus, the FAPESP project 2009/54789-9 aimed to expand and improve the facilities of the Marine Microorganism Collection of the Oceanographic Institute of the University of São Paulo-USP. The algae biobank, created in 1975, had been renovated 20 years later, but when the Oceanography graduation course started in 2002, the physical space became very limited. The demand for laboratories by professors and postgraduate students for their experiments, in addition to the tasks of the undergraduate classes grew a lot, and the existing infrastructure was no longer able to meet the development of all activities. The proposal submitted by Dr. Sônia Maria Flores Gianesella was comprehensive and pursued three main objectives: 1. to preserve biological resources of the Brazilian marine phytoplankton; 2. to support teaching and research in the areas of taxonomy, biodiversity, ecology, physiology, ecotoxicology, and marine microalgae biotechnology; 3. to optimize culture conditions to maximize the production of biomolecules, aiming at the commercial and industrial use of microalgae.

At that time, the USP biobank preserved about 210 cultures of marine microalgae and some heterotrophic flagellates. Currently, it is still considered one of the largest collections of marine microalgae in Brazil, with more than 230 marine and estuarine strains among diatoms, dinoflagellates, coccoid and filamentous cyanobacteria, and representatives of the groups Haptophyceae, Prasinophyceae, Chlorophyceae, Chrysophyceae, and Cryptophyceae. A catalogue of the collection was built (available at http://bmak.io.usp.br/bmak/algae/query.php), and the team offers several services such as deposit and distribution of strains; supply of culture medium or stock solutions; availability of equipment and controlled-conditions room for experiments; provision of teaching material for Elementary School and Higher Education; training and continuous professional development.

It is important to note that the Marine Microorganism Collection has served as support for subsequent projects that address topics such as physiological characterization of species; prospection of new marine biomolecules; evaluation of the effect of the growing conditions on biomass productivity and assessment of algae potential for fuel production. Finally, it became the stage for a mini-course to improve human resources in the area of marine biodiversity, that is, a collection that fulfills its role.

Another area of great appeal, which has a high demand for cured strains for bioprospecting, is agribusiness. Isolating microorganisms from nature, and identifying and preserving them with assured purity and viability are very challenging tasks. This makes microbiological collections primary sources of genetic resources aimed at scientific studies that seek, among others, to screen molecules with properties of potential application for the development of biological products. The microbe-plant interaction can have an important positive impact on increasing crop yields, as a result of microbial additives which meet the nutritional needs of the plants. Biological Resource Centers may certainly play a key role in helping more than 7 billion people gain access to safe and nutritious food (Fagunwa & Olanbiwoninu 2020).

To revitalize and computerize the collection of microorganisms of the agricultural and environmental importance of the Brazilian Agricultural Research Corporation (Embrapa), Dr. Itamar Soares de Melo received support from FAPESP through the grant 2009/54935-5. In addition, the development of a webpage on the "Embrapa Environment Portal" was planned, aiming at the dissemination of information about the collection, as well as the online availability of the database. Over about 20 years of studies, Embrapa built a collection that portrays biodiversity in mangroves, agricultural soils, and the caatinga (savannah-like), exploring the functional capabilities of fungi and bacteria. All this information, when well explored, contributes to SDG number 2 (Zero Hunger).

Within the same scope, the Brazilian Collection of Environmental and Industrial Microorganisms (CBMAI) at Unicamp – Campinas, was financially supported to adapt its infrastructure and protocols to act as a recognized center with competence to provide biological material with a guarantee of compliance (grant number 2009/54942-1). This project, carried out by Drs. Lara Durães Sette and Valéria Maia de Oliveira, highlighted the importance of Service Culture Collections, which develop their activities in line with internationally recognized protocols (OECD, CABRI and WFCC), in compliance with quality systems (ISO 17025), national regulations and intellectual property rights. CBMAI, founded in 2002, was one of the four Brazilian collections chosen to be part of the Biological Resources Center Network project, to assess the Conformity of Biological Materials.

Representing the environmental and industrial sectors, the CBMAI preserves strains isolated from natural substrates, for use in biotechnology, education and taxonomy, among bacteria, filamentous fungi and yeasts of biological risk 1 and 2. The investment granted by FAPESP helped CBMAI to achieve its mission as a service collection, fulfilling its main functions of acquisition, characterization, identification/authentication, maintenance and distribution of cured microbes, besides offering specialized consultancy and training courses, and dissemination of information associated with the biological material deposited in the collection. On January 31st, 2020, CBMAI officially received the ISO 17025 accreditation under number CRL 1478, which is the formal expression of recognition of its competence to carry out activities of 13 technical procedures in two assays related to the viability and purity and authentication of microbial cultures. A reassessment carried out in 2021 by INMETRO extended the accreditation of the same procedures for another 2 years.

In the projects "Support for the renovation and completion of the research infrastructure of the Tropical Culture Collection of the André Tosello Foundation" (grant 2009/54946-7), and "Support for the institutional infrastructure of the André Tosello Foundation's Collection of Tropical Cultures CCT/FAT: institutional technical reserve application plan" (grant 13/24669-7), Dr. Iracema de Oliveira Moraes raised an important critical point: the way in which the concept of biological collections is understood. From merely depository institutions providing inputs for R&D, she states that they should be recognized as a strategic heritage and critical asset for the development of science, technology and innovation of a country. As a curator, Dr. Moraes highlights the need to support collections where essential resources are found, such as CCT, so that the country can fulfill its commitments to the Convention on Biological Diversity (CBD), and other important international treaties and agreements.

The CCT was created as a service collection in 1988 and preserves around 7,600 strains among bacteria, filamentous fungi and yeasts. The implementation of a modern molecular identification system, the compliance with the ISO 17025 Quality System, and the establishment of an algae collection of technological interest were the objectives proposed in the project 2009/54946-7. The advances achieved with this grant led to a new request: expanding the infrastructure through the development of the Technical Reserve Application Plan (13/24669-7). A renovation carried out by the André Tosello Foundation itself allowed the physical area to increase by 25%, which brought a significant improvement to the practical activities carried out in the collection.

Today, the Collection of Tropical Cultures offers services, such as the deposit and distribution of strains, preservation of batches of freeze-dried and/or frozen microorganisms in liquid nitrogen, and microbial authentication by molecular and biochemical methods. For online consultation, a catalogue has been available since then (https://fat.org.br/catalogo-de-culturas-online/), with search by name, reference in collections and metabolites, for example. It is possible to obtain information about the deposited strains such as history, growth conditions, isolation source, taxonomic classification, bibliography, synonym, alternative name, Type strains and the level of biosafety.

Table 1 lists some other projects of great relevance, directly or indirectly involved in the structuring or use of microbial collections, that received support from FAPESP. It is also fair to remember other biobanks of great projection, such as the Collection of Phytobacteria Cultures of the Instituto Biológico (http://www.biologico.sp.gov.br/page/colecoes/fitobacterias), not only in the Southeast but also in other

Table 1. List of some other projects of great relevance, directly or indirectly involved in the structuring or use of microbial collections, financed by FAPESP. Obs. (#) = main project; (*) = linked to the main project.

Grant	Period	Title	Type	Proponent	Institution
#2011/50136-0	2011–2014	Biodiversity of toxigenic *Aspergillus* species in Brazil: occurrence, polyphasic taxonomy and distribution.	Research grant	Marta Hiromi Taniwaki	Institute of Food Technology (Ital)
#13/50954-0	2014–2020	New therapeutic agents obtained from symbiotic bacteria of Brazilian invertebrates	Thematic-Biota	Mônica Tallarico Pupo	University of São Paulo (USP), Ribeirão Preto (FCFRP)
*(15/01272-0) *(15/21675-1)	(2015) (2015–2017)	(Microbial strains: preservation, cultivation, extracts preparation, antibiotic screening and chemical profiling of extracts)	(Technical grants)	(Francine Pessotti) (Bárbara Matos do Prado)	
*(17/08280-3) *(18/19128-0)	(2017–2018) (2018–2019)	(Isolation, preservation and cultivation of microbial strains associated with social insects)		(Marina Giraldi) (Alexandre de Almeida Matias)	
#16/23218-0	2018–2028	Center for Research in Genomics Applied to Climate Change	CEPID/PITE	Paulo Arruda	University of Campinas (Unicamp – CBMEG)
*(21/04953-9)	2021–2022	(Isolation and characterization of microorganisms associated with plant species adapted to limiting nutritional conditions)	Post-doc	(Mariana Ramos Leandro)	
#19/03746-0	2019–2024	Integrating phylogeny, genetics and chemical ecology to unravel the tangled multiparty symbiosis of ants that cultivate fungi.	Thematic – Biota	Mauricio Bacci Junior	São Paulo State University (UNESP – Rio Claro)
*(20/04639-0)	(2020)	Lyophilization of fungi of genus *Escovopsis*.	(Technical grants)	(André Rodrigues and Karina Bueno de Oliveira)	
*(21/01072-1)	(2021)	Curating the microbial collection derived from attine ants		(André Rodrigues and Ariane Janaina Rodrigues)	
#19/01632-7	2019–2020	Selective isolation of fungi with biotechnological potential from marine and terrestrial Antarctic samples.	Scientific Initiation	Lara Durães Sette and Daniela Mayumi Kita	São Paulo State University (UNESP – Rio Claro)
#18/20000-9	2019	Systematics of hydnoid and corticioid fungi (Polyporales) from Brazilian Atlantic Forest.	Research grant	Adriana de Mello Gugliotta	Botany Institute, Secretary of the Environment (São Paulo).

regions of Brazil. One can say that the organization and availability of data on the microbial application of the collection have been the major attraction for new technology-based companies. This exchange of information creates a link between the source where knowledge can be found and the place where it will become a benefit to society. This is crucial for the biotechnological development of a country.

It is intriguing to think that most countries considered megadiverse are neither those that house the larger collections and preserve their microorganisms (Çaktü & Türkoğlu 2011) nor those that have an expressive number of biotechnology companies. A recent study on fungi in Microbial Culture Collections showed that no more than 3% of the total fungal species found in these centers are in practice used (Vasilenko et al. 2022). Even worse is the fact that many biological (not only microbiological) collections are in jeopardy because they are consistently undervalued and often underfunded (National Academies of Sciences, Engineering and Medicine 2020).

Brazilian culture collections should not be restricted to "surviving" within an umbrella project as a small part of the whole, but to thrive and help to minimize the huge gap that still exists in preserving and prospecting our biodiversity. This will require visionary and well-supported curators, working alongside competent and innovative scientists, to build a highly-expert task force in managing and curating their collections. Here is where we should come in.

Advances in Scientific Knowledge on Microbial Taxonomy

Ex situ microbial culture collections preserve large numbers of pure culture strains of bacteria *sensu latu*, fungi, including yeasts, protozoa and microalgae, over long periods. A strain retains its identity permanently and serves as a standard organism if no mutation or contamination occurs. Identifying a microorganism, however, is not an elementary task (Hyde 2022). Given so many changes in nomenclature and new techniques for analysis, it is mandatory (mainly in microbial repositories) to follow updates in this field.

Microbial resources play an essential role in understanding and developing life sciences because microorganisms are crucial to maintaining environmental health as well as the inner ecosystem of humans, higher animals, and plants. They are fundamental materials for scientific studies and may serve as references and model organisms as well. However, the use of misidentified taxa can have disastrous consequences by increasing the waste of money and scientific irreproducibility, besides delaying innovation. Thus, microbial culture collections play a crucial role in the long-term and stable preservation of these microbes, but also must provide authentic reference materials for scientists and bioindustries (Gams 2002; Wu et al. 2017).

Currently, there are more than 22,000 validly described prokaryotic species (https://lpsn.dsmz.de; last refresh 2022-10-05), but still representing a minority (estimated to be 0.1 – 10%) of the predicted diversity, which will likely be revealed by study methods on unculturable species (Rappe & Giovannoni 2003; Rinke et al. 2013; Parks et al. 2020). To date, about 150,000 fungal species have been described in the midst of 2.2 to 3.8 million that are thought to exist (Hyde 2022), which means that the diversity of this kingdom is also poorly known.

Brazil has great biodiversity, however little is explored in the area of microorganisms. Therefore, the correct identification at the species level is very important because there are several characteristics associated with each species. The identification carries a set of known information about each organism, its ecological role, its physiology and biochemical properties, and its social risk or benefit.

Microbial identification is an activity closely related to two other areas of taxonomy: classification, which is the arrangement of organisms into groups (taxa) based on similarities or relationships, and nomenclature, which is the assignment of names to the taxonomic groups.

Taxonomy is dynamic and subject to change as new information becomes available. This results in changes in classification, nomenclature, identification criteria, and recognition of new species. In the case of bacteria, there is no official classification scheme, but the nomenclature is regulated by the International Code of Nomenclature of Bacteria (Bacteriological Code) (Lapage et al. 1992), which contains the rules governing the way the names are to be used (LPSN 2022).

In 1975, the Bacteriological Code established the concept of "valid publication", which is an official and centralized system for registering names that can be used in the taxonomy of bacteria. This system, exclusive to the International Code of Bacterial Nomenclature (although virology has followed this principle), which started in 1980 with the publication of the Approved Lists of Bacterial Names, regulates the use of the more than 40,000 names that have accumulated over the last 200 years. On this list, just over 2,000 names were accepted for transfer to the modern system (LPSN 2022).

From this list, a journal was created for valid publication of new names or changes to existing names: the International Bulletin of Bacterial Nomenclature and Taxonomy, later the International Journal of Systematic Bacteriology (IJSB) and now the International Journal of Systematic and Evolutionary Microbiology (IJSEM). Names published in other journals must be published on an IJSEM Notification List to be considered valid (ICSP, 2022).

The fungal nomenclature follows the rules and recommendations of the International Code of Nomenclature for algae, fungi and plants, as adopted at the Eighteenth International Botanical Congress Meeting, held in Melbourne, Australia (2011) (http://www.iapt-taxon.org/nomen/main.php). In Mycology it is essential to maintain clear standards for taxonomic delimitation and MycoBank, in a way, works as a repository for fungal species safeguarding diversity. The MycoBank database is an online repository of all fungal taxonomic novelties (new names and combinations) currently published (http://www.MycoBank.org), which aims to provide open access to associated data such as descriptions and illustrations to the mycological community. This database was first released in 2004 (Crous et al. 2004). There are experts at MycoBank who check the newly proposed fungal nomenclature in terms of the validity, legitimacy and linguistic correctness of the proposed name. MycoBank also provides links to other databases containing information regarding DNA data, reference specimens, living cultures, and pleomorphic names, and is linked to other important mycological databases such as Index Fungorum, Life Science Identifiers, and the Global Biodiversity Information Facility (GBIF). MycoBank is run by the Westerdijk Fungal Biodiversity Institute (prior CBS) in Utrecht, The Netherlands (http://www.MycoBank.org), and is one of three nomenclatural repositories recognized by the Nomenclature Committee for Fungi; the others are Index Fungorum and Fungal Names.

Advances in molecular biology methods have greatly increased our knowledge in the microbiology field, which has resulted in new diagnostic tools, better accuracy in taxonomic delimitation, better strategies for controlling pathogens and toxin contamination, and improved industrial strains in multiple fields of biotechnology. Great advances have been made especially due to the advent of omics approaches, accompanied by robust technologies of high throughput such as NGS/WGS sequencing, RNA-Seq, and MALDI-TOF/MS.

The application of molecular biology techniques has helped to overcome problems of the traditional methodology, because it can reduce the time from several days to a few hours, allowing a specific and faster identification. These techniques, however, have revealed the existence of a much larger number of species than previously expected, most of them not yet identified or formally accepted. In addition, molecular identification is often faced with the limitation of reference sequences deposited in databases, such as GenBank, which do not cover all Brazilian microbial diversity. This comprehensive database, available to the public for free, receives genomic data from all over the world and contains more than 219 million nucleotide sequences (NCBI-GenBank Flat File Release 245.0 August 2021). The sequences, named at the genus level or lower, are obtained primarily through submissions from individual laboratories and batch submissions from large-scale sequencing projects, including whole genome shotgun and environmental sampling projects. Daily data exchange with the European Molecular Biology Laboratory Nucleotide Sequence Database in Europe and the DNA Data Bank of Japan ensures worldwide coverage (Taniwaki et al. 2023).

The suffix -omics is used to describe areas of modern biology which deal with the analysis of totalities of similar individual elements; this concept can cross several areas of biology. In terms of microorganisms, the main areas are microbial community DNA/metagenomics (meta = community-based) (Handelsman 2004; Dinsdale et al. 2008), genomes/genomics (= from individual organisms) (WHO 2020), RNA transcripts/transcriptomics (Sánchez-Pla et al. 2012) or metatranscriptomics, proteins/ proteomics (Anderson & Anderson 1998; Blackstock & Weir 1999) or metaproteomics, and metabolites/ metabolomics (Cevallos-Cevallos et al. 2009) or metametabolomics (O'Malley 2013).

The omics sciences encompass global analysis of biological systems, integrating different areas of knowledge, such as biochemistry, genetics, physiology and computing, with the aim of isolating and characterizing genes, proteins and metabolites, as well as studying the interactions between them, based on experimental techniques, software and databases. Bioinformatics, in turn, proposes new forms of science based on *in silico* experimentation, being very dynamic in updating and providing the basis for the generation of new data and knowledge that can be applied in basic and applied research with the development of new products and solutions. This process is closely related to technological innovation, which is achieved by uniting biotechnology and bioinformatics.

Omics-based approaches come regularly with an immense flood of data that are too big, too complex, and too fast-moving, and that must be thoroughly handled and structured to produce meaningful information and provide answers to highly complex scientific problems (Madden 2012). With the improvements in bioinformatics tools in the last decade, the main challenge of systems biology is the integration of "omics" information to give a more complete picture of living organisms and their roles and interactions with the ecosystem.

To provide integrated information using big data technology, the World Federation for Culture Collections (WFCC) launched 1966 the World Data Center for Microorganisms (WDCM), which offers several free services to Microbial Resource Centers and microbiologists all over the world. Among them are the Culture Collections Information Worldwide (CCINFO), with metadata from culture collections around the world; the Global Catalogue of Microorganisms (GCM), which gathers information from numerous strain catalogues with retrieval, analysis and visualization of microbial resource data; the Analyzer of Bioresource Citation (ABC), a tool to survey publications related to strains, patents, nucleotide sequences and genome information, and the Reference Strain Catalogue (RSC), which maintains a database from strains listed in the International Organization for Standardization (ISO) and other international or regional standards (Wu et al. 2017).

Among the 10 countries with the highest number of WFCC participation, the United States and Japan are the strongest ones. Brazil and Thailand, countries with high biodiversity, have a large number of collections, but the lowest average number of strains per collection. This likely suggests specialization based on the disciplines the collection serves, regional characteristics, or research focus (Wu et al. 2017).

Prospects for Microbiological Collections in the Next Decade

Microbial Resource Centers (MRCs) act as silos due to their own institutional context and expertise, available in specific microbial taxonomic groups globally. The fragmentation of the data associated with the holdings that the MRCs have long-term preserved is a tremendous constraint for the current research and development. To enable researchers to address societal challenges with a global dimension, foster innovative solutions from the bioindustries, and get involved the lay citizens in the microbiology advances, the MRCs need to facilitate access to high-quality resources, a portfolio of services, including access to the state-of-the-art facilities, expertise, education and training programs. By doing so, MRCs will be able to provide data on high-quality biological resources, assure long-term sustainability of microbial biodiversity, and increase knowledge and professional development to address societal challenges, namely on health, demographic change, well-being, food security, and safety. By this, they will contribute to the development of Sustainable Development Goals (SDGs) from the United Nations, namely on secure food (number 2), ensuring healthy lives and promoting well-being for all at all ages (number 3), ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all (number 4), preserving biodiversity (number 15) and marine ecosystems (number 14), climate change and mitigate actions (number 13) and fostering industrial innovation (number 9). No single MRC or Nation is able to mitigate or get a solution for the big societal challenges that our society faces which means that they need to cooperate and work in a network. The partnership among MRCs and between other relevant stakeholders, such as academia, bioindustries, national, international, and intergovernmental organizations, is foreseen in the global research landscape in the field of microorganisms. This positioning is also aligned with SDG 17 – Partnerships for the goals.

Collaboration and alignment among the Brazilian Microbial Resource Centers started in funded programs as early. Such constant efforts on networking and a timid integration of services over the years are a real challenge for the national microbial culture collections, for the host institutions/organizations that need to assume the collections as an irreplaceable asset and for the national funding agencies that require to contribute not only for founding mechanisms, but also to foster a policy of collaboration boosting the visibility of microbial culture collections and generate more use of its resources and improving research.

The ambition of the MRCs should be to create unique opportunities for carrying out advanced research by improving the access to data on microorganisms which is key to increasing the reproducibility of science and avoiding duplication of work. The most important tool to pave this ambition is to rely on an information system to reach the highest level of advanced and state-of-the-art research, in microbial diversity and resources. Curating the existing and newly published data on microorganisms, and linking the databases focused on macro-biodiversity and the MRC databases that manage micro-biodiversity-related data are especially relevant in the host-pathogen relationship and microbiome studies. This allows us to go beyond the current state-of-the-art and answer to the needs of research done in microbiomes or under the concept of one health. To achieve this high level of integration and access to the information in a FAIR (findable, accessible, interoperable, and reusable) manner, the MRCs need to be committed to generating data under stringent quality control systems such as quality certification (see, for example, the ISO 20387:2018 standard for general requirements for biobanking), performing authenticity checks of the genetic resources and implementing common Standard Operating Procedures (SOPs). As stated by Martins and co-authors (2022), standards are a key mechanism for the diffusion of technological knowledge with macroeconomic impacts by promoting productivity growth and economic advancement. They may spur innovation by establishing a baseline of accumulated efficient technological experience from which new technologies emerge and by increasing global competitiveness, which in turn boosts innovation. This will encourage collaborative research with both players in biotechnology and innovative small and medium enterprises that employ targeted screening strengthening microbial research in general.

Another area of great relevance is microbial prospecting. This is where various niches are surveyed to obtain useful microbes that produce pharmaceuticals, commercial enzymes, or industrial organic acids. Such niches may be extreme environments from which microorganisms new to science may be isolated and where these have to be preserved under optimal conditions. Alternatively, microbes held in existing MRCs could be screened for these activities, considered of fundamental importance to these areas, particularly in the era of human diseases resistant to conventional antibiotics. The microbiome era brings new challenges to culture collections, with the appropriate technologies, the long-term preservation of microbiome samples as a whole or in part (microbial consortia), or even the preservation and supply of DNA/RNA samples extracted from microbiomes, demanding the development of novel concepts and approaches.

The MRCs also need to strengthen the links between public and private research by bringing together the currently fragmented data and information as well as the necessary resources, both in terms of genetic resources and human capital, to stimulate research, development and innovation.

The biological sciences, in particular microbiology, are adding value to a multitude of products and services, producing what some have labeled the bioeconomy. From a broad economic perspective, bioeconomy refers to the set of economic activities relating to the invention, development, production, and use of biological products and processes (OECD 2009) replacing fossil-based resources. Currently, and on top of this, it has become evident that the linearity of the production systems without any use of their by-products is not sustainable. The circular bioeconomy goes far way and challenges the research and industry to generate the minimum amount of waste and add value to the by-products and the end-of-life of biobased products (Stegmann et al. 2020). Finally, it is quite fair to say that culture collections are key infrastructures underpinning the circular bioeconomy, and this is why funding them is absolutely crucial.

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Conflicts of Interest

The authors declare no conflicts of interest related to the publication of this manuscript.

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